# 02.24 Heavy Rainfall and Flood Hazards

## Introduction

Extremely heavy rainfall may occur anywhere and affect anyone. Predictions as to when and where these events will happen exactly, however, remain rather unreliable. Berlin has seen a rise in extreme rainfall events causing considerable damage in recent years (July 2016, June 2017, July 2017, July 2018, August 2019, September 2021). Extreme weather events, particularly heavy rain and flooding are likely to increase in frequency and intensity, due to climate change. Water tends to gather more on impervious surfaces, resulting in floods. Roads temporarily transform into rivers. Small bodies of water and ditches swell significantly. Residential and commercial areas might experience flooding. The urban infrastructure might be damaged substantially.

It is impossible to completely prevent all negative effects of flooding caused by heavy rainfall. Damages may be reduced considerably, however, through effective heavy rain risk management or preventive measures. Data on heavy rain hazards and their analyses form the basis for the development of action plans to prevent or mitigate damage caused by heavy rain. These action plans raise awareness among stakeholders and those potentially affected by such events. They further assist in gauging the danger and risk associated with flooding induced by heavy rainfall. Additionally, measures may be assessed and prioritised in their planning.

Berlin has a **comprehensive heavy rainfall information map**, which may serve as an initial guide. This **heavy rainfall information map** provides a straightforward hazard assessment, combining topographic depression analysis with data on fire service operations. It displays areas potentially at risk of flooding based on low elevations and refers to heavy rainfall events that have caused damage in the past. Areas potentially at risk of heavy rainfall may therefore undergo an initial assessment. Based on this, the protection of buildings, infrastructure, and new construction projects may be optimised. In areas where heavy rainfall hazard maps are available (see below), they should be used to assess the risks of flooding caused by heavy rainfall. It is essential, however, to compare these results with the actual conditions on site.

The **heavy rainfall hazard map** provides a detailed analysis of the spatial extent of floods, flood depths, and flow velocities for a variety of heavy rainfall scenarios. They are the cornerstone of the municipal heavy rainfall risk management.

The **heavy rainfall hazard map** illustrates the **spatial extent of floods**, **flood depths (water level above ground)**, and **flow velocities** during heavy-rainfall-induced floods for different scenarios (rare, extraordinary, and extreme events). Surface runoff from heavy rainfall is calculated in two dimensions here, while also taking into account the sewer network (**1D/2D coupled model**). In 2021, initial steps were taken to develop a heavy rainfall hazard map for individual areas. Due to the size of Berlin, the city is divided into multiple catchment areas. The Berlin Waterworks (BWB) and the Senate Department responsible for water management are planning to jointly develop heavy rainfall hazard maps for additional areas in order to gradually expand the overall map for Berlin. The areas are prioritised according to their immediate need for heavy rainfall prevention and the planned rehabilitation measures for the city’s sewer system. Until Berlin’s heavy rainfall hazard map is complete, the **heavy rainfall information map** (see above) provides an overview of the potential dangers of flooding caused by heavy rain and the recorded events across the city. The Federal Agency for Cartography and Geodesy is working with the federal states to develop a heavy rainfall information map that also includes the State of Berlin. The findings of the Federal Agency for Cartography and Geodesy’s heavy rainfall hazard map are planned to be integrated into the heavy rainfall information map mentioned above.

The heavy rainfall information map and/ or the heavy rainfall hazard map are an important element of risk prevention and form the basis for risk-adapted planning and prevention. The heavy rainfall hazard map may support planners, operators of critical infrastructure, entrepreneurs, homeowners, and property owners in identifying water-sensitive areas. From the map, risks associated with heavy rainfall may be deduced. Information on water depths, flow paths, areas of origin, and catchment areas may assist in the planning of targeted measures. The map plays a crucial role in preparing for rare, extraordinary, and extreme rainfall events, as well as in adapting to the risks of heavy rainfall caused by flood hazards.

