

Integrated planning for reducing flash flood risk through blue-green infrastructure

A guideline using the city of Amman in Jordan as an example

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Acknowledgments

We would like to thank our Jordanian research partners for their valuable contributions to, and excellent cooperation in, our research. The Federal Ministry of Research, Technology and Space (BMFTR) funded the project CapTain Rain as part of the funding measure “CLIENT II – International Partnerships for Sustainable Innovation” in the context of the framework program “Research for Sustainable Development” (FONA) under the funding code 01LZ2006A-F. The responsibility for the content of this publication lies with the authors.

Imprint

Publisher

Institute for Social-Ecological Research (ISOE)
Hamburger Allee 45
60486 Frankfurt am Main, Germany
www.isoe.de

The PDF version is freely available at www.isoe.de/en/research-and-teaching/publications (Open Access)
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Suggested Citation:

Schumann-Hindenberg, Daniel, Ahmad Awad, Katja Brinkmann, Linnea Fölster, Martina Winker (2025): Integrated planning for reducing flash flood risk through blue-green infrastructure. A guideline using the city of Amman in Jordan as an example. DOI: 10.5281/zenodo.17351802

Funding reference: Federal Ministry of Research, Technology and Space (BMFTR), 01LZ2006A-F.

October 2025, Frankfurt am Main

Project partners



With funding from the:



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1 Introduction

Jordan is one of the world's most water-scarce countries and has increasingly faced flash floods caused by heavy rainfall, often resulting in severe damage. The CapTain Rain research project ("Capture and Retain Heavy Rainfalls in Jordan" – www.captain-rain.de) aimed to address this challenge by enhancing rainwater retention and minimising flood-related risks. This guideline summarises the key outcomes of the participatory development of adaptation measures for climate change and flash flood protection, undertaken as part of the interdisciplinary CapTain Rain initiative.

The adaptation of urban areas to the risk of flash floods encompasses a range of measures, including technical solutions and other instruments such as behavioural prevention and communication. While large-scale technical measures, such as the construction of additional culverts, may offer a partial solution, they are constrained by limitations in construction methods, costs and the availability of space. Consequently, a comprehensive approach that encompasses a diverse array of measures on public and private land is necessary.

A variety of measures for the retention, safe discharge, storage and use of heavy rainfall have been documented and their individual characteristics understood. These measures can be applied to various types of urban infrastructure, including roads, parks, residential areas and drainage systems, and they can be implemented at different scales, ranging from neighbourhoods to catchment areas. Using multifunctional land use and blue-green infrastructure (BGI) to mitigate the impact of heavy rainfall is a promising additional approach, particularly in urban areas where land is under high pressure. Such measures utilise natural features, such as wetlands, green/blue roofs and rain gardens, to manage rainwater through absorption, filtration and storage. However, planning authorities often neglect the multifunctional aspects of BGI and its positive side effects, mainly due to a lack of knowledge. When identifying suitable measures, the various needs and perspectives of society must be considered and integrated by designing and evaluating promising adaptation measures in collaboration with local stakeholders and officials, who have different areas of responsibility. Priority areas must be identified and appropriate measures integrated in an iterative process that takes into account baseline data on site conditions and incorporates information and knowledge from scientists, practitioners and stakeholders. It is very important to obtain robust initial ideas by involving stakeholders from relevant institutions as well as citizens. This guideline supports the identification and planning of measures to reduce the risk of flash flood damage. Outlining a step-by-step planning approach, it serves as a practical reference for urban and infrastructure planners – especially those in the city of Amman (e.g. the Greater Amman Municipality, GAM) – as well as other stakeholders involved in fields ranging from road construction to urban master planning.

An initial site analysis, incorporating available data and spatial maps, is a crucial first step in understanding local conditions. In parallel, defining clear planning goals will help determine the scope of potential measures and facilitate informed decision-making. In this context, geospatial data as well as hydrological and hydraulic assessments play a central role in evaluating both needs and potential impacts. In areas with limited data availability, planning goals and content must be adapted accordingly. Emphasising available data, collaborating with local stakeholders, and exploring alternative sources – such as OpenStreetMap or freely accessible satellite imagery – can help address data gaps. This adaptive planning approach enables progress and resilience even in data-constrained settings.

1.1 Overview of the stepwise planning process

The structured approach to integrating new projects into existing landscapes or urban environments takes into account various factors, including infrastructure analysis, stakeholder engagement, scenario planning and impact assessment. Although it is primarily intended for urban planners and environmental managers, it can also help other stakeholders gain a better understanding of the planning process and their respective roles and responsibilities. The process is divided into three main steps: **Data collection and analysis, planning and localisation, and development and strategy** (Figure 1).

1. Data collection and analysis

- Definition of planning areas and data collection: Definition of the (catchment-) area for the planning process and procurement and processing of geographical data for the area.
- Categorisation of land use types: Categorization of the identified planning areas based on their land use types.
- Assessment of area potential: Assessment of the potential of these areas for integration into BGI.

2. Planning and Localisation

- Stakeholder engagement: Engaging stakeholders and prioritizing actions based on their input.
- Planning goals: Identification and prioritization of collective planning goals among stakeholders.
- Measures for flash flood protection: Identification of suitable measures that have the potential to decrease flash flood damages as well as the other identified goals.
- Determination of entry points and focus areas: Integrating additional geospatial-data (infrastructure, geology, and land cover) and results from hydraulic and hydrological analysis (e.g. flood prone areas) to evaluate potential hazards and determine the focus areas for detailed planning.
- Selection and localisation of measures: Selecting and localizing spaces within focus areas for the implementation of measures, taking into account specific planning goals.

3. Development and Strategy

- Scenario Development: Developing different scenarios for potential implementation of measures.
- Impact assessment and readjustment: Evaluating the different scenarios and strategic importance of the selected areas.
- Integration into Planning Concepts: Transferring the selected focus areas of interest and scenarios into concrete spatial planning concepts.
- Development of Detailed Plans: Creating detailed plans for the implementation of the selected areas

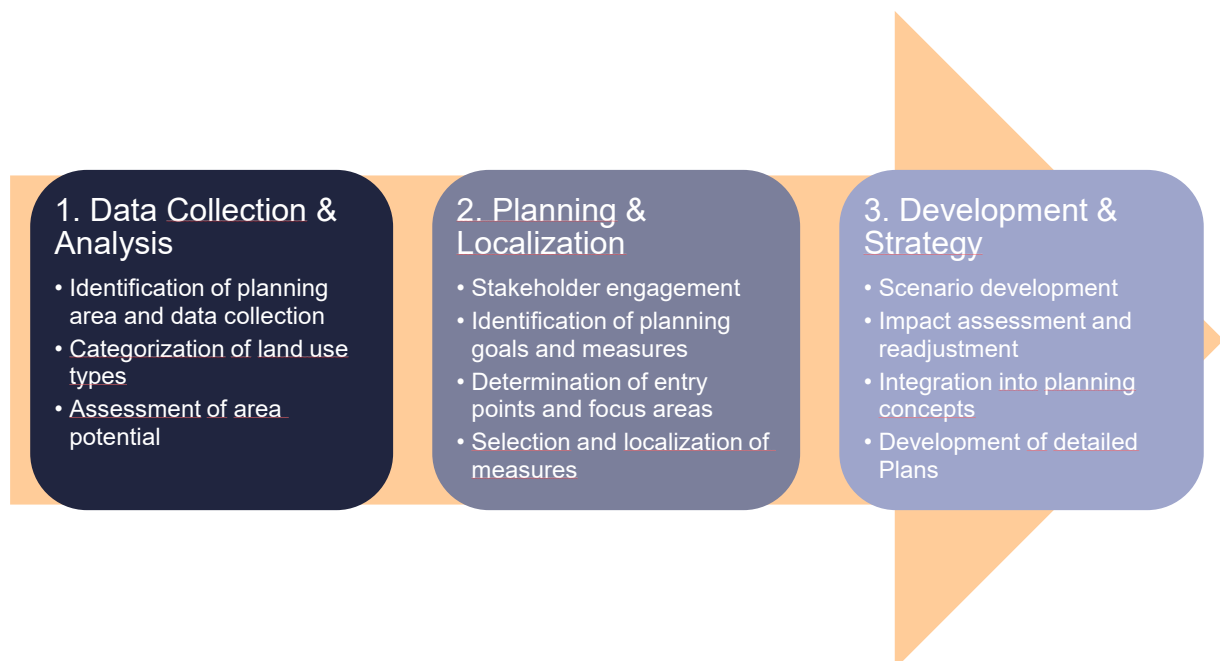


Figure 1: Overview of the stepwise planning process comprising data collection & analysis, planning & localization, and development & strategy.

2 Data collection and analysis

2.1 Identification of planning areas and data collection

The first step is to determine the planning area, which may be a catchment or sub-catchment area, or a specific urban area. The relevant geographical data for the subsequent analysis of this area is then collected and processed using a geographic information system (GIS). For our case study in Amman, the capital of Jordan, the planning area is the central catchment area, which extends to the area known as “Downtown Amman” (approximately 150 km² in size) and is characterised by high levels of urbanisation. The following datasets and maps were used:

Catchment areas: The total catchment area of Downtown Amman has been divided into eight sub-catchments, derived from hydrological analysis and topographic information. Hydrological modelling provides additional information for each sub-catchment, such as average slope, time of concentration and curve number as well as soil type. The sub-catchment polygons are also used in further processing the land use data and assessing the area’s potential.

Topography: Amman is situated on the East Bank Plateau, which is characterised by three major wadis running through it. The topography is distinct and rough, with elevations ranging from 471 to 1,101 metres above sea level (a.s.l.). On average, elevations increase from east to west and from north to south. The topographical roughness of the city, with varying elevations over short distances, gives rise to its distinctive hill-wadi systems. For example, downtown Amman is located in the Ras Al-Ain wadi, surrounded by seven hills.

