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Flood Risk Mitigation by Spatial Planning—Lessons Learned From Municipal Consultation

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ABSTRACT

The paper investigates which information on flood risk is needed for local land-use planning and how a risk-based planning approach can be implemented. The article is based on the results of a municipal consultation meeting at which German municipalities presented their planning cases in flood-prone areas. These cases included the conversion of existing settlements and buildings and new developments on previously undeveloped land. The team of researchers conducted pluvial and fluvial flood risk assessments based on water depth and flow velocities and analyzed the planning documents. On this basis, we advised the municipalities regarding risk-based planning. The flood event that hit the German states of Rhineland-Palatinate and North Rhine-Westphalia in mid-July 2021 increased municipal awareness for flood-sensitive planning. The consultation has confirmed that the biggest challenge is managing flood risk in existing built-up areas. The extreme event changed the flood statistics and thus the assessment basis, but municipalities seek legal certainty for decision-making. Currently, the lack of a clear planning basis creates uncertainty but also poses opportunities for change. In this context, we recommend, with reference to good examples from other European countries, an orientation towards the precautionary principle and the consideration of extreme flood scenarios.

1 | Introduction

Flood risk management in all its dimensions is often related to land—as a predominant pluvial or fluvial flood risk is location-specific although climate change may question the validity of existing fluvial and pluvial flood hazard maps. Exposure and vulnerability to disasters are usually determined by human activities in flood-prone areas and can be influenced by—predominantly local land use decisions (Burby 1998; Godschalk et al. 1999; World Bank 2017; Greiving et al. 2023, Dyca et al. 2024). In general (see Greiving et al. 2006; Struik et al. 2015; King et al. 2016; Freudenberg et al. 2016; Word Meteorological Organization 2016; Poljanšek et al. 2017; The Australian Institute for Disaster Resilience 2022; Der Arkissan et al. 2022; Potočki et al. 2022; Dyka et al. 2024), spatial planning with its formal instruments such as designations in regional plans and urban land-use plans should be responsible for or at least contribute to actions that aim to

— Mitigate the impact of a flood hazard (e.g., by creating retention basins, diverting run-off, or improving the rainwater infiltration capacities).

[Correction added on 21 May 2025, after first online publication: Due to a typographical error, author name Stefanie Wolf has been corrected.]

— Reduce the exposure of vulnerable land uses, such as human settlements (e.g., by constructing structural flood defense systems, keeping flood-prone areas free from further development, or relocating existing settlements to safer areas).

— Reduce existing or avoid future vulnerabilities (e.g., by setting building standards such as minimum elevation heights, prohibiting basements, or banning certain specifically vulnerable infrastructures).

Except for the relocation of settlements, the approaches described are primarily effective for new structural developments. The major challenge is to transform existing settlement structures to become flood-adapted. The reconstruction phase after flood events is an obvious window of opportunity for "building back better" (UN-ISDR 2015; Birkmann et al. 2023). However, the adaptation of existing structures faces high financial barriers (OECD 2016), conflicts with the preservation of the built heritage (UN-Habitat 2021; Ziegler et al. 2024), lack of technical and human resources in cases of small and medium-sized municipalities (Surminski et al. 2016; Fünfgeld et al. 2023) and the often reluctant attitude of residents regarding both, upgrading of existing buildings and relocation to safe places (Kisseler et al. 2023; Truedinger et al. 2023; Dillenardt and Thieken 2024).

To take measures, spatial planning authorities depend on an evidence basis to reduce flood risks according to a predetermined acceptable risk level (Haimes 2009; van Westen and Greiving 2017). This is where hazard and risk assessments and maps come into play under the EU Flood Risk Management Directive (The European Parliament and the Council of The European Union 2007; Meyer et al. 2012; de Bruijn et al. 2015; Kimura et al. 2023). In several countries (including Germany), these maps provide not only information for spatial planning authorities but also contain binding elements (so-called "hazard zones") (Fell et al. 2007; Schmidt-Thomé and Greiving 2013).

1.1 | Review of Spatial Planning Approaches to Natural Hazards in European Countries

Due to the varieties of natural hazards and risks patterns and the differences in regulative and planning approaches to (preventive) disaster risk management in European countries, no "one size fits all" solutions are available. Nevertheless, good practice approaches and experiences from multiple cases—as described in this article but also from other European countries—may have the potential to be tested and applied in other regions to support prevention-oriented decisions on land use.

Risk management approaches vary considerably among the European countries, and good practice examples of risk management approaches, including spatial planning, can be found in countries all across Europe. These approaches encompass spatial planning as well as other measures, such as disaster management plans and procedures. (Cantergiani et al. 2021; EEA—European Environment Agency 2017, 50–66,116 ff; De Groeve et al. 2014, 67 f.; Poljanšek et al. 2017, 422–430; Poljanšek et al. 2019, 154).

