Settlement dynamics in floodplains: from assessing future flood hazard exposure to developing spatial adaptation measures

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ABSTRACT

Based on empirical research from three Austrian flood-prone municipalities, this contribution discusses the impact of settlement dynamics in floodplains on future changes in flood hazard exposure. The authors present a methodological framework for a GIS-based assessment of settlement dynamics in 300-year flooding areas and reflect options of implementing a risk-oriented approach in flood-related spatial planning. Findings indicate the following: i) increases in flood hazard exposure are to a large extent determined by the kind of building land (residential, commercial etc.) displayed in local land use plans; ii) the supply of building land (i.e. vacant lots and development areas) in floodplains is a key driver of future flood hazard exposure; iii) "context matters", i.e. flood-related options in spatial planning are strongly influenced by topographic conditions (e.g. the amount of land available for permanent settlement) and iv) there is further scope to specifically use zoning or local development plans for implementing a risk-oriented approach in flood-related planning.

KEYWORDS

Flood hazard exposure; settlement development; exposure assessment; risk-based spatial planning.

INTRODUCTION

In the past years flood policy in Austria gradually shifted from a structural, security-based approach of flood protection towards an integrated, risk-based approach of flood risk management. Whereas the 'traditional' approach was informed by a firm belief in controlling rivers via engineering solutions, Austrian flood policy increasingly aims at reducing the vulnerability to flooding (Nordbeck, 2014). Due to its pivotal importance for flood risk prevention, spatial planning is assuming a more central role within the nascent paradigm of an integrated management of flood risks. Spatial planning is operative in reducing vulnerability by minimizing the exposure to flood hazards. Hazard exposure can be effectively reduced by allocating demands for future land uses according to the suitability of locations. Evaluating suitability focuses on the question whether the flood risk for the location concerned is tolerable and acceptable. Existing zoning regulations in state spatial planning laws provide the necessary regulatory framework (Kanonier, 2005). Flood risk evaluation and the subsequent

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land use decisions are usually based on the spatial extension of flood events with a defined level of occurrence (e.g. 100-year flood), thus regarding hazards rather than vulnerabilities.

Despite significant progress to halt the continuous upward trend in the exposure of people and assets in flood-prone areas, settlement development, however, remains the strongest driver of flood-related economic damage and losses (Elmer et al., 2012). In particular the unchecked increase in damage potential in extreme hazard areas beyond the regulated flooding zones (e.g. 300-year flooding areas where land development is not regulated by statutory provisions in spatial planning laws) provides a fundamental challenge for policy makers and illustrates the need to anticipate settlement development in floodplains and to develop risk-based spatial planning approaches (see among others Hess, 2011; Greiving, 2002). Risk-based spatial planning not only refers to hazards but also to vulnerability and potential damages when considering future land uses. A risk-based approach to spatial planning is calling for additional information, not only about hazards but also concerning hazard exposure, sensitivity and adaptive capacity.

Against this background the authors present an analytical framework for a GIS-based assessment of settlement dynamics in 300-year flooding areas. Based on empirical findings from three Austrian case studies the paper discusses options of implementing a risk-oriented approach in flood-related spatial planning. The contribution addresses the following research questions:

- What is the influence of settlement change in floodplains on future flood hazard exposure?
- What are the main driving factors of settlement growth in floodplains?
- What are (spatial planning) options to coordinate settlement development in floodplains and minimize the increase in damage potentials?

METHODS

This paper is based on empirical findings which were developed in the research project "RiskAdapt – Anticipatory Flood Risk Management under Climate Change Scenarios: From Assessment to Adaptation". In the course of this project the authors conceptualised and applied a framework for tracing settlement trajectories in floodplains and assessing future flood hazard exposure (for the year 2030). Combining elements of scenario-planning, zoning and hazard exposure mapping and integrating different forms of knowledge (scientific, local, practical) on floodplain development, the framework was empirically tested in the following three Austrian case study municipalities to assess future changes in hazard exposure: Gleisdorf (Styria), Altenmarkt im Pongau (Salzburg) and Perg (Upper Austria). The results were presented in stakeholder workshops (involving academics and practitioners from spatial planning and water management as well as local and regional decision makers) and used as inputs for the discussion of anticipatory adaptation measures.

