III-13

FLOOD RISKS IN CONSEQUENCE OF AGRARIAN LAND-USE MEASURES IN FLOOD FORMATION AND INUNDATION ZONES AND CONCLUSIONS FOR FLOOD RISK MANAGEMENT PLANS

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ABSTRACT

Investigations on the role of agricultural land use and its contribution to flood risks in runoff formation zones as well as in inundation zones were in the focus of the research project MinHorLam. Model-based assessments of runoff formation and erosion caused matter loads at different rainfall conditions and different farming practices were performed for schematised surface units. For inundation zones, the impacts of different land use patterns in floodplains on water levels and distribution of discharge and velocities at flood conditions were modelled for schematised cross sections. The application of schematised infiltration plots and of schematised flood plain cross sections allowed for clearer pointing at process behaviour than this can be achieved by using complex topographies and land use pattern as a model background. The results show the range, potentials, and limits of agricultural practices and land use towards runoff generation and flood water levels. Aspects of matter accumulations in flood plains and management options are considered on the basis of case studies related to extreme flood events.

For sociological interaction analyses, extensive interviews with official agents and farmers, based on detailed questionnaires, and three regional workshops were performed. Institutional actors rate the role of agriculture as cause for flood events moderate to low. More action and especially cooperation between different institutional actors towards the aim of risk prevention is required.

The results of the whole project can be helpful for the implementation of the EU Directive on the assessment and management of flood risks.

KEY WORDS: flood formation, inundation, land use, modelling, sociological interaction analyses

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INTRODUCTION

During recent decades, some extreme floods with catastrophic damages occurred at German rivers like e.g. Rhine (1994, 1995), Oder (1997), Danube (2002), Elbe (2002, 2006). These extreme floods were followed again and again by controversial discussions on the impact of agricultural land use on runoff generation in flood formation zones as well as on the characteristic of water surface levels in inundated floodplains. These aspects were in the focus of a research project which was concentrated on the mitigation of flood risks by non-structural measures in the agricultural sector. The project tasks were performed by a multidisciplinary team of hydrologists, hydro engineers, bio-geochemists and social scientists. In difference to case studies, the project works were targeted towards differentiated generalisable process and behaviour analyses and sociological interaction analyses and regional workshops.

Further information on additional project results beyond the scope of this paper may be taken from the project website http://www.minhorlam.de/ . There, aspects of matter accumulations in flood plains and management options are presented under the item " Entscheidungshilfe: Bewirtschaftung von Aueflächen".

MATERIAL AND METHODS

Analyses for Flood Formation Zones

Runoff generation in flood forming areas can be influenced by non-structural land use measures like agricultural management practices only in the land areas actually used for farming. Model-assisted analyses of runoff generation are performed for schematic model land units (Fig. 1), wherein the structural parameters (soils, slope, slope length, vegetation) and the boundary conditions (rainfall intensity or duration) are varied over wide ranges. An estimate of the effect of land use changes at the river basin scale can be made by summing up the effects of each individual land area within a river basin.

