CLEVER Cities

Drainage Analysis For Heavy Rainfall – Neugraben-Fischbek

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Content

0. Summary

Within the framework of the EU Horizon 2020 Project CLEVER Cities (GA 776604), a heavy rain hazard analysis was carried out for the Neugraben-Fischbek district and measures were identified that have the potential to alleviate the hazard of extreme heavy rain events. The developed measures have the potential to strengthen the natural water balance and avoid the pollution of surface waters and groundwater. Nature-based measures such as deep beds, sinks or similar can develop multiple benefits and were the focus of this work.

The simulation-based hazard analysis included the surface runoff and the runoff in the sewage system. A bidirectionally coupled hydrodynamic runoff model consisting of a 2D model of the surface and a 1D network model was used. The software used was HYSTEM-EXTRAN 2D (HE2D) from itwh GmbH. The basis for the simulation model and the drainage and flooding analysis were the digital terrain models for Hamburg and Lower Saxony, as well as the available data on the various drainage facilities. The study area, which also includes non-settled areas in Lower Saxony or, among others, the nature reserve "Fischbeker Heide" includes, partly, a dynamic topography, covers a total area of approx. 42 km^2. The investigation of the flood risks related in particular to the lower-lying populated area of the Neugraben-Fischbek district.

Several rain events with different return probabilities were selected as rainfall scenarios according to the concept of the heavy rain index (SRI). Rainfall events with the indices SRI-3, SRI-5 (intensive heavy rainfall), SRI-7 (exceptionally heavy rainfall), SRI-8 (extremely heavy rainfall, event of 18th June2020) and SRI-10 (extremely heavy rainfall) were used for the simulation. The heavy rain event on 18.06.2020 was used as a valuable verification and adjustment event for the calibration and validation of the simulation model.

For selected areas, measures were developed that aim to reduce the risk of flooding. Due to the special topography of the area under consideration with a relatively large, hilly tributary area, the topic of retention areas in the outer areas was also considered more intensively. In order to validate the effectiveness of the measures developed, renewed simulation runs were carried out for the various heavy rainfall events, taking into account the structural and topographical changes caused by the measures.

The project has exemplary and pilot character due to the methodology carried out and especially due to the application of coupled hydrodynamic runoff modelling to a relatively large catchment area. Thus, it represents a method that can also be transferred to other districts of Hamburg as well as other municipalities. Another innovative and forward-looking aspect of this project was the participation of a wide range of stakeholders (including district and ministerial water management, nature conservation, urban planning, universities) during the process of developing measures, which was another helpful building block for improving the level of detail of the processing.

1. General introduction and CLEVER Cities framework

„Drainage analysis for heavy rainfall“ was developed within the framework of the EU Horizon 2020 Project CLEVER Cities (GA 776604). As a front-runner city Hamburg, alongside Milan and London, intends to tackle local urban regeneration challenges in the project area in Neugraben-Fischbek. The goal of the CLEVER Cities is to promote sustainable and socially inclusive urban regeneration by means of locally tailored nature-based solutions (so-called Nature Based Solutions; in short: NBS). As solutions inspired by and in harmony with nature, this can include, for example, topics such a greening of facades or the retention of rainwater after heavy rainfall in nature conservation areas. Another goal is that the brainstorming, project development and implementation are co-created together with residents, private and public sector representatives and the administration in a so-called Urban Innovation Partnership (UIP).

Within the framework of the CLEVER CiBiX workshop (City Business Accelerator), which was conducted with specialists on the topic of rainwater management and heavy rainfall prevention from the administration and experts from specialist offices, the CLEVER working focus was developed to focus more strongly on the cross-sectional topic of "rainwater management". The dynamic topography and existing drainage problems in the project area led to the commissioning of the present analysis.

The "Drainage Analysis for Heavy Rainfall" was regularly accompanied by a UIP consisting of various departments of the Hamburg administration, the State Office for Roads, Bridges and Waterways, the urban project development company IBA GmbH, the Technical University of Hamburg (TUHH) and HAMBURG WASSER (HW). The drainage analysis provides initial "nature-based" ideas for problem solving for the Neugraben-Fischbek district. The feasibility of implementation is currently being examined.

The project area of CLEVER Cities is located in the city district Neugraben Fischbeck, south-west of Hamburg. The district has 31.589 inhabitants[1] and an area size of 22,5 km^2 [1].The focus of the drainage analysis for heavy rainfall is on the entire district. The hydrological catchment area with a size of 42 km^2 includes not only the study area but also areas from the adjoining federal state Lower Saxony.

The topic of heavy rainfall prevention is of particular focus of action for the Neugraben-Fischbek area due to differences in elevation within the area and repeated flooding with property damage due to heavy rainfall events. Furthermore, the drainage system is set up diversely with parts of the area drained by a storm drainage system and other parts with open area drainage. These systems are closely interrelated. The area offers the possibility to transfer the findings of the analysis gained on this scale to other districts of Hamburg or other municipalities (upscaling).

The foundation for the study is a drainage and flooding analysis based on the current state. A rainfall-runoff model was developed for the hydrological catchment area, taking into account terrain elevations, soil conditions and the sewage network. The basis for the modeling of the runoff models are model rainfall events, which are based on the Hamburg heavy rainfall index. Additionally, a calibration of the model was carried out by means of the data on the heavy rain event on 18th June 2020.

[1]Source: Hamburger Stadtteilprofile, Statistikamt Nord (Berichtsjahr 2019), https://www.statistik-nord.de/fileadmin/Doku-mente/NORD.regional/Stadtteil-Profile_HH-BJ-2019.pdf

2. Basic information

2.1. RISA

The urban development of the Free and Hanseatic City of Hamburg (FHH) has set itself the goal of dealing with the topic of stormwater from an overarching perspective with the guiding principle of a "growing" and "green metropolis on the waterfront". Both, the goal of a "green and fair city" and the goal of a "growing" city are relevant.

The additional surface sealing associated with the desired "growth" and the expected changes in precipitation as a result of climate change require a systematic analysis of the possible effects on stormwater. Both factors lead to the expectation of an increase in surface runoff, which, especially during heavy rainfall, can overload the existing drainage facilities or put additional strain on water bodies and thus cause considerable damage due to flooding.

Integrated Rainwater Management (IRWM) pursues the goal of preserving and restoring a local water balance in the city that is close to nature by focusing more on local infiltration and evaporation than on direct discharge of stormwater, thus contributing to water protection and flood prevention. The Hamburg environmental authority (today BUKEA, Ministry for the environment, climate, energy and agriculture, formerly BSU, Ministry for urban planning and environment) and HAMBURG WASSER have focused on the adaptation of the rain infrastructure for Hamburg and have bundled this under the name RISA (Regen-InfraStrukturAnpassung). The RISA field of action "natural local water balance" refers to the balancing of the components surface runoff, infiltration and evaporation of precipitation water. Infiltration absorbs a considerable proportion of the precipitation. For this purpose, rainwater management offers a variety of possibilities. In connection with the preservation of vegetation and surface permeability, it includes a wide range of different, primarily decentralized measures for runoff reduction, intermediate storage, rainwater utilization, infiltration and delayed discharge as a "modular system". They are supplemented by measures for the treatment of polluted rainwater runoff and flood prevention.

The integration of rainwater as a design element in nature-based solutions can also create attractive accents in the cityscape and in urban culture. In addition, there are further synergy effects with urban nature. Influences on the microclimate such as cooling through evaporation leads to reduction of heat islands.

2.2. Geographic and water management boundary conditions

In the following, topography, infiltration potential, receiving waters and water bodies as well as drainage in the study area are briefly described, as they were included in the analysis as framework conditions.

The basis for the drainage and flooding analysis in Neugraben Fischbek is the topography. Figure 1 represents the data from the digital terrain model from 2017, which was also used for further investigation in this analysis.