There are several good practices, especially regarding spatial planning (Cantergiani et al. 2021):

- Integration of disaster risk management (DRM) in planning laws (e.g., for floods: Austria, FMST—Federal Ministry for Sustainability and Tourism 2018; Germany, Thieken et al. 2016; Denmark, Jebens et al. 2016). Mainstreaming risk management into those legal frameworks that are relevant for exposure and vulnerability to floods can contribute to flood risk management as water management authorities lack the legal competences to manage land.
- Primary integration of risk assessment into spatial planning processes (van Herk et al. 2011; SCCA—Swedish Civil Contingencies Agency 2019). Importantly, planning authorities lack the competencies to assess flood risks on their own and are dependent on information from water management authorities. However, the effectiveness of integrating risk information into spatial planning depends on the binding nature with which this information must be used for planning processes. Hazard-zone maps that have legally binding effects are in force in Austria, France, Italy, Switzerland, and Germany—floods only. Hazard maps without binding effects exist, for example, in Greece, Spain, and the United Kingdom.
- Territorial approach/multihazard zoning as a basis for planning decisions (e.g., Austria, BMLFRW—Bundesministerium Land-und Forstwirtschaft, Regionen und Wasserwirtschaft 2024; Switzerland, BAFU—Bundesamt für Umwelt Schweiz 2020; France, Mancebo 2009). Given the interactions between different types of extreme events (e.g., landslides/rock falls triggered by heavy rainfall or pluvial flooding rainfall as causing factor for river floods in small catchments) it is recommended to base planning decisions on multi-hazard zoning that are ideally informed by coupled models.
- Innovative strategies (no regret strategies; retreat; burden sharing) (e.g., retreat in Austria, Schindelegger 2019a, 2019b; Germany, Greiving, Hurth, et al. 2018; Greiving, Juan, et al. 2018). Traditionally, spatial planning mitigates primarily future risks. Existing flood risks are related to built-up areas. Therefore, retreating from endangered areas is potentially the most effective measure to reduce existing risks but is at the same time often very controversial due to the relatedness of the population to their livelihoods. Consequently, stakeholder involvement (Defra—Department for Environment, Food and Rural Affairs 2011) plays a crucial role in acceptance building.
- Anthropogenic climate change has increased the likelihood of extreme precipitation and the associated increase in frequency and magnitude of river floods (high confidence (IPCC 2022). Thereby, climate change should be considered for flood risk management. Flood risk management and climate change adaptation actions and concepts should be coordinated: mainly for floods, due to the requirements of the second generation of flood risk management plans (e.g., Bulgaria, Denmark, Germany; Sweden, United Kingdom; see EEA—European Environment Agency 2017; ECA—European Court of Auditors 2018).

1.2 | Spatial Planning Approach to Flood Hazards in Germany

Within the European Union, the Flood Risk Management Directive sets a common legislative framework for flood risk assessments and related flood hazard and risk maps (The European Parliament and the Council of The European Union 2007), the implementation of which in Germany is up to the water management authorities (see Art. 74 German Federal Water Act, WHG). This national water management framework, however, does not address the role of spatial planning in flood risk mitigation. According to Section 76 of the Federal Water Resources Act (WHG—Wasserhaushaltsgesetz), floodplains of at least a flood event of a statistical reoccurrence probability of once in 100 years (HQ_{100}) must be defined and mapped as flood zones (WHG §78). The designation of new construction areas is prohibited in these flood zones (WHG §78).

In the field of spatial planning in Germany, the German Federation has used its legislative power to enact a Federal Regional Planning Act (Raumordnungsgesetz—ROG). The ROG intends a two-tiered structure within the federal states: first, spatial planning at the federal state level, and second, regional planning (Article 8 § 1 ROG). The spatially and factually determined objectives of regional plans are binding for all public planning authorities, including water management and local municipalities. The German municipal urban land use planning is determined by the Federal Building Code (Baugesetzbuch, BauGB) and comprises a more strategic and conceptually oriented preparatory urban land use plan for the entire area of a municipality (Flächennutzungsplan), and a legally binding land use plan (Bebauungsplan) for new development zones. Its designations on the permissible type and dimensions of land uses, buildable land, and transport areas are the basis for granting building permissions. That is why the German planning system belongs to the so-called "conforming" systems (Rivolin 2008; Reimer et al. 2014; Stein 2017).

On September 1, 2021, the so-called Federal Spatial Flood Protection Plan ("Bundesraumordnungsplan Hochwasserschutz", BRPH) came into force (BMI—Bundesministerium des Inneren und für Heimat 2021). Spatial objective I.1.1 BRPH introduces the principle of risk-based planning into German spatial planning: "In spatially significant infrastructure and settlement development, the risks of floods must be examined [...]; in addition to the probability of occurrence of a flood event and its spatial and temporal extent, this also concerns the water depth and flow velocity. Furthermore, the different sensitivities and desired levels of protection of types of land-use are to be considered for the examination of flood risks" (BMI—Bundesministerium des Inneren und für Heimat 2021, 4). This plan represents a remarkable shift in planning policy, as decisions on flood risk mitigation have previously been made based on flood hazard only, but not the flood risk, as the vulnerability component was usually not considered (Prenger-Berninghoff 2017).

This paper aims to explore how risk-based planning can work in practice for various typical urban planning cases and building regulations that are part of legally binding land-use plans. Land-use plans are also used for adapting existing developments. The planning cases address

1. Rezoning of existing settlements (e.g., from mixed uses to residential use).
2. Conversion of existing buildings.
3. New development on previously undeveloped land.

