Impact of urban development and climate change on urban drainage systems

Impact du développement urbain et du changement climatique sur les systèmes de drainage urbain

Manfred Kleidorfer[1], Christian Mikovitis[1], Alrun Jasper-Tönnies[2], Matthias Huttenlau[3], Thomas Einfalt[2], Martin Schöpf[4], Heiko Kinzel[4] and Wolfgang Rauch[1]

[1] Unit for Environmental Engineering, University of Innsbruck, Technikerstrasse 13, A6020 Innsbruck, Austria (Email: Manfred.Kleidorfer@uibk.ac.at; ChristianMikovits@uibk.ac.at; Wolfgang.rauch@uibk.ac.at)
[2] hydro & meteo GmbH & Co. KG, Breite Strasse 6-8, D-23552 Lübeck, Germany (Email: jasper-toennies@hydrometeo.de; einfalt@hydrometeo.de)
[3] alpS – Centre for Climate Change Adaptation , Grabenweg 68, A6020 Innsbruck, Austria (Email: huttenlau@alps-gmbh.com).
[4] hydro-IT GmbH, Technikerstrasse 13, A6020 Innsbruck (email: kinzel@hydro-it.com)

RÉSUMÉ

Les variations d'intensité des précipitations et les zones pavées ont un impact sur les réseaux de drainage urbain. Le changement climatique et le développement urbain sont deux facteurs à prendre en considération lors de l'analyse des changements à long terme des performances du système. Ces prévisions futures présentent toutefois un haut degré d'incertitude et il est donc préférable de ne pas tenter de prévoir l'avenir en considérant un scénario futur spécifique, mais plutôt d'analyser différents scénarios et la façon dont le système réagit à chacun d'entre eux. Cette tâche combine la modélisation du développement urbain, des projections du changement climatique régional en matière de précipitations ainsi qu'un modèle hydrodynamique de réseau unitaire d'assainissement, afin d'évaluer les risques d'inondation et d'identifier des stratégies d'adaptation solides pour les infrastructures de drainage urbain. Un environnement SIG basé sur le Web a été utilisé comme plate-forme de visualisation des bâtiments touchés par les inondations, afin de communiquer les résultats des différentes simulations aux parties concernées, permettant ainsi d'évaluer l'efficacité des mesures d'adaptation et d'identifier de solides stratégies d'adaptation.

ABSTRACT

Urban drainage networks are affected by changes in precipitation intensities and paved areas. Both, climate change and city development, are effects to be considered when analysing long-term changes of the system performance. Those future projections are highly uncertain. As such it is reasonable not to try to predict the future and to consider one specific future scenario but instead to analyse different scenarios and the system's response respectively. This work combines urban development modelling, regional climate change projections of precipitation and a hydrodynamic model of a combined sewer system in order to evaluate flood risk and to identify robust adaptation strategies of urban drainage infrastructure. In order to communicate the different simulation results to stakeholders, a Web-GIS environment was used as a platform for visualizing buildings which are affected by flooding. In this way it is possible to assess the effectiveness of adaptation measures and to identify robust adaptation strategies.

KEYWORDS

Climate change, Combined sewer overflow, Flooding; Hydrodynamic modelling, Urban development

1 INTRODUCTION

Urban drainage networks are affected by changes in precipitation intensities and paved areas (both causing direct reactions in urban stormwater runoffs). Both, climate change and city development, are effects to be considered when analysing long-term changes of the system performance. Several studies show the impact of climate change and/or urbanisation (Ashley *et al.* 2005; Semadeni-Davies *et al.* 2008; Arnbjerg-Nielsen & Fleischer 2009). However, those future projections are highly uncertain. As such it is reasonable not to try to predict the future and to consider one specific future scenario but instead to analyse different scenarios and the system's response respectively.

The project 'Dynamic Adaptation of Urban Water Infrastructure for a Sustainable City Development in an Alpine Environment (DynAlp)' investigates the impacts of different city development and climate change scenarios on the performance of a combined sewer system. It combines urban development modelling, regional climate change projections of precipitation and a hydrodynamic model of a combined sewer system in order to evaluate flood risk and to identify robust adaptation strategies of urban drainage infrastructure. In order to communicate the different simulation results to stakeholders, a Web-GIS environment was used as a platform for visualizing buildings which are affected by flooding.

2 METHODS

2.1 Case Study & hydrodynamic simulation

The analysed case study is a medium sized city of 125.000 inhabitants with an alpine climate (i.e. extreme rainfall events happen during summer period as thunderstorms). The total catchment area is approximately 2.000 ha, whereof 760 ha are impervious (i.e. the average fraction of imperviousness is 0.37). The combined sewer system is modelled as a fine-grained network consisting of more than 5000 nodes, 4500 sub-catchments, 5700 links and more than 50 outfalls. The entire system drains to one central wastewater treatment plant. For simulation of rainfall runoff and hydrodynamic flow routing in the sewer pipes the Storm Water Management Model (SWMM) was used.