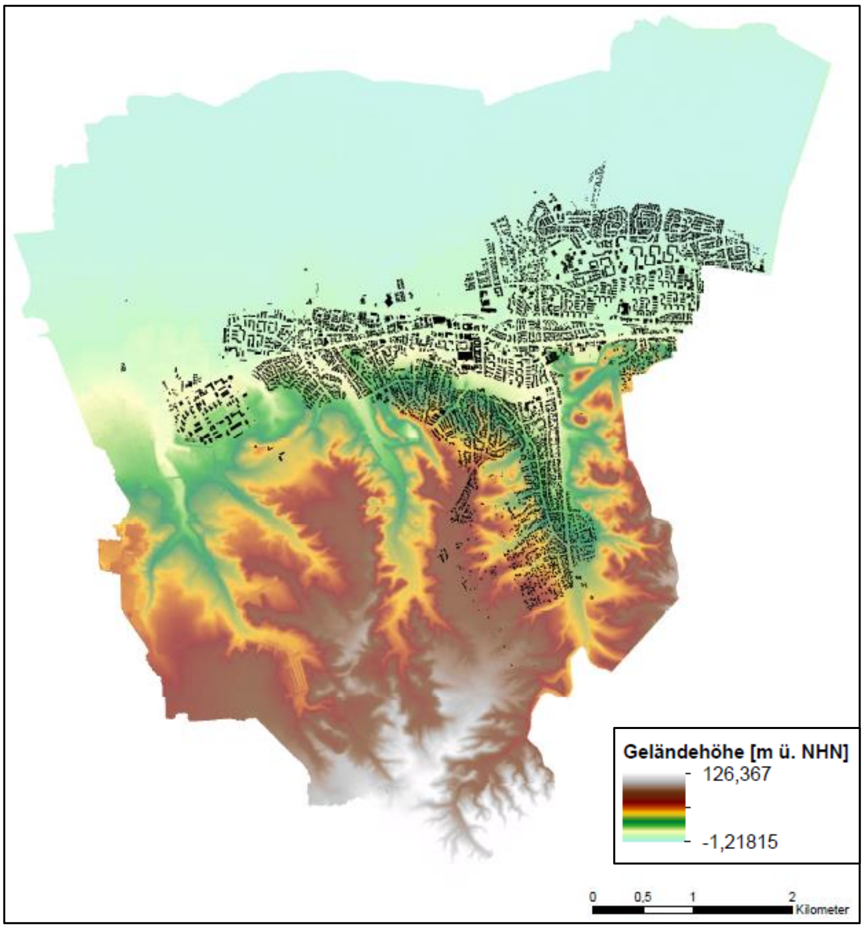


Figure 1: Geländemodell und Gebäude im verwendeten Modellgebiet

The geological layer structure, the distance to the groundwater surface and the terrain or slope inclination were used to assess the infiltration potential. The geological data was taken from the drilling data from 2017 and an interpolation between the drilling points was carried out. The infiltration potential in the southern area of Neugraben-Fischbek can largely be classified as "infiltration possible" to "infiltration probable". The corresponding infiltration depths are between >5 metres and 2-5 metres. This classification can be attributed to high groundwater table depths (up to 90 m at higher altitudes), which are still 2.5 - 5 metres in the dry valleys, as well as the sandy soil near the surface. If the slope is also considered, the pronounced slopes in the southern part of Neugraben-Fischbek result in significantly lower percolation depths in many places. In these areas, the construction of infiltration systems is not recommended. In the northern area of Neugraben-Fischbek, there is little potential for infiltration. Here, the depths capable of infiltration are partly less than one metre due to the peat and bog soils as well as the very low groundwater table depths.

There are a large number of ditches/drainage ditches running through the bog in the study area. Drainage ditches, stormwater retention basins and stormwater pipes are also used for drainage.
The sewer system in the study area is a separate sewer system. In the Neugraben-Fischbek district the wastewater sewers havein total a length of about 80 km. The wastewater collected is transported to the Köhlbrandhöft-Dradenau sewage treatment plant in Hamburg. The stormwater pipes have a length of about 42 km and are divided into 29 catchment areas. Retention basins and receiving waters are located in the CLEVER Cities project area and form important components of the drainage system. Further technical drainage elements are road drainage systems in the study area. This system consists of gutters, trench piping and soakaways, which can collect, convey and infiltrate road runoff in areas without stormwater drainage systems. In some places there are connections between the street drainage systems and the stormwater drainage system and even connections to the sewage water system. In areas with steeper gradients some streets in the south drain completely via the street surfaces. When these streets reach a storm sewer system, there are often several gullys in succession to collect the surface runoff from the relatively large connected area.

The study area is located in protection zone III of a water protection area. The requirements of preventive groundwater protection must therefore be taken into account when planning drainage and measures. Surface infiltration systems (swales and surfaces) are to be preferred. Shafts are not regular infiltration systems and, especially in the case of road drainage, cannot be approved under water law.

The nature reserve "Fischbeker Heide" is located in the south-west of Hamburg in Harburg. The approx. 763 ha area covers a large part of the non-settled area within the study area. The maintenance and development plan drawn up in 2017 is available for the nature reserve. It defines the development goals for the Fischbeker Heide nature reserve and the measures required for the conservation and development of its fauna and flora. It has been prepared in close consultation with the specialist authority and forms the technical basis for the implementation of the development objectives and the execution of the measures (EGL 2017 https://www.hamburg.de/fischbeker-heide/). In the present study, the areas designated as "potential retention areas" ("RA") are partly located in the nature conservation area "Fischbeker Heide". It must be ensured that the conservation objectives of the nature reserve are not impaired and that the measures do not contradict the maintenance and development plan.

2.3. Description of the simulation model

The analysis of cloudburst induced flooding and the development of heavy rainfall prevention measures are based on the analysis of fire brigade data and the results of flooding simulations. The flooding simulations are carried out with a coupled hydrodynamic runoff model consisting of a 2D model of the surface and a 1D vertical network model. This means that the model calculates the runoff processes on the surface, in the screening network and in the existing watercourses based on precipitation data as a load parameter. The interaction between these systems is also taken into account by means of a bidirectional coupling, so that e.g. overflow processes and backwater effects from the watercourses into the screening network can be mapped. The main results of the flood calculation are the temporal course of the water depths and flow velocities. The maximum values of these variables form the basis for the present drainage analysis for heavy rainfall and the development of the heavy rainfall hazard maps.

The flood simulations are carried out using the HYSTEM-EXTRAN 2D (HE2D) software from itwh GmbH (itwh, 2020). HE2D calculates the surface runoff on the basis of the full 2D surface water equations (dynamic wave approach) using a cell-centred explicit finite volume method. The calculation method was verified using several benchmark tests (itwh, 2020). For the calculation, the model area is divided into an unstructured triangular grid. The net precipitation, which is calculated by an integrated precipitation-runoff model (NA model), is supplied to the triangular elements in time steps during the simulation. The NA model takes into account wetting and interception losses as well as depression and infiltration losses depending on the existing surface conditions (e.g. road, building or forest). Depression losses are calculated using the limit value method and represent the losses that occur due to retention in the small-scale terrain irregularities that are not recorded in the digital terrain model (DTM). Infiltration losses are calculated using the Horton approach extended according to Paulsen (itwh, 2020).

The 2D surface runoff model is coupled bidirectionally with a hydrodynamic 1D sewer network runoff model - HYSTEM-EXTRAN (HE) - via the manholes and street drainsand gullys in the study area. In the event of overloading of the sewer, the overflow is supplied to the surface runoff model in time steps. Depending on the altitude, street drains can also become sources of overflow. Conversely, water from the surface enters the sluice through the street drains (and manholes) if free capacities are available there. A so-called suction capacity is assigned to the street drains in the model, which parameterises their hydraulic capacity. The suction capacity is a constant value over time (e.g. 15 l/s) and forms the upper limit for the intake of surface water.

The runoff from buildings that have a connection to the sewage system is also supplied directly to the corresponding drainage system (using the linear storage cascade approach). Here, the capacity of the roof drainage is taken into account by determining a design rainfall intensity. If this is exceeded by rainfall, the runoff is distributed to the calculation elements of the 2D surface runoff model adjacent to the building.

Culverts of piped watercourse sections and flood relevant outlets of the channel model are connected to the 2D model with a bidirectional horizontal coupling - in contrast to the vertical coupling via manholes and street drains. In this process, the water levels are synchronised.

