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► To cite this version:

T. Einfalt, H. Hoppe, T. Schmitt, A. Speicher, B. Mehlig. KISS - Guidance for municipalities to meet climate change and increased risk of urban flooding. Novatech 2013 - 8ème Conférence internationale sur les techniques et stratégies durables pour la gestion des eaux urbaines par temps de pluie / 8th International Conference on planning and technologies for sustainable management of Water in the City, Jun 2013, Lyon, France. <hal-03303515>

HAL Id: hal-03303515

<https://hal.science/hal-03303515v1>

Submitted on 28 Jul 2021

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KISS - Guidance for municipalities to meet climate change and increased risk of urban flooding

KISS - Aider les municipalités à faire face au changement climatique et aux risques d'inondation en ville

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RÉSUMÉ

Le projet KISS (adaptation au changement climatique pour l'assainissement urbain et l'aménagement urbain) est un projet du LANUV NRW qui comprend une analyse détaillée des fortes pluies et de leurs conséquences en milieu urbain pour la Rhénanie du Nord – Westphalie. L'objectif principal était de formuler des recommandations pratiques pour les villes face au changement climatique, portant sur les volets de l'assainissement urbain et l'aménagement urbain avec un focus sur les inondations. Dans le cadre de ce projet, les résultats suivants ont été obtenus: (1) une vue synoptique des directives et développements courants (DWA et DIN); (2) une vue synoptique des modèles de simulation capables de considérer à la fois le système d'assainissement et le flux en surface; (3) une analyse d'un ensemble d'événements de crue locale le long de la chaîne pluie intense ⇔ inondation ⇔ mesures de protection; (4) recommandations pour l'analyse des événements, la sélection des mesures appropriées et leur mise en œuvre.

ABSTRACT

The KISS project (climate change adaptation in urban drainage and urban development) is a project of the LANUV NRW in which a detailed analysis has been performed for heavy precipitation and its consequences for urban areas in North Rhine – Westphalia (NRW). The main objective was the development of practical recommendations for climate change adaptation in the areas of urban drainage and urban development, and guidelines for flood protection. Within the framework of the project, the following results have been produced: (1) Overview of guidelines and actual developments (DWA and DIN guidelines); (2) Overview of models able to cope with both sewer system and overland flow; (3) Analysis of rainfall induced flood events in NRW for the chain cause – effect – measure: heavy precipitation ⇔ inundation ⇔ flood protection; (4) Guidelines for event analysis, selection of appropriate measures and their planning.

KEYWORDS

Climate change, Model, Stormwater, Urban flooding

1 MOTIVATION AND OVERVIEW

KISS (climate change adaptation in urban drainage and urban development) is a project of the LANUV NRW in which a detailed analysis has been performed for heavy precipitation and its consequences for urban areas in North Rhine – Westphalia (NRW). The main objective was the development of practical recommendations for climate change adaptation in the areas of urban drainage and urban development, as well as guidelines for flood protection. Therefore, this study is a review and a synthesis of previous works, highlighting best practice combinations of methods linked to concrete examples. As such, the paper summarizes the outcome of the project where 27 real events have been documented, possible measures for flood damage reduction have been systematically listed and commented, and the tools on the regulatory side (guidelines) and on the engineering side (models) have been reviewed and checked for their ability to cope with small scale flooding beyond design of the infrastructure.

Thus, the project aims to give a best practice overview for planners working on the resilience of cities against flash floods and their effects.

Within the framework of the project, the following results have been produced:

- Overview of guidelines and actual developments (DWA and DIN guidelines)
- Overview of models able to cope with both, sewer system and overland flow
- Analysis of rainfall induced flood events in NRW for the chain cause – effect – measure: heavy precipitation \Leftrightarrow inundation \Leftrightarrow flood protection
- Guideline for event analysis, selection of appropriate measures and its planning

2 OVERVIEW OF EXISTING GUIDELINES IN GERMANY

In Germany, the technical framework for hydraulic design of sewer systems dates back to 1956 and the publication of the "Guidance for the calculation of storm water and combined drain and sewer systems" by the Association of Waste Water Systems. The framework was extended in 1977 through the publication of the guidelines ATV-A 118 [ATV, 1977]. These recommended design frequencies for new construction or renovation varying between $n = 1.0$ and 0.2 depending on the economic importance of the drainage area. Local conditions were considered via a site-specific design reference rainfall $r_{15,n=1}$ according to REINHOLD (Reinhold, 1940) and the peak runoff coefficient, depending on the percentage of impervious areas present and the design rainfall intensity selected. No further mention was given to runoff characteristics and possible flooding from severe storm situations.

