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A dynamic urban development model designed for purposes in the field of urban water management

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ABSTRACT

Urban drainage systems are a critical part of city infrastructure. Population growth and urban development can put severe pressure on these systems, especially due to sealing of surfaces and land use change. For a comprehensive adaptation of urban water infrastructure to constantly changing and evolving systems, a detailed simulation of the dynamics in city development is crucial. This can be done by either trying to predict future conditions as accurately as possible (with all their uncertainties) or by developing different scenarios and trying to develop adaptation measures, which are resilient to a range of future conditions. To achieve resilience and take a manifold of possibilities into account, a manifold of simulations are executed within given model boundaries. The presented urban development model is developed to offer the possibility of running several simulations with as few input data as possible to cover the possible range of changes. For a comparison of the simulated urban development scenarios, hydrodynamic simulations are performed to show differences in flooding according to the developed areas. In general, a percentage increase in effective impervious area results in a twice as high increase in percentage in total flooding volume.

Key words | hydrodynamic simulation, multi-scenario analysis, simulation variation

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INTRODUCTION

Population growth and urban development, especially the sealing of surfaces and land use change, can put severe pressure on urban water infrastructure as some severe flooding events in the recent past have shown. In particular, connecting newly developed areas to the existing drainage structures puts areas at risk which have not been endangered by flooding before (Ashley *et al.* 2005). For a comprehensive adaptation of urban water infrastructure to constantly changing and evolving systems an analysis of a manifold of scenarios to cover the dynamics in city development (population and land use change) is crucial as the nonlinear development of urban development may lead to very different outcomes (Verburg *et al.* 2004).

Conventional planning and management practices undergo a shift toward integrative approaches which are coupled to city development but also take social changes into account (de Haan & Rotmans 2011; Urich *et al.* 2013). The capabilities of deterministic planning practices based on a fixed amount of narrow scenarios is limited and especially under conditions of rapid changes, such as ongoing urbanization, a shift toward flexible design and multi-variant analysis is imminent (Savic & Walters 1997; Zhang & Babovic 2012; Deng *et al.* 2013). Therefore, development of several scenarios within the model boundaries defined by estimated population growth and existing spatial conditions is necessary to take all urban development possibilities into account.

Previous studies have shown that ongoing urbanization puts more and more pressure on existing drainage systems. The provision of drainage services for newly developed areas increases surface runoff and consequently runoff peaks in conduits. Higher runoffs lead to a higher risk of flooding and decrease the performance of stormwater treatment systems (Semadeni-Davies *et al.* 2008; Astaraie-Imani *et al.* 2012). In addition to potential flooding problems, urbanization might result in higher peaks and frequencies

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of stormwater discharge contaminated with pollutants from different surfaces. Especially road and roof runoffs are rich in heavy metals which are not degradable by the environment. A close relation of water quality and city growth has been demonstrated before (Roesner 1999). This problem might intensify due to increased rainfall intensities and longer dry periods as a consequence of climate change which potentially also leads to a possible violation of regulations in the future (De Toffol *et al.* 2009; Kleidorfer & Rauch 2011).

According to the *World Urbanization Prospects* (United Nations 2012) most population growth will be absorbed by urban areas on a global perspective which leads to increasing proportions of the population living in cities. Nevertheless, there is a significant diversity in the urbanization levels, especially in Europe where the majority of the urban population will remain in cities with fewer than 500,000 inhabitants. Furthermore, European cities have already experienced a rapid urbanization wave within the past century. Along with that a fast build-up of urban infrastructure including sewer systems occurred. Nowadays, these systems are already in need of repair or will be in a possible critical condition within the next years or decades (Tscheikner-Gratl *et al.* 2014). In addition, ongoing urban sprawl leads to a higher proportion of the population living in areas with a relatively high risk for natural disasters where flooding is considered as the ‘most frequent and greatest hazard’ (United Nations 2012). These constant changes, such as increase of population, urban sprawl or ageing of infrastructure, point to the need for a thorough analysis of city development with the scope of their influence on urban drainage.

This work presents a framework to automatically generate and simulate scenarios using as few as possible input data to mimic city growth. In contrast to other systems using complex transportation or socioeconomic models, e.g., UrbanSim (Waddell *et al.* 2008) which need a huge amount of input data and/or massive computational power, we applied a simplistic approach. Even if data are available it takes a long time to obtain the data and get the simulation to run. This work enables fast setup of the simulation and a quick reconfiguration and adaption of boundary conditions to model even unanticipated situations like population stagnation or decline. The automatic development of designated areas for Innsbruck, Austria, is shown using a programing toolbox (http://dynamind-toolbox.org) developed at the University of Innsbruck for parceling the available area and the placement of buildings and population. Finally, the impact of urban growth scenarios on surface runoff is shown by comparing flooding results from the US Environmental Protection Agency (EPA) storm water management model (SWMM) (Gironás *et al.* 2010) of the base year 2000 and the final year 2030 in timesteps of 5 years for three predefined main scenarios. Consequently, the objective of this work is to present a simplistic urban development model specifically designed to fulfill the needs of decision-makers and planners with a focus on urban infrastructure, exemplary for urban drainage by providing a manifold of automatically generated scenarios based on defined boundary conditions.

MODEL DEVELOPMENT

Model

The simulation framework ‘DynaMind’ (Urich *et al.* 2012), a scientific workflow engine with focus on dynamics, is used to read the input data and simulate parceling of areas, generation of households, distribution of population and calculation of drainage-relevant parameters like dry weather flow (DWF) and the peak runoff coefficient. The following already existing base modules are used:

(a) ‘Parcel generation’: parcels are generated within given boundaries also known as Superblocks and Cityblocks (Keating & Krumholz 2000) including a ‘Manhattan Grid’ street layout.

(b) ‘Building generation’: places buildings onto parcels and offers the possibility to assign attributes to buildings and consequently to the parcels.