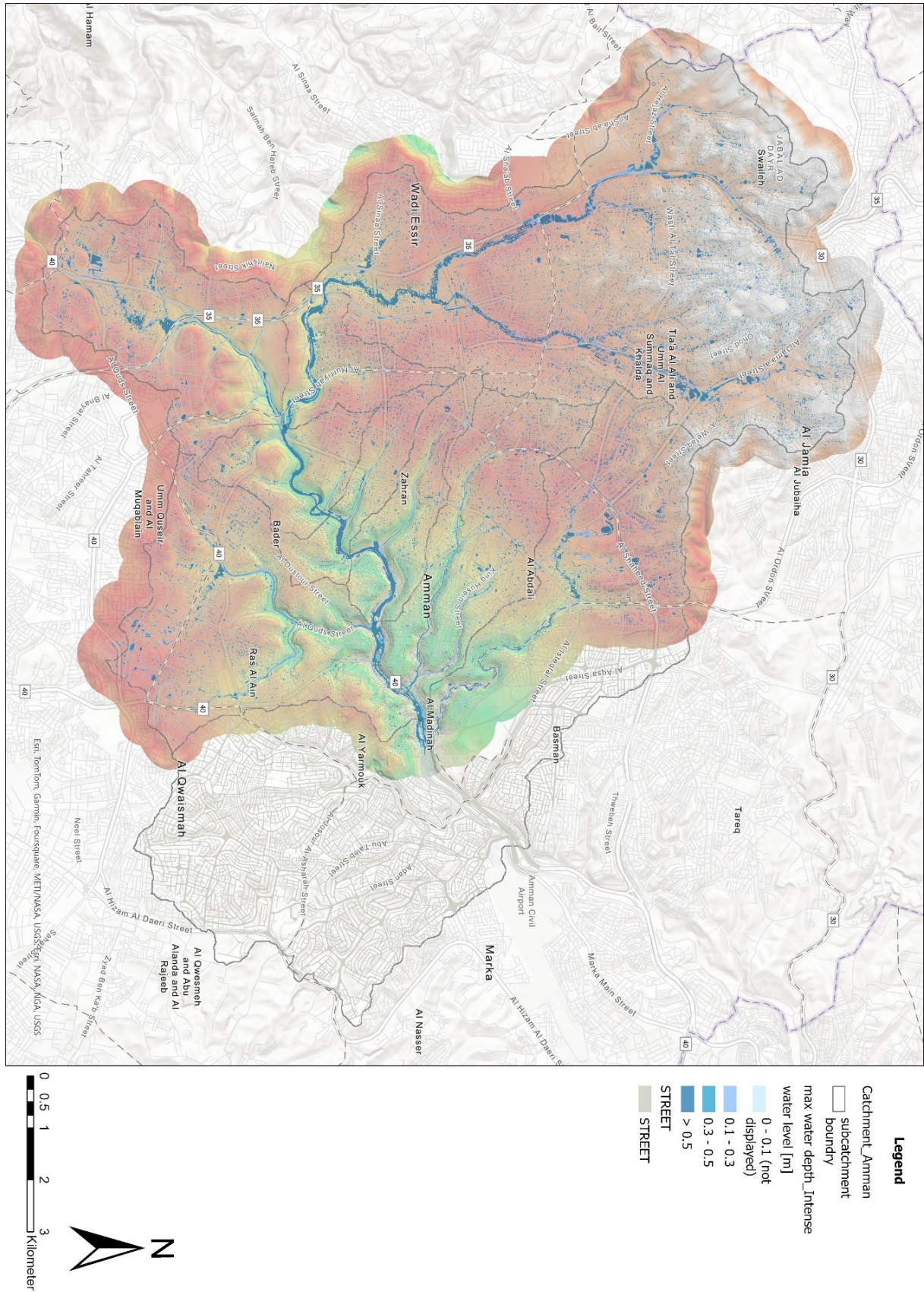
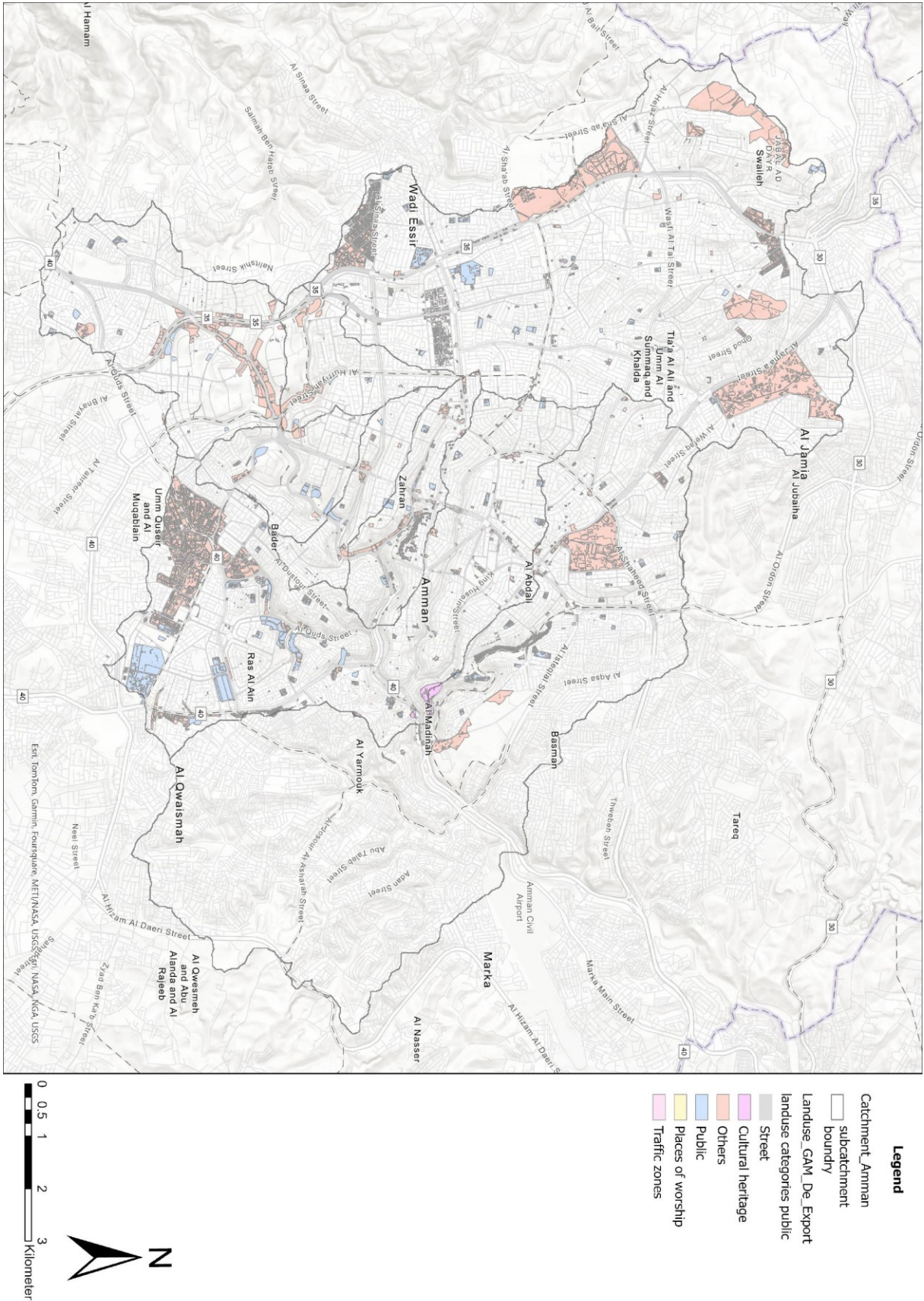


Figure 2: Topographic conditions (left) and flowpaths (right) of the catchment area encompassing downtown Amman.



Land use: The land use map of the catchment area was derived from existing geographical data provided by the Greater Amman Municipality (GAM), comprising several GIS layers, including information on buildings, property boundaries, roads, and land use. Existing building areas were used to distinguish between developed and non-developed parcels. This dataset was supplemented with data generated as part of the CapTain Rain project, including digitised buildings and land cover maps derived from remote sensing analysis (Awad, 2023).

2.2 Categorization of land use types

To identify suitable focus areas and the optimal solution on site the planning area, the available geographical data is processed and analysed. For this, the available dataset needs to be homogenized, whereby a meaningful categorisation and grouping of land use information is essential to demonstrate current land use types and to define appropriate areas for the integration of specific measures in accordance with the planning goals and scope of the defined areas (e.g. masterplan or conversion area etc.). For the planning area of our case study, we generated a land use layer map combining all relevant information (building type, development status, property boundaries, ownership (private, public), road types, green spaces) ten overhead categories (commercial, residential A/B and C/D, streets, cultural heritage, low-income public housing, places of worship, mixed-use developments and traffic zones), as well as a total of forty-seven land use subcategories. Building and parcel boundaries distinguish between open areas and buildings within individual parcels while maintaining their land use. In addition, the grouped land use categories were derived from the existing GAM typology and were also provided with their development and open space ratio.

This was derived by spatially intersecting buildings and property boundaries, as well as information on non-built-up areas, which was derived from the land cover map (including green spaces, rangeland, cropland, woodland, and barren land; see Awad, 2023). Next, we assigned a utilisation factor to each land use category. This factor describes the potential open space (as a fraction of the parcel) that could be used to implement various measures (see Appendix A). Multiplying this factor by the area gives an indication of the amount of space available for the specific category within the catchment area.

In order to develop the Amman catchment area strategically, it is helpful to summarise the area balance of the subcatchments according to land use categories and utilisation factors. This provides insight into the distribution and sufficiency of open spaces across the catchment, and helps answer questions such as: Which neighbourhoods have the largest open spaces? Does public open space provide sufficient areas for mitigating/adapting to the risks from flash floods?

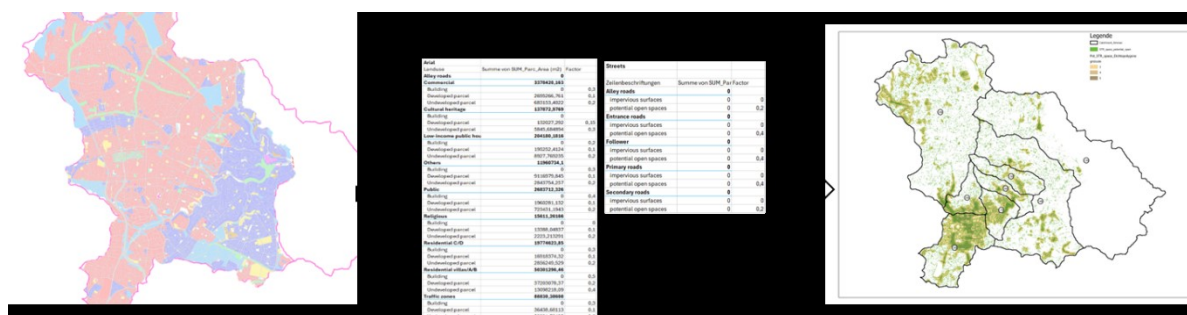


Figure 4: Workflow of the categorization of the land use for the Amman catchment area: For each of the 47 land use categories (left) a utilisation factor was assigned (middle) resulting in a new land use layer map combining all relevant information (right).

2.3 Assessment of area potential

The assessment of area potential provides an initial overview of suitable usage and space availability, taking specific land use patterns and ownership (private/public) into account. Figure 5 below presents an example of what an overview of classified public spaces might look like.

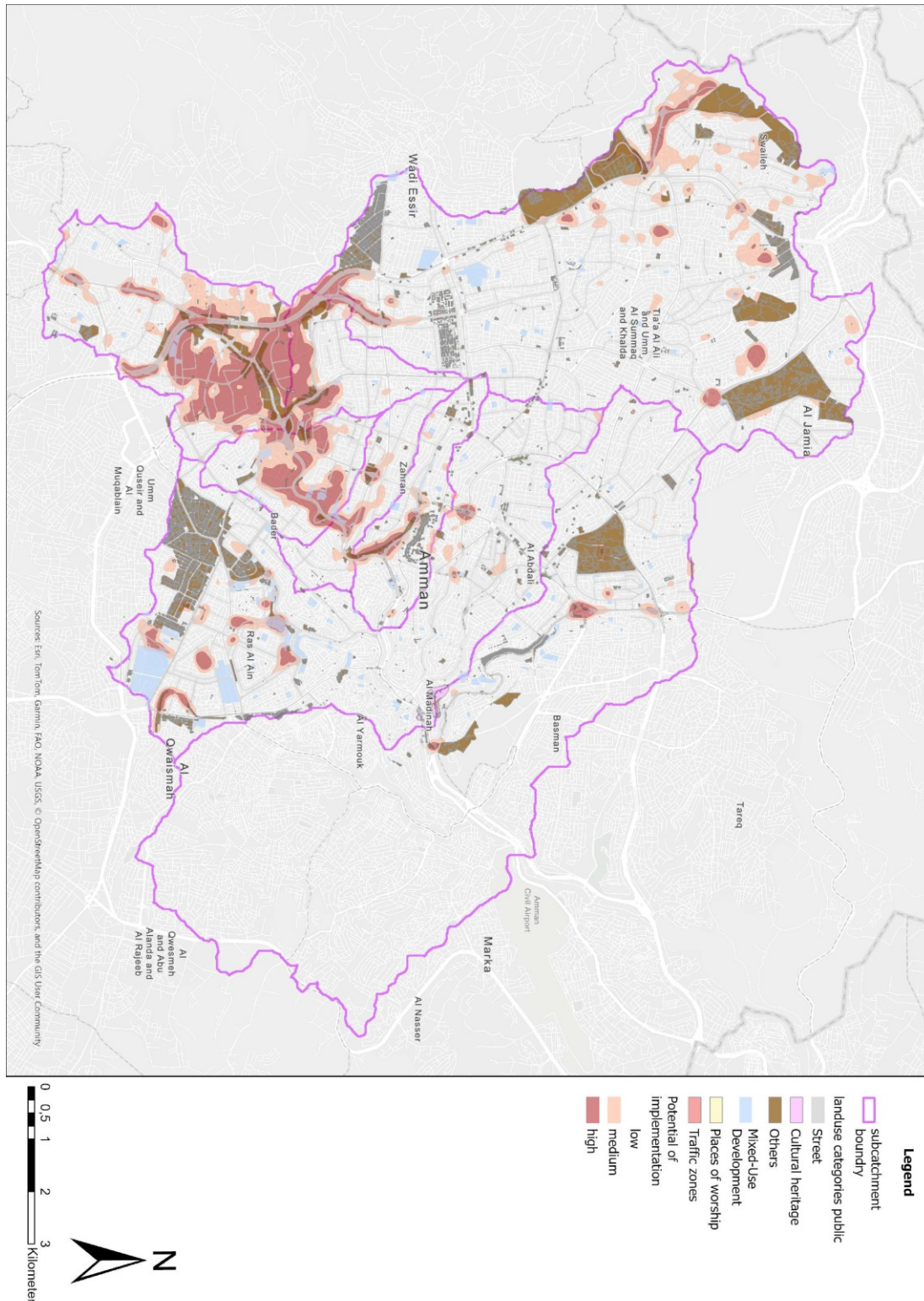


Figure 5: Overview of the public areas in relation to the utilisation categories for the “downtown” Amman catchment area.