The specific reason for many municipalities in Germany to prioritize flood issues in spatial planning was the devastating flood event of mid-July 2021. Between July 13 and July 16, precipitation summed up to 150 mm in 72 h in the Eifel region and led to a large-scale flood event and vast destructions in the federal states of North Rhine-Westphalia (NRW) and Rhineland-Palatinate (RLP) (Schäfer et al. 2021; Mohr et al. 2023). Especially in the low mountain ranges of the Inde Valley (NRW) and the Ahr Valley (RLP), flash floods formed due to the valley morphology (Schüttrumpf 2021; Schüttrumpf et al. 2022). The overall economic damage for Germany is estimated to be over 30 billion euros, with damages of over 12 Billion Euros in NRW and damages of over 18 billion Euros in RLP (BMI und Bundesfinanzministerium 2021). The Ahr Valley was most severely affected with over 130 flood-related fatalities (Thieken et al. 2023), multiple building damages (Korswagen et al. 2022; Lemnitzer et al. 2023), and severe infrastructure damages (Kreienkamp et al. 2021; Burghardt et al. 2022; Szymczak et al. 2022). Similar situations were found in NRW, where a hospital had to be evacuated (Wiesehahn and Kaifie 2024). The hospital is located outside the designated flood zone and was prepared to withstand an extreme event ($HQ_{Extreme}$) according to official flood hazard maps. Discharge values for $HQ_{Extreme}$ differ within the state of NRW between reoccurrence periods of more than once in 200 years and once in 1000 years (flussgebiete.nrw 2024). However, the inundation area of the flood event of mid-July 2021 exceeded previously mapped extreme flood limits ($HQ_{Extreme}$) (Kisseler et al. 2023; Weber et al. 2023). The flood of mid-July 2021 revealed Germany's poor resilience due to long outages of critical and sensitive infrastructures (Manandhar et al. 2023). Three years after the flood, there are still ruins of buildings, and an increased vacancy rate in flood-affected areas can be observed. Concomitantly, a controversy arose concerning the relocation of critical and sensitive infrastructure, and even of residential areas in severely flood-prone areas (Kisseler et al. 2023; Truedinger et al. 2023). Updated flood zones have already been designated and issued for the river Erft based on the new HQ_{100}. However, the subsequent correction of the established flood zones also poses challenges for local authorities. Although existing buildings are not affected by the provisions of Art. 78 § 1 and 2 WHG under current water law (Federal Administrative Court, BVerwG, judgment of June 3, 2014–4 CN 6.12—EA para. 10–14), the updated risk information for existing buildings can trigger a so-called "planning requirement" (Bruckwicki 2017). Due to climate change, flood statistics are very likely to shift due to a higher probability of extreme events in the future (Kundzewicz et al. 2010; Tradowsky et al. 2023), a risk-based approach is more forward-looking than the existing static approach that is limited to the areas that are prone to the HQ_{100} and disregard further variables like flood depth, velocity, and the entire vulnerability dimension (Greiving et al. 2023).

The paper presents the results of municipal consultation on the consideration of the aforementioned objective of risk-based planning in local land-use planning. It is guided by the following research questions:

1. What information on flood risk is needed and what quality standards are required for a local land-use plan?
2. How can risk-based planning be implemented in the practice of local land-use planning?
3. What options do local planning authorities have for flood risk mitigation in urban land-use planning?
4. What are the barriers and success factors in regard to risk-based planning?

2 | Methods

2.1 | Evaluation of Urban Planning Documents and Consultation Event

Our paper is based on a participatory municipal consultation event (Fleischhauer et al. 2012). Taking advantage of existing connections within the government-funded KAHR-Project with the city region of Aachen, NRW, Germany, the event was conducted on May 23, 2024. A total of 46 people took part—mainly from small and medium-sized municipalities, but also from consultancy companies and regional water management authorities, which indicate a high interest in external scientific advice on how to handle flood risks in urban land-use planning.

Figure 1 presents an overview of the city region, its flood hazard profile, and exposed built-up areas. Table 1 specifies the main characteristics of the risk settings that were covered by the participants.

Within the city region, municipalities had the opportunity to apply for consultation regarding flood risks in the context of ongoing land-use plan approval procedures that address the typical aforementioned planning cases. Documents were reviewed beforehand regarding flood risks in the context of spatial planning and water resources management by members of the KAHR-Project, including the conduct of a flood hazard rating (see section on GIS-based flood risk assessment).

We evaluated the land-use plan documents about the urban development concept in general and the consideration of flood risks in particular. The subjects of the evaluation were the plan maps, textual designations, and the rationale section including the environmental report. The criteria for assessing the quality of the plans were, in addition to compliance with general urban planning requirements, in particular their conformity with the objectives of the Federal Spatial Flood Protection Plan and the validity of the evidence base about the analysis of flood risks.

After an introductory presentation on risk-based planning, the consultation event itself consisted of three sessions in which representatives of various planning departments presented their planning cases and addressed open questions regarding the evidence basis on flood risks, but also the legality of their proposed flood risk mitigation concepts. All typical planning cases (rezoning, conversion/extension of existing buildings, and new developments) were addressed. This was followed by the presentation of our analyses and recommendations and finally an open discussion with all participants.