For the urban development model presented in this article additional C++ modules were written to fulfill the objective of a dynamic simulation:

(a) ‘Population distribution’: first, this module takes the given population predictions and splits population according to the timesteps set in the model. As a second step the module looks for suitable areas to position the population and assigns it. Suitable areas are distinguished according to the year (optional) set in the Superblock and the distance from already populated parcels. If no year is set, the area is treated as available from the beginning of the simulation. If the actual simulation year is ahead of the set development year of an area it is updated to the actual year. As in most other urban development models distance is used to rank available areas (e.g., UrbanSim in addition to other criteria). The distance is calculated as the Euclidian distance from the centroid of one Superblock to another. Selection of an area for development is based on the rank, consequently the distance. The flexibility of the module allows also for a preference of short or long distances. The distance value is multiplied with a random factor $x = \{\omega \in \mathbb{R} \mid a \leq X(\omega) \leq 1\}$ to provide arbitrariness within the model where $a \in \mathbb{R} \mid 0 < a < 1$ and can be used for calibrating the model.

(b) 'Supplementary distribution': as population is distributed by the module 'population distribution', floor space and consequently buildings for commercial and industrial purposes are calculated within this module for the dedicated commercial or industrial zones: the amount of space per person (m^2) used for workplace purposes is defined within this module as a value set by the user and scaled up to the amount which is defined by estimated population growth. As of 2010 official statistics state a floor space consumption of 40 m^2 per person for living purposes (Statistics Austria 2012). This results in double the amount of impervious area per person due to transport needs, but also takes into account floor space needed for economy and industry.

(c) 'Attribute calculation': this module calculates attributes for each building/parcel. For this example this includes DWF, impervious area and effective impervious area (EIA), which represents that fraction of the impervious area that is connected to the urban drainage system. The proportional factor $\{x \in \mathbb{R} \mid 0 \leq x \leq 1\}$ between impervious area and EIA is set within this module and can be used for calibration purposes. For each building and parcel DWF and the impervious area (and EIA) is calculated on the basis of Austrian regulations (ÖWAV – RBII 2009) and statistical data on water demand per person (Statistics Austria 2012). DWF is defined to be 4 l/s for 1,000 inhabitants for residential areas. Industrial areas are calculated on hectare basis with an amount between 0.2 and 1 l/s. EIA basically is defined by the total impervious area connected to the sewer system and the fraction of 'effectiveness'. As mentioned, the DWF is calculated from water consumption in liters per day and person while building size and consequently the impervious area is calculated from the number of persons on a parcel. These data allow for an ample analysis of changes in potential stormwater runoff in a changing urban environment. Infiltration can be directly incorporated into the EIA by simply using a smaller fraction of impervious area.

A schematic of the dynamic development cycle is visualized in Figure 1 starting with the input followed by the setup of the cycle where main parameters as start year and end year are set. Afterward the dynamic cycle begins where population is distributed among available areas and based on those numbers, supplementary distribution (e.g., workplaces), parcels and buildings are created including the assignment of attributes described in 'attribute calculation'. A fixed number of cycles is defined within the simulation framework where one cycle represents 1 or more years of urban development (e.g., 3, 5 or 10 years). At the end of each cycle a polygon-shape file with attributes according to the module setup is generated for further usage with other programs.

Dynamic evolution of the city suggests that changes over time in city development are considered. The actual development cycle depends on initial values set in the simulation, but due to stochastic behavior provided through random values described previously the model leads to different patterns in development. This allows for consideration of uncertainties which cannot be avoided when trying to generate future development scenarios. Development within partially urbanized Superblocks is commenced within the next cycle until the area is fully developed.

Input data

Input data are provided as a polygon-shape file with areas designated for development. These polygons and corresponding values can be extracted from open data layers

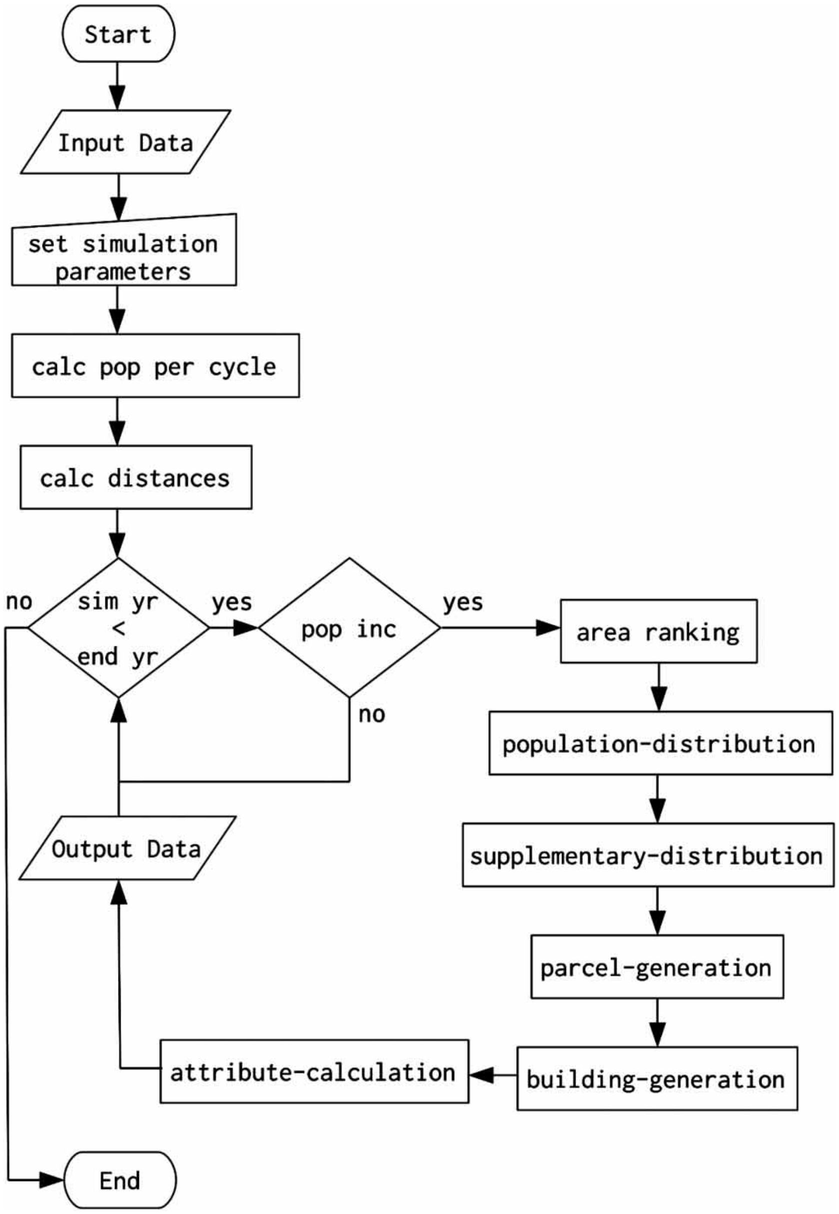

Figure 1 | Flow chart showing the functioning of the dynamic urban development cycle.

like openstreetmap (http://osm.org), but for more accurate results official development master plans should be used. The following attributes are needed for each polygon provided: TYPE, DENSITY, MAXIMUM_HEIGHT and TIMEFRAME.