To examine these areas in more detail, it is essential to consider specifics such as availability, boundary conditions (e.g. slope and soil type) and additional indicators (e.g. overlays with strategic masterplan concepts, flood-prone areas and risk zones). A more detailed analysis of land use data helps identify opportunities to integrate BGI into urban landscapes, improving ecological resilience, enhancing water management, and increasing green spaces in urban environments. This analysis involves mapping existing land uses, evaluating environmental benefits and suggesting strategic locations for BGI elements, such as green/blue roofs, detention basins and urban forests. This approach supports sustainable urban planning and contributes to the city's overall ecological health.

3 Planning and localization

3.1 Stakeholder engagement

As the successful implementation of flash flood measures requires the involvement of various stakeholders, a stakeholder analysis should be carried out at the start of the planning and implementation process. Stakeholders can be classified into various institutional groups, including state entities, companies, citizens, scientific institutions, and international organisations and their entities involved in international cooperation. These groups may possess data and geospatial information, have access to influential decision-makers and processes, and be able to provide practical knowledge, expertise and guidance. They may also be directly or indirectly affected by the situation. A stakeholder analysis allows an overview of stakeholder groups to be generated and key stakeholders, supporting stakeholders and veto players to be identified before engagement. Furthermore, it facilitates a deeper understanding of stakeholders' motivations, resources and relationships with each other. This helps to identify the relevant stakeholders for the participatory planning process.

In addition to the responsibilities, roles and duties inherent to the planning processes themselves, it is important to address the individuals responsible for different infrastructures (e.g. roads, drainage, retention basins, water resources, green areas, water infrastructure, urban planning and housing), as well as the owners of the different involved areas (e.g. streets, properties, recreation areas and playgrounds). Regarding properties in particular, the situation can be very diverse, involving a wide range of people, from private landowners and tenants to refugees and directors of private companies, schools and hospitals. Here, it is not only important to involve them, but also how they are addressed and the form of participation chosen.

Such processes often involve different teams and sub-processes. A core team of professionals is usually responsible for developing the technical and detailed planning, while citizens and other non-professionals participate in specific time slots through workshops or bilateral chats.

Furthermore, it is crucial to identify the entity responsible for overseeing the process and establish transparent responsibilities. In our case study, GAM played a primary role alongside key stakeholders from various professional backgrounds, including different GAM departments (e.g. the planning department, the housing department and the urban green department), Mihayuna and a contracted engineering or planning office.

3.2 Identification of planning goals

Before beginning the planning process and discussing specific spaces and measures, it is helpful to establish the relevant planning objectives for the project in question (Trapp & Winker, 2020). This involves prioritising collective objectives and group cohesion, while personal preferences and sensitivities take a secondary role. Identifying shared planning goals can facilitate more effective conflict resolution, as a common understanding of the goals and contributions can inform decision-making.

Formulating joint planning goals can facilitate the selection and feasibility of subsequent measures, given that their contribution and intensity may vary according to the planning goals in question. This is

especially important in areas with very limited space, where a clear focus and consequent decision-making for the most appropriate measures can be supported. This guideline addresses planning processes for flash flood mitigation, with flash flood protection and reducing damage as the main planning goals. However, demonstrating the potential contribution of additional goals to water provision, groundwater recharge, and enhancing the quality of stay can help to gain greater societal support and acceptance. Furthermore, the planning goals are transparent to all parties involved, enabling open negotiation and collaboration. Once the implementation concept has been drafted, its efficacy in achieving the planning goals can be evaluated for subsequent readjustments and approval. Here, planning goals can be used as an overall tool for decision-making and approval purposes.

Planning Goals defined and adjusted according to Winker et al. (2022) that were relevant within the scope of the CapTain Rain project:

- **Reduction of flash flood damage:** The overall aim of flood protection is to divert, collect or temporarily store large volumes of rainfall in order to prevent overload and/or severe flooding damage. Here, the focus is specifically on flash floods. Measures that influence precipitation water (e.g. evaporation, seepage, storage and use) reduce and delay runoff, thereby reducing the risk of overload. If an overload does occur, measures should be considered to channel and store precipitation water temporarily, for example by using surfaces for multiple purposes. The planning objective of flood prevention comprises the reduction of rain runoff and peak runoff.
- **Water supply (provision):** The public supply of drinking water is often a matter of general interest. To secure the water supply in the municipality's catchment area, it is important to support the formation of new groundwater (e.g. by avoiding further sealing and possibly reversing it, as well as implementing seepage measures). Where surface water or bank filtrate is used for the water supply, these sources should also be protected. Conversely, to reduce drinking water consumption, alternative sources (e.g. rainwater or greywater) should be used for non-drinking applications.
- **Groundwater recharge:** Groundwater is water found in the subsoil. This invisible resource is an essential part of the water cycle and fulfils important ecological functions. It must be comprehensively protected in terms of both quantity and quality. The consistent application of the precautionary principle is therefore of great importance.
- **Erosion reduction:** Land erosion and landslides are caused by heavy and prolonged rainfall. This is particularly the case for exposed soil and in steep locations. It is therefore important to take precautionary measures to reduce erosion, as well as identifying areas at risk of landslides in order to adjust urban planning and monitoring and warning systems.
- **Urban climate:** A healthy urban climate is a key objective of urban development. Various environmental, landscaping and regulatory measures are intended to improve the urban climate (e.g. by reducing heat stress). There is a distinction between pollution in open spaces (e.g. streets and green areas), commercial areas (e.g. businesses and office buildings) and residential areas. In open spaces and commercial areas, the situation during the day is relevant, whereas in residential areas, the situation during the day and at night is relevant. Improving the urban climate is considered to have an impact on human health.
- **Quality of stay:** The frequency with which city dwellers use public places, and for how long, depends heavily on how they perceive the quality of these places. This perception can vary greatly depending on the social group and subjectively, as needs for protection, sensory experience, well-being or comfort can differ. From an urban planning perspective, increasing the quality of stay can be achieved by designing places that are accessible to as many population groups as possible and offer a variety of uses, while protecting against undesirable environmental influences such as heat and noise. Quality of stay is therefore also an important aspect of environmental and climate justice..
- **Water protection:** The aim of water protection is to maintain or restore water bodies to a good condition. To this end, water bodies and their banks and surroundings should be maintained or

restored so that the biocoenoses typical of the respective natural area can develop. Input of substances into water bodies should also be reduced. Consistent application of the precautionary principle is crucial here.

- **Biodiversity:** According to the Convention on Biological Diversity (CBD), biodiversity refers to “the variability among living organisms from all sources, including terrestrial, marine, and other aquatic ecosystems, and the ecological complexes of which they are a part”. This includes diversity within and between species, as well as diversity of ecosystems (CBD, 2006). High biodiversity increases the resilience of ecosystems to external disturbances, such as climate-related effects (e.g. drought and heat) and pests and plagues that may occur in this context. Maintaining, sustainably using and interlinking biological diversity across the city is seen as a key issue. The focus here is on diversity within individual animal and plant species, as well as species and landscape diversity. When planning the greening of buildings and properties, it is essential to observe appropriate guidelines for protecting biodiversity and using native plants.
- **Health promotion:** The World Health Organization states that urban neighbourhoods should promote physical, mental and social well-being. Green and blue spaces are an important element of health-promoting urban development. Green spaces can reduce blood pressure and stress hormone levels when combined with physical activity in a natural environment, such as walking. Aesthetically pleasing urban nature provides an incentive for exercise. Even the visual perception of plants and diverse vegetation contributes to stress reduction and has a positive effect on physical well-being. Similarly, noise reduction through green spaces can help reduce cardiovascular disease and the perception of stress. Reducing heat stress and binding aerosols, coarse and fine dust can also promote cardiovascular and respiratory health, as well as subjective mental and physical well-being. The health-promoting effects of the socio-cultural ecosystem services of blue building blocks are comparable to those of green building blocks. The impact of the binding of aerosols, coarse dust and particulate matter on human health is comparable for blue and green building blocks.
- **Environmental Education:** Formal environmental education aims to encourage responsible behaviour towards the environment and natural resources. Contact with green and blue spaces (e.g. school gardens and areas near bodies of water) promotes scientific understanding and practical knowledge of environmental protection and healthy nutrition. Environmental education for children and adults employs a variety of didactic methods.
- **Production of food and renewables:** The aim is to ensure an independent supply of food and energy, regardless of local deliveries. Food is often transported over long distances. Therefore, the supply depends on transport infrastructure and costs. The electricity and heat supply in cities is largely fossil-based. Therefore, areas close to consumers or offering secondary raw materials for energy supply in inner-city areas should be used.
- **Urban Gardening and Agriculture:** Gardening and agriculture in cities are increasingly being pursued as independent activities, promoting urban participation and independence in the supply of fresh food. This is characterised by limited areas that are often not originally intended for gardening, such as tree grates, fallow land, courtyards, etc. Gardeners and farmers must adapt to the specific soil and climate conditions of urban areas.
- **Cultural heritage:** The aim of cultural heritage is to preserve, protect and integrate historical, architectural and cultural assets into the urban environment. Amman has a rich cultural heritage, ranging from ancient Roman ruins such as the Citadel and the Roman Theatre, to traditional neighbourhoods like Downtown Amman. The latter includes underground archaeological sites that require protection. When selecting measures, planners must ensure they are compatible with heritage conservation. For example, certain measures aimed at reducing flash flooding at cultural heritage sites may not be feasible, such as infrastructure like large drainage tunnels or retention basins, or technical solutions that could damage or displace cultural assets.

3.3 Identification of measures for flash flood protection

Measures for rainwater management and flash flood protection encompass a blend of innovative and traditional approaches to effectively manage stormwater and, in this case, reduce the damage caused by flash floods. These measures include:

- BGI, which uses natural elements such as wetlands, green/blue roofs and rain gardens to manage rainwater through absorption, filtration and storage.
- Technical measures, or grey infrastructure, which uses engineered solutions like pipes, culverts, and dams to control and direct the flow of stormwater.

Each measure has unique characteristics and performance, and can be selected according to which planning goal it best addresses, ensuring an effective and tailored rainwater management strategy. While some measures address flash flooding directly, others focus more on the impacts of climate change, such as heat or drought. However, all measures can serve more than one objective. This underlines the enormous synergy potential of planning, as there is no single correct approach, but rather a variety of options. This degree of freedom is a good starting point for a participatory planning process.

A diverse range of measures suitable for future implementation in the city of Amman were identified for the current case study. So-called “infocards” were created for each of these measures, providing a brief summary of the measure itself, its contribution to certain planning goals, and its costs (see Appendix B). Upon closer inspection, it becomes clear that some measures are highly specialised and can be used selectively to achieve specific outcomes, such as water retention during heavy rainfall. Many of the technical measures fall into this category. Others are more versatile and can be used more broadly to address various climate impacts and planning objectives. Examples of these include blue-green measures such as roof and facade greening, green and open spaces, and multifunctional areas. In practice, and particularly in the application of the infocards (see Winker et al., 2022 for details), it has been demonstrated that a combination of different measures is typically employed to achieve the desired outcome in line with the required planning goals.