# Statistical Base

All data sources used are listed below:

## Map 02.24.1 Heavy Rainfall Information Map

- Topographic depression analysis of the BWB, 2022 (submitted on February 21, 2022; BWB 2022, unpublished)
- Fire service operations during rain, 2007 to 2017 (submitted on November 1, 2023; BWB 2023, unpublished)
- Fire service operations during rain, 2018 to 2021 (submitted on November 1, 2023; BWB 2023, unpublished)
- Urban and Environmental Information System (ISU5), 2021 – Changes to ISU areas (SenStadt 2021)
- Flood Hazard Map for Floods with Low Probability, 2019 (SenStadt 2019)
- Protected Areas and Protected Objects by Nature Conservation Legislation in Berlin (incl. Natura 2000), as of May 11, 2023 (Geoportal Berlin)
- Map of Bodies of Water, as of May 24, 2023 (Geoportal Berlin)

## Map 02.24.2 Heavy Rainfall Hazard Map

- ATKIS® DTM – Digital Terrain Model
- ALKIS® – Official Real Estate Cadastre Information System
- Rainwater and wastewater sewer network models (BWB)
- Data on charges (BWB)
- Drainage master plan (GEP), (BWB)
- Road drains
- Green Roofs
- Aerial photographs (orthophotos)
- Soil-scientific characteristic values
- Road survey
- Fire service operations and Flood Atlas
- Coordinated Storm Rainfall Regionalisation Analysis (KOSTRA) of Germany's National Meteorological Service (DWD)

Please note, it is not possible to specify the dates for the individual datasets, as the most recent data was used at the time of compilation. For detailed information, please refer to the individual reports (cf. Table 1).

# Methodology

Both maps are comprised of multiple layers that are distinct in terms of their subject matter and location. Some of these layers are self-contained. More specifically, the maps contain the following specialised layers:

## Map 02.24.1 Heavy Rainfall Information Map

The heavy rainfall information map is primarily based on the following resources:

1. **Topographic depression analysis** of the Berlin Waterworks (BWB) and

2. **Fire service operations** of the Berlin Fire Brigade (*Berliner Feuerwehr*) for the State of Berlin.

The **topographic depression analysis** is based on the topographic analysis of the digital terrain model (ATKIS® DGM - Digital Terrain Model, 2021), incorporating information on building areas, passageways, and floors (ALKIS® - Official Real Estate Cadastre Information System, 2021), which was conducted by the BWB in 2022. A GIS analysis was performed to identify depressions, flow paths, and accumulated runoff based on the pre-smoothed DTM. Buildings were integrated into the DTM as barriers to runoff, which cannot be overcome by water. Depressions in enclosed courtyards were excluded. The following depression attributes were derived based on a zonal statistics analysis and are part of the factual data display:

- Catchment area (DrainArea [m²]),
- Depression area (FillArea [m²]),
- Maximum depth of the depression (FillDepth [cm]),
- Lowest elevation within the depression (BottomElev [m]),
- Highest elevation within the depression (FillElev [m]) and
- Depression volume (FillVolume [m³])

Relevant depressions were identified based on the following criteria:

- Depression depth of at least 20 cm,
- Depression area of at least 4 m²,
- Depression volume of at least 2 m³,
- Catchment area of the depression of at least 200 m².

The dataset capturing **fire service operations** compiles 'water'-related reports from the Berlin Fire Brigade, which indicate a connection to heavy rain and which were recorded on days with heavy rainfall. The dataset was collected by the Berlin Fire Brigade and processed by the Berlin Waterworks (BWB) (i.e. Flood Atlas). The BWB cross-referenced the fire service operations with precipitation data from the BWB for the day and location in question, assigning an expected return period (T) to the rainfall event. Duplicates were removed. The following attributes were derived and are part of the factual data display:

- Date (created)
- Return period (T)
- District

The data was geocoded using the Berlin address file. The timeframe of the reports includes two periods, the years 2005 to 2017 and the years 2018 to 2021. These datasets were combined into one dataset, covering the period from May 2005 to September 2021. For the purpose of aggregation and presentation, the data was grouped and classified based on block segment areas and road areas of the Urban and Environmental Information System (ISU5 2021).