The Federal High Court (BGH) weighed in on these guidelines with the landmark decisions of 1989 and 1991, which criticized the strict formal execution of design standards in practical application without any further acknowledgment of the local vulnerability to flooding. The decisions demanded that appropriate flood protection use significantly longer return periods than once per year (Werp, 1992).

The European standard specification EN 752 (CEN, 2008), first published in 1996, cites necessary flood protection as the determining criterion for the hydraulic performance of municipal sewer systems. The 2008 edition recommends the use of design rainfall frequencies for simple calculation methods (for catchment areas up to 200 ha or a 15-minute flow time) and flood frequencies for other applications. To the extent no other requirements are established by the national responsible agencies, the requirements apply for new construction and planned renovations. The flood frequencies of 1 time in 10 years for rural areas and 1 time in 30 years for city centers, industrial and commercial zones, or 1 time in 50 years for below surface transportation facilities indicate the differentiation in the targeted level of protection on the basis of economic importance and the potential damage in the catchment area as well as a special concern for the vulnerability of sub-surface transportation systems.

Based upon the specifications in EN 752, the German guidelines were reformed in 1999. DWA-A118 (Hydraulic Dimensioning and Verification of Drain and Sewer Systems; (DWA, 2006)) adopts the criteria and frequency values of the EN 752. Furthermore, it takes into account the consequences of the High Court's decisions regarding the need for extended assessments (Werp, 1992). An additional criterion for the verification of the calculation of the hydraulic capacities has been introduced, i.e., the frequency of surcharge and, additionally, an appraisal of local conditions by means of a local flood risk evaluation is now required to determine the potential flooding of the sewer system.

3 OVERVIEW OF MODELS

As part of the KISS project, urban runoff and sewer flow models commonly applied both in Germany and internationally for flood risk analysis were described and characterized in view of their ability to cope with surcharged sewer systems and distinct surface flow occurring during flooding of urban drainage areas.

With regard to the distinct stages and processes of surcharged sewer systems and urban flooding, simulation models for flood risk analysis are required to accurately describe the hydraulic phenomena of surcharged and flooded sewer systems, particularly

- the transition from free surface flow to pressure flow in the sewer pipes,
- the rise of water level above ground with water escaping from the sewer system,
- the occurrence of surface ponding and distinct overland flow during surface flooding, and
- the interaction between surface flow and pressurized sewer flow.

The consideration of distinct surface flow and its interaction with sewer flow in surcharged sewer systems is denoted as “dual drainage modelling” with flow components on the surface and underground, first described by Djordjevic et al. (1999).

The survey carried out within KISS focused on commercially available software packages with the features of dual drainage modelling and the direct coupling of surface and sewer flow during surcharge and flooding. Urban runoff models that have been evaluated to meet these criteria are

- DYNA – GeoCPM (tandler.com GmbH and Pecher Software GmbH, Germany) http://www.tandler.com/kommunale_gis/siedlungswasser/ueberflutungsnachweis/ueberflutungsnachweis.htm
- Hystem-EXTRAN (itwh mbH, Germany, (surface flow module under development) http://www.itwh.de/S_extinfo.htm
- InfoWorks CS/SD with InfoWorks 2D (Innovyze, USA) -<http://www.innovyze.com/>
- MIKE URBAN (DHI, Denmark) - http://releasenotes.dhigroup.com/2011/MIKEURBANrelinf.htm#New_Features
- SWMM (U.S. EPA, USA) - <http://www.epa.gov/nrmrl/wswrd/wq/models/swmm/>