Icons	Measures	Reduction of flash flood damage	Water supply (provision)	Groundwater recharge	Erosion reduction	Urban climate	Quality of stay	Water protection	Bio-diversity	Health promotion	Environmental education	Production of food and renewables	Urban gardening and agriculture
	Water harvesting:												
	Terracing	●	●	●	●	●	●	●	●	●	●	●	●
	Roof top harvesting (Enjasa)	●	●	●	●	●	●	●	●	●	●	●	●
	Blue-green infrastructure:												
	Rain gardens	●	●	●	●	●	●	●	●	●	●	●	●
	Green roofs	●	●	●	●	●	●	●	●	●	●	●	●
	Blue roof	●	●	●	●	●	●	●	●	●	●	●	●
	Bioswale	●	●	●	●	●	●	●	●	●	●	●	●
	Infiltration trench	●	●	●	●	●	●	●	●	●	●	●	●
	Detention basin	●	●	●	●	●	●	●	●	●	●	●	●
	Multifunctional Area	●	●	●	●	●	●	●	●	●	●	●	●
	Rainwater harvesting	●	●	●	●	●	●	●	●	●	●	●	●
	Urban Forest	●	●	●	●	●	●	●	●	●	●	●	●
	Object protection:												
	Mobile flood protection elements	●	●	●	●	●	●	●	●	●	●	●	●
	Controlled flooding	●	●	●	●	●	●	●	●	●	●	●	●
	Structural measures:												
	Check Dams	●	●	●	●	●	●	●	●	●	●	●	●
	Dike/Flood barriers	●	●	●	●	●	●	●	●	●	●	●	●
	Diversion channel / culvert	●	●	●	●	●	●	●	●	●	●	●	●
	Expansion of canalisation	●	●	●	●	●	●	●	●	●	●	●	●

● = no impact ● = low impact ● = high impact

Figure 6: Overview about different measures and their benefits regarding different planning goals. Base for the development of this overview was Winker et al. (2019)

3.4 Determination of entry points and focus areas

The process of identifying entry points for flood mitigation measures typically involves focusing on specific sub-units within the planning area. These sub-units are referred to as “focus areas” here. These can be sub-catchment areas, neighbourhoods, streets or other defined spaces. These entry points may form part of existing urban planning processes, such as road or sewage construction, or other urban or infrastructure developments (e.g. the Royal Village Project Area). Another approach to identifying entry points is driven by the need to reduce damage caused by regular heavy rainfall, as determined by the following criteria:

- Areas with high potential for implementing measures (e.g., due to the availability of open spaces)
- Areas with high flood risk or vulnerability
- Areas with good data availability or suitability for modeling

For our case study we used the latter approach and selected three focus areas (Figure 6), each with different characteristics, to develop various solutions. These are examples of how different characteristics and needs can guide the identification of entry points:

1. Eastern part of Marj Al Hamam: This sub-catchment was chosen for hydraulic reasons and features a variety of land uses. Upon closer inspection, the Royal Village Project and a preschool were identified as specific neighbourhoods requiring detailed planning.

2 a. Sports City and later b. Jordan University: This public area has many green spaces, offering significant potential for BGI. Initially focusing on the sports area, the project later changed towards and inclusion of the area of Jordan University.

3. Al Abdali: This area includes critical infrastructure, such as hospitals, making it a priority for flood mitigation measures to protect these essential services.

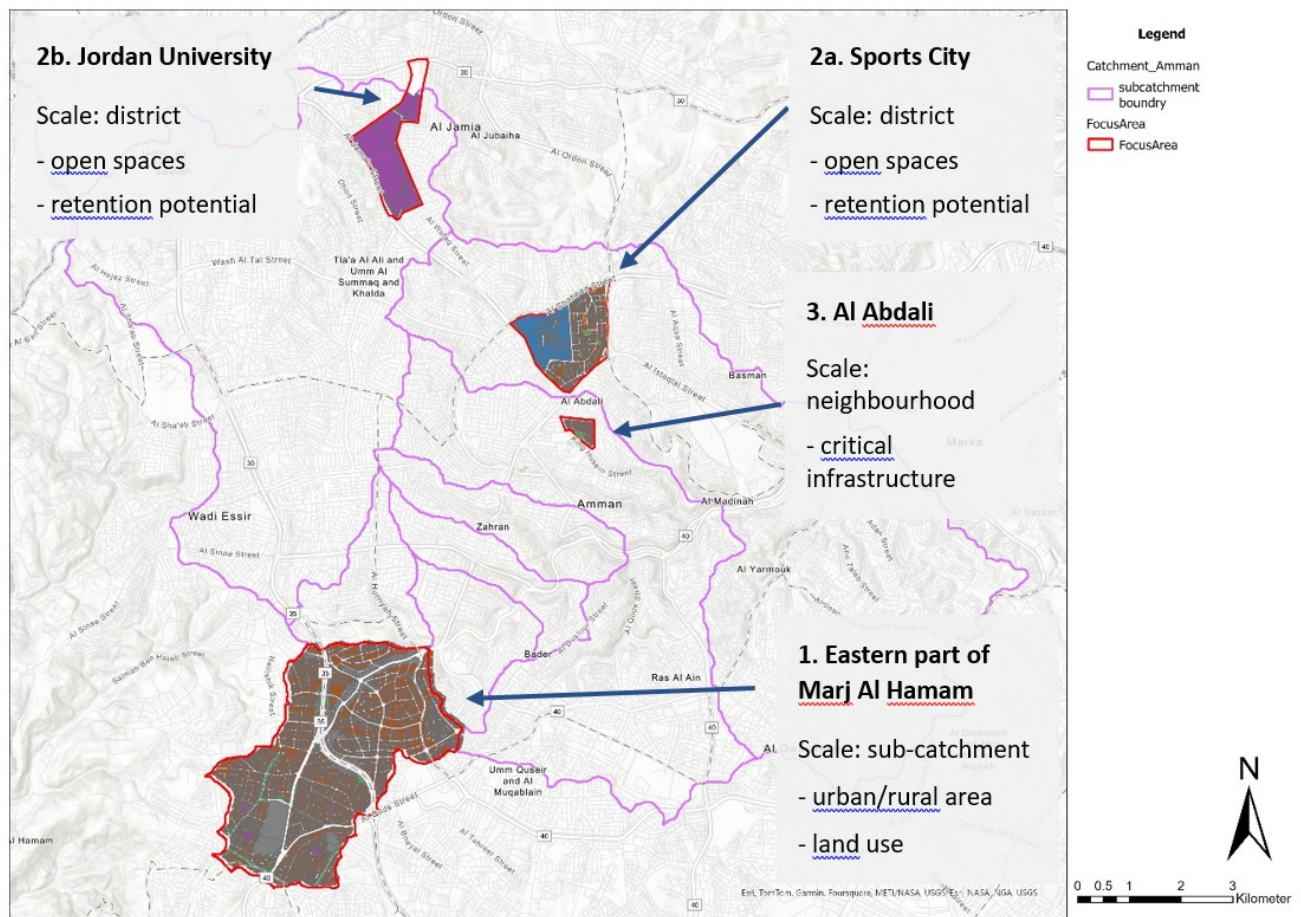


Figure 7: Location of the focus area and catchment of downtown Amman

The graph below illustrates the process of identifying entry points according to the criteria of potential public open space and high flood risk.

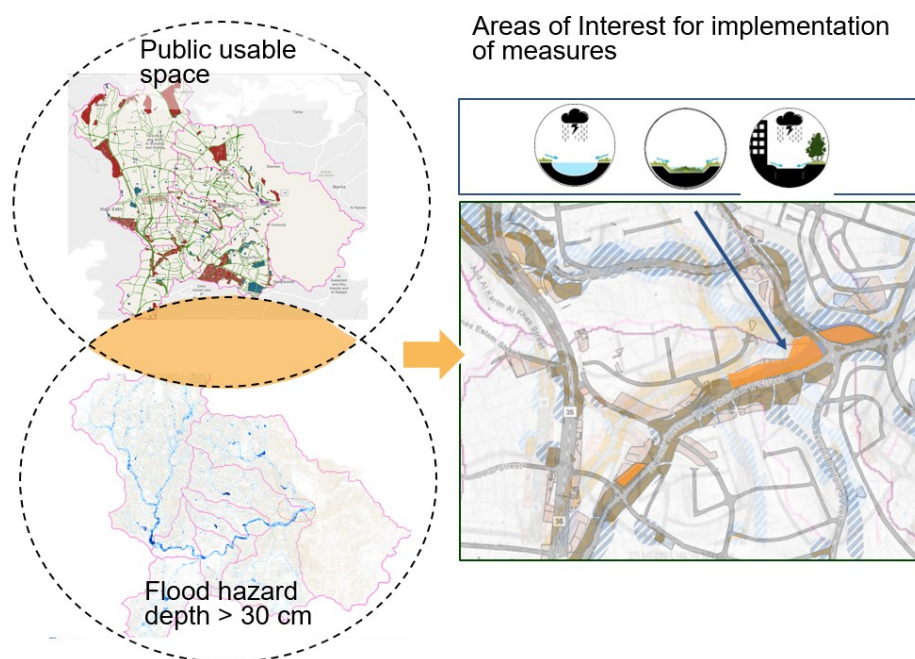


Figure 8: Overlay of flood hazard with potential availability of public spaces.

During a large stakeholder workshop held as part of the CapTain Rain project in January 2022, planning goals were jointly determined for each of the focus areas, along with possible measures to contribute to these goals (see Table 1). This process generated a shared vision of what flash flood-oriented planning for the selected areas could entail, as well as identifying additional objectives to consider. The workshop also included a quality check of the three focus areas, the results of which were discussed with the stakeholders.

Table 1: Planning goals for each focus area and a pre-selection of measures. Results from the CapTain Rain stakeholder workshop in January 2023.

Focus Area/Group	Eastern part of Marj Al-Hamam	Sports City	Al Abdali
Selected planning goals	• Groundwater recharge • Quality of stay • Health promotion • Protection of food & renewable raw materials	• Urban climate • Biodiversity • Quality of stay • Health promotion	• Reduction of flash flood damage • Health promotion • Erosion control • Urban gardening (general greening)
Possible measures	• Rooftop harvesting (Enjasa) • Rain gardens • Bioswales • Infiltration trenches • Diversion channel/culvert	• Rain gardens • Green roofs • Bioswales	• Green roofs • Bioswales • Rain gardens • Porous roads (new) • Higher curb stones and small walls (new)

3.5 Selection and localization of measures

The selection and localisation of measures is an iterative and participatory process. To this end, several workshops were held with the key stakeholders identified. During the first stakeholder workshop, a brainstorming session was held to share knowledge, with the following aims:

- Share information held by each stakeholder about existing plans, approaches or other knowledge relating to the focus area.
- Prioritise planning goals.
- Sharing the workshop results within the institution to identify synergies and/or conflicts.

The identified focus areas were visualised on a map or touch table. During the workshop, participants gathered around the map to discuss the analysis results regarding flooding and explore possible options. It is important to document the following:

- existing knowledge of flash flood events and damage in the area;
- already existing or planned infrastructure;
- possible spaces for measures, as described in Chapter 2.3

The following example shows the allocation of measures with comments from participants from an online workshop, which can be an alternative if a face-to-face meeting is not possible.