2.2 | GIS-Based Flood Risk Assessment

A flood hazard rating after Hydraulic Engineering (2006) Equation (1) was carried out for submitted development plans based on the $HQ_{Extreme}$ for areas prone to fluvial flooding. For land-use plans of areas far from rivers, the flood hazard rating was carried out on the basis of results for an extreme scenario in heavy rainfall risk maps(Hydraulic Engineering 2006)

$$\text{Hazard to people}\left[\frac{m^2}{s}\right] = \text{innundation depth}\,[m] \cdot \left(\text{flow velocity}\left[\frac{m}{s}\right] + 0.5\right) \qquad (1)$$

The GIS-based flood risk assessment is conducted according to Equation (1) based on data presented in Table 3. Results display the level of flood risk for people to get injured due to water depth, flow velocity, or a combination of both (Hydraulic Engineering 2006). Results are categorized into low to extreme flood risk (Table 2) (Hydraulic Engineering 2006). To ensure broader applicability, open-source data is preferable. However, as for the case study of Stolberg, Steinweg (Figure 2), flood risk maps have been generated based on a 1D-numerical model (MKULNV 2014). Thus, corresponding flow velocities to the $HQ_{Extreme}$ inundation areas on floodplains are not published, as the 1D-numerical model only computes flow velocities within the river channel. However, the first results from high-resolution 2D-numerical modeling were available to the authors (KAHR 2024, Table 4).

3 | Presentation of Case Study Stolberg

In the following, the most relevant case, a rezoning of an existing settlement in the city of Stolberg, is presented in detail. The case study represents a highly affected area by fluvial flooding.

3.1 | Initial Situation and Spatial Context

The case study is a 2.5 ha area in the historic old town of Stolberg. To the west, the area verges on the river Vicht. The area is characterized by townhouses in block development. With three to four stories, the individual plots are very densely built up, both in height and width. Some entrances are elevated and can be reached via a few steps. The buildings date from

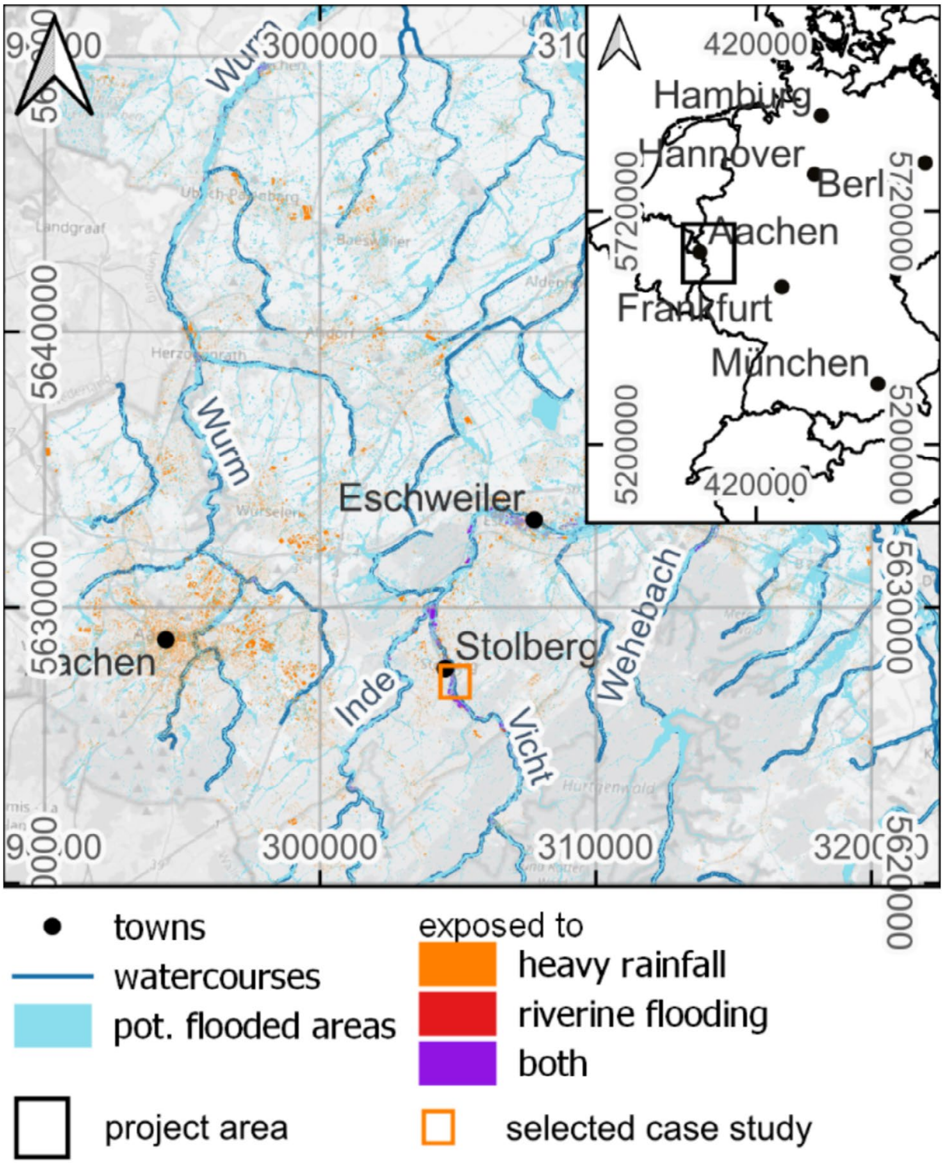

FIGURE 1 | Overview of the project area and location of the case study areas. Data sources: Background: OpenStreetMap contributors, towns: Geofabrik GmbH (2018b), waterways: Geofabrik GmbH (2018a), country boarders: ESTAT (2020), pot. flooded areas: Riverine: MUNV (2021a), pluvial: Bundesamt für Kartographie und Geodäsie. (2024). Exposed areas are determined by buildings affected by pot. flooded areas by heavy rainfall, $HQ_{Extreme}$, or both.

different construction periods. A large number of the buildings are listed as monuments or worth preserving. Unsealed open spaces are very rare—even on private property. The historic shopping street Steinweg with stores on the ground floor runs through the area. Apartments are located on the upper floors. In the side streets of the commercial street, the ground floors are also intended for shops but are mostly empty due to their lack of size and attractiveness. The upper floors are also used for residential use.