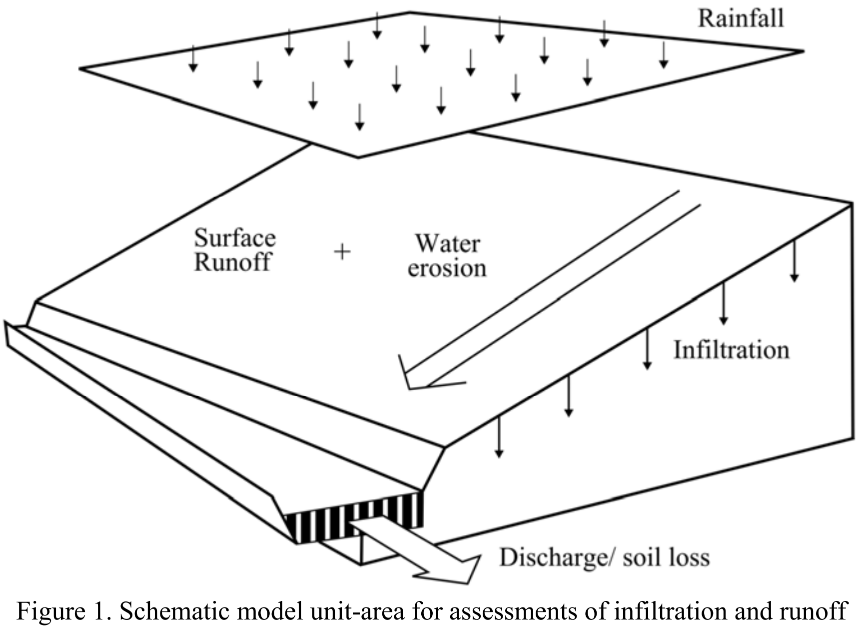

Figure 1. Schematic model unit-area for assessments of infiltration and runoff

The parameters of soil physical and soil water properties were derived based upon the USDA soil texture triangle. Storm event boundary conditions were derived from meteorological statistics using the digital database KOSTRA – DWD 2000 (Barthels et al., 2005). For extreme events, a comparison was made with precipitation curves actually encountered in different river basins in connection with real extreme floods. Land-use and soil-farming-dependent parameters, such as Manning's roughness coefficients for overland flow or average ground cover and erosion resistance of the soil, are taken from soil survey guidelines (Ad-hoc-AG Boden, 2006).

An infiltration model, based on the Green-Ampt (1911) approach and modified by Chu & Marino (2005, 2006) is used to partition rainfall into infiltration and surface runoff. The model is suitable for simulating infiltration into layered soils of non-uniform initial moisture distributions during an unsteady/ steady rainfall event. The effects of the changing infiltration characteristics as a function of land use and farming type were considered numerically by individual sets of parameters for pasture, conventional and conservation tillage and direct seeding. The driving parameters of the Green-Ampt-model are the soil moisture deficit, the wetting front suction potential, and the effective saturated conductivity. The soil moisture deficit was simulated with the software HYDRUS–1D (Simunek, et. al., 2008) in consideration of different drainage times. The water flow parameters were derived from the soil type, bulk density and organic matter content using pedotransfer functions as proposed by Zacharias & Wessolek (2007), Rawls (1983), and Rawls & Brakensiek (1983) and Mualem (1976). The wetting front suction calculation was based on soil water retention curve (van Genuchten 1980) while the saturated hydraulic conductivity was derived from the sand and clay content according to Tietje & Hennings (1996). Further impacts of plant residues, vegetation cover, and rainfall caused soil crusts were adjusted by pedotransfer functions (Rawls et al., 1989).

The schematic model land unit is set to a seize of 1 ha, a slope of 5 % with a soil profile of a 70 cm sandy loam layer with an underlying low permeable layer. Infiltration modelling was based on an initial water content after 15 days of gravity drainage and a 12 h block rainfall with a recurrence interval of 100 years, i. e. 95 mm precipitation volume. Further on, an extreme rainstorm event which occurred in the course of he Elbe flood 2002 was considered as well. Assumed farming practices comprised conventional tillage, conservation tillage, direct seeding and pasture

Inundation Zones

Agricultural land use in floodplains and its impacts on water levels and flow velocities at flood conditions were in the focus of the own model-based investigations. The assessment of the hydraulic parameters were performed by a specially developed quasi-2D model of a variable schematic floodplain cross section which was partitioned into lamellae (Fig. 2). For a river section of infinite length, the model allowed for the calculation of water levels and lateral distribution of flow velocities and discharge portions within the considered cross section at steady uniform turbulent flow conditions. Depth dependent hydraulic roughness coefficients could be assigned to each lamella individually according to the assumed land use type within the considered lamella.

The model calculations were performed for a wide variety of data sets. These comprised assumed schematic floodplain cross-sections with horizontal left and right foreshores, each of 600 m in width, combined with two different riverbeds (profile 1: w = 200 m and d = 3 m; profile 2: w = 100 m and d = 2 m). Foreshore land use was set either to a completely uniform cover by grassland, maize or forest or to complete cover by a grassland/maize combination or a grassland/forest combination. The combinations comprised varying portions of each of the land use types. Model peak flows of 2000 m^3s^{-1} and 3000 m^3s^{-1} were considered for the standard investigations and ranged from 2000 m^3s^{-1} to 5000 m^3s^{-1} for additional special investigations. The considered longitudinal bed and foreshore slopes ranged from 0.1 ‰ to 2.0 ‰. The chosen combinations of cross-sections geometries and discharges were selected in approximation to conditions known from the Oder River with a 100-years-flood peak flow of about 3000 m^3s^{-1}.