## Map 02.24.2 Heavy Rainfall Hazard Map

In Berlin, heavy rainfall hazards are analysed based on a coupled **1D sewer network and a 2D surface runoff model** (**1D/2D coupled model**). This approach integrates the calculation of runoff processes in the sewer network (1D) with the two-dimensional hydrodynamic modelling of surface runoff (2D). It allows for a bidirectional exchange of water volumes, i.e. an exchange in both directions, between the surface and the sewer network at manholes and road drains. Together, the Berlin Waterworks (BWB) and the Senate Department responsible for water management have developed a statement of work 'Preparation of Heavy Rainfall Hazard Maps for Berlin's Combined and Rainwater Catchment Areas' (*Erstellung von Starkregengefahrenkarten für Berliner Misch- bzw. Regenwassereinzugsgebiete*). This document forms the basis for defining heavy rainfall hazards.

Prerequisites include data on **topography, buildings, roads, impervious soil coverage, soil-scientific characteristics, and sewer networks**. The current sewer network (combined or separate sewerage system) provided by the BWB is used for the **1D sewer network model**. The drainage infrastructure is represented by a sewer network model and encompasses elements such as manholes, road drains, sewer sections between manholes and their catchment areas. A detailed and comprehensive **2D surface model** without overlaps is created based on the Digital Terrain Model. Standardised roof shapes derived from the building data are then integrated into the model. Walls or curbs are represented by break lines. The formation and concentration of runoff is impacted by the surface of the investigated area. Distinctions are therefore made between building areas, roads, paths, bodies of water, and green spaces based on the relevant data sources (cf. Chapter Statistical Base). Walls, curbs, and other linear elements, although not represented in the DTM due to resolution limitations, may act as runoff obstacles. If they are significant for runoff, they are subsequently added in as break lines.

Key datasets for **building areas** include ALKIS building data and the green roof dataset (for allotment garden areas). When it comes to the runoff formation of roofs, a distinction is made between discharging and non-discharging roofs, based on the records of precipitation charges. The model considers discharging roofs as directly connected to the sewer system (1D runoff formation). For non-discharging roofs, the runoff is modelled using the surface runoff model. In this case, the effective precipitation is spread across the surrounding surface by applying the principle of marginal distribution. **Roads and pathways** include all paved areas, such as roads, pathways, squares, and private impervious areas. Runoff from these areas is modelled using the 2D surface runoff model, without distinguishing between discharging and non-discharging areas. All standing and flowing waters from the ALKIS dataset are considered **bodies of water**. The remaining areas are assumed to be **green spaces**. These areas receive appropriate runoff parameters based on relevant literature. The parameters include runoff loss through wetting and accumulation in depressions as well as initial and final curve numbers. The model reflects the precipitation intercepted by vegetation (interception), the soil infiltration capacity, and the surface roughness.

In the context of flood risk areas (SenUVK, 2018), Berlin has already developed flood hazard maps and defined flood risk areas as part of the **Floods Directive**. To prevent overlaps with the heavy rainfall hazard maps, the **bodies of water** are assumed to be fully operational hydraulically. Additionally, certain bodies of water (e.g. of the first order (navigable waters), *Nordgraben*) are considered to be able to hydraulically cope with brief heavy rainfall events. Only prolonged, extensive rainfall events are expected to be ‘triggering’. The model assumes that discharge, i.e. an overflow of these bodies of water is methodologically impossible. Moreover, these waters are assigned uniform pre-flood water levels for a moderate flood (for rare and extraordinary events) and for a 100-year flood (for extreme events). For rare and extraordinary events, the actual pipes and culverts are included in the model. For the extreme event, it is assumed that culverts are either partially obstructed (diameter > 0.5 m (>DN 500)) or fully obstructed (diameter ≤ 0.5 m (≤ DN 500)), unless a debris screen prevents obstruction.