3.2 | Project and Description of Measures

To eliminate the vacant stores on the ground floors of the side streets and also to meet the interests of the building owners, it is considered to replace vacant stores with apartments. The problem, however, is that the plan area is almost entirely located in the legally designated flood hazard zone of the river Vicht. Nevertheless, inquiries exist to change the land-use plan and officially allow residential use on the ground floor. Until now, living on the ground floor was prohibited in the binding land-use plan.

3.3 | Effects of the 2021 Flood and Risk Assessment

The majority of the area (59%) lies within the designated flood zone (HQ_{100}) of the river Vicht. The first row of buildings is located very closely to the main channel. The area is quite steep with 0.84% on the main street, and was completely flooded during the flood event of mid-July 2021. Water levels reached over 2 m in areas close to the river Vicht (Figure 3, right). Risks

TABLE 1 | Overview of participating cities, towns, and institutions and their hazard profiles.

Type	City, town, or institution	No. of participants	River flood hazard profile	Pluvial flood hazard profile	Planning case
Large region/city (pop. > 100,000)	City region of Aachen	8	X	X	
	City of Aachen	4	X	X	Conversion
Medium city/ town (pop. 20,000–100,000)	Alsdorf	1		X	
	Baesweiler	3		X	New development
	Eschweiler	2	X	X	
	Herzogenrath	3		X	Rezoning
	Stolberg	7	X	X	
	Würselen	3		X	
Small city/town (pop. < 20,000)	Monschau	1	X	X	
	Roetgen	1		X	
	Simmerath	2		X	
Higher level actors	Public administration	3	—		
	Research	6	—	—	—
	Consultancy	2	—	—	—
Total	—	46	—	—	—

TABLE 2 | Hazard to people due to flooding as a function of velocity and depth after Hydraulic Engineering (2006).

Inundation depth (m) $\cdot \left(\textbf{flow velocity} \left[\frac{m}{s}\right] + 0.5\right)$	Degree of flood hazard	Description
< 0.75	Low	Caution: Flood zone with shallow flowing water or deep standing water
0.75–1.25	Moderate	Dangerous for some (i.e., children): Danger: Flood zone with deep or fast-flowing water
1–25–2.5	Significant	Dangerous for most people: Danger: flood zone with deep fast-flowing water
> 2.5	Extreme	Dangerous for all: Extreme danger: flood zone with deep fast-flowing water

are significant for the main street, the Steinweg, and extreme for the row of buildings closest to the river Vicht (Figures 2 and 3, right).

4 | Results

It is strongly recommended that residential use in the ground floor zones continue to be ruled out. The danger to life and limb is too great in case of another flood event. Instead, two planning options are proposed by the authors.

Planning Option 1 foresees the continued provision of shops and services on the ground floors and the prohibition of housing. The exclusion should be explicitly justified concerning the risk of flooding. The municipality should also invest in upgrading the public space to make the side streets more attractive. In this way, store vacancies can be eliminated. Upgrading may also include measures to unseal and green the private property along the river Vicht. Buildings that are not worth preserving could be demolished and replaced by flood-adapted buildings. The ground floor can then be connected with the first floor to a residential unit, but only provide adjoining rooms such as a kitchen, bathroom, garage, etc. In addition, doors and windows are also planned to be watertight.

Planning Option 2 foresees the demolition of the buildings in the long term. The vacant areas could be unsealed and planted.