2.4. Nondynamic flow direction and sink determination

In addition to the more realistic representation of flooding through the simulation model described in chapter 2.3, the existing results of a flow direction and sink analysis, the so-called heavy rain hazard map from HAMBURG WASSER, are also used (https://t1p.de/starkregen-hh). The identification of existing sinks and flow paths is GIS-based (ESRI ArcGIS) and is the result of extensive individual work steps. For this purely topographical analysis, a digital terrain model (DTM, as of 2017[2]) with a point spacing of one metre was used. The original point data were converted into a 1 m grid for this purpose. The coupled simulation of the runoff event (sewer network and

[2] Source: Freie und Hansestadt Hamburg, Landesbetrieb Geoinformation und Vermessung, 2017. Datenlizenz dl-de-by-2.0.

surface) can approximate the actual filling levels of existing sinks. In addition to the simulation results of the coupled 2D surface model, the contents of the flow direction and sink map can be used to assess where sinks and flow paths may occur regardless of the actual water level. Thus, the superordinate flow paths and the topographically maximum extent and depth of the sinks represent the "worst case" of flooding. The representation of the sinks and in particular the superordinate flow paths helps to assess the hazard situation and serves as a first assessment of the potential success of proposed measures. An actual examination of the effectiveness takes place via the simulation model described in chapter 2.3.

In addition, surface flooding can occur due to both - a sewer network working at full capacity and a simple blockage/obstruction of one or more road gullies/culverts. This occurs mainly in the autumn months with heavier leaf fall. Likewise, due to the limited absorption capacity of the riverbeds during extremely heavy rainfall, a temporary backwater can occur on the surface. In the case of steep slopes, it can also happen that rainwater on the surface is not channelled to the storm drain. In this case, the rainwater exceeds the inlets and is not completely drained into the sewer.

3. Methods

3.1. Precipitation scenarios

In the following, the precipitation scenarios are explained. For this purpose, the used rain radar, the heavy rain index (extreme value statistics), the selected heavy rain for the drainage analysis and the extreme heavy rain event of the 18th June 2020 are explained.

HAMBURG WASSER operates a modern rain measuring network of currently 18 weighing gauges. In these devices, the collected precipitation is measured with a sensitive scale and documented every minute. The measurement data is sent by radio every five minutes to a HAMBURG WASSER server, where it is archived and corrected if necessary. The data goes directly into the processing of the radar raw data of the German Weather Service as a reference value.

Unlike conventional precipitation gauges, the rain radar does not measure precipitation directly. The radar emits energy pulses in the form of electromagnetic waves. The wavelength is designed to scatter off the precipitation particles. The radar antenna then measures the backscattered small fraction of the energy. From the position of the antenna and the travel time of the electromagnetic wave, it is possible to determine the position and distance of the reflecting precipitation particles. HAMBURG WASSER operates three drop spectrographs set up on the ground and uses the DWD's DX and SWEEP products. An updated product is available every five minutes. No quality check or calibration is carried out by the DWD in advance. The product shows the echoes closest to the ground in a 125 km range near the radar. The display is in polar pixels and offers a very high temporal availability. HAMBURG WASSER uses the data from the radar sites in Boostedt, Rostock and Hanover for the visualisation and analysis of rain events, for the calculation of the heavy rain index, for the provision of the online heavy rain map and also for an operational quantitative precipitation forecast with a forecast period of up to three hours. The data can be visualised in geographic information systems together with other infrastructure and area data. They are available for integration in simulation models such as for the drainage analysis for heavy rainfall in Neugraben-Fischbek.

Every ten years HAMBURG WASSER carries out extreme value statistics in accordance with DWA-A 531 and a trend analysis of heavy rainfall from the measured precipitation. The last analysis in 2010 did not show any relevant increase in the frequency of heavy rainfall for Hamburg. Only for the frequent but uncritical heavy rainfall could a slight increase be determined, which will be evaluated again for plausibility by the upcoming analysis in 2021.

Irrespective of the question of whether heavy rainfall events are increasing, the media presence of flooding events and the public debate on the potential impacts of climate change have increased awareness of the need for a risk assessment of heavy rainfall. Therefore, a scale was established that makes the phenomenon of "heavy rain" easier to understand and compare. Since there was still no number-based classification and no name categorisation for heavy rain, a scale from one to twelve was developed in 2015

(SCHMITT, 2015), which can be used to classify and name the strength of heavy rain similar to wind strength. The previous extreme value statistics of the long-term precipitation measurements, which are based on a logarithmic regression of the extremes, were not changed (DWA, 2012 & DWD, 2017), but assigned to the scale accordingly. For extreme heavy rainfall, increase factors were introduced.

Table 1: Precipitation totals and duration stages selected from KOSTRA-DWD 2010R as the basis for the Hamburg heavy rain index (extract), HAMBURG WASSER

Wiederkehrzeit T [a]	1	2	3,3	5	10	20	25	30	50	100	> 100								
Kategorie	Starkregen				Intensiver Starkregen				außergewöhnlicher Starkregen		extremer Starkregen								
Starkregenindex SRI [-]	1	1	2	2	3	4	4	5	6	7	8		9		10		11		12
Erhöhungsfaktor [-]										1	1,2	1,39	1,4	1,59	1,6	2,19	2,2	2,79	>2,8
Dauerstufe	Niederschlagshöhe hN [mm]																		
5 min	4,9	6,3	7,4	8,2	9,6	11,1	11,5	11,9	13,0	14,4	17	20	20	23	23	32	32	40	40
10 min	7,7	9,7	11,1	12,3	14,3	16,3	16,9	17,5	18,9	20,9	25	29	29	33	33	46	46	58	59
15 min	9,4	11,8	13,6	15,1	17,5	19,9	20,7	21,4	23,2	25,6	31	36	36	41	41	56	56	71	72
20 min	10,6	13,4	15,4	17,1	19,9	22,7	23,6	24,4	26,5	29,3	35	41	41	47	47	64	64	82	82
30 min	12,2	15,6	18,1	20,1	23,5	27,0	28,1	29,0	31,5	34,9	42	49	49	55	56	76	77	97	98
45 min	13,5	17,7	20,7	23,2	27,4	31,5	32,9	34,0	37,1	41,2	49	57	58	66	66	90	91	115	115
60 min	14,3	19,1	22,6	25,4	30,3	35,1	36,6	37,9	41,4	46,2	55	64	65	73	74	101	102	129	129
90 min	15,8	20,9	24,6	27,7	32,8	37,9	39,5	40,9	44,7	49,8	60	69	70	79	80	109	110	139	139
2 h	17,0	22,3	26,2	29,4	34,7	40,1	41,8	43,2	47,1	52,5	63	73	74	83	84	115	116	146	147

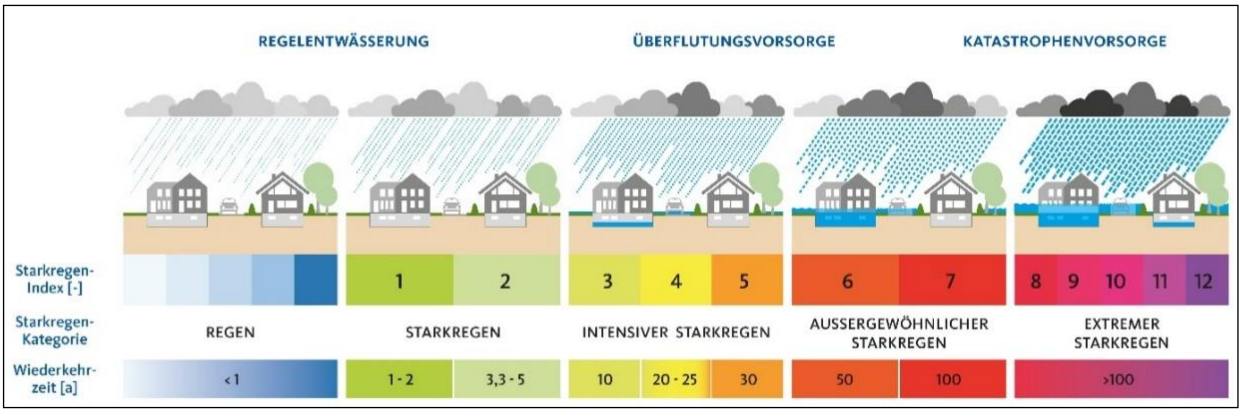


Figure 2: Hamburg presentation of the heavy rain index for risk communication, HAMBURG WASSER

For the analysis of possible flooding and the development of the heavy rain hazard maps, precipitation scenarios of different statistical return periods with rain durations of 60, 90 and 120 minutes were selected. Preliminary investigations with a simplified model showed that the rainfall duration of one hour is sufficient to adequately represent the concentration process in the model area. Thus, one-hour model rains were used for the development of measures. The final calculation was then carried out with two-hour model rainfall.