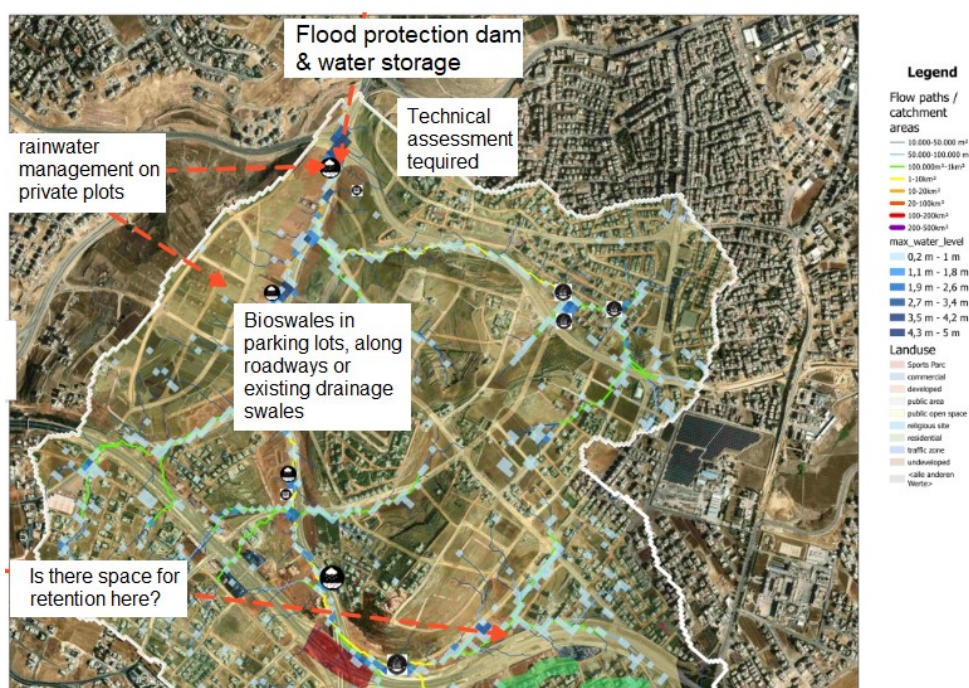


Figure 9: Online whiteboard (<https://conceptboard.com/>) showing the results of an online workshop within the CapTain Rain projects for the selection and localisation of measures.

After the workshop, the host or respective expert team evaluates the results. These results are then passed on for further planning and assessment by professional urban planners and engineers. In the CapTain Rain project, the results were presented, explained and jointly discussed with the stakeholders in a second workshop. Depending on the specific process, further revisions and adjustments may be possible. In other processes, the integration stage ends here.

4 Development and Strategy

4.1 Scenario Development

If sufficient capacity is available, the planning process can be supplemented by simulating and analysing different scenarios in order to assess the impact of various measures. Hydrological and hydraulic models can provide valuable insights into the potential outcomes of measures aimed at mitigating the effects of heavy rainfall and flash flooding. This allows a broader range of options to be considered. As part of the CapTain Rain project, a comprehensive scenario analysis was conducted, integrating the results of various research activities. In collaboration with Jordanian stakeholders, several possible future scenarios were selected to simulate the effects of changes in heavy rainfall, as well as measures to reduce flash flood damage, using hydraulic and hydrological models. Further details on this scientific approach, along with the hydraulic and hydrological results, can be found in the CapTain Rain Wiki (<https://gitlab.pik-potsdam.de/peterh/captainrain/-/wikis/Home/>) and the final CapTain Rain project report (Brinkmann et al. 2025).

Altogether four possible future **rainfall scenarios** were developed for Amman based on the results of a retrospective and prospective analysis on heavy rainfall events.

Table 2: Developed possible future rainfall scenarios (baseline, moderate, intense, catastrophic).

Scenario	Description	Rainfall amount and duration
Baseline	Most intense period of a well-known past heavy rainfall event (Amman: Feb. 2019 / Wadi Musa: Dec. 2022)	19–64 mm in 5.5 h
Moderate	Baseline + 20 % climate change effect	23–77 mm in 5.5 h
Intense	Max. station and total length of baseline event (Amman: Airport station / Wadi Musa: PDTRA station 180)	136 mm in 27 h
Catastrophic	~ Annual rainfall amount in one event	300 mm in 27 h

The **measures scenarios** were developed in a participatory manner during two stakeholder workshops and then refined by experts (Table 3). The measures were attributed to the scenarios according to their location (public space versus private space).

Table 3: Description of the selected measures scenarios, which were simulated using hydraulic models

Scenario	Description	Selected measures
Public space scenario	Public areas such as streets, plazas, public and municipal plots of land, undeveloped municipal areas, public green spaces. Measures in such areas are more easy to implement: only a limited number of stakeholders need to be involved (the city administration), planning and implementation from a single source, direct start and implementation in the near future possible.	retention basin, infiltration trenches, bioswales
Public and private space scenario	Public areas as well as private land (developed and undeveloped). Measures are more complicated to implement: various professional and private stakeholders have to be involved, the municipality is more in the role of steering and guiding the process than implementing measures; process requires thorough preparation and a participatory element, also when starting directly, implementation will require time.	retention basin, infiltration trenches, bioswales, multifunctional areas, pipe infiltration trenches

4.2 Impact assessment and readjustment

Due to the large number of scenarios, it is not possible to show the combination of all possible rainfall and measure scenarios. As an example, the results of the combination of the baseline rainfall scenario with the two different measure scenarios are presented in the following section. It should be noted that the baseline scenario is currently the heaviest precipitation event observed in the area.

4.2.1 Scenario results for the focus area Marj Al Hamam

The focus area of Marj Al Hamam was selected for the scenario analysis as it is located on the outskirts of Amman, where urban, densely built structures begin to blend with rural elements, displaying a clear peri-urban character. Generally, some blocks are densely built, while agriculture is practised next to them or they remain undeveloped. This area was also chosen because it is a complete sub-catchment. It was interesting to see how the catchment itself could be improved in terms of flash flood mitigation, particularly in view of the planned further developments, and to assess its potential contribution to the situation downstream. A thorough allocation of measures was carried out in this focus area, and hydro-logical modelling of water flows and their changing patterns was undertaken. This also enables us to obtain quantitative results regarding the impact of the measures.

Public space scenario

In this scenario, only public spaces were considered for the implementation of measures. The total potential usable space amounts to 0.43 km², corresponding to 4 % of the total focus area. A total of 11 measures were identified and allocated in public spaces, including one retention basin, eight infiltration trenches and two bioswales. The measures require an area of 49,048 m², corresponding to 11 % of the potential usable space. Infiltration trenches situated along streets, especially main roads, occupy nearly half of this area.

Most of the measures are located in the lower part of Marj Al Hamam, in an area that still has a very high percentage of open land (mainly rangelands and croplands). Only one infiltration trench is located in the upper part of Al Quds Street. This means that the main impact of the measures is on the downstream areas of Haman, rather than on the focus area itself. Nevertheless, this example illustrates how easy it is to mitigate the effects of further development and sealing of the area by allocating just 1 % of the focus area to measures.

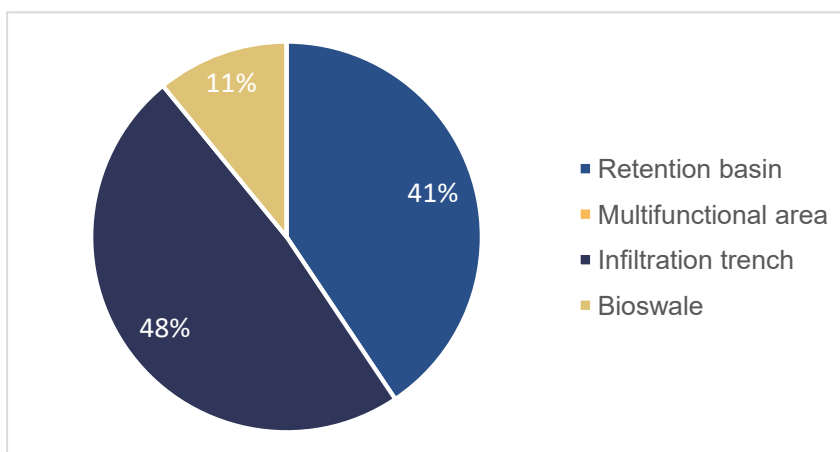


Figure 10: Percentage distribution of space requirements for measures in the “Public space” scenario.

Rooftop harvesting, rain gardens and diversion/culverts were not considered in the subsequent planning process, since the scenario definition was confined to public land. In the case of the diversion channel/culvert, this was because the focus was on small-scale projects and BGI. The detention pond was later added by professional planners because its effectiveness in reducing peak flows in the downstream

area depends heavily on its location. Data analysis in this case shows an overlay of high flow concentration and public open space availability.

In total, the measures can retain 16,376 m³ of water. Hydraulic simulation results for different rainfall scenarios show a reduction in peak runoff of 34 % for the base scenario, 21 % for the intense scenario, and 6 % for the catastrophic scenario (Brinkmann et al. 2025).

As most of the measures are located in the lower part of the focus area, their major impact in terms of reducing runoff volumes and flash flood damages is seen further downstream. Nevertheless, they also have some impact on critical areas in the focus area itself like the huge inundation potential at the intersection of Dead Sea Road and Airport Road.

With regard to the selected planning goals (Figure 6) flash flood reduction is certainly achieved as already discussed. As all measures retain and infiltrate water into the ground, they positively affect groundwater recharge. However, it is not possible to quantify the overall benefit. It cannot be expected that these measures will promote health. Perhaps the infiltration trenches and other measures along main roads with heavy traffic can contribute to cleaning and rinsing the water, as well as holding back heavy metals, microplastics, etc. Food production is not achieved, but the production of renewable raw materials may be possible with a good selection of plants, such as reeds, for greening the measures. These can then be used for composting or in processes relating to renewable energies.

Private and public space scenario

This scenario focuses on private areas and public land. The potential usable area is 20 % of the total catchment area. The potential usable space is 2 km², which corresponds to 20 % of the focus area. Within this scenario, 23 measures have been identified: 11 in public spaces and 12 on private land, which are in addition to the measures in the public space scenario. The measures include five retention basins, seven multifunctional areas, eight infiltration trenches, two bioswales and one pipe infiltration trench. All measures require an area of 0.18 km², 0.13 km² of which is located on private land. The measures “multifunctional area” and “retention basin” are particularly noteworthy as they represent four new locations and require most of the area (82 %). Overall, the measures require an area of 0.18 km², corresponding to 10 % of the potential usable space and 2 % of the focus area. Most of the measures are situated in the upper part of Marj Al Hamam, in an area which can be classified as urban and characterised by high levels of sealing (Figure 12).

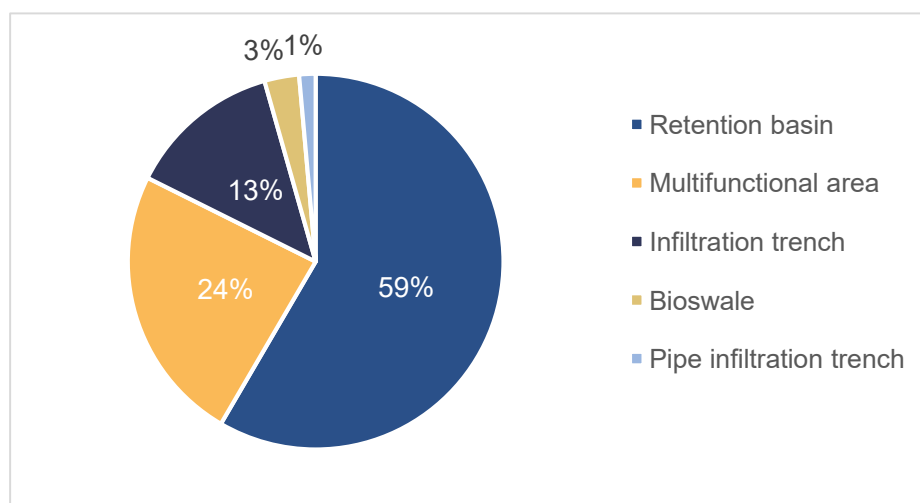


Figure 11: Percentage distribution of space requirements for measures in the “Public and private space” scenario.