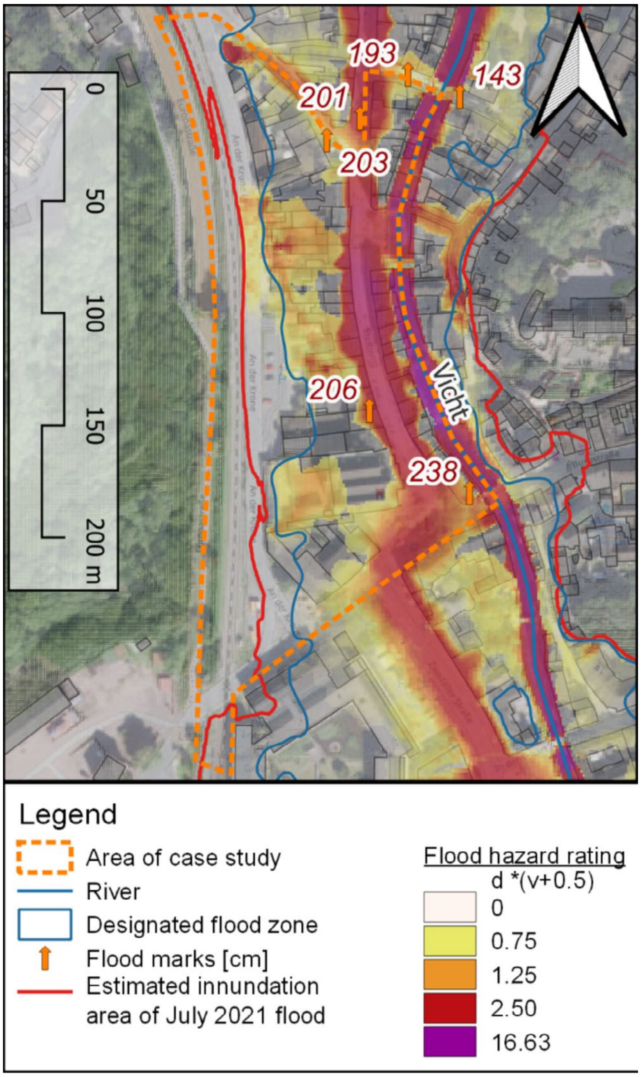

FIGURE 2 | Case study "Stolberg, Steinweg," background: Bezirksregierung Köln (2021), river: Geofabrik GmbH (2018a), designated flood zone: MUNV (2021a).

It should also be examined whether the river can be restored at this point.

Reference is made to two municipalities that have adopted a similar strategy. Due to the risk of flooding along the Triebisch stream, the town of Meissen in Saxony has preserved monuments, demolished buildings that are not worth preserving, replaced them with new flood-adapted buildings, and excluded residential use in all ground floor zones (Hartz et al. 2021). In addition, outbuildings in the backyards were demolished and the open spaces were redesigned. In the Bavarian municipality of Simbach am Inn, buildings along the river Simbach were demolished, and the course of the river was restored (Mayr et al. 2016)

After the joint discussion, the City of Stolberg has decided to continue to prohibit residential uses on the ground floors in side streets of the shopping street. In a subsequent consultation meeting of the Municipal Council with the scientists, the designations which should be made in the legally binding land-use plan were discussed to minimise flood risks and to prevent damage to people, buildings, and infrastructure as far as possible in case of future heavy rainfall or river flooding. Apart from the prohibition of residential uses at ground floors, the plan will designate minimum elevation heights in combination with the obligation to make building openings watertight. In addition, the city will look at how to increase the amount of greenery in the area by making green roofs obligatory.

5 | Discussion

In the discussion with the municipal representatives, it became clear that the municipalities want a reliable evidence basis for their planning to ensure legal certainty. This is linked to the desire for clearly defined hazard zones. The dilemma is that precisely this reliability cannot be guaranteed due to model uncertainties and the influence of climate change (Restemeyer et al. 2018; Kimura et al. 2023). Further, historical floods can

TABLE 3 | relevant scenarios for GIS-based flood risk assessment and corresponding data sources.

Case study	Relevant scenario	Data source	
		Velocity (m/s)	Inundation depth (m)
Stolberg, Steinweg	Fluvial flooding, $HQ_{Extreme}$	Preliminary model results from Felix Steudtner within the KAHR-Project	MUNV (2021b)

TABLE 4 | Overview of case study characteristics.

	Stolberg, Steinweg
Size of planning area	2.5 ha
Location	City centre
Description of flood risk	Area (59%) lies within the designated flood zone (HQ100) Degree of flood hazard by a $HQ_{Extreme}$: significant to extreme
Planning project	Residential use on the ground floor
Solution approach	No residential use on the ground floor + building precautions

FIGURE 3 | (lelft) documentation of flood marks on August 3, 2021, (right) situation after the flood at the Vicht river on August 3, 2021. *Source:* IWW.

improve the statistics only to a limited extent, as the water body and the catchment area have often changed significantly in the meantime and the climate may also have changed (DWA-M 552 2024). In addition, there is also a risk of flooding in the event of more extreme flood events outside the flood hazard zones, which are designed for an HQ_{100}. Moreover, the flood hazard is determined not only by the spatial extent of the affected area but also by the depths of flooding and flow velocities. For this reason, advanced hazard zone maps which consider these factors for determining different zones in accordance with a given hazard intensity (e.g., extreme rainfall intensity) should be used by spatial planning authorities, but are not yet common in Germany (Fell et al. 2007; Maranzoni et al. 2022; Greiving et al. 2023). That is why the authors prepared individual hazard zone maps for the municipal consultation.

Instead of probabilities, annual values (the reciprocal of the annual exceedance probability) or statistical recurrence intervals (the period in which the HQ was exceeded) are specified for urban floods (DWA-M 552 2024). The operating time of existing gauging stations, especially on second and third-order watercourses, is generally significantly shorter than 100 years. Nevertheless, to estimate flood discharges with annualities of 1/100 years (HQ_{100}) or less, distribution functions are used (DWA-M 552 2024). However, some assumptions must be made when setting up the distribution function, which is why the determined HQ_{100} or $HQ_{Extreme}$ is subject to some uncertainties (Fischer et al. 2019). Short time series, or gauge time series in which there were relevant changes in the catchment area or at the gauge, can be supplemented by results from rainfall-runoff simulations (DWA-M 552 2024). The existing uncertainty about the effects of climate change also argues in favor of more scenario-based approaches that show a corridor of future change paths (Restemeyer et al. 2018; Steen and Ferreira 2020). These requirements do not call into question the legal certainty of land use planning per se, but they do place greater responsibility on local authorities when exercising their judgment prerogatives, which they are entitled to carry out given the uncertain facts on flood hazards (Jacob and Lau 2015; BMVI 2017). Consequently, local planners must decide which flood scenario they want to base their urban planning on to take care of a resilient urban development (Scott et al. 2014; White and O'Hare 2014).