In agreement with the client, it seemed sensible for reasons of transparency and comprehensibility to designate the selected heavy rains according to the heavy rain index. In order to represent the entire spectrum of heavy rainfall and its possible impacts, Euler II model rainfall of the indices SRI-3, SRI-5, SRI-7, SRI-8 and SRI-10 were used.

The need for flood prevention on properties and in public spaces were taken into account by choosing the heavy rain category "intensive heavy rain" with indices SRI-3 and SRI-5. The category "exceptionally heavy rain" represents the transitional area of flood prevention to disaster prevention as a communal task and is represented by the index SRI-7. The inclusion of the heavy rain category "extreme heavy rain" with index SRI-8 is based on experiences of recorded extreme heavy rain such as on the 1st August 2002 (Winterhude and Hamburg city centre), 10th May 2018 (Bergedorf and Lohbrügge) or 18th June 2020 (Neugraben). These rain events caused immense damage in Hamburg and were therefore taken into account as rare but realistic threats to Hamburg's infrastructure. The addition of the category SRI-10 is intended to cover the imponderables for future rainfall events due to climate change.The rainfall heights in Table 2 were taken from KOSTRA-DWD 2010R and show an overview of the model rainfall used.

Table 2: Heavy rainfall heights for drainage analysis from KOSTRA-DWD 2010R (SRI-3 to SRI-10)

Starkregenhöhen in mm für Hamburger Gefährdungsanalysen aus KOSTRA-DWD 2010R	SRI-3 T=10a	SRI-5 T=30a	SRI-7 T=100a	SRI-8 T>100a	SRI-10 T>>>100a
D=60min	30	38	46	55	74
D=90min	33	41	50	60	80
D=120min	35	43	53	63	84

For the verification and adaptation of the simulation model, the heavy rain event of the 18th of June 2020 was used, which affected Neugraben-Fischbek significantly. Critical locations where damage occurred due to the heavy rain event could be identified from press reports. For this event, radar-based rain grids with a spatial resolution of 500m x 500m and a temporal resolution of five minutes were generated. This provided a good representation of the dynamics of the heavy rain event.

3.2. Structure of the simulation model

To calculate the flooding caused by heavy rainfall, a coupled 2D surface runoff model was developed. The model construction includes the following steps:

- Preparation, verification and correction of the digital terrain elevations
- Definition of the model boundary
- Generation of a detailed 2D calculation grid based on the processed terrain heights
- Incorporation of the buildings as runoff obstacles
- Determination of the roughness coefficients based on the surface conditions
- Construction of a rainfall-runoff model based on land use
- Consideration of the screening network through bi-directional coupling of manholes, street drains, outlets and culverts
- Mapping of open and piped watercourses
- Test simulations, checking of results and model adjustments in an iterative process
- Parameter optimisation and model validation based on a comparison of the simulation results with the photos, videos and fire brigade operations of the heavy rain event of 18th June 2020

For the representation of the topographic conditions in the 2D surface runoff model, the heights from different digital terrain models were merged into one data set. For the majority of the Hamburg model area,

a DTM with a grid size of 0.25 m (DTM025, corresponding to 16 points per m²) from 2011 was used. The DTM created was checked and adapted, especially in regard of the continuity of the flow paths, to ensure a realistic representation of the runoff paths. At bridge crossings, which are often completely or partially included in the DTM, the heights at the ground level were reduced by linear interpolation. Culverted watercourse sections and trench culverts were identified using various data sources and a visual inspection of the DTM and mapped in the 1D model.
On the basis of a comparison of the screening data (bottom heights of the outlets and shaft terrain heights) with the digital terrain heights, a clear and systematic difference between these two sets of data was detected, which was confirmed by a survey. The suspected cause for this height discrepancy is, apart from the vegetation in the trench, which possibly leads to a shadowing during laser scanning, mainly a silting of the trench. This was reversed in August 2020 by maintenance work commissioned by the Harburg district authority. Since the survey of the trench took place afterwards, the current bed heights are in the model.

The surface runoff calculations are carried out by the simulation model on the basis of an irregular triangular grid, which represents the topography of the study area. The model contains a total of 6.3 million calculation elements, whose area ranges from 0.025 m² to 15.4 m² with an average of 6.33 m².

The resolution of the calculation grid was optimised step by step to ensure that essential surface structures, including small-scale height differences, are mapped in appropriate detail. At the same time, excessive calculation times were avoided by eliminating unnecessarily small calculation elements. An automatic refinement of the calculation grid was carried out in areas with a large height gradient. For critical areas and flow paths, a manual refinement was carried out by creating so-called detailed areas. Breaklines were set along ditches and retention basins so that these structures remain line-sharp in the 2D model. Buildings were created as non-overflowing runoff obstacles in the calculation grid. For this purpose, the building polygons from the current ALKIS and building area data were used. To avoid unnecessarily long calculation times, the geometry of the building polygons was simplified by a maximum of 1 m by applying generalisation algorithms. In doing so, neighbouring polygons are merged and unimportant polygon support points are removed. Any remaining geometries that were unfavourable for the calculation were then adjusted by manually adjusting the building polygons.

The precipitation losses were determined on a locally differentiated basis using ALKIS and land use data. In the settlement area, a distinction was made mainly between buildings, roads and permeable areas. Outside the settlement area, an additional distinction was made between wooded areas, agricultural areas and heathland. For impervious surfaces, wetting and depression losses are taken into account. For permeable areas, precipitation is additionally reduced by infiltration and interception losses. The parameters were first set to reasonable initial values based on literature and then adjusted in the course of the model fitting (chapter 3.3) in order to achieve the highest possible agreement with the observed data of the heavy rainfall on the 18th of June 2020.

A design rainfall rate of 266 l/(s*ha) was assumed for the roof areas with an allocation to the sewer network in accordance with KOSTRA-DWD-2010R.

The software HYSTEM-EXTRAN 2D (HE2D) by itwh GmbH uses the Manning-Strickler approach for the parameterisation of the surface roughness in the runoff calculation. The Manning-Strickler values (KSt

values) were determined depending on the existing land type. For this purpose, the land use data for Lower Saxony and Hamburg were combined and classified into groups with uniform KSt values.
In order to take into account the increased flow resistance at very shallow water depths, so-called thin-film runoff, water depth-dependent KSt values are used for permeable surfaces according to the recommendations of the Landesanstalt für Umwelt Baden-Württemberg (LUBW, 2019). In the course of comparing the simulation results for the heavy rain event 18th June 2020 with the photos and videos of the flooding, the KSt values were adjusted to achieve the highest possible agreement with reality. Based on the currently calculated water level, the KSt value is selected dynamically for each calculation element during the simulation. For water levels of > 2 cm to 10 cm, the KSt value is interpolated linearly from the pair of values.

The stormwater runoff is taken into account via bidirectional coupling of the existing sewer network model with the 2D surface runoff model via manholes and street drains in the area. The sewer network model was developed by Hamburg Wasser and is continuously updated. The street drains that are not included in the sewer network model were automatically assigned to the nearest manhole. This automatic allocation was subsequently checked and corrected if necessary. Street drains are equipped with an absorption capacity (corresponds to the maximum hydraulic capacity) of 15 l/s. Missing external pipes relevant to the flood analysis, e.g. road drainage pipes, were added. Retention basins, which were represented as 1D elements in the sewer network model, were replaced by the representation in the terrain model. The exchange of water volumes also takes place bi-directionally in the model at the street drains, so that these drainage elements can also become the source of flooding if the height conditions are appropriate.