To assess future changes in flood hazard exposure, the current exposure of risk elements needs to be known. Therefore, in a first step, the calculated flooding areas and inundation depths for 100-year flood events (HQ_{100}) and 300-year flood events (HQ_{300}) were intersected in ArcGIS with the (geo-referenced) federal building and housing register (2013). Based on the attributes "type of building" and "built-up area" it was determined to which extent e.g. residential, commercial, industrial or public buildings are exposed to the respective flood hazard scenarios.

In a second step a scenario of settlement development (in potentially flood-prone areas) was generated for each case study until the year 2030. Based on the analysis of census and economic data as well as spatial planning instruments (i.e. municipal zoning plans and regional development plans) we calculated population and household trends, the availability of building land reserves and the expected demand for housing and commercial or industrial land uses. The settlement scenarios were complemented by in situ knowledge of local decision makers (mayors, chief officers and heads of the municipal building authorities) and the municipalities' spatial planning consultants. In the course of in-depth interviews they were asked i) to comment on expected trajectories of land use change in their municipality, ii) to identify priority areas of settlement development and iii) to specify the development of vacant building plots or the expected demolition of buildings until the year 2030. Their input was used to check the plausibility of the scientific assumptions and to increase the robustness of the exposure scenarios.

In a third step, the settlement scenarios were mapped in ArcGIS (see Figure 1) based on the nomenclature of the building and housing register (i.e. each new point feature was assigned attributes regarding the expected building type and built-up area). The digital cadastral map was used as a reference frame to ensure the best possible localisation of the new buildings within the building lot.

The above-outlined assessment of future exposure was presented as part of an integrated flood risk assessment in each case study area in the form of scientist-stakeholder workshops (see Löschner et al., 2015). The aim of the workshops was to discuss the assessment and management of current and future flood risks, in particular by i) reflecting determinants of risk based on different scenarios (maps), ii) identifying/verifying local context conditions and pre-existing policy processes, and iii) developing and prioritizing adaptive measures for extreme flooding scenarios.

To stimulate discussion, the workshops began with a presentation of the quantifiable results of the flood risk assessment. This scientific input was delivered in an interactive setting via plotted maps and aimed at providing an impetus for the discussion and development of adaptation measures in a World Café setting. Accordingly, the discussion was grouped into three roundtables (with three to five representatives) each having a different focal point

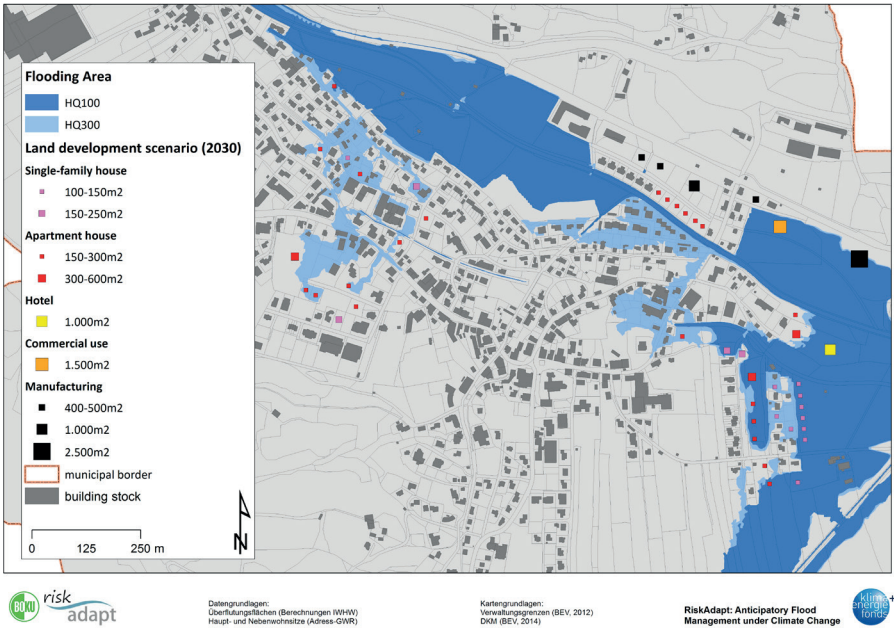

Figure 1: GIS-based land development scenario in potentially flood-prone areas.