Despite the large number of recent flood events and a raised flood risk awareness, the municipal consultation has shown a great reluctance to seriously consider retreat from highly flood-prone areas. Only a few individual cases are known where this has succeeded (Mayr et al. 2016; Hartz et al. 2021). In the absence of legal requirements, the decisive factor was the provision of appropriate financial resources for setting up a buy-out program (Freudenberg et al. 2016). Interestingly, however, these buy-outs in Germany were not financed by urban development or urban renewal programs, but by financial incentives of water management authorities, which considered retreat as a more cost-efficient flood risk mitigation strategy than improved areal protection. An example in this context is the town of Simbach am Inn in Bavaria (Mayr et al. 2016). The river Simbach flows through the town, and the maintenance obligation for the river lies with the Free State of Bavaria (Wasserwirtschaftsamt Deggendorf 2024). After the flood event in 2016, the Free State of Bavaria initiated—among other things—the partial renaturation of the Simbach to improve flood protection. In order to create more space for the Simbach in the urban area, the Free State purchased land, including the demolition of individual buildings (Werner Consult 2020). The improved flood protection creates a new "Green Centre" in Simbach. The Free State of Bavaria is financing 75% of the entire project; the city will contribute 25% of the costs (Häuser 2021). According to its statement, the town would not have been able to carry out the transformation and renaturation without the financing of the Free State. Nonetheless, urban renewal programs should be capitalised better in this context (De Gregorio Hurtado 2021; Lobo et al. 2023). They would enable municipalities, opposite to completely voluntary buy-out programs, to implement a holistic resettlement program and the creation of new retention areas even in cases of single opposing land owners, without whose land the implementation of the program would make no practical sense.

Another problem for local authorities is the collision between water and planning regulations. Urban development planning and the granting of building permissions are generally prohibited within the flood zones established under water law. The responsible water authority decides on exceptions by Art. 78 WHG. However, these water law regulations only apply to first-time developments and not to existing buildings or brownfield redevelopments and do not cover areas that are prone to extreme flood events or are only affected in case of dam failures. Moreover, flood zones exist only along water bodies, but not for urban flooding caused by surface water run-off. Municipalities must have hazard maps drawn up for this purpose. Overall, there is a remarkable "levee effect" which describes a feeling of false security behind structural protection systems (Ventimiglia et al. 2020). This effect triggers additional settlement development in protected, but still flood-prone areas that cannot be prohibited by water law. Here comes the new Federal Spatial Flood Protection Plan into play which forces municipalities to consider flood risks more comprehensively by taking into account not only areas that are legally demarked as flood hazard ones. However, the consultation proved the fact that this new plan is—regardless of its binding effects—still not sufficiently known by its addressees on the local level. This underlines the need for more communication and training activities by the superior planning authorities of the German federal states. According to the discussions during the municipal consultation, liability issues seem to stimulate flood prevention by spatial planning. According to the jurisdiction of the German Federal Court of Justice (BGH, NJW 1996, p. 3208) on official liability (see Art. 34 Constitution Law in conjunction with Art. 839 German Civil Code), flood protection in planning, ordering, and implementation is a statutory task of the provision of services of general interest by self-governed municipalities. Municipalities must carry out measures that are recognizably necessary, feasible, and economically reasonable. The same applies if the municipality does not carry out flood protection measures for existing settlements. There is also an obligation to refrain from measures that are detrimental to flood protection (Kommunalagentur 2015). That could be the case if the city of Stolberg were to adjust the existing land-use plan to make the use of ground floors for residential purposes permissible as requested by some homeowners. In the event of official liability, a municipality successfully sued by owners for flood damages would potentially hold the honorary city councillors who approved the land-use plan liable. They would probably have to reimburse the costs incurred by the city because of the claims for damages. That is why this liability risk can prevent local politicians from neglecting flood protection in favor of economic development prospects.

The findings discussed are also supported by insights from the discussion of these issues in the European context (Cantergiani et al. 2021). Territories should emphasize risk prevention activities over response and reaction efforts, as the investment is significant but worthwhile. The experiences of the Dresden Region (Gerber et al. 2016; LfULG 2020; Müller 2020; Seifert 2020; RPV OEOE—Regionaler Planungsverband Oberes Elbtal/Osterzgebirge 2020) and Rotterdam (City of Rotterdam 2013; Hölscher et al. 2019; Port of Rotterdam 2024) demonstrate the necessity for authorities to prioritize long-term planning inspired by the precautionary principle as propagated by this paper since climate change may exacerbate conditions more rapidly than expected, prompting the need for proactive measures.

New methodologies for risk assessment need to be adopted, incorporating maps and systems for observation, evaluation, and scenario planning (). These methodologies should address not only long-term but also medium- and short-term risks as seen in Nouvelle-Aquitaine, ORRNA—Observatoire regional des risques Nouvelle Aquitaine 2021; GIP ATGeRi 2021) while encouraging public engagement and education, as demonstrated in Rotterdam (Bosschaart et al. 2016). For example, flood prevention areas should be designated based on hazard intensity, using criteria like flow speed and water depth, as is the case with more advanced approaches to hazard zoning presented in this paper, but is also practiced in the Dresden Region (Seifert 2020; RPV OEOE—Regionaler Planungsverband Oberes Elbtal/Osterzgebirge 2020. Furthermore, the analysis of historical data for return periods should be complemented by scenario-based methodologies, as demonstrated in the City of Pori (2010), Po River Basin (Peiró et al. 2021), and Dresden Region (LfULG 2017, 2020; RPV OEOE—Regionaler Planungsverband Oberes Elbtal/Osterzgebirge 2020).