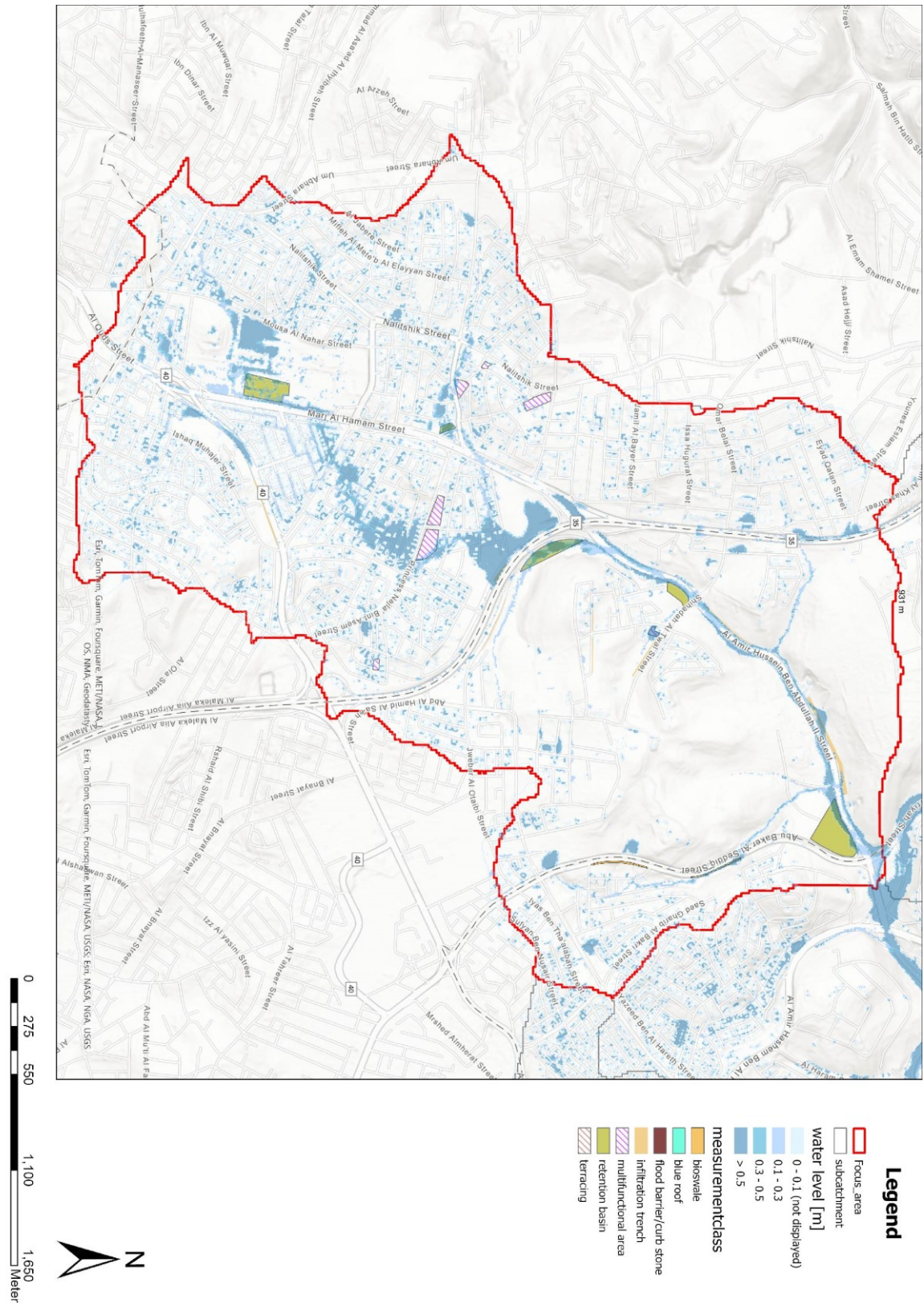


Figure 12: Overview of the allocation of the measures in the focus area Marj Al Hamam for the “private and public space scenario”.

Model results show that Marj Al Hamam itself will benefit most from the measures. Two significant areas are subject to regular inundation: one in close proximity to the Prince Hussein Interchange, and the other in the vicinity of the intersection between Prince Hia Bent Hamza Street and Prince Nails' Bent Asem Street. The planned retention basins at the interchange and the two multifunctional areas at the intersection might help here. However, the retention basin and multifunctional area on Princes Najla' Bint Asem Street are located directly within a major runoff pathway. Additionally, the multifunctional areas are located directly behind an existing hotspot. This indicates that they will contribute directly to reducing the existing flash flood damage in their immediate vicinity. The large retention basin in the Royal Village (see also Chapter 4.2) is necessary to prevent damage to the neighbourhood downstream, as well as to the Royal Village itself. This large open and unsealed area would have a significant impact if it were to be transformed into housing areas without such measures in place.

It should be noted that there are two retention basins with a combined surface area of 52,156 m² in the lower area. While it is unlikely that these will be a priority for implementation, they will become relevant in the event of heavy rainfall, providing additional backup volume. Therefore, it is strongly recommended that these reservoirs are designed for multifunctional use (e.g. in combination with urban forests). Furthermore, this scenario did not consider the measures of rooftop harvesting, rain gardens on private land, and diversion channels/culverts. During the ongoing planning process and discussions with stakeholders, it became clear that the selected measures would have a significant impact on reducing flash flooding. Therefore, additional measures were no longer required. We cut down on measures that demand high resource intensity in terms of planning and implementation. Rooftop harvesting and rain gardens are resource-intensive because a large number of landowners need to be addressed, while diversion channels/culverts are costly and ultimately only guide water without retaining it.

This scenario has two focal points. Firstly, it aims to reduce the risk and damage of flash floods in the downstream areas and central Amman. Secondly, it considers potential improvements to the focus area itself based on how water flows during flash floods. As previously discussed, the selected planning goals will certainly achieve flash flood reduction. As all measures infiltrate water into the ground as well as holding it back, they have a positive effect on groundwater recharge. This effect is even greater than in the public space scenario because the additional measures cover an area of 0.13 km², three times the size of the public space scenario, and also contribute to health promotion. However, the overall benefit cannot be quantified. The retention basin is located next to a very dense neighbourhood and could be designed as a green space for recreation. However, it would require a good access for pedestrians as they have to cross Marj-Al-Hamam-Street. Also the multifunctional area, maybe even in combination with the pipe infiltration trench, can create benefit. They are located close to Rosary Kindergarden and Rosary School. Both facilities seems to be completely sealed. A multifunctional area for kids to play and for further leisure or even school activities might be beneficial. In addition, the multifunctional areas in the highly dense area at the crossing of Prince Hia bent Hamza Street and Prince Nails' bent Asem Street can improve the quality of stay as well. Production of food is not achieved as a primary goal. But maybe some urban gardening elements could also be integrated in the multifunctional areas. Renewable raw materials can be produced by choosing the right plants for greening and using them for composting or renewable energy, such as reeds. The multifunctional areas deliver manifold opportunities and their design depends on local needs, space requirements and capacities. It depends very much on their individual and detailed design.

Overall, the selected measures are able to hold back a volume of 36,209 m³. The hydraulic simulation results of the different rainfall scenarios showed a peak run off reduction of 75 % for the baseline scenario, of 46 % for the intense scenario, and of 13 % for the catastrophic event (Brinkmann et al. 2025). The comparison between area requirements and retained volume between public and private land highlights the benefits of additional measures on private lands. However, measures on public space have a lower area consumption (27 %) compared to measures on private land (73 %) with nearly similar volume retained (Table 4).

Table 4: Distribution of the potential area requirement and possible volume retained in public and in private space.

	Public space		Private space	
Total potential area requirement [m ²]	49,048	27 %	130,476	73 %
Volume retained [m ³]	16,376	45 %	19,833	55 %

4.2.2 Scenario results for the focus area Al Abdali

The Al Abdali area was selected as it exhibits the typical structure of inner-city neighbourhoods, which are often built on hillsides with steep slopes. These areas are generally densely built up, with open spaces consisting of car parks and small green areas. This focus area was selected to examine the scale of a neighbourhood. As several hospitals are located in the area, the effects on this critical infrastructure and how object protection can be implemented were a major focus. In this focus area only a first sketch of potential flood protection measures were developed, no calculation was undertaken so far regarding the required area and the volume of water holt back.

Public space scenario

The public space scenario focused on multifunctional areas, bioretention, the use of open spaces for detention and flood barriers in form of higher curb stones. The first sketch considered the area around the Abdali Hospital, which is located to the south of the focus area. It was found that three bioretention areas could be established in this southern area, and that five spots could be designated as multifunctional areas. Two open spaces with greenery and scrubs could be used for detention, and flood barriers could be installed by adjusting the curbs to keep the water mainly on King Hussein Street and direct it into Umyyah Ben Abd Shams Street.

According to expert knowledge, it is not possible to hold or infiltrate the water in the area, even during periods of heavy rainfall, due to its topographic conditions and limited unsealed space. Therefore, the main focus is on protecting the four hospitals surrounding the focus area. This kind of object protection means keeping the hospitals functioning and free of water, as well as ensuring that their access routes remain free of water and accessible.

The suggested measure could also offer some additional benefits: It could improve the quality of the available open spaces ("quality of stay"), as well as the cooling effect they provide. This is an important consideration in such a densely populated area, which has many hospitals and a correspondingly high number of visitors, as well as people who come to the area to work. Furthermore, large undeveloped areas are currently used solely for parking, which is an inefficient use of land in such densely populated areas of the capital. These parking spaces could be converted into multifunctional areas. In addition to reducing flash floods, the planning goals health promotion, erosion control and urban gardening were also selected for this focus area. Once multifunctional areas have been implemented and existing open spaces upgraded, elements enabling urban gardening could also be integrated if this remains a high priority.

Private and public areas

In this scenario, additional measures are added, such as blue roofs in combination with retention systems (bioretention or rain gardens) and rainwater harvesting and terraces. Given the lack of information regarding the structural characteristics of the buildings in question, it is difficult to ascertain the number of blue roofs that could be installed. In general, however, all roofs are flat, indicating basic potential for blue roof installation. This approach should therefore be pursued. Some hospitals may also have the potential for blue roofs and this should be considered further. Typically, around 20 % of rooftops are suitable. This measure can be combined with retention systems and rainwater harvesting regardless of roof suitability. While these measures will not eliminate the effects of flooding altogether, they will

reduce the impact and, at the same time, contribute to water conservation by utilising rainwater and improving green spaces by allowing more water to infiltrate the ground and become available to plants. However, a more detailed examination of soil conditions and infiltration capacity is recommended. Furthermore, the existing terracing could be renewed and extended to improve water retention and infiltration. This traditional agricultural technique was widely used in the past and should be reactivated where possible.

4.3 Integration into planning concepts

As part of a master's thesis, an example of a detailed concept was elaborated for our case study (Sharma, 2024). This detailed concept was developed for **Royal Village**, an undeveloped plot of land in the lower part of the focus area within the Marj Al-Hamam catchment area. The proposal is for a mixed-use development comprising a hospital and sports area at one end and a retail centre at the other, with various commercial outlets in between. The design also incorporates various types of residential villas and apartments to the west. While this design could meet future housing needs, the development is located in an area at high risk of flash flooding. The increased imperviousness of new constructions would further endanger existing structures.

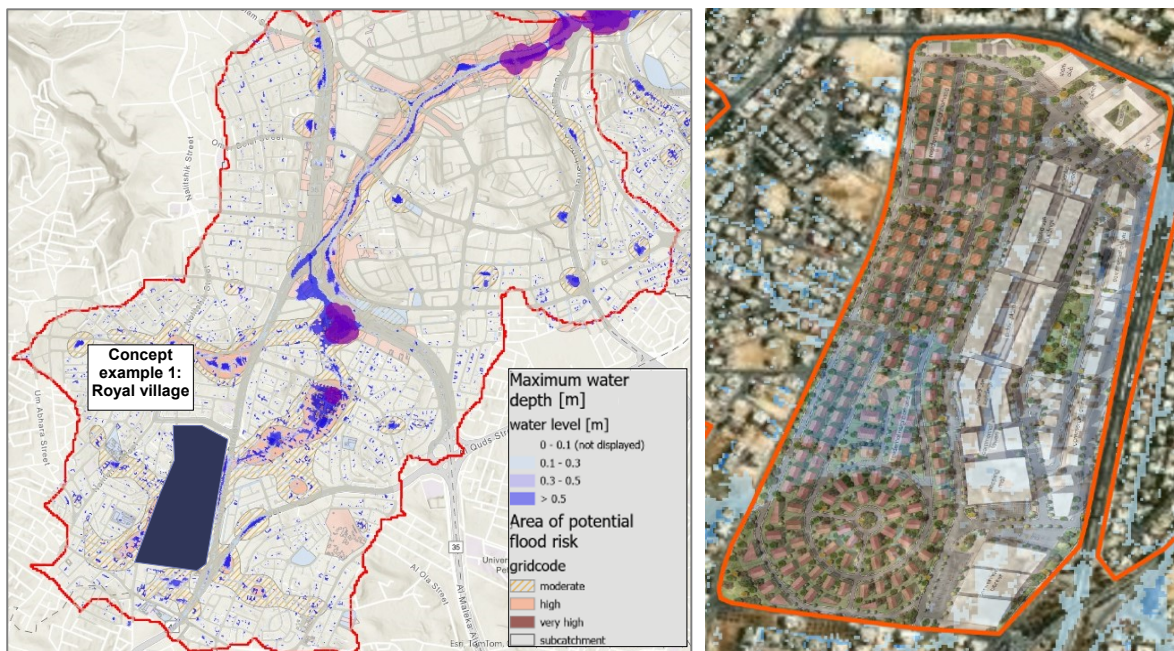


Figure 13: Map of the focus area Marj Al Hamam showing flood risk zones, max water depth and the location of the concept example 1: Royal village (right); Concept design for the Royal Village Project (left, source: alnasser + partners, <https://alnasserpartners.com/project/70/royal-village.html>).