Culverted watercourse sections or trench culverts were created as closed hydraulic 1D transport elements. The profile was set according to existing planning documents, obtained from site visits or estimated using Google Streetview. For the Falkengraben, the heights and profiles of the culverts were measured on site. The bed heights of the culverts were taken from the DTM. The coupling of ditch piping with the 2D model is bidirectional, as in the case of manholes and street drains, so that backwater effects or a flow reversal are also taken into account.

3.3. Verification and improvement of the simulaton model

The flood model was successively improved and refined based on a review of the results of test simulations, e.g. by adding missing culverts, ditches, external pipelines or other runoff-relevant elements to the model. A basic plausibility check of the flow paths, calculated water depths and flow velocities was carried out.

Parameter optimisation was carried out for the runoff formation parameters (e.g. interception, depression and infiltration losses) and for the KSt roughness coefficients. Simulations for the event of 18th June 2020 were carried out with different parameter values. The model parameters leading to the highest agreement with the photos and videos of the flooding was selected. By using radar-based precipitation data for these simulations, which were validated using measurements from the local rain gauge, a good spatial (500m x 500m) and temporal (5-minute intervals) coverage of the precipitation event can be assumed. Due to the relatively small number of observation data as well as their rather qualitative character, another procedure, Curve Number Method (CN method), was carried out to calculate the runoff for parts of the catchment area in order to further verify the applied parameters. The advantage of this hydrological method of calculating runoff is that the parameters involved are very well documented for different soil conditions and land types. This made it possible to confirm the plausibility of the set parameters and the calculated discharges even in places without "measured data".

3.4. Flood simulations

The flood simulations are carried out for the described precipitation scenarios with the software HYSTEM-EXTRAN 2D (HE2D) of the company itwh GmbH in version 8.3.4:

- Event of the 18.06.2020 as radar-based rain grids
- 1-hour Euler II model rainfall according to KOSTRA-DWD-2010R for
    - SRI 3 (10-annually)
    - SRI 5 (30-annually)
    - SRI 7 (100-annually)
    - SRI 8 (approx. 1.000 annually)
    - SRI 10 (>>> 1.000 annually)

The precipitation heights are initially included in the NA calculation and are reduced by the precipitation losses (wetting losses, interception and infiltration losses) according to the type of surface (e.g. permeable or impermeable). The effective rainfall heights determined in this way are then put into the calculation elements of the 2D surface runoff model in time steps. Sufficiently long lag times are applied to fully represent the runoff processes.

The results of the simulations are flood depths, flood areas and flow velocities.

3.5. Risk analysis

The following sections describe the general procedure for identifying and analysing potential flooding from heavy rainfall events.

With regard to the analysis of potential flooding, focus areas were identified. This was done by looking at surface runoff, fire brigade operations, documentation of previous heavy rainfall events, operations from HAMBURG WASSER operational management system and the flow path and sink map. The potential threat to the focus areas was then assessed (e.g. danger to existing infrastructure, traffic safety and realistic improvement options).

Furthermore, details were examined and identified that relate to measures that can be implemented as quickly and easily as possible. The following boundary conditions lead to the selection of the measures:

- Rather few individuals affected / small measures (= can be implemented more quickly)
- Private land affected (one contact person)
- Water flows from public to private land

- Measures in the green area, less technical measures (nature-based solutions preferred)

The proposed measures were tested and evaluated for suitability through simulations.

Due to the topographical conditions of the Harburg Hills, heavy rainfall causes an inflow from unpopulated areas into populated area. Often, the streets of the settlement are located in the "valleys". Here, the runoff is concentrated and is an amplifying cause of flooding. This is especially true when it comes to local road low points or low points on properties. In addition to solving the problems locally at the point of damage, there are possibilities to retain rainwater to a large extent before it enters the settlement area. Therefore, chapter 4.3 identifies places where a surface inflow of rainwater into the settlement area takes place, the so-called potential retention areas (RA). In the first step, the identification takes place mainly via the static flow path and sink map described in chapter 2.4. Here, the strong flow accumulation (the flow path) indicates at which locations a greater stormwater runoff can be expected. Furthermore, sinks along the "main flow paths" indicate potential locations for retention measures in the green area. In the populated area, however, these sinks can also represent hazard sites. After identifying the sites, the following boundary conditions are examined:

- Examination of the topography for natural low points and potentially easy-to-build impoundment possibilities in order to achieve damage-free temporary retention
- General flow paths from the flow path and sink map
- Results of the simulation model for rain events SRI 3 to 10
- Existence of vegetation and open spaces in the vicinity
- Location in the Fischbeker Heide nature reserve and existing biotopes
- Existing drainage facilities
- Use of the affected areas

3.6. Development and assessment of measures

Based on the principles used for the identification of the focus areas (fire brigade operations, flow path and sink analysis, results of the flooding situation), possible measures are developed. Environmental factors such as the existing drainage infrastructure, the infiltration potential and the topography in the focus area are also taken into account.

The aim of the measures is to reduce the previously identified flood potential. In particular, the focus is on preventing drainage onto private property and on enabling damage-free drainage or temporary retention (in public spaces). Ideally, the water occurring during heavy rainfall should be discharged or retained from the areas without causing damage. In particular, near-natural solutions that offer advantages for nature and the local water balance are used. Examples of measures developed are rain gardens, infiltration trenches and swales, protective walls and earth walls.

The measures developed are incorporated into the 2D model as elements of the terrain model in order to carry out simulations for the model rainfall described in chapter 3. In the process, decentralised retention options such as swales and rain gardens are represented as sinks in the terrain model. Measures such as walls, embankments and dams are incorporated as elevations in the terrain model. The effectiveness of the measure is analysed by means of a comparison with the results of the current state and the measure is optimised if necessary. The heavy rain index 5 is used as the decisive precipitation intensity for which the effectiveness of the measures was considered and adjusted.

For better comparability between the planned and actual state, differential grids of the maximum water depths are created. These can be used to identify the local change in flood risk.