The resulting model is used to calculate flooding for different precipitation scenarios with varying return periods, relying on the Coordinated Storm Rainfall Regionalisation Analysis (KOSTRA) of Germany’s National Meteorological Service (DWD) for precipitation volumes. The revised dataset KOSTRA-DWD-2020 was used for this purpose. The following scenarios have been defined for Berlin in regard to heavy rainfall risk management:

- **rare event: 30 or 50-year rainfall event (T = 30a or T = 50a) with a Euler Type II precipitation pattern,**
- **extraordinary event: 100-year rainfall event (T = 100a) with a Euler Type II precipitation pattern, and**
- **extreme event: 100 mm rainfall event (T extreme) with block rainfall.**

The prevailing **duration category of 180 minutes** in Berlin was derived from a sensitivity analysis, with the highest water level being the most important factor. To model the timeline and intensity of the event, either the **Euler Type II distribution** (for rare and extraordinary events) or a 60-minute **block rainfall** (for an extreme event) was assumed. The model takes into account both the duration of the rainfall, i.e. the duration category of the analysed scenarios, and a one-hour time lag. A plausibility check is carried out based on the results of the exceptional event. On-site checks are executed to review any implausible runoff paths and accumulated water, while also recording any hydraulically relevant structures that may have been overlooked.

This method requires a large amount of data and computational power. It was therefore not applied to the whole city at once. Instead, it is carried out gradually for selected areas. Nevertheless, the method delivers rather accurate and sound results, providing insight into the formation and concentration of runoff. Coupled 1D/2D simulations continue to be run for additional areas and are subsequently published online. The table below illustrates the areas for which heavy rainfall hazard maps have already been created.

| Table 1: Areas for which heavy rainfall hazard maps have already been created. | | | |
|---|---|---|---|
| Area | Year | Contractor | Report |
| Obersee/Orankesee | 2021 | Hydrotec Ingenieurgesellschaft für Wasser und Umwelt mbH | Pilot study on heavy rainfall risk management at *Obersee* in Berlin Lichtenberg |
| Moabit | 2021 | Ingenieurgesellschaft Prof. Dr. Sieker mbH | Heavy rainfall hazard maps, Berlin catchment area *APw Bln VIII Moabit* |
| Flughafensee | 2021 | Institut für technisch–wissenschaftliche Hydrologie GmbH | Development of heavy rainfall hazard maps for the *Berlin Flughafensee* rainwater catchment area |

***Table 1: Areas for which heavy rainfall hazard maps have already been created***

# Map Description

## Map 02.24.1 Heavy Rainfall Information Map

The heavy rainfall information map illustrates the results of the BWB's **topographic depression analysis** and the **operations of the Berlin Fire Brigade** across the State of Berlin. It shows the extent of the depressions and classifies the number of fire service operations per block segment area. The map also shows for which flood hazard maps and for which flood risk areas there are heavy rainfall hazard maps based on the detailed coupled 1D sewer network/2D surface runoff simulation (1D/2D simulation):

- block segment areas with one fire service operation (yellow),
- block segment areas with two to five operations (orange),
- with more than five fire service operations (red)
- as well as no or an unknown number of fire service operations (grey).

These fire service operations linked to heavy rainfall act as an indicator for the likelihood of a reoccurrence and, therefore, an elevated risk of flood damage due to heavy rain. The individual **fire service operations** are displayed as dots when the map is zoomed in to a scale of 1:25,000 or more. Figure 1 provides a visual of the annual number of heavy-rainfall-related fire service operations. The year 2017 is particularly striking, with its heavy rainfall event from June 29 to June 30, 2017, and 1,004 recorded operations. On these two days, Berlin experienced unusually long and intense rainfall, which was mainly concentrated in the northwest of the city. Several regions experienced daily rainfall volumes equivalent to those of a 100-year event. Notably, Berlin-Tegel measured a daily rainfall total of 195.8 mm.