Common features of the models include the use of a hydrologic approach to transfer rainfall into surface runoff and sewer inflow subsequently, as well as dynamic flow routing based on the Saint-Venant-Equations. The latter provides general validity for surcharged drainage systems including pressurized sewer flow and backwater effects. Water levels above ground result in surface ponding. At this point, distinct surface flow might occur where surface characteristics, e.g. street configuration, profile and slope (longitudinal and lateral), sidewalks, curb height and buildings, are important factors and constraints to be considered. The hydraulic surface flow simulation is mostly done by simplified versions of the 2-dimensional shallow water equation. The coupling of surface and sewer flow is realized by interpreting inlets to the sewer system as possible sinks or sources in the mathematical model of both the surface and sewer flow simulations. The models listed above depend mostly on surface elevation laser scan data that are processed into detailed digital surface and elevation models using individual processing routines and methods.

An important consideration in conjunction with the characterization of selected urban runoff models, is the simulation of urban flooding caused by extreme pluvial rainfall events. The limited spatial extension of extreme pluvial rainfalls, e.g. occurring as summer thunderstorms, must be considered using extreme rainfall depths as system loads. Often these rainfall depths, measured at a single rain gauge are equally distributed over large catchment areas, thus changing their statistical features of return period and probability of occurrence. A second important consideration is the limited capacity of drainage elements on private properties and street inlets, which in turn limits the inflow to the sewer system during times of extreme rainfall intensities. This might actually reduce surcharge effects within the sewer system. Finally, the design performance of source-based stormwater management installations, e.g. infiltration swales, near source retention and storage devices, is assumed to be maintained during heavy rainfall, when infiltration or storage capacity might actually be temporarily exceeded. These effects are often neglected within urban runoff and flooding simulation, thus affecting the accuracy of runoff and flooding model.

4 EVENT ANALYSIS

4.1 Scope

Recent rainfall events beyond design rainfall within NRW were investigated under the KISS project. Based on radar analyses, the return periods of these events were estimated and compared to observed amounts of damage. It has been shown (Einfalt et al., 2012) that there is a functional relationship between the locally observed precipitation return period and the onset of measurable damages.

4.2 Example

4.2.1 Event analysis structure

For event analysis, all available precipitation data were collected, quality controlled and analyzed in terms of their temporal and spatial distribution (Figure 1). The available radar data are from Essen radar of the German Weather Service (DWD), with a resolution of $1^\circ \times 1$ km in space and 5 minutes in time.

The available data of rain gauges and of weather radar have to undergo a detailed quality control process (Michelson et al., 2004) before they are ready to be used for analysis purposes. The data for this project had already been processed previously for a larger analysis project (Frerk et al., 2012).

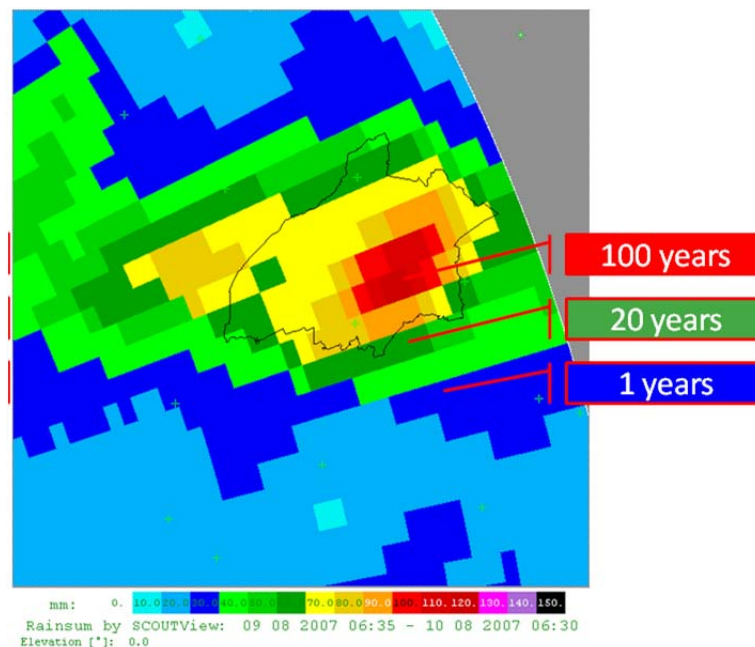


Figure 1: Spatial distribution of the precipitation of the event of 9 August 2007 close to Delbrück. Shown are daily sums with a pixel resolution ($1^\circ \times 1$ km pixel size) and the return periods for three selected pixels