(based on the cycle of flood risk management): structural measures of flood protection; planning measures of flood prevention and coping measures to increase flood preparedness. At the end of the World Café, the moderators presented all adaptive measures from the roundtable discussions in the plenum. In a next step, the participants prioritized the different measures according to their own preferences.

RESULTS

This section presents key results of the exposure assessment as well as findings from the three stakeholder workshops concerning proposed planning measures of flood prevention. Based on the respective land development scenarios, the GIS-based assessment of future changes in flood hazard exposure indicates that all three case studies can expect an increase in potentially affected buildings until the year 2030 (see figure 2).

Specifically, the following findings can be derived from the analysis:

– Current protection against 100-year flood events: The current (2015) number of buildings in 100-year flooding areas reflects the effectiveness of the local flood-protection scheme. In the case of Gleisdorf current building stock is only marginally affected (due to a retention basin and linear flood protection measures). In Perg, on the other hand, where flood protection infrastructure is largely missing, more than 175 buildings with a total area of around 4 ha are flooded in HQ_{100}.

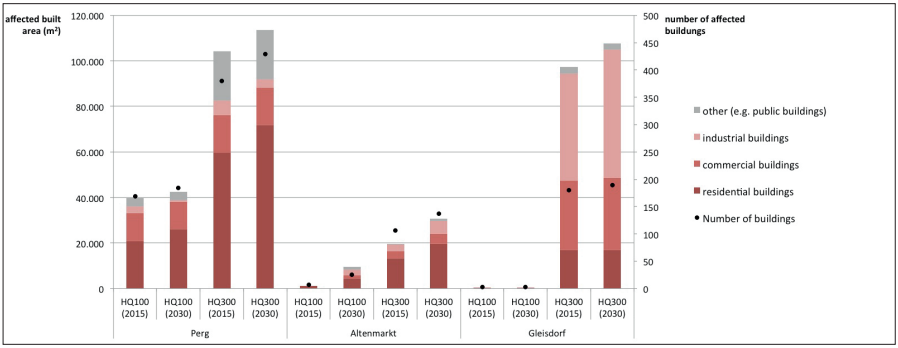

Figure 2: Buildings located currently (2015) and in the year 2030 in 100- and 300-year flooding areas

– Current exposure to 300-year flood events: All three cases have large building stock (2015) in 300-year flooding areas. In Gleisdorf, the exposed buildings consist mainly of large-scale commercial and industrial buildings which are located adjacent to the flood-protected areas. In the other two case studies the potentially affected buildings are overwhelmingly residential buildings (i.e. single-family homes or apartment buildings).
– Future settlement development in 100-year flooding areas: Depending on state planning law and local zoning plans, the three municipalities can expect varying land development in 100-year flooding areas until the year 2030. According to the scenario in Gleisdorf no new buildings will be erected in these areas. In Perg around fifteen new (apartment) buildings shall be built until 2030, in Altenmarkt around eighteen (residential, commercial and industrial buildings) shall be developed, leading to a sharp future increase in flood hazard exposure in 100-year flooding areas.
– Future settlement development in 300-year flooding areas: In all municipalities high settlement dynamics can be expected in 300-year flooding areas until 2030. In Perg, future land development in these areas (50 buildings/ca. 9.400 m²) is mainly due to the construction of small-scale residential buildings. In Gleisdorf, on the other hand, a total of nine new large-scale manufacturing and commercial buildings (total area of around 10.400 m²) can be expected; whereas in Altenmarkt future land development (30 buildings/ca. 11.300 m²) reflects a mix of both residential and commercial/industrial uses.

Despite differences in topography, land use and hazard potential, two general conclusions regarding the driving factors of future flood hazard exposure can be drawn from the comparison of the three case studies. First, the different type and dynamic in future land development in flood hazard areas indicates that increases in flood hazard exposure are to a large extent determined by the kind of building land (residential, commercial etc.) displayed in the zoning plans. This becomes evident from the average area affected per building (see figure 2), as it shows that the three municipalities set different priorities (e.g. commercial/industrial vs. residential land uses) in land development. Secondly, findings indicate that future flood

hazard exposure depends on the supply of suitable building land (i.e. the amount of vacant lots and development areas). While some municipalities have the possibility to provide building land in areas outside of flood hazard zones, others are constrained i.a by alpine topography and thus have no alternative but to develop valley basins all the while keeping the hazard exposure and the flood risk as low as possible.