TYPE is defined as either 'residential', 'commercial' or 'industry' where 'residential' is dedicated for housing purposes, 'commercial' for office buildings including public buildings like schools or universities, and 'industrial' areas dedicated for industry businesses, but also department stores or warehouses. DENSITY classes 1–3 resemble the denseness of floor area (the sum of floor space divided by parcel area) where class 1 stands for values below 0.8, 2 for 0.8–1.5 and 3 more than a value of 1.5. From the density class a calculation of the approximate maximum height of buildings is possible or it can be provided by the user if there is knowledge about height restrictions. The TIMEFRAME sets the Superblocks earliest development year.

This attribute is optional, but if knowledge about building restrictions exist it can be provided as a date.

Output data

The simulation generates two different types of output for each cycle: the first output is a file which defines buildings created by the simulation in the commonly used KML (Keyhole Markup Language) standard (Open Geospatial Consortium Inc. 2008); second, ESRI shapefiles containing all input data and additional information on the EIA for each cycle.

CASE STUDY

The city of Innsbruck was chosen as an exemplary example as the municipality is well known, data are available and population within the urban area is expected to increase within the next decades.

Innsbruck is located in the federal state of Tyrol which is part of western Austria. The city is located in the Inn Valley at an elevation of 574 m above sea level. The area of the whole municipality is 104.84 km^2, permanent settlement is only possible on 32.3% of the total area. Population by the end of 2013 amounted to 125,431 inhabitants plus another 23,426 secondary-residence residents. Figure 2 shows the development and prognosis of inhabitants of the city of Innsbruck and surrounding municipalities divided into a driving time of below 15 minutes and from 15 to 30 minutes from the city centre (Statistics Austria 2012). In addition, the gray dotted vertical line indicates the beginning of stagnating population within the city. The gray bars in the background show the simulation period (2000–2030): left and in gray, the beginning and calibration of the model (2000–2010); dark in the middle, the validation phase (2010–2014); and light to the right, the projection period (2015–2030).

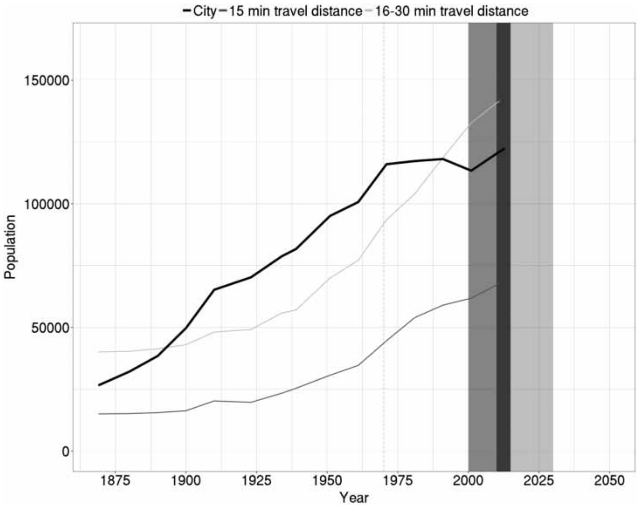

Figure 2 | Population development of the city of Innsbruck, including population within a traveling distance of 15 minutes and 16–30 minutes.

Apart from the inhabitant data mentioned above the official development plan of Innsbruck (Stadt Innsbruck 2002) ranging from the year 2000 to 2020 was transformed into a GIS (geographic information system) vector format along with a few mandatory fields. This plan gives plausible estimations provided by the government where designated development might happen in the future. As these areas are generously assigned on undeveloped blocks, mostly green land and/or fields, more land is available for development as needed. In addition to the designated areas, available parcels were marked as available for development.

Slightly more than 950 ha within Innsbruck are impervious (Stadt Innsbruck 2012), composed of 50% building areas and another 50% road and parking surfaces. Eighty percent of these areas are connected to the sewer system and consequently effective. Therefore, 740 ha are defined as EIA connected to the drainage system to account for not connected parts and losses. This value was derived in a previous study by calibrating the sewer system model (Kleidorfer & Rauch 2011) and is also used for future development projections in the model.

Further, this amounts to 75 m^2 impervious area per person of which a fraction of 80% would generate runoff into the sewer system. The difference between impervious area and EIA results from unconnected parts (i.e., decentralized treatment of stormwater runoff in infiltration facilities) and model-specific consideration of losses in the model parameter EIA.

SIMULATION

Urban development

Within this investigation, one cycle resembles a timestep of 5 years starting from the year 2000. The simulation includes five steps (until 2030) with population dynamics based on official projections. A timestep of 5 years was chosen because results from simulations using less than 5 years did not show a significant difference, but raised calculation time. When simulating a steep increase in population, the usage smaller timesteps might be advisable to determine possible steps leading to critical situations. The simulation was conducted for three different scenarios which resemble slow, average and fast development of the city. The boundary conditions are mainly controlled by altering the population data supplemented by changes in the 'supplementary module' which controls economic growth by changes in commercial and industrial space per inhabitant.

These three main scenarios have been set up and tested:

- Scenario A can be seen as a base scenario according to population projections and economic development (in terms of area need) with an increase of inhabitants by 12% until 2030 starting from 113,000 inhabitants in the year 2000. This means that commercial and industrial usage is developed at the same level (increase of 12%) as residential within each timestep. As described before, this means 40 m^2 impervious area consumption per person for buildings plus another additional 40 m^2 for other areas (e.g., roads).
- Scenario B projects less population increase and consequently also less increase in economy. This translates to a population increase of 8% from 2000 to 2030. This consequently means less sealing of residential areas compared to Scenario A. Commercial and industrial are developed at the same rate as the residential category.
- Scenario C takes parameters for residential development from Scenario A, but less economic development. This gives a normal population growth and less growth in economy (+8% from 2000–2030). This scenario can be seen as a combination of population projections of Scenario A paired with an economic projection of Scenario B.