4.2.2 Characterization through comparison to KOSTRA statistics

The resulting precipitation values from adjusted radar data were statistically analysed in terms of maximum precipitation amounts for different time intervals. These values were then compared to point rainfall extreme value statistics (Figure 2) from KOSTRA (Bartels et al., 2005) in order to assess the approximate return period of the precipitation at the most intense pixel. The colour code of Fig. 2 associates the green to yellow colour with rainfall amounts sewer system and its managers are able to accommodate, while the red colour stands for events which are beyond sewer operators' responsibilities and constitute rare events whose consequences have to be borne by the community.

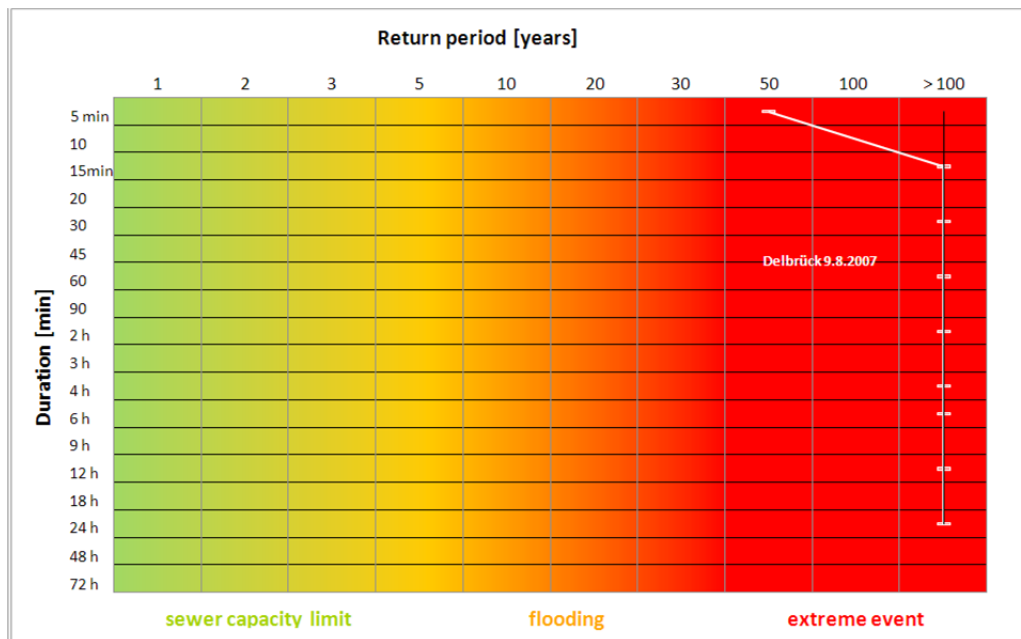


Figure 2: Location of the observed precipitation (white line) at the point with the highest precipitation, as compared to the locally valid extreme value statistics (KOSTRA)

4.2.3 Analysis of press releases concerning heavy rain events and urban flooding

An extensive press search was carried out in order to analyse the types of rainfall events that lead to flooding in urban and especially the inner-city area. This took into account reports of severe rainfall events and floods in North Rhine-Westphalia over the last 10 years.

This overview was also the basis used for selection of the rainfall events in section 4.2.1. In the course of this search, more than 40 events were evaluated with respect of the effects of heavy rainfall.

4.2.4 Event modelling and integrated planning for two case studies

With regard to two catchments in the municipalities of Gelsenkirchen and Wuppertal in which heavy rainfall had led to damage, combined sewer system-surface flow models (1D-2D) were already available (Hoppe et al., 2012). Integrated planning scenarios based on these models were incorporated into the KISS guidelines.

In both these cases, flood prevention combining measures both on the surface and in the sewage system were displayed in the DYNA-GeoCPM® model. These measures are currently being implemented.