These constraints were also partly reflected in the stakeholder workshops. Along with structural measures of flood protection as well as coping measures to increase flood preparedness, the stakeholders proposed a range of planning measures to mitigate the likely future increase in flood hazard exposure. In sum there was a strong consensus to display 300-year flooding zones in local land use plans in order to improve the information base for extreme flood events. To reduce an increase in damage potential in hazard zones many participants also demanded that extreme flood events should be considered in issuing building permits, in order to foster flood-proof building adaptations in these areas. Finally, workshop participants advocated a harmonization of hazard data available, more widespread application of local land use plans to better allocate land for retention basins or flooding corridors and to allow for a gradual land development, from low to high flood hazard areas. Generally the proposed planning measures can complement existing flood-related statutory provisions in spatial planning laws.

CONCLUSIONS

The findings presented were generated on the basis of case study analyses. As all case studies can expect high population, economic and settlement growth until the year 2030 they each face an increase in flood hazard exposure. However, the different levels in increase indicate that "context matters". Development options are strongly influenced by topographic conditions. The amount of land suitable for permanent settlement is a limiting factor for spatial planning in general and flood-related planning in particular. Besides topography the availability of suitable building land, i.e. vacant lots and development areas, inside and outside of potential floodplains is a key driver of future flood hazard exposure. Where alternatives to floodplain development are rare an increase in flood hazard exposure can be expected, especially in areas where building bans are not in force due to low probability and intensity of flooding. Finally, increases in flood hazard exposure are to a large extent determined by the kind of development intended. As the three cases were chosen to reflect different spatial types (i.e. alpine, peri-urban, urban) the results concerning the drivers of settlement growth in floodplains seem to be generally applicable to other floodplain situations. The respective characteristics of flood hazard, however, are unique to each case.

Despite fundamentally different spatial contexts, the results of the stakeholder workshops show that preventing an increase in damage potential is a challenge common to flood-prone municipalities. The proposed planning options, however, only partially reflect the increase of flood hazard exposure caused by settlement growth both in areas with low flooding probabili-

ty (i.e. 300-year flooding areas) and in areas of residual risk (i.e. areas protected up to a certain degree of flooding). Proposed measures, like harmonizing hazard data or allocating land for retention basins or flooding corridors focus on flood hazards rather than on vulnerabilities. A risk-based approach in flood-related spatial planning calls for an adjustment of land use intensities (influencing flood hazard exposure) according to the probability and intensity of flood hazards. Land use adjustment in floodplains is reflected in proposed measures like considering extreme flood events in issuing building permits or zoning land use intensities according to the level of flood hazards. Furthermore, local development planning fits into the requirements of a risk-based planning approach. Local development plans are implemented to specify the layout of building land in areas to be developed, thus enabling regulations to ensure flood-adapted buildings and infrastructure. Participatory development planning is able to spread information about existing flood risks and thus contributes towards increasing risk awareness of people involved. Collaborative approaches integrating flood protection and development planning offer possibilities to reduce an increase in damage potential by reducing hazard exposure and raising adaptive capacity.

In order to cope with settlement dynamics in floodplains flood managers will have to broaden their portfolio and have to move beyond flood protection (via technical measures) and risk prevention (via the allocation of land uses) and strengthen (local) adaptive capacities, including the leverage of spatial planning instruments to develop flood-adapted buildings and land uses. The EU Flood Directive (2007/60/EC) provides a strong impetus for the shift towards an integrated flood risk management. The directive is currently in the final stage of implementation with flood risk management plans being completed. As flood risk management plans aim to reduce the likelihood and the adverse consequences of flooding measures of risk-based spatial planning should be considered in order to correspond to the demand of White (1942) to “readjust land occupance and floodplain phenomena in a harmonious relationship”.

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