Table 1 | Simulation scenario definitions with figures for the end year 2030

Scenario	Population projection	Population change (%)	Economic projection (%)
A	126,500	+12	+12
B	122,000	+8	+8
C	126,500	+12	+8

Table 1 gives an overview of all three scenarios. Furthermore, each main scenario is simulated 50 times to test variations. As already explained, random values within distance calculations vary algorithm parameters enabling generation of a manifold of scenarios within boundaries of the main scenario. In this example, factor *a* is set to 0.8 according to the numbers described in the case study section. In addition, for variations in area EIA values are altered by a uniformly distributed random value from 0.95 to 1.05 before the export of the data. In total, 150 scenarios have been developed.

Calibration and validation

As available areas for development within the municipality are scarce and the official development plan of the city is used for providing input data, boundary conditions are tight and only little variation is possible. For calibrating the model a timespan from 2000 to 2010 was chosen, the next 4 years until 2014 are used for validation. As already mentioned, these three periods are visualized as bars in Figure 2. The model and the data were setup accordingly to fit real development which happened within these 10 years. To accomplish this, the variables in the modules described previously were modified until simulation data provided by the model resembled real development.

Calibration happened through tweaking the variables described before (values in modules population distribution, supplementary distribution and attribute calculation) until developed areas and population density resembled equal values as in reality (spatial and temporal). The calibration parameters include the set area types, density, maximum height and development year in available areas, the distance adjustment variable *a*, amount of space used for residential and workplace purposes per person and the proportional factor between impervious area and EIA. This task may not be fully accomplishable due to insufficient data.

Despite calibration the model may not reflect real development beyond two decades due to uncertainties in the population projections and development plans, changes in politics and regulations and irrational choices made by inhabitants or planners. This may also happen because of external influences like hosting big sport events, for example, the Olympics or the European Football Championship (which have significantly driven urban development in Innsbruck in the past).

Hydrodynamic application

As a proof of concept of the urban development model and its output, runoff and flooding calculations with the open source software SWMM are performed to show the impact of the sealing of additional areas. For better performance in computing also a parallel computing version of SWMM is used (Burger *et al.* 2014). Therefore commonly used design storm events of type Euler II are used which are described by Kleidorfer *et al.* (2009). Figure 3 shows the 120 minutes Euler II design storm event with a return period of 0.5, 5 and 15 years, which is used as an input for the hydrodynamic model. In addition, a real rainfall event from 17 July 2010 is used for simulation. This rainfall is only available with a resolution of 10 minutes and adapted for illustration purposes to a 5 minutes sampling interval. Rainfall data for this event were taken from a rain gage near the city centre where rainfall volume totaled 45 mm during the event recorded. Simulation minute 0 reflects 11:20 h and, as can be seen, the main event started around 12:10 h and lasted 40 minutes with a peak intensity of 16.4 mm per 10 minutes (98.4 mm per hour). In addition to the intense rainfall, the event was accompanied by heavy hail showers which caused gullies to clog. After the main event small showers persisted for another 2 h with smaller peaks up to 2.5 mm per 10 minutes (15 mm per hour).

In total, 454 SWMM simulations were conducted: 3 main scenarios × 50 sub-scenarios × 4 rainfall files, each for the final results of 2030, plus 4 for each rainfall for the base scenario. Each future scenario and sub-catchment affected by a change are adapted in size and imperviousness. This adaption was performed with QGIS (http://qgis.org) using previously exported SWMM sub-catchments in intersecting the results. The combined sewer system used for

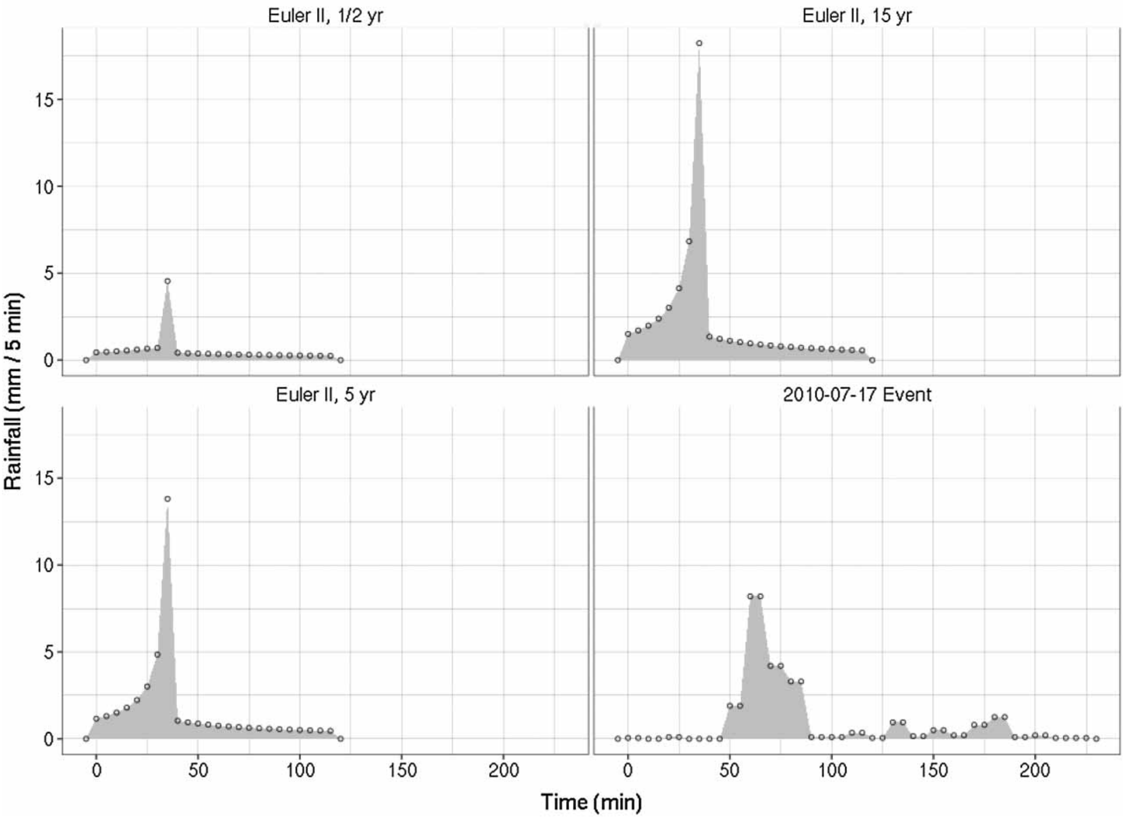

Figure 3 | Design storm rainfalls Euler II, 0.5 year, 2 years, 5 years and 15 years, 5 minutes steps plus one real event from 2010 used in SWMM to test the effect of changing EIP on the sewer network.

simulation consists of 5,358 nodes, 4,528 sub-catchments, 5,695 links and 53 outfalls.