4. Results

4.1. Results of the flood simulation

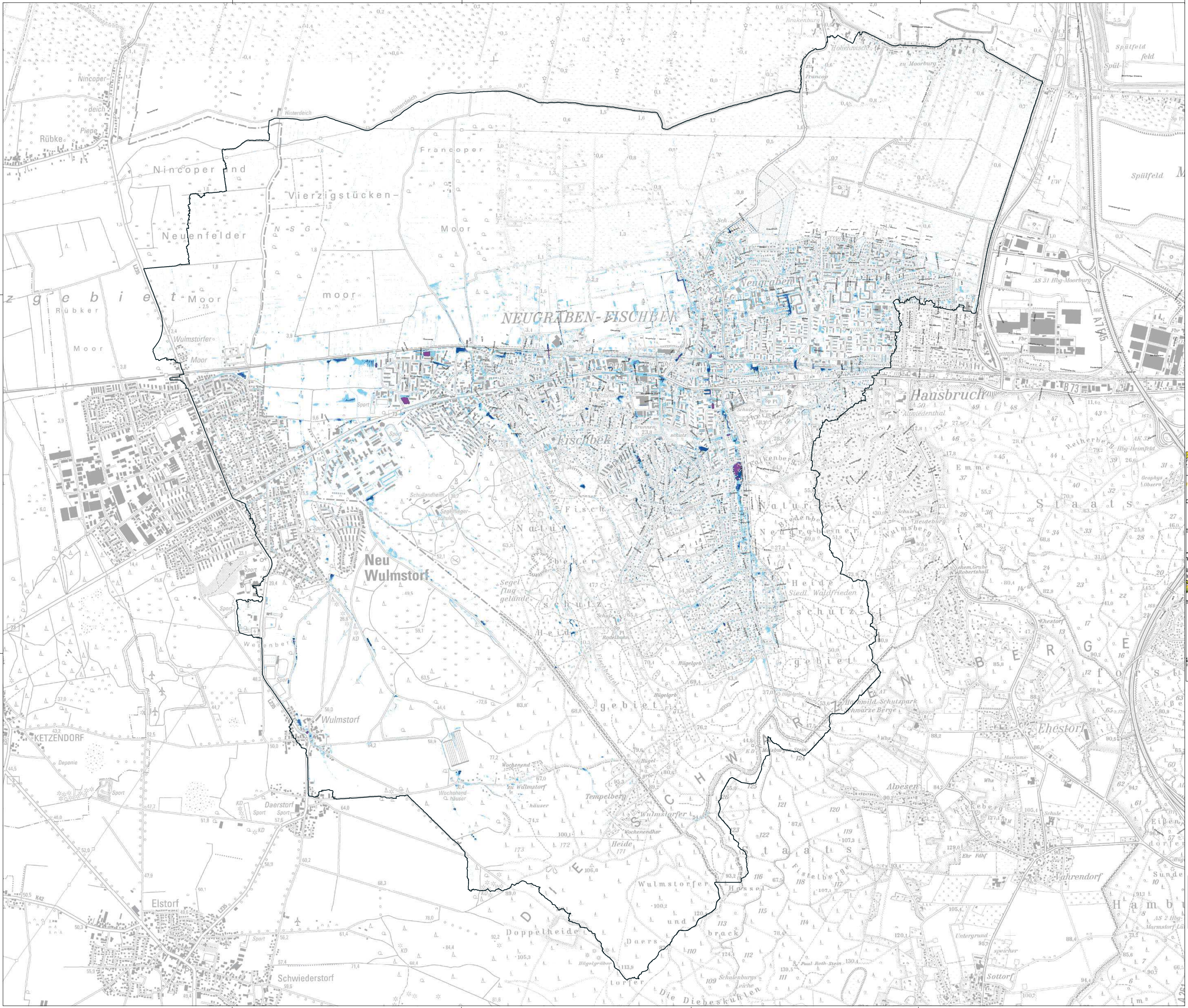
The results of the coupled 2D surface runoff calculation were presented in the form of heavy rain hazard maps. For each precipitation scenario, an overview map of the calculated maximum water depths was created. The maps for the scenarios described in Chapter 3.1 are available for the current situation. For the proposed measures, maps were produced for SRI-3, 5 and 7. The results are also transferred digitally as an ArcGIS project and can thus be analysed in detail. The GIS project also includes the calculated maximum flow velocities for each scenario as well as an evaluation of the hazard. Each building was assigned a hazard class according to DWA M-119 (2016) based on the maximum water level adjacent to the building.

Due to the high level of detail of the model used, the explicit and integrated consideration of the drainage infrastructure and the water bodies, and the step-by-step testing and optimisation of the model, the results are generally considered to be very reliable. The volume error of the simulation model is negligible at less than 1%. The calculated discharge values are generally within the plausible range. The flow paths were thoroughly checked and can be considered reliable. With regard to the calculated water levels, however, uncertainties cannot be ruled out despite the quality assurance steps mentioned above. Especially for the outer areas, which are largely forested in the study area, a very high sensitivity of the model was found - smallest changes in the parameters lead to strong changes in the calculated water depths in the settlement area. Basically, it is difficult to estimate the retention that takes place in the forested areas. In addition, the event-specific initial soil moisture is also very decisive for the resulting runoff, water levels and flow velocities. This means that depending on the prevailing soil moisture, a precipitation load leads to a range of results. A direct link between precipitation frequency and flooding frequency is therefore not given. Since concrete flood observations were only available for one event, the model was adjusted according to the associated hydrological situation. A further uncertainty arises from insufficient knowledge of the stormwater management facilities on private properties and the associated retention capacities. Due to the size of the study area, not all runoff relevant structures such as garden walls could be incorporated into the model.

The already projected measure to increase the capacity of the flood retention basin should be incorporated into the simulation model. It can be assumed that this measure will lead to a significant relief of the flooding hazard in the Falkengraben area. This can only be done once the current planning for it has been completed.

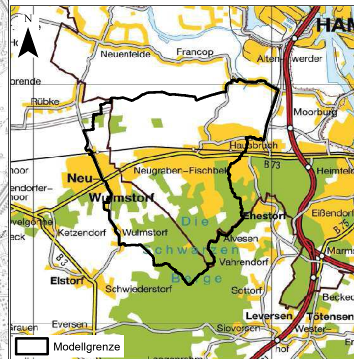
Heavy rainfall hazard map Neugraben-Fischbek

for heavy rainfall index 8



Maximum water depth

- < 5 cm
- 5 cm - 10 cm
- 10 cm - 30 cm
- 30 cm - 50 cm
- 50 cm - 100 cm
- > 100 cm



CLEVER Cities

Hamburg

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Starkregenvorsorge - Gefährdungsanalyse und Maßnahmenplan Neugraben-Fischbek

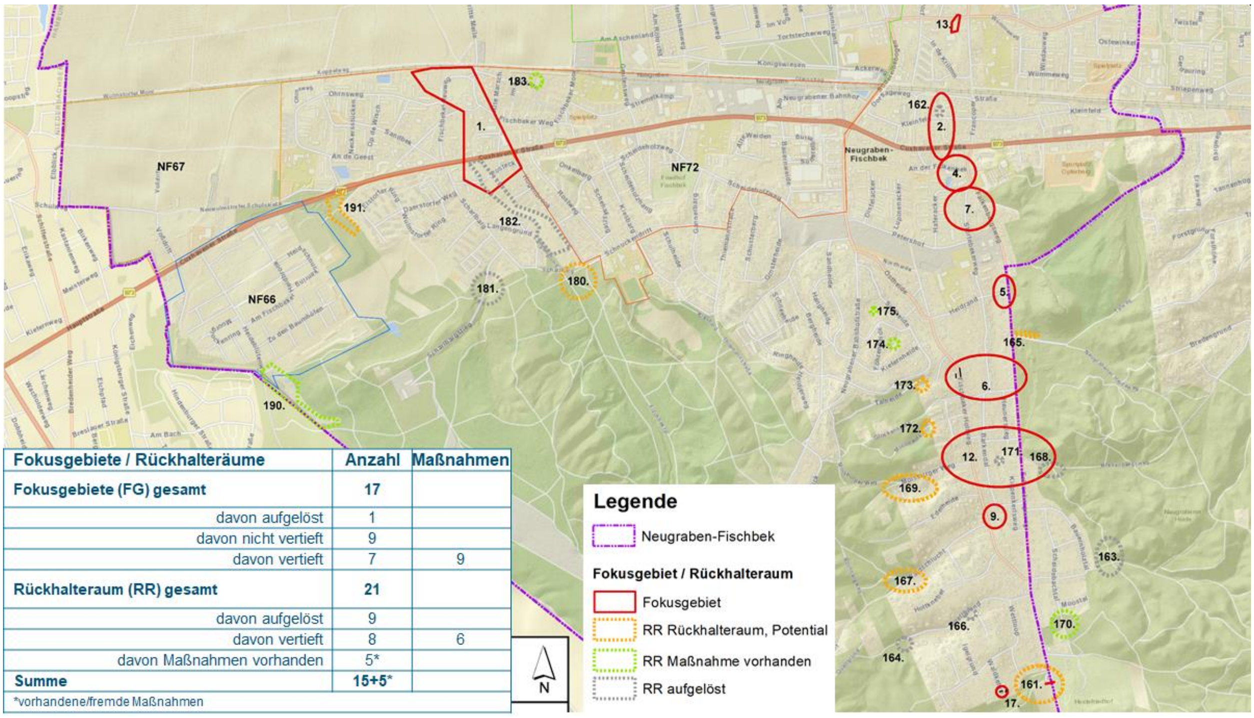
HAMBURG WASSER		
	Maßstab	1:11.000
	Stand	08.01.2021
	Bearbeitet	Wahl
	Infrastrukturkoordination und Stadthydrologie	

N

0 0,375 0,75 1,5 Kilometer

Due to the relatively large hydrological catchment area and the shifting topography, the study area is generally at high risk of flooding. However, due to the high infiltration capacity of the soils and the retention of precipitation in natural depressions, the risk is greatly mitigated. This can be seen in particular in the relatively low documented damage for the event of 18.6.2020, which in its statistical characterisation is to be placed between an SRI-7 and an SRI-8.