The Wuppertal project catchment area lies in the city's outer region. A separate sewage system is used for drainage of this catchment. Flood visualizations relating to an industrial estate were performed in the course of planning operations designed to optimize utilization of an existing storm-water tank.

In this industrial area, floods have caused damage in the past. Both rainwater and stream water are discharged together via the storm sewer. Separation of the streams cannot be implemented in the short term. The objective of the flood risk mitigation measures described here is to cope with extreme weather events, to activate a flood plain on an area of fallow land lying between a former landfill and a disused railway line above the industrial estate. Owing to the close link-up between the rainwater drainage system and the stream pipe-work, extreme weather events were also taken into account in the analysis.

The measures carried out in public areas, in the sewage system and on the surface, comprise the installation of a throttle-controlled orifice and an inlet and outlet structure on the area of fallow land (Figure 3). Seepage drains and seals are planned on the area of fallow land and the embankment with a view to providing for sagging resistance if ponding occurs in the area. In addition to the measures to be carried out in public areas, the owner of the industrial estate is planning property protection measures. These will range from conducting a survey of the private drainage systems, the renovation of back pressure safety installations, to measures to safeguard basement window shafts.

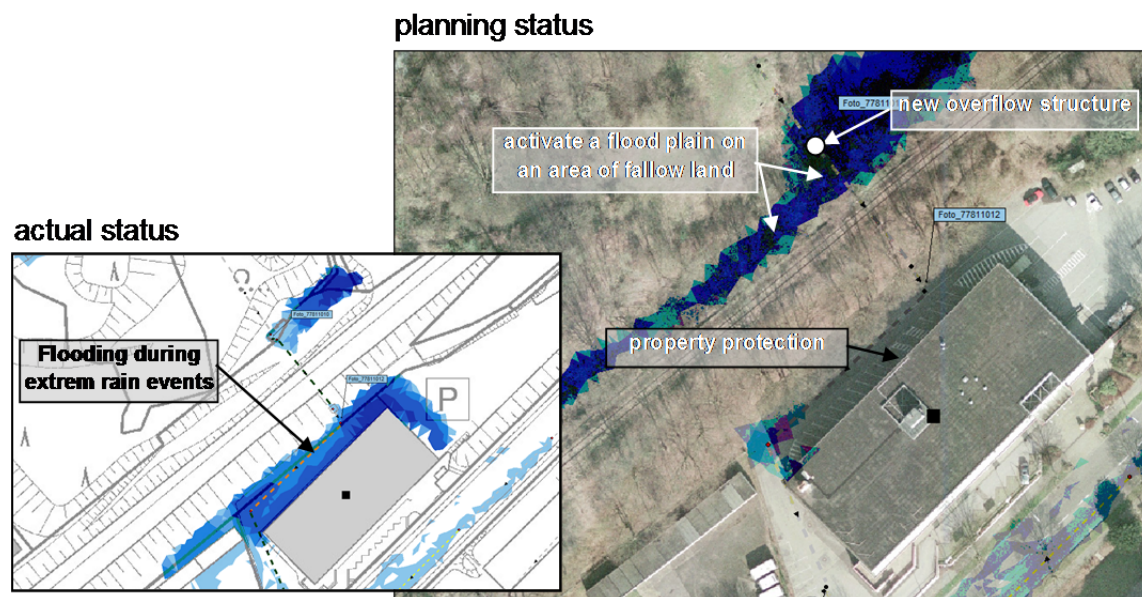


Figure 3: Example for measures to protect a building against flooding

4.2.5 Consequences from press analysis and case studies

It could be shown that practically all the severe rainfall events reported on in the press (4.2.3) recur at intervals considerably in excess of 50 years. Rainfall events with such long recurrence intervals exceed the quantities that can be discharged into the sewage system. Consequently, flood risk mitigation measures can only consist of a combination of measures in the sewage system itself and on the surface, of the type that are currently being implemented in Gelsenkirchen and Wuppertal.

Model calculations using the DYNA-GeoCPM program show that severe rainfall events can be reliably visualized if sound basic data on the sewage system and the digital elevation model are available. Consequently, the guidelines also contain a summary of the basic data required in order to assess precipitation events and plan the pertinent measures.