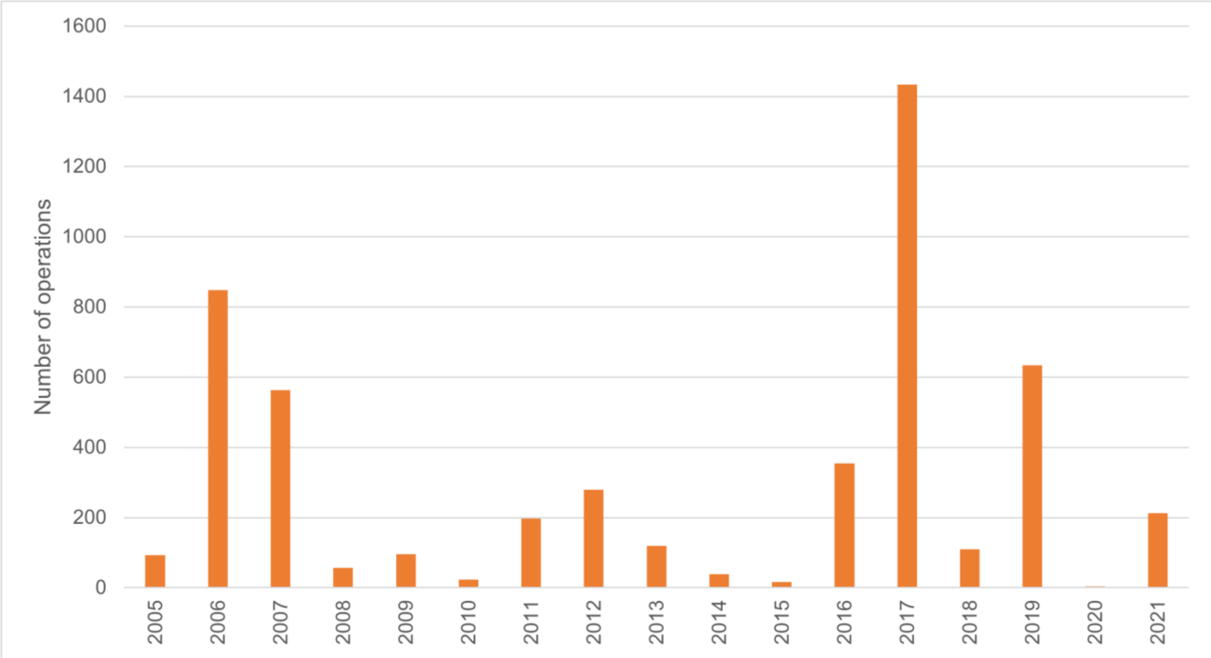


*Fig. 1: Number of fire service operations due to heavy rainfall by year for the period from May 2005 to September 2021*

Figure 2 illustrates the distribution of fire service operations both by month and by year. Heavy rain-related fire service operations occur most frequently in the months between May and September, with concentrations peaking between June and August.