Further details on the applied models may be taken from Quast et. al. (2011).

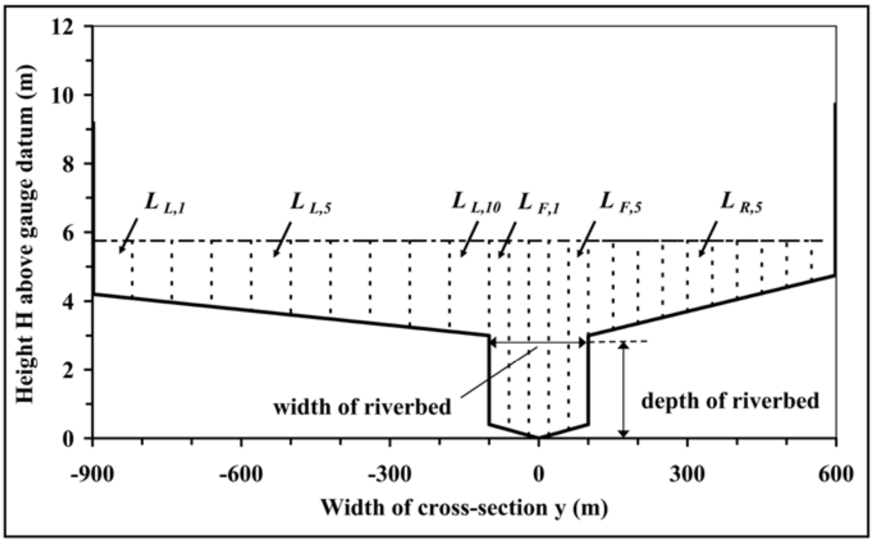

Figure 2. Schematic model cross-section of floodplain partitioned into lamellae for left floodplain, riverbed, and right floodplain)

Sociological interaction analyses

17 in-depth personal interviews with farmers have been conducted and the results have been verified with 42 telephone interviews within the framework of the joint research project. The aim was to learn about the problem awareness and risk perception of farmers concerning flood risks as well as their behavioural logics and decision making logics. These extensive qualitative interviews have been analysed and documented using the qualitative contents analysis according to Mayring (2008). As interview partners we chose farmers who work in explicitly declared flood, inundation or polder areas.

Flood risk reduction through agricultural measures as perceived by authorities

A second strand of research was conducted with the objective to explore, if at all and on what way the concerned administrative bodies and local authorities take agriculture into account when handling issues of flood risk management at the institutional level. What are the influential factors that raise the chances for a successful administrative management of flood risks by non-structural agricultural means? Empirical surveys addressing members of national, laender and county level public agencies have been undertaken to analyse and discuss these questions (309 answers of 861 persons who have been contacted). The results have been specified by nine qualitative interviews.

Theoretical background used for this part of the study is the actor centred institutionalism approach (Mayntz & Scharpf 1995, Scharpf 2006). The approach serves as a framework for the acquisition and categorization of social facts. The promoted perspective regards social and political processes as influenced likewise by institutions (accepted frameworks) and by the behaviour and interactions of organisations and related people. Institutions are regarded as a context that affects the acting of corporative actors in a stimulating, enabling and restricting manner rather than in a determining. They influence the preferences and acting of actors and define the interaction structures. At the same time institutions are subject and result of actors' decisions and interactions themselves (Ostrom 2005). Accordingly, the acting of actors is dependent on their varying perceptions and ways of interpretations of institutional frameworks.

RESULTS AND DISCUSSION

Flood Formation Zones

Runoff reduction potentials due to agricultural practices were found for schematic model land units especially during brief convective storm events with a high intensity. With regard to the formation of extreme floods, ,such convective storm events are of minor relevance , because of their usually local occurrence only. For extreme flood forming long advective storm events with generally lower precipitation intensities, the influence of land use impacts on storm runoff generation, if any, is restricted to the initial hours of the storm event (Fig. 3).