A simple 1D model for sewer pipes and a coupled 1D-2D model (1D sewer pipes, 2D surface routing of ponded water) was used. As the 1D-2D model is computationally demanding the 1D model was initially used for screening multiple different development and climate change scenarios and the 1D-2D model for more detailed investigations of selected scenarios and events. Water levels of inundated areas water were evaluated in a defined area in the city centre. The chosen 2D surface routing model used is a simplified 2D simulation model as provided in the software PCSWMM. The surface flow routing is modelled as a mesh of 1D channels (considering a digital elevation model of the surface and "obstacles" as e.g. buildings) More description regarding this type of flood modelling is available from James *et al.* (2013).

Different performance indicators were evaluated, including pollutant emissions to the receiving water. This work focuses on (increased) flood risk caused by climate change and/or urban development. Typical performance indicators of a hydrodynamic model to express flood-risk are ponded volume (i.e. the water leaving the system through manholes after the system capacity has been reached) or number of flooded nodes. A better estimation of flooded areas is possible when water levels on surfaces are calculated in a 2D surface routing model. When these inundation depths are intersected with vulnerability-sensitive parameters of buildings (i.e. water levels at which water starts to enter a building) the number of affected buildings can be calculated. The risk level is for example zero when the building entrance is on ground level or when there are windows below ground level. This risk level has to be identified individually for each building. As this data is usually not available, this data was collected for a specific investigation area in the city centre within this study.

2.2 Climate change & urban development

The climate change projections are based on regional climate models (ECHAM5, HadCM3) for different IPCC Emission Scenarios (according to SRES (IPCC 2000): A2 (regionally oriented economic development; high emission scenario), A1B (strong economic growth, balance across fossil and non-fossil energy sources; medium emission scenario) and B1 (ecologically friendly service and information technology; low emission scenario). The regional climate model-runs (Loibl 2010; Isotta *et al.* 2014) were improved by applying an empirical regional statistical downscaling method according to Jasper-Tönnies *et al.* (2012). This approach is based on the analysis of the correlation between daily temperature, daily rainfall and rainfall intensities (taken from historic long term rainfall measurements).

In the next step corresponding rainfall events from the past were transferred into the future to match future daily temperature and precipitation for of the regional climate models (period 2021 - 2050). This enables to derive realistic synthetic rainfall records for the future and to calculate typical future rainfall characteristics for different durations and return periods. These rainfall characteristics now can again be used to generate design-rainfall events for the future, which can be used in urban drainage models.

The urban development model used in this study was presented by Mikovits *et al.* (2014) and Mikovits *et al.* (2015). The model itself is designed to run with minimal data needs. The aim of this approach is not to try to predict the future development, but to generate a large set of different possible scenarios. As such, also in this work different spatial scenarios were analysed.

3 RESULTS

Figure 1 shows the increase of rainfall intensities for the duration of 15 minutes for the period 2021 – 2050 compared to the period 1971 – 2000; the return periods are between 0.5 and 100. Also results for different climate model/ emission scenarios are shown. For example the 5 year rainfall event is expected to be approximately 20% higher for both the A2 and the B1 emission scenarios (Echam5). In general the increase is higher for smaller return periods. Differences in results are small between the A2 and the B1 scenarios as also differences in the assumed emissions are small in the period 2021 - 2050.