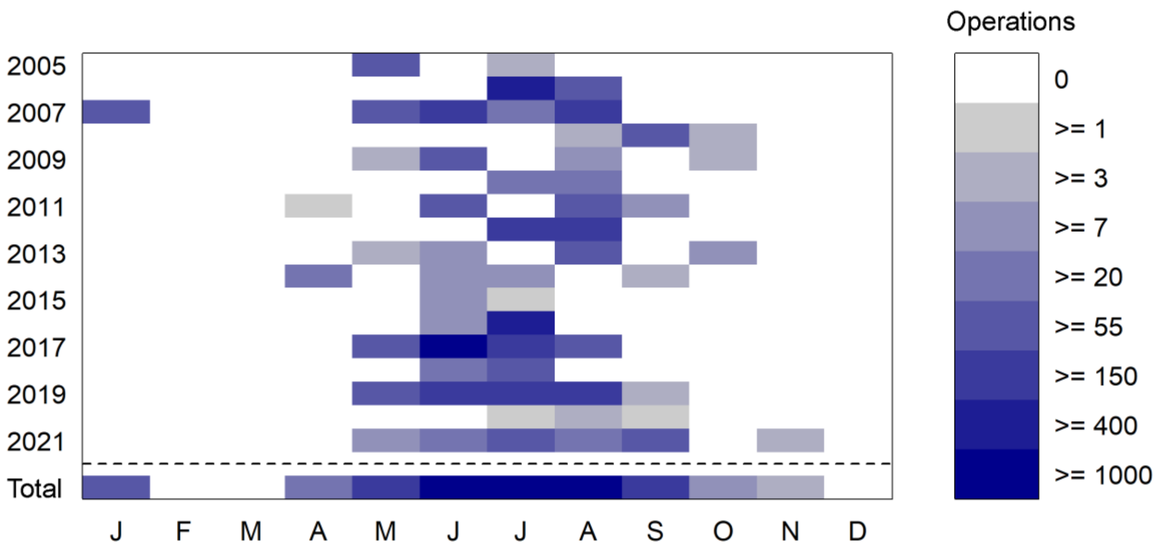


*Fig. 2: Number of operations (colour coding) by year (rows) and month (columns) for all operations between 2005 and 2021*

The depressions (turquoise) represent low points in the terrain where water might accumulate, potentially leading to the flooding of roads, squares, green spaces, and buildings. This is a purely topographic analysis that is not based on any specific precipitation scenarios. The depressions are therefore depicted independently of rainfall events and with their maximum potential volume. Drainage through sewerage systems (sewers, etc.) or factors such as infiltration into the ground were not taken into account in the analysis. Uncertainty in the depression data mainly arises from obstacles that impede the flow, such as bridges, railway and road embankments, or large culverts. Although they are crucial in determining the actual extent of a depression, they were not always considered. Additionally, small-scale structures such as curbs etc., cannot be factored in due to limitations in precision and resolution of the terrain model used.

Additionally, the map highlights areas for which **detailed heavy rainfall hazard maps** based on a **coupled 1D/2D simulation** are available. The **flood hazard map** not only illustrates the spatial extent of flooding from a river flood but also provides information on water depth for low-probability flood scenarios. A comprehensive description of the flood hazard and flood risk maps may be found in the Environmental Atlas. For Berlin, maps were developed only for risk areas and only for floods caused by river flooding. Floods caused by sewarage systems exceeding their capacity or groundwater surfacing, failure of dams installed for water-management purposes, or heavy rainfall are not shown on the maps.

The heavy rainfall information map therefore indicates areas potentially at risk of flooding and shows previously recorded heavy rainfall events. The map presented here combines a simple risk assessment, based on a topographic depression analysis, and data on fire service operations. It therefore offers a preliminary indication of areas prone to heavy rainfall-induced flooding, identifying topographic low points (depressions) and areas with a history of damage from such events. This facilitates an initial assessment and classification of areas at risk from heavy rainfall for existing buildings, infrastructures, and new buildings. Urban and land-use planning, for example, may then incorporate heavy rainfall preventive measures based on the heavy rainfall information map. With the map, areas that are potentially at risk may be identified and awareness for those involved may be raised early on. Please note, the heavy rainfall information map does not exempt individual projects from the responsibility to investigate and verify the hydraulic conditions on site. It is required to compare the model with the actual on-site conditions. All information is provided without a guarantee of accuracy. No liability will be assumed for damages resulting from the use of the retrieved information.