RESULTS AND DISCUSSION

Urban development

The examples for all scenarios in Figure 4 show that urban development and consequently a change in EIA for Scenario A is happening in many parts of the city between 2000 and 2010, although only small areas get developed. Since 2000 city regulations enforce the application of infiltration methods on newly established buildings whenever groundwater levels allow it. Even though this regulation is in force, the EIA of most areas increases simply due to the fact that there was no sealing at all before (e.g., undeveloped agricultural areas). From 2010 to 2020 larger parts of the city get developed leading to an increased EIA. Until 2030 steady development is happening although most large areas have already been developed from 2010 to 2020.

Total changes in EIA including variations between sub-scenarios are visualized as boxplots in Figure 5 where each boxplot consists of all sub-scenarios of one main scenario. As expected, the highest increase can be seen in Scenario A from 738 ha to a median value of 807 ha, respectively, a median of 775 ha for Scenario B and 782.5 ha for Scenario C. Figure 6 shows the development from start year 2000 until 2030 through each cycle for each scenario. Values for the impervious area (top) and EIA (bottom) represent mean values including the standard deviation from all 50 sub-scenarios. As can be seen values increase from base year in 5 year timesteps until 2030.

Calibration and validation

Figure 7 gives an example of the calibration of the development year 2005 displaying simulated and real buildings at one development area in 2005. As can be seen, the height and base size of generated buildings are not uniform, but slightly adjusted by random factors during the development cycle. Also the shape and layout of the generated buildings do not necessarily reflect

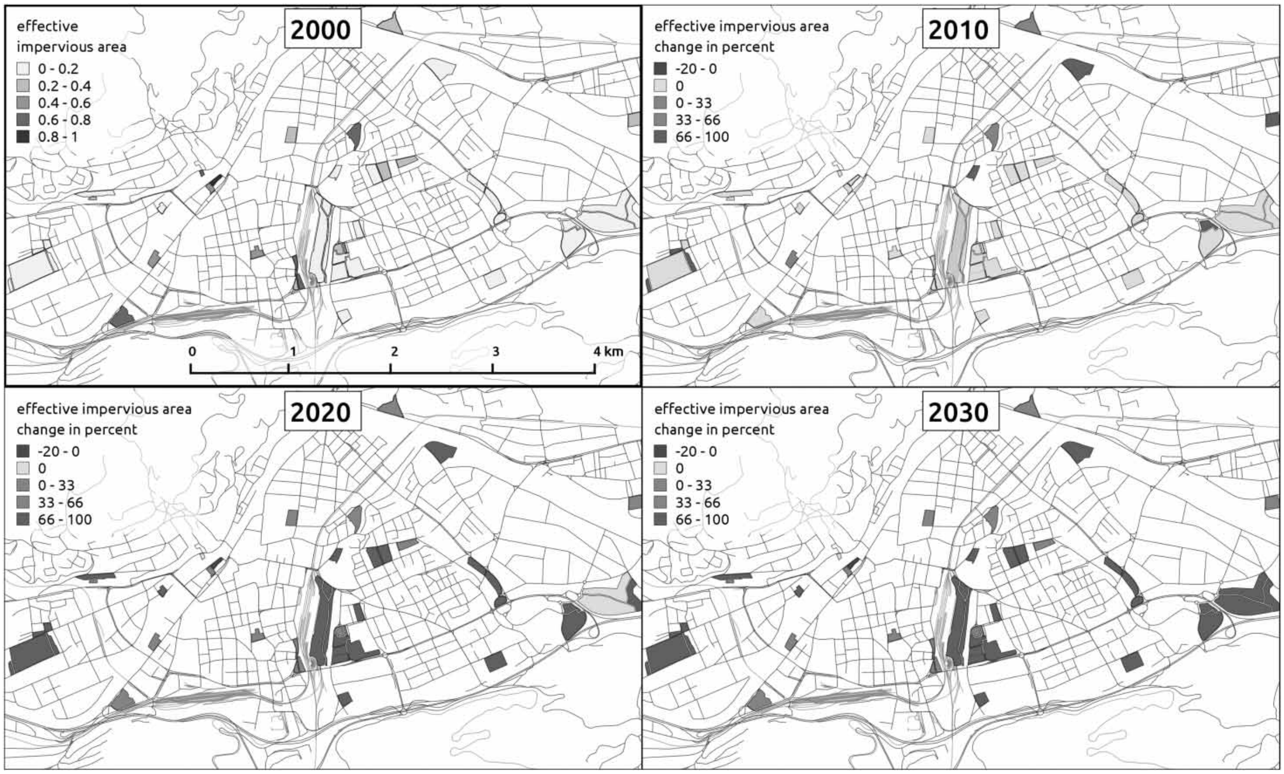

Figure 4 | Development of the EIA for Scenario A (main scenario) in steps of 10 years.