The results of the flood simulation were used to identify potentially vulnerable areas, to analyse the flooding situation in the identified focus areas and to develop countermeasures as well as to identify suitable retention areas. The identified focus areas and retention areas are shown in the figure below.



Fokusgebiete / Rückhalteräume	Anzahl	Maßnahmen
Fokusgebiete (FG) gesamt	**17**	
davon aufgelöst	1	
davon nicht vertieft	9	
davon vertieft	7	9
Rückhalteraum (RR) gesamt	**21**	
davon aufgelöst	9	
davon vertieft	8	6
davon Maßnahmen vorhanden	5*	
Summe	**15+5***	
*vorhandene/fremde Maßnahmen		

Figure 4: Overview map of the focus areas and retention areas

4.2. Results of the measures in focus aras

Decoupling from the rainwater system and decentralised management of rainwater on the properties promotes infiltration and evaporation, thus making a direct contribution to a balanced water balance. Retention on the property reduces the volume of precipitation in the sewage system and can thus contribute to reducing the risk of flooding in downstream areas. However, it should not be neglected that such facilities for decentralised management are usually not designed for heavy rainfall events, so that runoff will occur during stronger events. Nevertheless, a reduction of the flooding "peak" downstream of the measure can be achieved through the runoff delay and mitigation achieved.

As a measure for decentralised management, rentention (green) roofs can be used on the one hand, and on the other hand, infiltration systems such as swales or soakaway elements can absorb the water from roofs and paved surfaces on the properties. Another option is to collect rainwater in cisterns and use it for irrigation or service water.
Another option to prevent water from running off in the first place is to unseal surfaces or convert them into partially sealed surfaces, such as grass pavers or seepage paving.
Green roofs have a positive effect on the local water balance by retaining and evaporating rainwater. The greater the thickness of the green roof, the more water can be retained. Green roofs with slopes and without backwater (runoff throttling) can only develop their retention effect to a lesser extent in heavy rainfall. So-called retention green roofs have an even greater retention effect due to additional storage space in the form of a shallow infiltration trench on the roof, and can also ensure retention of the rainwater that accumulates during heavy rainfall events. The retention and throttled drainage allows for smaller dimensions of any subsequent retention and infiltration systems. However, a particularly high infiltration capacity is required here (throttle retention vs. infiltration capacity). Furthermore, green roofs can contribute to cooling buildings and have a positive effect on the microclimate in the surrounding area. Green facades also have a positive effect on the microclimate due to their evaporation properties and at the same time offer energy benefits for buildings due to their insulating and shading properties.

In the case of infiltration in swales or infiltration trenches, the rainwater is cleaned by the revitalised soil zone. Infiltration in manholes is only recommended to a limited extent and is not permissible in water protection areas, as no treatment takes place through manhole infiltration and this can result in a potential risk to groundwater. This must be taken into account in the project area.
A decoupling of roof surfaces and paved areas on private properties seems to make sense especially in the vicinity of the Falkengraben. There, the inflow of rainwater into drains, street drainage pipes or ditches could be reduced through decentralised management. At best, these measures also provide for certain safeguards for heavier precipitation (e.g. retention green roof or dimensioning of the swales / infiltration trenches for annualities above those specified in the regulations). Of the total 12.3 ha of roof area and paved surfaces considered, 69% drain into the sewer system. This means that more than 30% of the areas in this area are already managed decentrally. This can be extended to other properties by further sensitising the owners (e.g. savings on rainwater charges) or through appropriate subsidies. Prerequisites such as good infiltration capacity seem to be well met in large parts.
After extensive analysis of individual areas, various measures could be proposed and tested for effectiveness during heavy rainfall events of different strengths (SRI 3, SRI 5 and SRI 7).

In the areas considered, it was possible to identify reasons that favour flooding. These include, among others, local low points along the road that do not include further drainage options in the public space, small diameters of stormwater drains and unfavourable inlet situations in ditches that have counter-slopes and lead to backwater when water levels are high. Lack of drainage infrastructure leads to flooding that needs to be managed. Water accumulation on roads can threaten road safety, as well as adjacent houses and potentially groundwater.

Multifunctional land use can be achieved through appropriate measures to protect against heavy rainfall events. For example, playgrounds can be used for this purpose that are used as drainage for rainwater that accumulates. The creation of a nature discovery area and the integration of the theme of water can be seen as a great opportunity through multifunctional use. Rainwater can be drained by infiltration into depressions or depression-rigs.

Rainwater pipes and drainage channels are also used to drain rainwater. These often drain into existing ditches. In Neugraben-Fischbek, the Falkengraben should be mentioned here, which drains the water at affected areas. Box gutters (kerb drainage/hollow kerb gutters) with outlets into the ditch, soakaways as well as street drains are potential measures in the study area. In order to improve the flooding problem, the suction capacity of existing street drains can be increased. The use of pumps for the drainage of street low points can be used to bridge them. It should be noted that technical solutions within the scope of this project are not in line with the objectives of the CleverCities project and will therefore not be further discussed.

In the street space, so-called "rain gardens" can be used, which store and soak up the surface water of the street in an underground infiltration trench as well as in an above-ground bed. Decentralised retention can prevent flooding. Raising kerbs can also be a useful solution. This is often suggested in combination with other measures.

Another important measure against flooding is property protection. Raised thresholds in the access area of properties and in front of basement entrances or basement windows, walls, earth walls and green roofs are options to be considered. Manholes and appropriate surface design can be used to drain water specifically into recessed areas on properties, allowing water to build up without causing damage. Figure 5 shows the measure of a wall as object protection. The effects of the heavy rain event of 18th June 2020 can also be seen here.

Source: André Zand-Vakili

Figure 2: Road situation on the day of heavy rain on 18th June.2020 in Neugraben-Fischbek

The following figure shows an example of a measure for coping with heavy rainfall events. The water levels in the current state are shown on the left. On the right, the measures of the "walls" on the property boundary and the "drainage channel" on the road are shown. The higher water level on the road can be clearly seen. This increases by up to 20 cm in depth. At the same time, it can be seen that the waterlogging has decreased significantly. The maximum water level is reduced by approx. 8cm at SRI 3. The "wall" also has a positive influence on water levels in the area to the south. The water is prevented from overflowing to the south by the barrier. Here, the maximum water level is lowered by approx. 17 cm for an SRI 3 and by approx. 14 cm for an SRI 5. The solution shown here with a continuous wall is effective with the specified height in combination with an additional drainage channel.

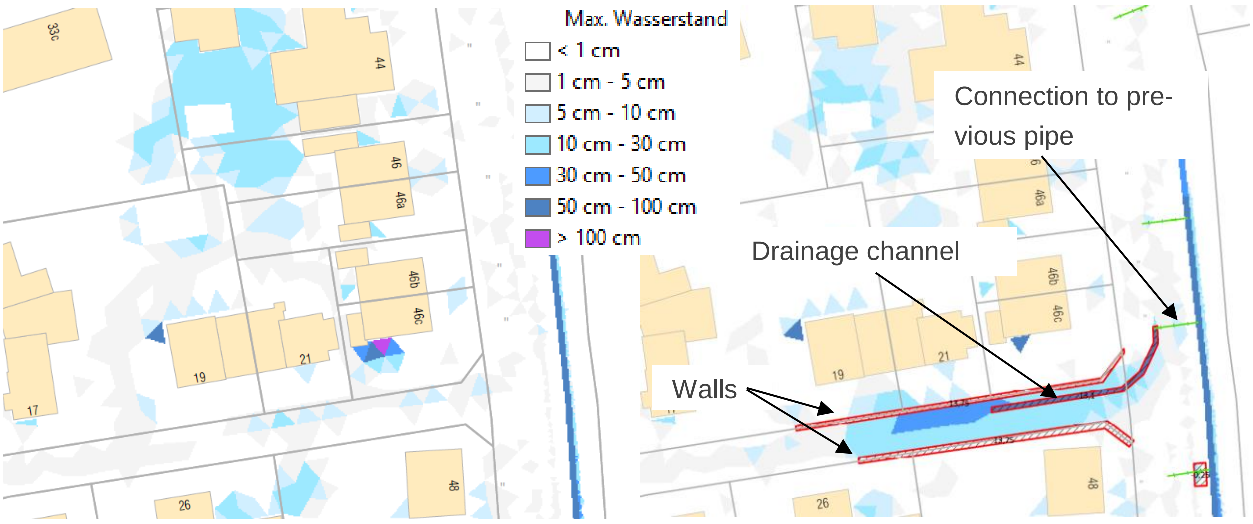


Figure 3: Simulation results max. water level. Left: SRI 3 in the actual state. Right: SRI 3 with measures

4.3. Results of the measures in retention areas

A total of 21 potential retention areas have been identified in the study area. In the following, the results of the examination and closer analysis as well as the resulting measures are summarised.