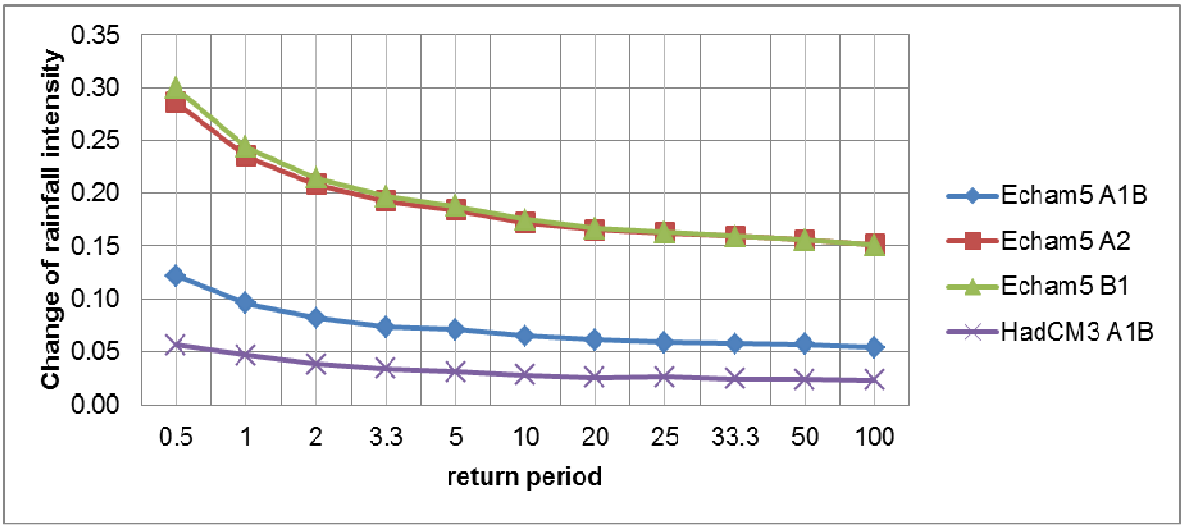
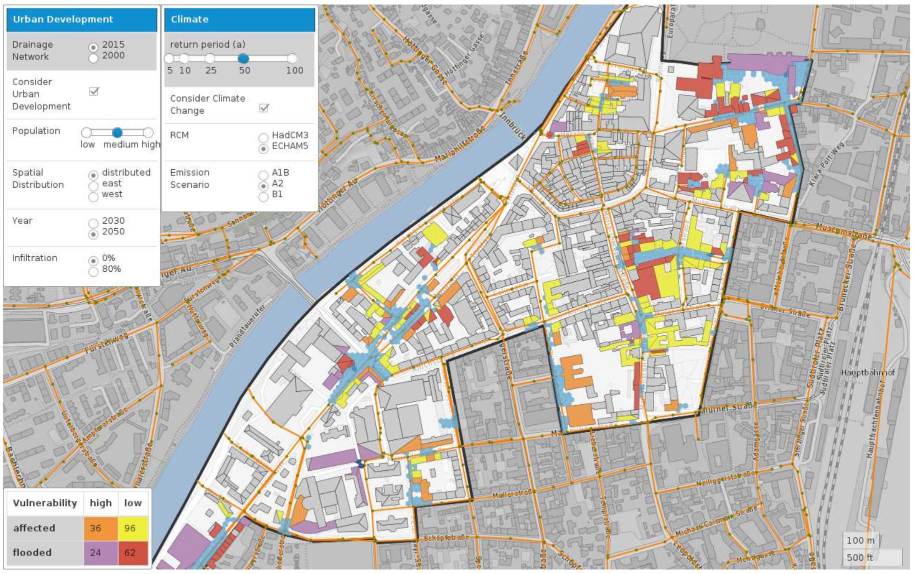


Figure 1. Change of rainfall intensity for duration 15 minutes and return periods between 0.5 and 100

Also when evaluating simulation results the impact is higher for smaller return periods. This is reasonable not only because the climate signal is higher for smaller return periods, but also as current design return periods are between 3 to 5 years. For events with higher return periods the system's capacity is already exceeded under current climate conditions. These results are expected as for design return periods the ponded volume is in general rather small and small changes cause a large percentage change.

Figure 2 shows a screenshot of the Web-GIS (web-based geographic information system) visualisation of the simulation results. The user can choose pre-calculated climate change and urban development scenarios, and affected buildings in the investigation area are visualized. Buildings of special importance (e.g., hospitals, schools and critical infrastructure for electricity and telecommunication) are marked. Additionally, more detailed information about the simulation results (e.g., hydrograph of ponded volume at all simulation nodes, water levels in different areas of the city, etc.) are available in the Web-GIS environment (Mair *et al.* 2014). The main advantage of the web implementation of the visualization is that the simulation results (data size > 100 GB) do not have to be transferred between different computers and that the visualisation is also available on mobile devices. The coupling of an urban development model, a hydrodynamic sewer model and climate change projections enables to investigate different future scenarios with a risk-based approach. In this way it is possible to assess the effectiveness of adaptation measures and to identify robust adaptation strategies.



Urban Development

Drainage Network ● 2015 ○ 2000

Consider Urban Development ☑

Population: low — medium — high (medium selected)

Spatial Distribution ● distributed ○ east ○ west

Year ○ 2030 ● 2050

Infiltration ● 0% ○ 80%

Climate

return period (a): 5 10 25 50 100 (50 selected)

Consider Climate Change ☑

RCM ○ HadCM3 ● ECHAM5

Emission Scenario ○ A1B ● A2 ○ B1

Vulnerability	high	low
affected	36	96
flooded	24	62

Figure 2. Screenshot of the Web-GIS applications with all results selectable by the user

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