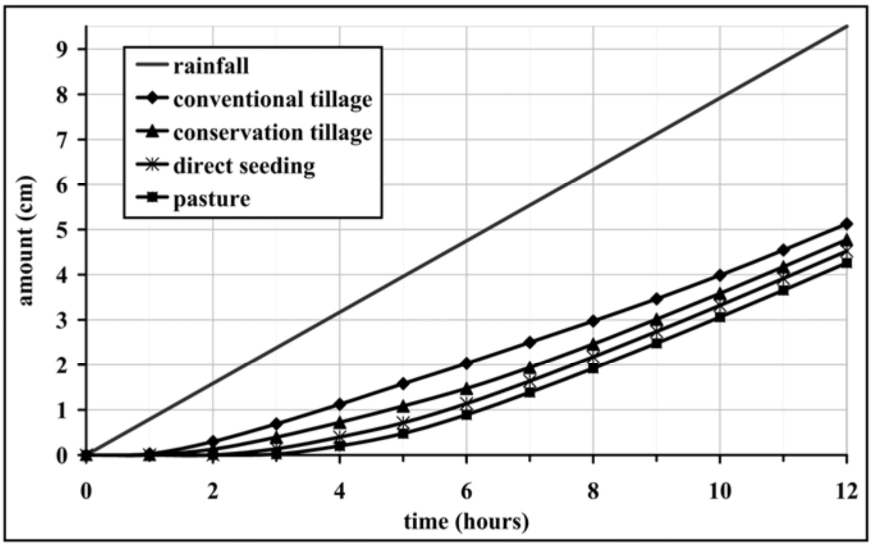

Figure 3. Cumulative runoff for pasture, conventional tillage, conservation tillage and direct seeding

The impact of agricultural management practices on infiltration rates and the actual reduction of the surface runoff is strictly limited to the initial phase of the rainfall event. With longer-lasting rainfall, the soil infiltration capacity decreases to a stage where infiltration and surface runoff are at the same level regardless of different farming practices. The runoff reducing impacts from agricultural practices become even less for conditions of fully saturated top soils or for silty soils. The achievable runoff reductions decrease also when the duration of the considered storm event is e.g. 24 or 72 hours instead of 12 hours.

A comparison between the model precipitation and storm events which triggered observed extreme flood events indicates that the model precipitation event is in magnitude below flood causing real events. An example is the Elbe flood causing extreme storm event of August 2002 in large parts of the Ore Mountains which brought a precipitation of more than 200 mm in 72 hours. Taking these data for a model simulation of infiltration and runoff made clear that effects of non-structural measures disappear completely under such conditions (Fig. 4).

Runoff retardation effects diminished with increasing durations of the storm events, because hillside lengths of approximately 100 m resulted in retardation times due to vegetation cover and different farming practices of a few minutes only. The calculated concentration times ranged from about 5 to 20 minutes. Even if the potential flow path length is increased to 200 m, there will be no significant changes in flow retardation. In such case, the concentration times were determined to be about 8 minutes for conventional tillage up to 28 minutes for pastures. Steeper slopes above 5 %, which are typical for flood forming areas, will cause reductions of flow retardation.

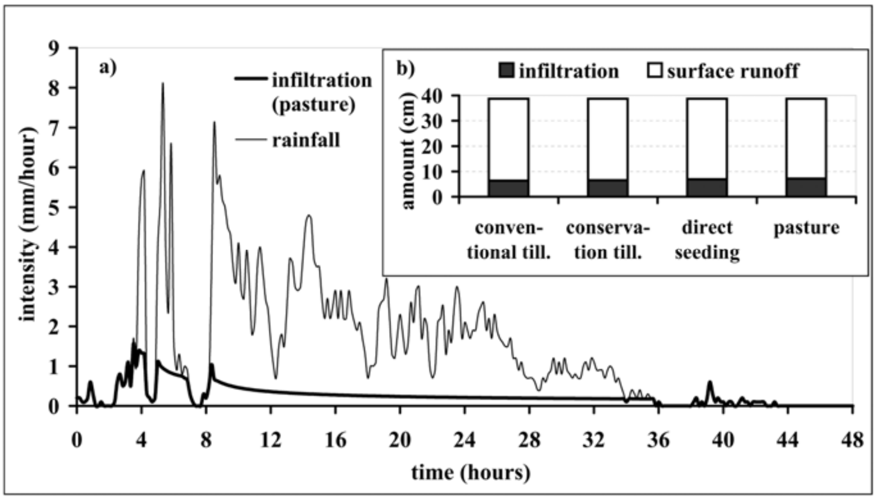

Figure 4. Infiltration process on the schematic model unit-area a) for pasture and b) comparison of cumulative amounts of infiltration/ surface runoff at different farming practices for the extreme precipitation event of 12-14 Aug 2002 at Zinnwald-Georgenfeld