The BGI design example from the master's thesis shows that each building is surrounded by green space. There is potential to reduce the stormwater runoff from these buildings by installing green or blue roofs, harvesting rainwater and storing it on site.

- The public commercial buildings have a good potential to implement green roofs.
- The space between the commercial buildings, initially proposed as a plaza, could be converted into a "green corridor", which would serve as a multifunctional space for retaining stormwater from the entire development, above or below the ground. This space would greatly enhance the area's aesthetics, biodiversity, and quality of life.
- The streets could be redesigned to incorporate bioswales and infiltration trenches to slow the flow of stormwater and convey it to the green corridor for retention.
- Parking spaces have good potential for using permeable paving to increase infiltration in these areas.



Figure 14: Concept design for blue green infrastructure for Royal Village (Sharma, 2024).

The second example illustrates a **concept comprising public and privat lands**. The area is located in the south-western part of the catchment area (the eastern part Marj Al Hamam). It is a mixed-use area comprising multistorey apartment buildings, a secondary school and a mosque. Around 70 % of the area is sealed, with 12 % remaining undeveloped (Figure 15).

Parts of the area, particularly the school, are located within a potential flood hazard zone. In terms of vulnerability and sensitivity, a high risk has been evaluated (mainly due to critical infrastructure). In terms of vulnerability and sensitivity, a high risk has been evaluated (mainly due to critical infrastructure).

Therefore, this example is not very effective at minimising the risk of flash flooding at existing building sites. To integrate a sufficient number of measures to meet the objective of reducing the risk of flooding would require about 30 % of the total area. The following examples could be considered:

- Blue or green roofs on suitable buildings.
- A combination of swales and infiltration trenches along the streets, also known as bioswales, to improve infiltration and facilitate the conveyance of runoff from the streets and surrounding areas to the open green space created in the school grounds.
- Rain gardens at the school could be used to detain rainwater and enhance the quality of the outdoor space.

The exemplary illustration of the school grounds shows the integration of BGI in existing buildings and sites (Figure 16).

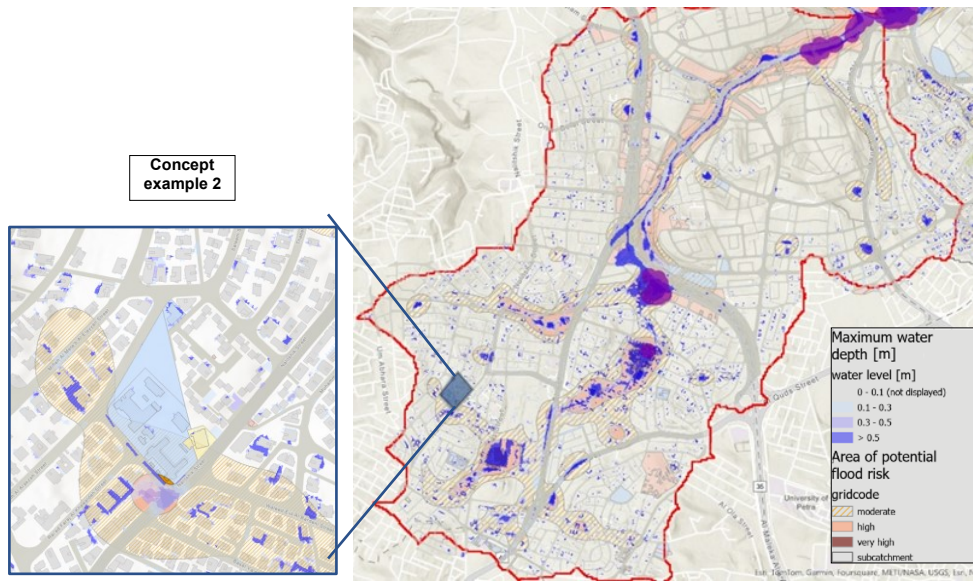


Figure 15: Map of the focus area Marj Al Hamam showing flood risk zones, max water depth and the location of the concept example 2 comprising public and privat lands.



Figure 16: Conceptual design of measures in public areas (Sharma, 2024).

4.4 Development of detailed plans

The 3-step guideline described above primarily aims to develop and integrate BGI in a strategic and holistic manner from an early stage. This mainly addresses public and municipal responsibilities.

The subsequent process of preliminary and detailed design for construction planning would be part of the general process of infrastructure, building and landscape architecture. It is therefore important that the boundary conditions, such as local stormwater management and further planning objectives, are clearly described so that they can be effectively integrated by the commissioned engineering office.

In order to follow up the successful integration of the boundary conditions, it is also necessary to establish regular round tables to evaluate the process and to get a picture of the adaptation of the process and strategy.

5 Recommendations for Jordan

Based on our experience of an integrated planning process for blue and green infrastructure in Amman, we have developed recommendations for urban planning that can effectively reduce the risk of flash flooding and create a more resilient, sustainable urban environment. These recommendations for integrated stormwater management can be transferred to many urban and rural areas in Jordan and the MENA region.

- ✓ **Stakeholder Engagement:** Continue to involve stakeholders in the planning and implementation process to ensure comprehensive input and support. As many measures address the additional aims and needs of stakeholders, these processes increase acceptance and willingness to collaborate.
- ✓ **Planning Goals:** It is important to agree on shared planning goals regarding the mitigation of flash flood risks. Aims can be a. to guarantee the basic functioning of infrastructures in the focus area and safe lives during flash floods; b. to mitigate flash flood damage in the focus area; c. to mitigate flash flood damage downstream e.g. in the city centre of Amman. It is important to agree on shared planning goals regarding the mitigation of flash flood risks. Aims may include: a. guaranteeing the basic functioning of infrastructures in the focus area and safeguarding lives during flash floods; b. mitigating flash flood damage in the focus area; c. mitigating flash flood damage downstream, e.g. in the city centre of Amman.
- ✓ **Detailed Feasibility Studies:** Conduct detailed feasibility studies (preliminary planning) for the proposed measures, especially for private areas, to assess structural integrity, retention and soil infiltration capacity. It is worthwhile to work on already urbanised areas as well as on new developments.
- ✓ **Pilot Projects:** Implement pilot projects in selected focus areas to evaluate the effectiveness of the proposed measures and make any necessary adjustments. Initial tests of planning, implementation, and operation can also provide valuable insights for the development of larger future projects.
- ✓ **Monitoring and Evaluation:** Establish a monitoring and evaluation framework to assess the impact of the implemented measures on flash flood reduction, groundwater recharge, and other planning goals.
- ✓ **Public Awareness and Education:** Enhance public awareness and education regarding the importance of flash flood protection and the benefits of BGI.
- ✓ **Integration of private areas:** Raising public awareness is a key starting point for encouraging the implementation and enhancement of measures on private properties. The necessity and extent of private area integration depend heavily on the chosen goals and the specific design of the neighborhood.
- ✓ **Integration into Urban Planning:** Incorporate the proposed measures into the broader urban planning framework to ensure long-term sustainability and resilience. Establishing an additional round table for ongoing exchange among professional stakeholders can support continuous coordination and strategic alignment across projects.
- ✓ **Maintenance and Operation:** Round tables, participatory processes, and shared pilot projects can help develop collaborative maintenance and operation routines. These are essential, as existing divisions of labor and responsibility often require adjustment.
- ✓ **Dealing with Data Scarcity:** A lack of reliable data may lead to increased reliance on estimations when defining risk zones and implementation strategies. Therefore, it is crucial to prioritize measures that provide broad ecosystem service benefits – a “no regrets” approach. For instance, a bioretention system can enhance water balance, biodiversity, and urban livability, even if it is not optimally placed from a flood risk perspective. Alternative data sources such as news reports and social media posts can also support assessments. Missing data should not be seen as a disqualifying factor but rather as a prompt to adapt site-specific strategies and objectives.

6 References

- Awad A. (2023): Analysis of the spatial-temporal dynamics of land-use changes using a mixed-method approach: A Case study from Amman, Jordan. M.Sc. at the faculty of life Sciences, technical university of Munich, Germany.
- Brinkmann, K., Ziegler, D., Hohmann, C., Hoffmann, P., Maus, C., Awad, A., Schuhmann-Hindenber, D., Leberke H. and Allemyar, A.B. (2025): Integrated multi-scenario analysis. In: Brinkmann, K. and Ziegler, D. (eds.): Capture and retain heavy rainfalls in Jordan. Findings of a transdisciplinary German-Jordanian research project. Frankfurt am Main. DOI: 10.5281/zenodo.16894182, pp. 69-80.
- CBD (Convention on Biological Diversity) (2006): Global Biodiversity Outlook 2. Secretariat of the Convention on Biological Diversity, Montreal, 81 + vii pages. Available at <https://www.cbd.int/doc/gbo/gbo2/cbd-gbo2-en.pdf> (accessed 6.12.2024).
- Sharma T. (2024): A comparative scenario analysis of WSUD measures for stormwater management in Amman, Jordan, HafenCity University Hamburg.
- Trapp J. H., Winker M. (eds.) (2020): Blau-grün-graue Infrastrukturen vernetzt planen und umsetzen. Ein Beitrag zur Klimaanpassung in Kommunen. Gefördert vom Bundesministerium für Bildung und Forschung. Berlin: Deutsches Institut für Urbanistik Difu.
- Winker M., Frick-Trzebitzky F., Matzinger A., Schramm E., Stieß I. (2019): Die Kopplungsmöglichkeiten von grüner, grauer und blauer Infrastruktur mittels raumbezogenen Bausteinen. Ergebnisse aus dem Arbeitspaket 2, netWORKS 4. netWORKS-Papers 34. Berlin: Deutsches Institut für Urbanistik Difu, Germany. Available at <https://repository.difu.de/handle/difu/2562131> (accessed 6.12.2024).
- Winker M., Matzinger A., Anterola J., Frick-Trzebitzky F., Pillen J., Schramm E. (2022): Infokarten für die Planung blau-grün-grauer Infrastrukturen (Infocards for planning blue-green-grey infrastructures). Forschungsverbund netWORKS. Frankfurt am Main, Germany. Available at https://www.networks-group.de/sites/default/files/networks4-infokarten_druck-a4_220dpi.pdf (accessed 6.12.2024).

7 Appendix

Appendix A: Assignment of a utilisation factor for each of the 47 land use categories within the Amman catchment.