## Map 02.24.1 Heavy Rainfall Hazard Map

The **heavy rainfall hazard map** illustrates the **spatial extent of floods**, **flood depths (water level above ground)**, and **flow velocities**, providing insights into heavy rainfall-induced floods for different scenarios, including rare, extraordinary, and extreme events.

The **heavy rainfall hazard map** provides a detailed assessment of the spatial extent of floods, flood depths, and flow velocities for a variety of heavy rainfall scenarios. They play a crucial role in wastewater planning and are the cornerstone of the municipal heavy rainfall risk management. For the State of Berlin, these maps are particularly important for managing the heavy rainfall risks associated with rare (T = 30a, T = 50a according to KOSTRA-DWD as Euler Type II with a duration of 180 minutes), extraordinary (T = 100a according to KOSTRA-DWD as Euler Type II with a duration of 180 minutes), and extreme events (TExtrem = 100mm in 60 minutes as block rainfall).

The **water level**, or rather the **water level above ground** or **inundation depth**, is categorised into four classes. The highest observed water level is shown for each scenario. Levels below 0.1 m are not displayed, as the accuracy of the method and the underlying data does not allow for reliable assessments at these depths. Damage may still occur at these water levels, however. There is also an increased risk of accidents (e.g. due to aquaplaning). With inundation depths of 0.1 m or more, the risk of water penetrating into buildings or lower-lying parts of structures, such as basement flats, garage entrances, or underpasses, especially through ground-level features such as windows or light shafts, is considerably greater. Apart from the immediate risk of drowning, particularly for infants and children, there is also the risk of electric shock. Moreover, at a water level of 0.1 to 0.3 m, traffic is restricted, and as inundation depths rise (0.3–0.5 m), these risks amplify. Water is able to penetrate into buildings with slightly higher basement windows or raised entrances. Escape routes may be blocked due to the static pressure of the water. Furthermore, there is a risk of damage to parked vehicles, and roads become impassable for standard vehicles. Higher flood depths (> 0.5 m) significantly increase the risk of drowning for both children and adults. The static load on building and structural components increases, potentially posing an additional threat to human health in the event of collapse. At this point, only specialised vehicles are able to navigate the roads.

The **flow velocity** and **direction** (colour-coded flow arrows), which are based on the depth-averaged maximum velocity, are displayed when the map is zoomed in to a scale of 1:25,000 or more. From this, the flow paths as well as the origin and catchment area of local floods may be derived. Even minor flow velocities of up to 0.5 m/s may pose a risk to older individuals, those with limited mobility, infants, and children, when traversing a flow path, especially at greater depths. Seals may break due to increased pressure. With accelerating flow velocities (0.5–1.0 m/s), the risk increases during the crossing of a runoff path, which then also applies to adults. Due to the combination of static and dynamic forces the risk of failure of building and structural components increases. Higher flow velocities (> 1.0 m/s) may result in larger solid objects being carried by the flow (e.g., cars, tree trunks). These objects not only pose a direct threat to human safety but may also cause additional damage to building and structural components, amplifying the risk of failure. The water may be contaminated by foreign substances such as oil, faecal matter, or chemicals, leading to greater damage. For instance, damaged oil tanks not only jeopardise the building they are in, but also affect neighbouring structures as well as the environment. The structural integrity may also be compromised by undermining, potentially leading to the collapse of building and structural components. Time plays a key role in heavy rainfall events. The longer water persists, the greater the risk of further structural damage.

The heavy rainfall hazard maps feature **additional information**. Apart from plots, they also display bodies of water, vegetation areas, roads, parking areas, sidewalks, tree pits, median strips and verges, railway tracks, and building functions. These details are presented as background maps and reflect the current status, rather than that of the heavy rainfall hazard map.

Please note, the heavy rainfall hazard map does not exempt individual projects from the responsibility to investigate and verify the hydraulic conditions on site. It is required to compare the model with the actual on-site conditions. All information is provided without a guarantee of accuracy. No liability will be assumed for damages resulting from the use of the retrieved information.

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