Inundation Zones

The lamellae-wise land use change on the horizontal foreshores from forest to the hydraulically less rough grassland resulted in a non- linear stepwise drop of water surface levels. When this change was assumed for the complete foreshores, water level was lowered by about 40 cm at 2000 m^3s^{-1} and 70 cm at 3000 m^3s^{-1} for cross section profile 1 (Fig. 5). Changing land use from full grassland cover to maize led to a rise of water levels again, which increased with the discharge (Fig. 5). It is evident that forest grassland alterations impact the gradients of water level changes more than grassland maize alterations. The same land use changes led to similar reactions but of much larger water level differences when applied to the cross section profile 2. Due to its smaller river bed, foreshore land use has essentially greater impacts on discharge capacities and water levels..

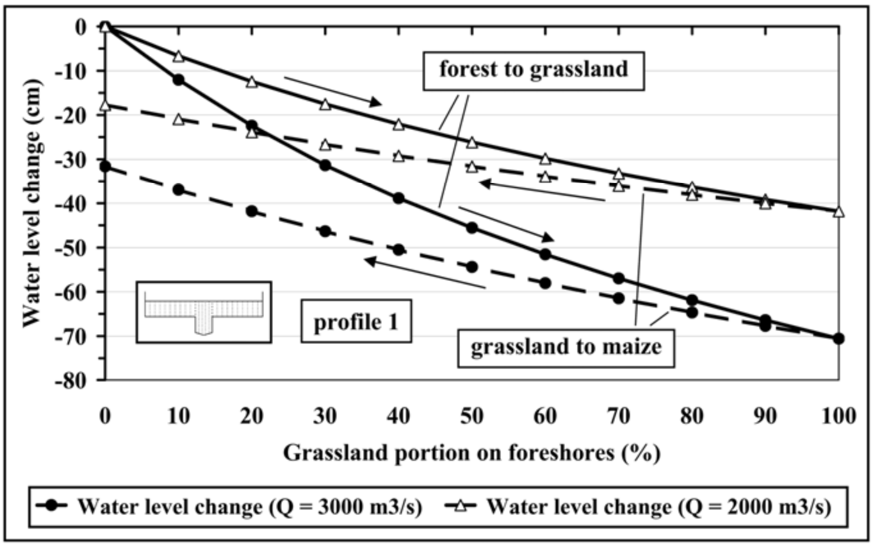

Figure 5. Water level changes depending on proportions of forest/ grassland and grassland/ maize at different peak flows (bed slope 0.25 ‰; foreshore width 2 x 600 m; riverbed width 200 m; riverbed depth 3 m [profile 1]) for land-use changes (forest → grassland → maize)

Flow velocities were 0.14 ms^{-1} and 0.21 ms^{-1} at the considered peak flows of 2000 m^3s^{-1} and 3000 m^3s^{-1} when foreshores were covered completely by forest. Flow velocities on foreshores covered completely by grassland determined as 0.42 ms^{-1} and 0.61 ms^{-1}. for the considered peak flows of 2000 m^3s^{-1} and 3000 m^3s^{-1}. With none of the scenarios for a modelled peak flow of 3000 m^3s^{-1}, flow velocities on the foreshores exceeded 0.75 ms^{-1}. Higher velocities occurred only when either foreshore widths were reduced drastically, when peak flows were increased (e.g. up to 5000 m^3s^{-1}).