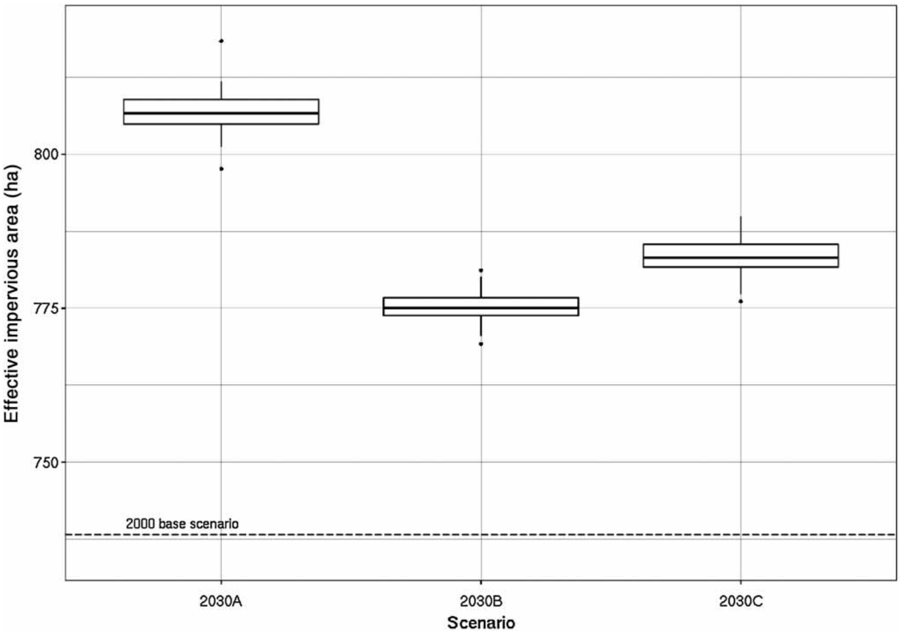

Figure 5 | Boxplot of the total EIA for the final timestep (2030) for all scenarios, as a dotted line in the base year 2000 for comparison.

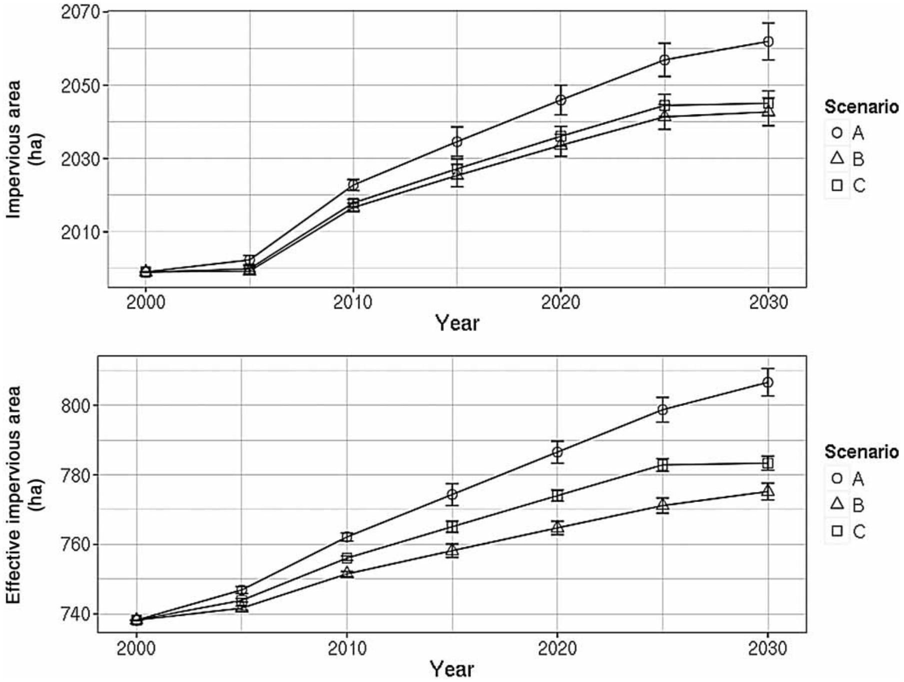

Figure 6 | Detailed graph with results of urban development from start year to end year in 5-year timesteps including the standard deviation of the 50 sub-scenarios as impervious area and EIA.

reality. Despite that, due to calibration measures the EIA of both simulation and real development provide comparable results. Consequently, for the purposes within water sciences, it is not mandatory to simulate exact location and shape of buildings in contrast to being unavoidable in other disciplines such as architecture or cityscape planners.

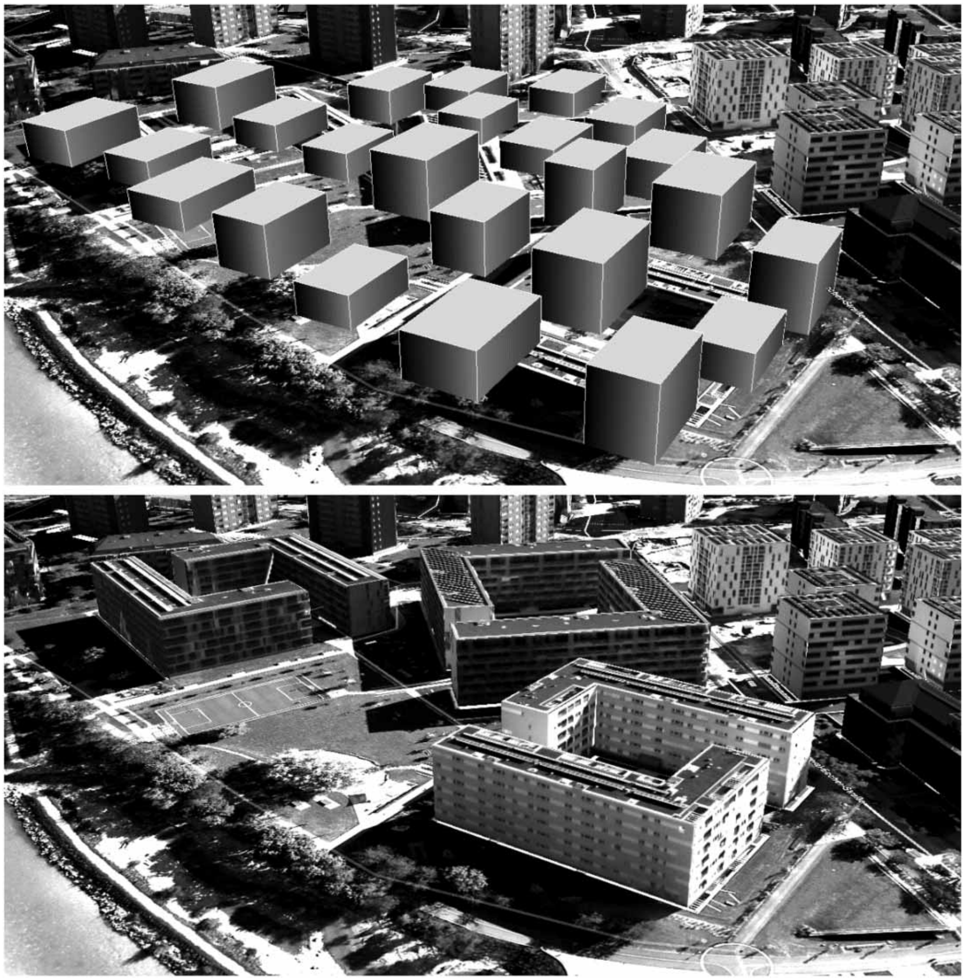

Figure 7 | Top: 3D visualization of generated buildings demonstrating variation in height and base area. Bottom: real development in this area; visualization in Google Earth.