ID	Utilisation factor	Land use categories of GAM (Greater Amman Municipality) for the City of Amman
Kat_01_	0	Alley roads_impervious surfaces
Kat_02_	0,2	Alley roads_potential open spaces
Kat_03_	0,2	Commercial_Building
Kat_04_	0,1	Commercial_Developed parcel
Kat_05_	0,2	Commercial_Undeveloped parcel
Kat_06_	0	Cultural heritage_Building
Kat_07_	0,1	Cultural heritage_Developed parcel
Kat_08_	0,2	Cultural heritage_Undeveloped parcel
Kat_09_	0	Entrance roads_impervious surfaces
Kat_10_	0,4	Entrance roads_potential open spaces
Kat_11_	0	Follower_impervious surfaces
Kat_12_	0,4	Follower_potential open spaces
Kat_13_	0,2	Low-income public housing_Building
Kat_14_	0,1	Low-income public housing_Developed parcel
Kat_15_	0,2	Low-income public housing_Undeveloped parcel
Kat_16_	0,3	Others_Building
Kat_17_	0,1	Others_Developed parcel
Kat_18_	0,2	Others_Undeveloped parcel
Kat_19_	0	Primary roads_impervious surfaces
Kat_20_	0,4	Primary roads_potential open spaces
Kat_21_	0,4	Public_Building
Kat_22_	0,2	Public_Developed parcel
Kat_23_	0,4	Public_Undeveloped parcel
Kat_24_	0	Railway_impervious surfaces
Kat_25_	0	Railway_potential open spaces
Kat_26_	0	Religious_Building
Kat_27_	0,2	Religious_Developed parcel
Kat_28_	0,4	Religious_Undeveloped parcel
Kat_29_	0,3	Residential C/D_Building
Kat_30_	0,1	Residential C/D_Developed parcel
Kat_31_	0,2	Residential C/D_Undeveloped parcel
Kat_32_	0,5	Residential villas/A/B_Building
Kat_33_	0,2	Residential villas/A/B_Developed parcel
Kat_34_	0,4	Residential villas/A/B_Undeveloped parcel
Kat_35_	0	Secondary roads_impervious surfaces
Kat_36_	0,2	Secondary roads_potential open spaces
Kat_37_	0	Side roads_impervious surfaces

ID	Utilisation factor	Land use categories of GAM (Greater Amman Municipality) for the City of Amman
Kat_38_	0	Side roads_potential open spaces
Kat_39_	0	Square_impervious surfaces
Kat_40_	0,4	Square_potential open spaces
Kat_41_	0	Stairs_impervious surfaces
Kat_42_	0	Stairs_potential open spaces
Kat_43_	0,3	Traffic zones_Building
Kat_44_	0,15	Traffic zones_Developed parcel
Kat_45_	0,3	Traffic zones_Undeveloped parcel
Kat_46_	0	Unclassified roads_impervious surfaces
Kat_47_	0	Unclassified roads_potential open spaces

Appendix B: Infocards of seven measures recommended for future implementation in the city of Amman



Raingarden

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DESCRIPTION

- Rain gardens are designed to collect, store, filter and treat water runoff. A variety of elements is used such as grass filter strips, water ponds, mulch areas, planting soil, plants.
- Rain gardens catch water runoff from roofs, roads and other (sealed) surfaces.
- can be combined with e.g. with rainwater harvesting measures and permeable paving.

PRIMARY PLANNING GOALS

- Reduction of flash flood damages
- Increase urban climate and biodiversity

CRITERIA FOR IMPLEMENTATION

- Mainly public or private area
- Along streets
- Required area > x

MAINTAINANCE

Maintenance operations have to be done on a regular basis including watering, pruning, pollarding, substitution of mulching and periodic review of the irrigation system (if present). The appropriate cycle of inspection is 1-2 years

PLANNING GOALS

Reduction of flash flood damage
Water supply (provision)
Groundwater Recharge
Erosion Reduction
Urban Climate
Quality of Stay
Water Protection
Biodiversity
Health Promotion
Environmental Education
Production of food and renewables
Urban Gardening and Agriculture



Source: FHH, Wissensdokument wassersensible Straßenraumgestaltung



Bioswales

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DESCRIPTION

- Bioswales are channels designed to concentrate and convey stormwater runoff while removing debris and pollution.
- Bioswales can also be beneficial in recharging groundwater through infiltration (see infiltration trench)
- Filled with rubble or stone
- Covered by grass that should be longer than 3 inches to survive flooding

PRIMARY PLANNING GOALS

- Reduction of flash flood damages
- Increase urban climate and biodiversity

CRITERIA FOR IMPLEMENTATION

- Mainly public or private area
- Flat sites
- Along streets
- Required area > x

MAINTAINANCE

Requires regular inspection and cleaning of silt and other sediments to maintain infiltration capacity and prevent risk of long-term clogging and weed growth

PLANNING GOALS

Reduction of flash flood damage
Water supply (provision)
Groundwater Recharge
Erosion Reduction
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Quality of Stay
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Biodiversity
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Urban Gardening and Agriculture



Source: Wikipedia



Runoff from the street flows directly into an adjacent bioswale

Source: Wikipedia



Infiltration trench

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DESCRIPTION

- Infiltration trenches are shallow excavations filled with rubble or stone which allow water to infiltrate into the surrounding soils from the bottom and sides of the trench.
- The excavations are flat areas planted with grass and under everyday conditions not filled with water.

PRIMARY PLANNING GOALS

- Reduction of flash flood damages
- Improvement of urban climate and biodiversity

CRITERIA FOR IMPLEMENTATION

- Public or private area
- Flat sites
- Along streets
- Required Area:..

MAINTAINANCE

Requires regular inspection and cleaning of silt and other sediments to maintain infiltration capacity and prevent risk of long-term clogging and weed growth

PLANNING GOALS

Reduction of flash flood damage
Water supply (provision)
Groundwater Recharge
Erosion Reduction
Urban Climate
Quality of Stay
Water Protection
Biodiversity
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Production of food and renewables
Urban Gardening and Agriculture



Source: FHH, Wissenschaftsdocument wassersensible Straßenraumgestaltung



Source: Hamburg Wasser: Infiltration trench with multifunctional use



Detention Basin/Retention Basin

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DESCRIPTION

Detention of stormwater for limited time to reduce flashflood. In dry season they are dry. In some cases the design can provide a constant minimum level of water (retention).

PRIMARY PLANNING GOALS

- Reduction of flash flood damages

CRITERIA FOR IMPLEMENTATION

- Mainly public or private area
- Required area > x

MAINTAINANCE

Periodical inspection and cleaning of silt and other sediments to maintain retention volume

PLANNING GOALS

Reduction of flash flood damage
Water supply (provision)
Groundwater Recharge
Erosion Reduction
Urban Climate
Quality of Stay
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Biodiversity
Health Promotion
Environmental Education
Production of food and renewables
Urban Gardening and Agriculture



Source: Retention: FHH Hamburg Altona Eckhoffplatz, 2022



Source: Wikipedia: Detention basin



Multifunctional Area

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DESCRIPTION

- Multifunctional areas are usually public areas used of recreation or traffic which can be occupied with a second use.
- Such areas can be streets, public places, green areas and playgrounds as well as bank structures of creeks and rivers.

PRIMARY PLANNING GOALS

- Reduction of flash flood damages
- Increase quality of stay

CRITERIA FOR IMPLEMENTATION

- Public or private area
- No steep slopes
- Required Area:...

MAINTAINANCE

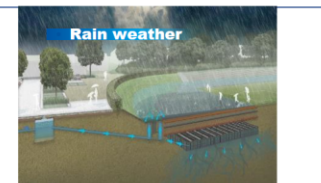
Requires inspections and maintenance after heavy rainfall events. A clear distribution of the different tasks of the involved stakeholders is required

PLANNING GOALS

- Reduction of flash flood damage
- Water supply (provision)
- Groundwater Recharge
- Erosion Reduction
- Urban Climate
- Quality of Stay
- Water Protection
- Biodiversity
- Health Promotion
- Environmental Education
- Production of food and renewables
- Urban Gardening and Agriculture



Source: FHH Altona: Retention and Recreation



Source: Hamburg Wasser: Retention and Sportsarea



Green roofs

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DESCRIPTION

- Green roofs can be divided into two categories –
- extensive (lightweight, grass plant covered rooftop)
 - intensive (capable for more complex plant structures, commercial or larger scale residential projects).

PRIMARY PLANNING GOALS

- Reduction of flash flood damages
- Increase in biodiversity and open space quality
- - Strengthening of evapotranspiration
- - Reduction of costs (precipitation fee)

CRITERIA FOR IMPLEMENTATION

- Buildings
- Private area or public property
- Flat or slightly inclined roofs

MAINTAINANCE

Periodical inspection and cleaning of silt and other sediments to maintain retention volume

PLANNING GOALS

- Reduction of flash flood damage
- Water supply (provision)
- Groundwater Recharge
- Erosion Reduction
- Urban Climate
- Quality of Stay
- Water Protection
- Biodiversity
- Health Promotion
- Environmental Education
- Production of food and renewables
- Urban Gardening and Agriculture



Source: Extensive greenroof, Alexa, Berlin (FBB, G.Mann)



Source: Intensive green roof DRK-Hospital Westend, Berlin (FBB, G.Mann)



Model of layers and components used in some green roof systems

Source: Wikipedia



Blue roofs

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DESCRIPTION

A blue roof is designed explicitly to provide initial temporary water storage. Blue roofs are constructed on flat or low sloped roofs in urban communities where flooding is a risk. Water is stored in blue roof systems until it either evaporates or is released downstream after the storm event has passed. Blue roofs that are used for temporary rooftop storage can be classified as "active" or "passive" depending on the types of control devices used to regulate drainage of water from the roof.

CRITERIA FOR IMPLEMENTATION

- Buildings
- Private area or public property
- Flat or slightly inclined roofs

MAINTAINANCE

Periodical inspection and cleaning of silt and other sediments to maintain retention volume

PRIMARY PLANNING GOALS

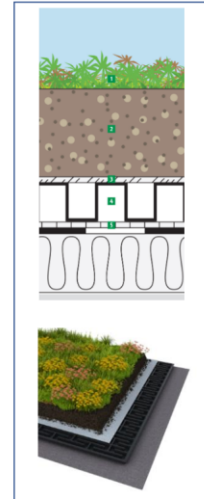
- Reduction of flash flood damages
- Water reuse (Water provision, Urban gardening)

PLANNING GOALS

Reduction of flash flood damage
Water supply (provision)
Groundwater Recharge
Erosion Reduction
Urban Climate
Quality of Stay
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Biodiversity
Health Promotion
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Production of food and renewables
Urban Gardening and Agriculture



Source: Optigrün, <https://www.optigruen.de/>



Rainwater harvesting

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DESCRIPTION

Rainwater can be collected in small or medium reservoirs to provide service water in buildings, outdoor areas, agricultural use (urban gardening)

CRITERIA FOR IMPLEMENTATION

- Buildings
- Private area or public property

MAINTAINANCE

Regular inspection and continuous control of water level

PLANNING GOALS

Reduction of flash flood damage
Water supply (provision)
Groundwater Recharge
Erosion Reduction
Urban Climate
Quality of Stay
Water Protection
Biodiversity
Health Promotion
Environmental Education
Production of food and renewables
Urban Gardening and Agriculture



Source: Wikipedia

PRIMARY PLANNING GOALS

- Reduction of flash flood damages
- Water reuse (Water provision, Urban gardening)



Source: Wikipedia



Urban Forest

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DESCRIPTION

In areas along streets or public areas the planting of trees or bushes will provide a good local climate through shadow, and evaporation. The roots build a good protection against erosion. Urban forests serve as recreational spaces for citizens and also provide natural/semi-natural habitats for various faunal species such as birds and invertebrates. The multi-functionality of urban forest has been emphasized serving as Nature based Solution

CRITERIA FOR IMPLEMENTATION

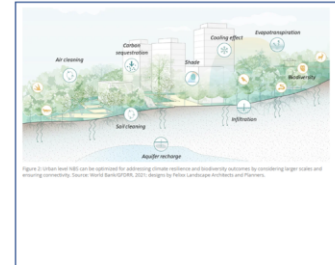
- Public areas property
- Along Traffic areas

MAINTAINANCE

- Regular inspection and Irrigation

PLANNING GOALS

Reduction of flash flood damage
Water supply (provision)
Groundwater Recharge
Erosion Reduction
Urban Climate
Quality of Stay
Water Protection
Biodiversity
Health Promotion
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Source: [Nature-based solutions for resilient cities and restoring local biodiversity \(worldbank.org\)](#)

PRIMARY PLANNING GOALS

- Improving Urban Climate and Biodiversity
- Avoid Erosion



Source: wikipedia