This has been taken into account in the subsequent finalizing of the proposed measures.

5 KISS RECOMMENDATIONS

The recommendations structure possible measures from the following action fields:

- Sewer network and catchment
- Natural river course and catchment
- Urban planning
- Property protection and planning
- Communication and organisation

The measures have been organized in the form of short profile sheets. Altogether, 16 measures have been described, forming a catalog of proven best practice measures. The optimal areas of application and the advantages and disadvantages of the various measures have been compiled in these descriptive profiles. In addition, they contain information on important standards and bibliographical references relating to examples of the measures implemented. The following measures have been described:

Engineering measures aiming at flood prevention in the drainage system include

- Expansion of the hydraulic performance of the sewage systems
- Activation of storage capacities in the sewage system or construction of new ones
- Real-time-control systems designed to activate storage and treatment capacities and match them with one another
- Engineering remediation of culverts, inlet structures and screening plants
- Renovation of throttles in retention basins and other hydraulic constraints

Engineering measures aiming at flood prevention in the catchment area include

- Diversion of rainwater on the surface
- Retention of rainwater on the surface
- Measures relating to street gullies
- Measures relating to private drainage systems
- Measures designed to protect property
- Seepage of rainwater
- Across-the-slope structures and dike systems pertaining to urban receiving waters

More extensive flood prevention measures include elements of operation, organization and communication

- Integrated plans relating to the measures, information management and visualization of results
- Measurement and monitoring of structures, management of readings for the purpose of planning the measures
- Information on the water management-related analysis of measures from an urban development angle
- Restrictions on utilization - possibilities and limits

6 CONCLUSIONS

Due to uncontrolled surface runoff or flooded sewage systems, severe rainfall events in cities may jeopardize inhabitants and material goods. This fact applies to large cities and small towns alike. As the matter is currently being assessed, climate change will lead to higher temperatures in Germany, so that basically more humidity can be stored in the atmosphere. Along with the increasing probability of severe rainfall events that goes hand in hand with this, the hazard and damage potential will also grow in the decades to come.

Significant damage due to severe rainfall occurs, above all, in places where valuable or readily-damaged building structures or infrastructure can be affected by urban flooding. Flood hazards due to heavy rainfall may occur on a large scale, as both uncontrolled runoff and flooded sewage systems or watercourses can be stated as the cause of the damage. Consequently, from a spatial angle, the hazard potential cannot be limited solely to the hydrological sphere.

The KISS project pays special attention to practical aspects such as the necessary data pool, hazard analyses, design-related or protective measures, the models applicable to the latter, the guidelines that are valid in this context, and the extent to which they can be or are being revised.

As regards the assessment of historical severe rainfall events, it must be stressed that detailed basic data must also be available for small-scale investigations. The data concerned include the following data pools: Precipitation data, measured both by radar and by rain gauges, discharge readings, land utilization data, sewage system data, high-resolution data relating to topography (laser scan data, if

applicable), and appropriate verification of the data by means of site visits. All the data have to be subjected to quality control.

At the same time, a systematic hazard analysis procedure consists of analysis of the topography and features of the terrain, of the drainage system, including the sewage system, of the development structure and of the positions of buildings and infrastructural facilities.

Measures have been compiled and assessed both for the areas of activity comprising the sewage system, receiving waters, municipal planning, property protection and communication, and for the following focal points of impact: retention, increase in discharge capacities, flood risk mitigation, and decoupling of drainage systems. The list of measures envisaged presents the boundary conditions under which each measure is particularly effective, the cases in which it should not be used, the guidelines to be observed, and where further information can be obtained on the measure.

On the basis of the state of the art, the content of the KISS project presents the requirements for urban drainage systems and urban development. This is performed in terms of practical applications, taking into account the requirements ensuing from climate change - and the possible severe rainfall-induced flooding associated with it. At the same time, KISS is showing what response can be given in terms of planning and redevelopment. The recommendations proposed can be used as a checklist for implementation of future measures for new developments and for already constructed areas.

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