Hydrodynamic application

Figure 8 clearly shows that a scenario analysis of city development in combination with different rainfall data is an absolute necessity. Changes in total flood volume are plotted against changes in EIA. Scenarios A, B and C are additionally accentuated by ellipses for easy comparison. The linear smooth lines with a confidence interval of 0.95 show the data grouped by each rainfall event. This image visualizes the simulation results without the Euler II, 0.5 year rainfall as no or almost no flooding occurs. In addition, Figure 8 shows clearly the correlation between area and flooding volume. As expected, Scenario A shows the highest total increase in total flooding volume followed by Scenarios B and C.

In contrast, Figure 9 shows that the distribution of changes in number of flooding nodes shifts compared to the base scenario 2000, but is only slightly affected by the differences in Scenarios A, B and C, no matter which rainfall is used. This suggests that the additional volume from newly connected areas (changes in EIA) causes problems at the same nodes, but no detailed spatial analysis has been done within this work.

Figure 10 shows the differences in flooding volume compared to the base year 2000 versus changes in flooding nodes. As stated previously, a change in volume from variations in EIA (Scenarios A, B and C) does not cause a change in flooding nodes. The changes in number of flooded nodes are dominated by the stochastic variation within each of the main scenarios. It can therefore be

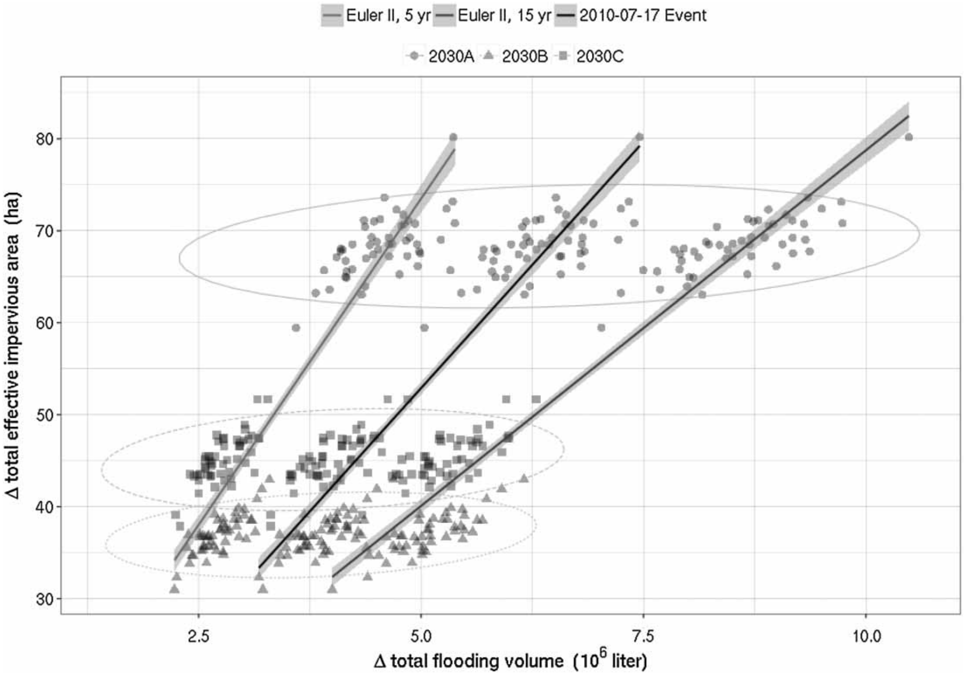

Figure 8 | Differences in impervious area versus difference in total flooding volume for (sub-)Scenarios A, B and C and rainfalls Euler II 5 and 15 years and 17 July 2010 event.

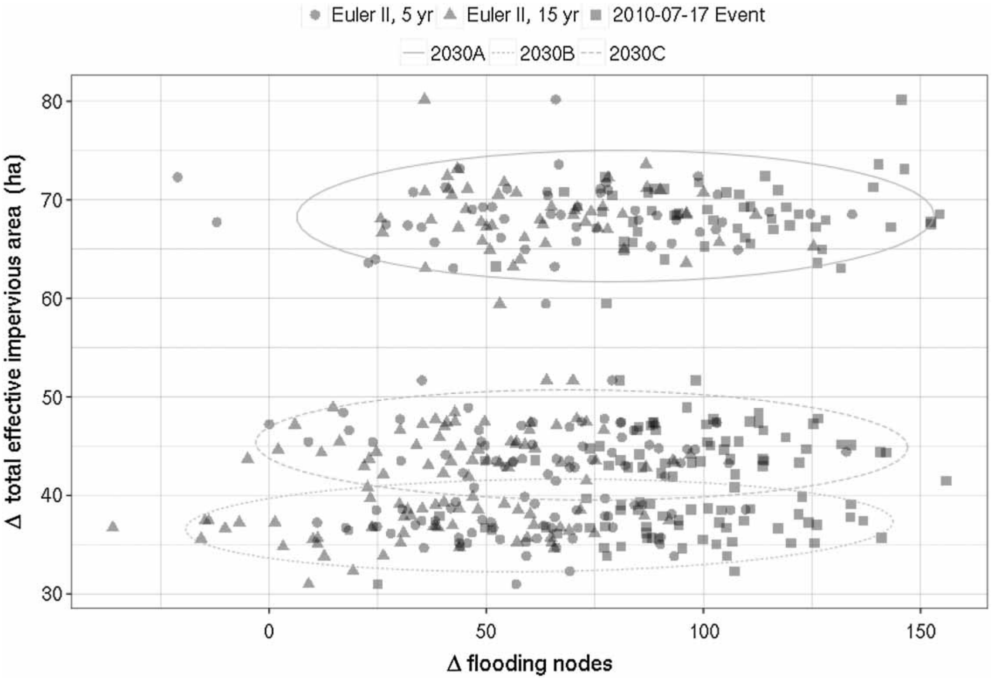

Figure 9 | Differences in impervious area versus difference in number of flooding nodes for (sub-)Scenarios A, B and C and rainfalls Euler II 5 and 15 years and 17 July 2010 event in relation to the base year 2000.