Several studies have highlighted the importance of binding laws that govern all aspects of DRM. In this context, the City of Pori (2008) and Rotterdam (van Vliet and Aerts 2015; City of Rotterdam 2022) emphasize the need for legislation to incorporate preventive measures, maintenance schedules, and frequency of updates. The Po River Basin (Peiró et al. 2021) serves as a model for linking legal obligations to spatial planning through risk assessment. Local governance is critical for the success of any DRM strategy, necessitating that all administrative levels understand risks and allocate the necessary resources for their management, as seen in the Alpine Region (PLAN-ALP 2021; Probst et al. 2019; Schindelegger 2019a, 2019b), Andalusia (Junta de Andalucía 2014), and the Po River Basin (Peiró et al. 2021). However, the binding nature of these laws must be supplemented with alternative support from informal administrative instruments. Consequently, regional and national levels should provide local authorities with financial assistance, guidance, and knowledge, as illustrated in the Po River Basin (Peiró et al. 2021).

Effective prevention relies on knowledge applied to defining urban and development areas. Local planning processes must prioritize risks far more than they currently do, as they serve as the main regulatory tool for land use. Authorities should focus particularly on areas with buildings constructed without adequate consideration or outdated risk management practices, as not only seen in the City of Stolberg but also in the City of Pori (2008, 2010), Po River Basin (Peiró et al. 2021), and Nouvelle-Aquitaine (GIP ATGeRi 2021; Nouvelle-Aquitaine Region 2024). Potential solutions include gradual relocation, insurance, or urban rehabilitation as discussed by the example of the City of Stolberg in this paper. It is essential to note that the promotion of urban rehabilitation, along with the EU's "2050 zero land-take" (EC 2020) goal, must acknowledge climate change impacts and associated risks, guiding the redesign of cities and territories accordingly. Irregularities in urban planning have been identified and linked to increased costs. To safeguard lives while minimizing expenses, the most effective approach is to refrain from urbanizing high-risk areas, ensuring their maintenance and future safety through well-defined accountability.

6 | Conclusions

The flood event in mid-July 2021 caused reason for municipal spatial planners to act. It also increased their disaster-driven awareness of flood-sensitive planning. The consultation revealed the central challenges of dealing with flood risks in planning and showed solutions that have emerged in the dialogue between science and practice. These solutions align with good practices and experiences of other European countries. The Stolberg case has confirmed that the biggest challenge in flood risk management is dealing with built-up areas. This is where the interests of residents, retailers, cultural heritage protection, and flood protection must be weighed against each other. This also applies to the global south, whose cities are widely characterised by informal settlements that are often located in flood-prone areas. While for a long time, the focus here was on resettlement (Ajibade 2019; Arnall 2019), the spotlight is now increasingly on on-site upgrading settlements to improve their resilience to flooding without taking away people's livelihoods (Der Sarkissian et al. 2022; Du et al. 2022). Therefore, there is a need for compromises, and planning and structural flood prevention must be supplemented by behavioural precautions and emergency preparedness given the given risk for life and limb.

Advanced hazard zone maps, which consider flooding depths and flow velocities, are recommended but not commonly used in Germany yet. These more differentiated maps are important for ensuring compliance with the legal principle of proportionality (see the decision of the Federal Constitutional Court BVerfGE 23, 127, 133). Planning precautionary measures that restrict private property rights must always be determined depending on the given plot-specific flood risk and not simply on the fact that the property is flood-prone. Advanced hazard maps are therefore also relevant abroad as visible by the fact that similar approaches are used by many European countries as shown by the examples of Austria, Switzerland, and France (Poljanšek et al. 2017) and elsewhere (e.g., in many Latin American countries such as Chile and Ecuador, see Greiving et al. 2021).

However, the 2021 extreme event changed the flood statistics and thus the risk assessment basis. At the moment, we are in a state of in-betweenness in our study areas, as the event has not yet been fully hydrologically processed, and the cooperation between local planning and state water management authorities remains rather weak and scattered. Nevertheless, municipalities seek legal certainty for decision-making. Currently, the need for an update in spatial planning and the lack of a clear evidence basis create disorientation but also pose opportunities for change. Legal certainty can still be guaranteed by exercising the judgment prerogative which the local planning authorities are entitled to exercise because of the given pending evidence basis. In this context, we recommend an orientation towards the precautionary principle and the consideration of extreme flood scenarios. The precautionary principle is laid down in Art. 20a of the German Constitution, but also addressed by Art. 191 of the Lisbon Treaty on the Functioning of the European Union.

While the New Federal Spatial Plan Protection Plan obliges German municipalities to take comprehensive account of flood risks, they do not have the know-how to accomplish this mission. Hence, there is a strong requirement for communication and training activities, particularly, for small and medium-sized municipalities, to make informed decisions and meet their responsibility to ensure a resilient urban development that avoids liability risks. This is exactly what the KAHR project is about. However, the duration of the project is limited, and it would be desirable if municipal consultation would be made permanent.

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Data Availability Statement

Data available on request due to privacy reasons.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.