Additional retention space can be created through terrain adjustments and the retention capacity can thus be improved. On the Falkengraben, for example, earth banks have been built several times along the slope from east to west, enabling cascade-like retention of precipitation water. The Office for Nature Conservation, Green Planning and Energy has confirmed that such measures do not impair the conservation objectives of the nature reserve, which must be observed. Silvicultural measures also serve to retain water. Existing earth banks in the terrain will be raised and extended so that the maximum retention depth is increased. In addition to earth banks, deep beds will also be placed in retention areas in order to interrupt and retain the runoff coming from the road itself and to infiltrate the rainwater.

Simulations of runoff behaviour are used to achieve a stronger and better use of existing retention volumes. Optimisation of inflow and outflow conditions and upgrading of dams were proposed as measures. These and other measures, when implemented, are to be included in the regular update cycle of the EU Floods Directive by the LSBG and thus influence the designation of floodplains.

The following figure shows the potential effect of a measure in a retention area. The simulation result of the flow depths shows that a clear retention is created and the inflow to the Falkengraben is reduced (lower picture). The implementation of an earth wall is estimated to be simple.

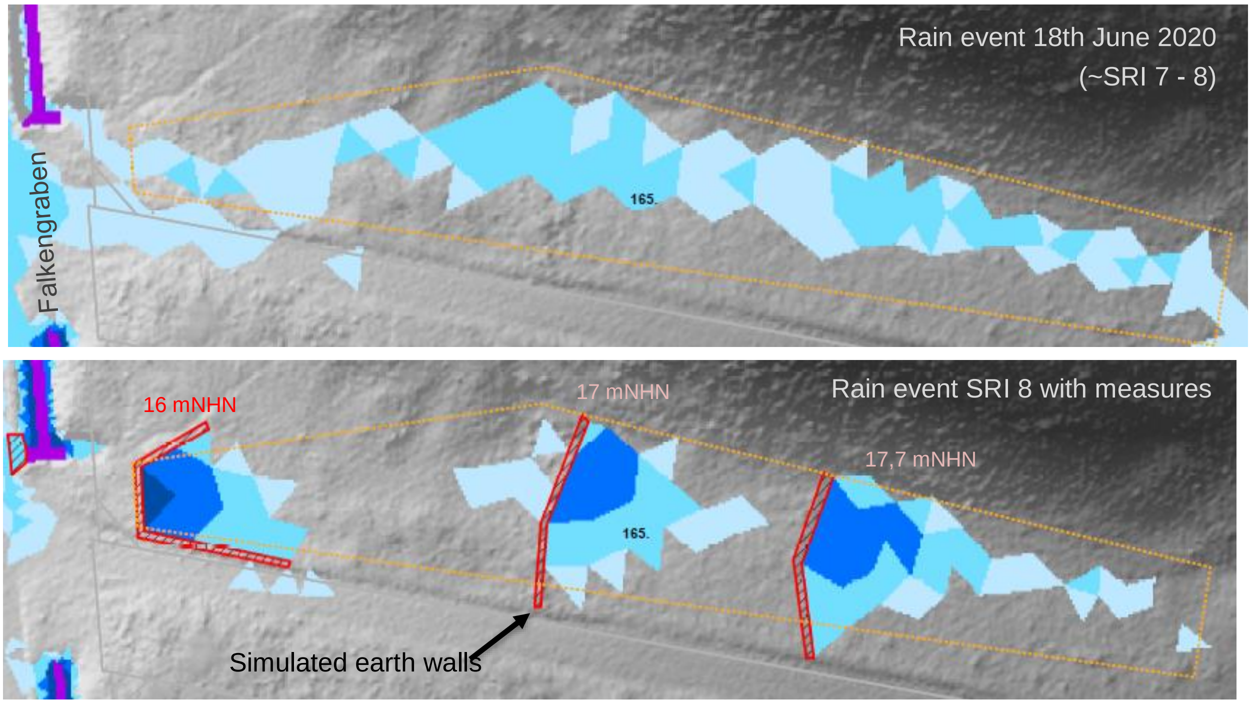


Figure 4: Illustration above: Simulation rain event 18th June 2020, below: Rain event SRI 8 with measures

5. Overview of measures

There are various options for measures in the focus areas and retention areas worked out in more detail. In addition to the so-called focus areas in the settlement area, in which concrete hazard prevention is in the foreground, the retention areas aim at retaining precipitation water before entering the populated area.

The measures for the focus areas were developed with the aim of developing nature-based solutions and measures for decentralised stormwater management, such as

- Rain Gardens
- Emergency waterways
- Multifunctional areas
- Green roofs
- Unsealing
- Swale (trench) infiltration

Figure 5: Exemplary representation of possible rain gardens in two streets of the study area (source photos: Hamburg Wasser, source visualisations of rain gardens: MUST Städtebau)

For emergency waterways, e.g. targeted drainage channels / street drains or ditches are a possibility. Object protection is a good option for individual buildings at risk. In addition to specific measures on the building, walls and mobile closure options in access to roads are possible.

In the case of retention areas that are already naturally present in the terrain, the capacity is to be expanded and/or secured, e.g. through additional earth walls. These areas are to be kept free in the future. For already existing retention areas it is important to maintain their function in the long term.

The measures described in chapters 4.2 and 4.3 were tested by comparing the simulation results for the current situation and the condition after implementation of the measures. If necessary, adjustments were made to the measures to improve their effect. The proposed measure options are conceptual proposals and need to be planned and elaborated in more detail for implementation and, if necessary, coordinated with other stakeholders.

The study shows that the implementation of nature-based stormwater management solutions can make an important contribution to flood prevention during heavy rainfall events. A transfer of the method with regard to the analysis of the drainage situation as well as the development of measures also to other districts of Hamburg seems sensible and possible. For the first nature-based measures, implementation is currently being examined.

6. Literature

DWA (2012), Arbeitsblatt DWA-A 531: Starkregen in Abhängigkeit von Wiederkehrzeit und Dauer, Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e.V. (DWA), Hennef, ISBN 978-3-94 2964-28-9

DWA (2016), Merkblatt M 119– Risikomanagement in der kommunalen Überflutungsvorsorge für Entwässerungssysteme bei Starkregen, DWA-Regelwerk

DWD (2017), Deutscher Wetterdienst, KOSTRA-DWD-2010R, Starkniederschlagshöhen für Deutschland – KOSTRA, DWD, Offenbach, 2017

EGL – Entwicklung und Gestaltung von Landschaft (2017), Pflege- und Entwicklungsplan für das Naturschutzgebiet Fischbeker Heide, Auftraggeber Freie und Hansestadt Hamburg, Behörde für Umwelt und Energie, Link: https://www.hamburg.de/fischbeker-heide/ (Abruf Dezember 2020)

Itwh GmH – Institut für technisch-wissenschaftliche Hydrologie GmbH (2020), HYSTEM-EXTRAN Modellbeschreibung, Hannover

LUBW - Landesanstalt für Umwelt, Messungen und Naturschutz Baden- Württemberg (2020), Leitfaden Kommunales Starkregenrisikomanagement in Baden-Württemberg, Anhänge 1a, b, und c.

Schmitt, T. G. (2015), Weiterentwicklung des Starkregenindex zur Verwendung in der kommunalen Überflutungsvorsorge. In: gwfWasser|Abwasser (156), Nr. 7-8, S. 774-781

Wikipedia (2021), Eintrag über Hamburg-Neugraben-Fischbek, zuletzt besucht am 06.01.2021