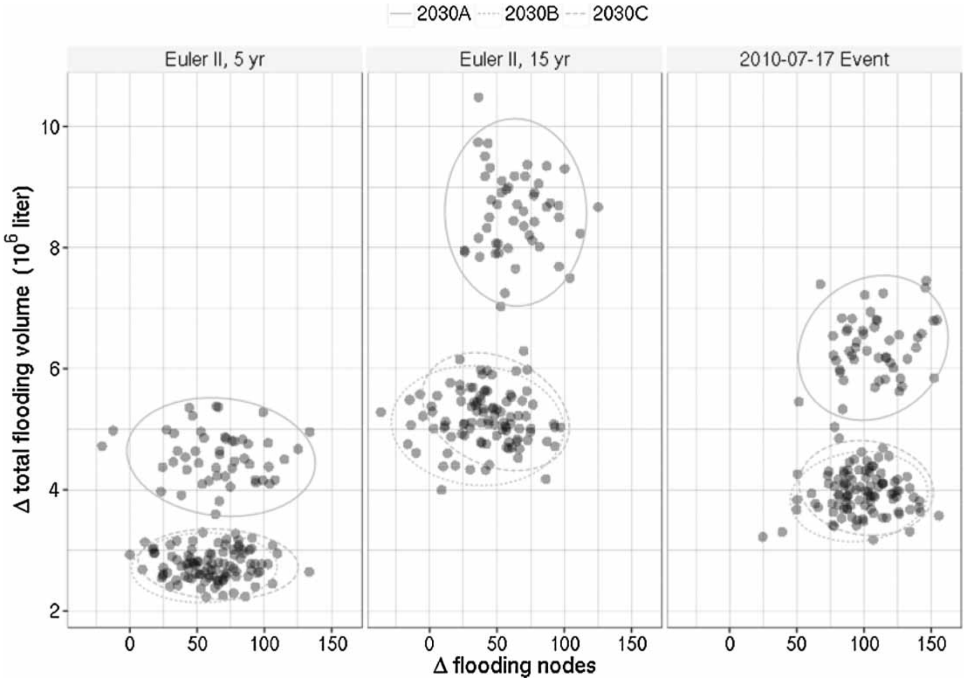

Figure 10 | Differences in flooding volume versus difference in number of flooding nodes for (sub-)Scenarios A, B and C and rainfalls Euler II 5 and 15 years and 17 July 2010 event in relation to the base year 2000.

assumed that only location and number of development areas cause different nodes to flood while not affected by (slight) changes in EIA, whereas EIA almost only affects flooding volume.

Table 2 summarizes the flooding results and gives insights into the total amounts of EIA of the city and the amount of total flooding volume calculated. As the number of flooded nodes does not change significantly throughout the scenarios they are not included in the table. The change in percent has been calculated for each scenario by summing up all sub-catchment areas, respectively, SWMM flood volume results for the year 2030 in contrast with the values from the base year 2000.

Table 2 | Effective impervious area for the year 2000 and all scenarios in 2030 including the corresponding total flooding volume

		Flood volume [rel. to 2000] (%)		
Year and scenario	**EIA [rel. to 2000] (%)**	**E II, 5 year**	**E II, 15 year**	**2010 event**
2000	–	–	–	–
2030 A	+9.3	+12.5	10.1	10.2
2030 B	+5.0	+7.5	6.0	6.3
2030 C	+6.0	+7.6	6.2	6.5

CONCLUSIONS

This study presents a simple urban development model which is linked to an urban drainage model. We show that the consideration of the dynamic development of urbanization is useful for a thorough analysis of the existing sewer system to identify areas which are at risk of flooding for future conditions. This allows for a pro-active adaptation by considering the interactions between urban development and urban drainage. For example, as such an adaption strategy the implementation of decentralized stormwater treatment (e.g., in infiltration facilities) during reconstruction of already populated areas can be tested. Results displayed already show the potential of this tool for urban developers and civil engineers. The direct coupling of DWF and pollution load from different surfaces would trigger even more insight. A coupling of the model with water supply and other urban networks is conceivable and possible.

The results enable not only a comparison of which and how areas change in terms of drainage as the EIA and the DWF are automatically calculated. Also a comparison of results between different scenarios is easily possible by only adjusting boundary conditions. As input needs are low this method could be used by planners without the necessity of buying and preparing large amounts of data. Moreover, this toolbox could be easily adapted for usage in other parts of the world where data are simply not available. Furthermore, this framework allows for testing consequences of new types of urban design on drainage (Brown *et al.* 2009; Urich *et al.* 2011). In addition, the model presented allows for an analysis of working solutions and subsequent further generation of sub-scenarios based on these solutions. This optimization might also take place by using evolutionary algorithm real options (Zhang & Babovic 2011).

Specific lessons learned from this work are as follows:

- A methodology has been developed for the use of urban development simulation to compare growth scenarios for cities and urban regions.
- Calibration and validation are necessary, but may not reduce or eliminate all future uncertainties.
- For robust results it is necessary to generate sub-scenarios using stochastic values which superpose simulation parameters.
- City growth can lead to a significant increase in overflow volume from the sewer system. In addition, the number of overflow nodes can increase and cause damage in areas not known for flooding problems before. Despite uncertainties the urban development results allow for an analysis of tendencies.
- Without spatial analysis of city growth and generation of multi-scenarios, an ample testing for weaknesses in water networks is not possible. The necessity of usage of a sophisticated, data-driven model can be avoided if a multi-scenario analysis is conducted.

The presented model demonstrates that it is well designed to test robustness of urban infrastructure networks, no matter whether city simulations exactly reflect future conditions. Calibration needs special attention as it is directly dependent on available temporal and spatial data. As there are usually only fractions of calibration data available the benefits of this model become apparent: because dozens or even hundreds of possible future developments are generated. This circumstance essentially resulted in choosing a simulation framework automatically providing a series of possibilities in terms of a multi-scenario generation.

OUTLOOK

As the results are based on a specific case study characterized by limited data the model requires further applications and also a comparison with well established urban simulation frameworks to be able to be generally applied. More details on scenario analysis can be found in Mikovits *et al.* (2014b) with a focus on spatial variation. A comparison with a focus on data availability and needs is demonstrated in Mikovits *et al.* (2014a).

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