Sociological interaction analyses

Selected result of the online survey on the institutional framework, the risk perception and the state of corporative action are presented in the following. Beside mandatory regulations, Laender governments can influence farmers' decision on land use by two further means: economic incentives and information campaigns. Especially within the frame of the EU common agricultural policy (e.g. 2006/144/EC), the German Laender governments are in possession of a powerful instrument by binding the payments to certain actions. However, till date only a few agricultural programs in the Ger-man states are explicitly related to flood prevention or to the reduction of damage involved with floods. In addition, most of the instruments that aim at flood risk minimisation are related to structural measures and address public corporations like land and water management associations. Political programs that address farmers and aim at reducing flood risks by agricultural means are still quite rare. Expert knowledge based, about 20 agricultural practices were identified by the project partners that bear the option to contribute to non-structural flood risk management in agriculture. Among the political programmes examined, a surprisingly unequal reference to these practices was made, rang-ing from four to zero single measures per state (Nov. 2009).

Most interviewees regard the part that agriculture plays as a small one (46%) or as even not existing (16%). However, more than a quarter states that agriculture plays an average part in emerging and enhancing of flood events, and 7% would regard this part as big or even very big.

The possibilities to minimise flood risk by non-structural agricultural measures are judged divergingly. From the point of view of the interviewees the most successful measures are the "installation of structures which will support the infiltration or which will restrain the water", the "transformation of arable land to grassland" and "supplementary erosion measures". On the other hand, "conversion to organic farming", "no-tillage measures" and "diversified crop rotation systems" are judged to be the least favourable measures.

Several questions addressed the need and quality of the cooperation among different administrative bodies and with other partners such as water and land management associations, water works, farmers' associations, science centres and universities, consulting engineers and the emergency ser-vices. The results show a rather high need for coordination with all mentioned organisations and agencies for a successful agricultural flood protection. The interviewees who identified one of these bodies as a relevant partner in the majority of cases regard the need for coordination as high (32% up to 48%). In the case of water and land associations and emergency services the need for coordination for a successful agricultural flood protection is regarded in 22% respectively 19% of cases as very high.

Additionally, a focus was given to the cooperation patterns between the authorities and external partners, especially whether cooperation is generated formally or informally (established by the own or higher-ranked administrative body or e.g. by personal networks), and if it takes place regularly (e.g. once a month) or ad hoc (in the case of need). By far dominated informal cooperation with private or semi-public bodies like farmers' and water management associations. Formalised cooperation takes place with other administrative and communal units. Regular meetings were clearly less frequent than ad hoc ones.

CONCLUSIONS

The modelling results for different schematic elementary areas indicate a distinct decrease of land use impacts on flood attenuation at extreme flood-producing storms. For different types of soil combined with varying forms of land use relevant flood-causing amounts of precipitation can be specified which would produce maximum surface runoff. Up to this point, surface runoff is influenced by vegetation cover and farming practices (conservation agriculture, direct seeding). From this point however, independent of the form of land use in runoff forming areas, there exists no chance to reduce flood discharge by non-structural measures of agricultural land use. Furthermore, no effective retardation of discharge is obtainable by vegetation cover and different farming practices. In contrast to this, the effects on preventing erosion are still effective even for extreme rainfall events. Thus, the endangerment of downstream areas by deposition of erosion loads as well as a degradation of due to the loss of nutrient-rich top soil can be diminished.

Arable crops in inundation zones will not lead to significantly higher water levels with risks of overtopping the dike crest. At crops of high hydraulic roughness like e.g. maize, critical rising of water levels (ranging from about 70 cm up to 100 cm and more) may occur when maize farming is done concentratively within the complete inundation zone. For such situations, special hydraulic analyses are reasonable. Nevertheless, the hydraulically relevant riverine parts of the foreshores should be kept generally free from crops.

The results of the entirety of the performed variant investigations for flood forming as well as for inundation zones can be helpful for the implementation of the EU Directive on the assessment and management of flood risks, especially for the elaboration of the requested flood risk management plans. Preparation of such materials is in progress.

Summarising this part of the project revealed that the contribution of non-structural agricultural measures to flood risk prevention and damage diminution as perceived by authorities is mostly average what corresponds to the current state of the art. However, better results from agricultural land use especially with regard to soil erosion prevention and increase of water infiltration could be achieved with an improved tailoring of political instruments. Additionally, more information and awareness creation especially in concerned regions in the western and southern parts of Germany is recommended. Also the cooperation between the different corporative actors in this field would profit from enhancement e.g. through more formalised procedures that take regional structures into account or through capacity building with regard to cooperation and communication skills.

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