PUBLIZIERBARER ENDBERICHT

A) Projektdaten

Kurztitel:	DynAlp
Langtitel:	Dynamic Adaptation of Urban Water Infrastructure for Sustainable City Development in an Alpine Environment
Programm inkl. Jahr:	ACRP, 4th Call 2011
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Schlagwörter:	Climate Change, Rainfall, Urban Development, Urban Drainage, Flooding
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B) Projektübersicht

1 Kurzfassung

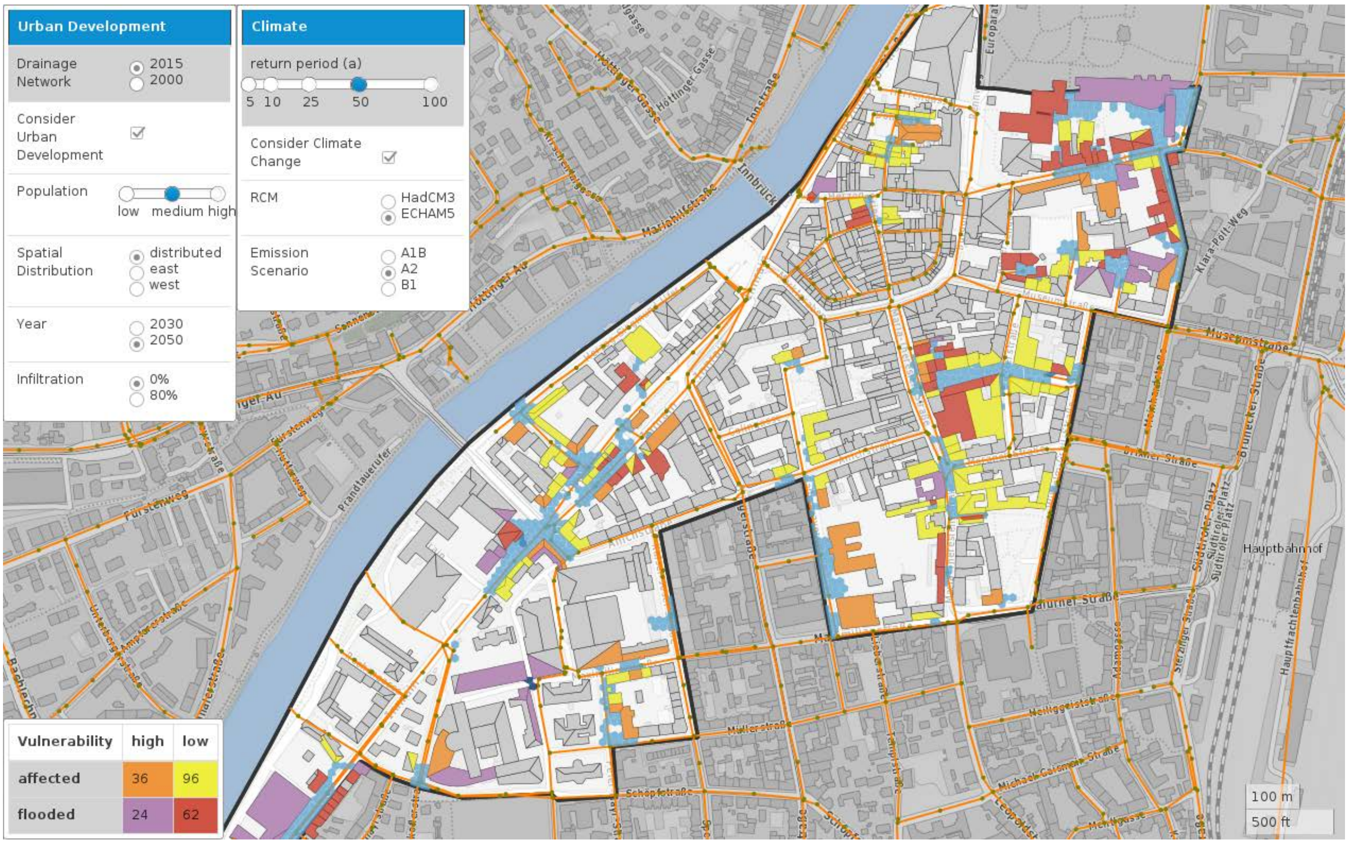
Städtische Infrastrukturnetzwerke wie Entwässerungssysteme oder Wasserversorgungsanlagen sind von höchster Bedeutung für den Lebensraum Stadt. Sie schaffen die Grundlage für Gesundheit und Sicherheit der Bevölkerung, ihre Zuverlässigkeit ist eine Bedingung für die wirtschaftliche und soziale Entwicklung des urbanen Raums. Diese Anlagen der Grundversorgung der Bevölkerung haben sehr lange Lebensdauern von 50 bis 100 Jahren (in einigen Fällen auch länger) und sollten daher vorausschauend geplant werden. Mit sich ändernden Randbedingungen durch ein sich änderndes Klima, eine veränderte Besiedelungsstruktur (wachsende oder schrumpfende Städte), veränderte Nutzungsgewohnheiten durch die Bevölkerung (z.B. sinkender oder steigender Wasserbedarf) oder veränderte umweltrelevante Anforderungen an die Leistungsfähigkeit der Anlagen können Anpassungsmaßnahmen notwendig werden.

Durch die Veränderungen des Klimas muss mit einer Zunahme von Starkregenereignissen, sowohl in deren Häufigkeit als auch in der Intensität gerechnet werden. Dies bedeutet, dass bestehende Entwässerungsnetze, deren Zweck es ist, Niederschlagswasser schadlos aus besiedelten Gebieten in die Flüsse abzuleiten, überlastet werden. Damit steigt einerseits die Überflutungsgefahr, das Risiko für Sachschäden und im Extremfall auch die Gefahr für Leib und Leben, und andererseits auch die Belastung für Flüsse durch Zunahme der Schmutzemissionen aus dem Entwässerungssystem. Zusätzlich zu Veränderungen des Niederschlags durch klimatische Veränderungen führen Bevölkerungswachstum und Stadtentwicklung, im Besonderen die Versiegelung von Oberflächen und Landnutzungsänderungen, zu einer erhöhten Belastung der urbanen Wasserinfrastruktur. Speziell der Anschluss neu besiedelter Flächen im Stadtgebiet an das bestehende Kanalisationssystem kann das Risiko einer Überflutung steigern. Durch den gezielten Einsatz von Verfahren, die das Niederschlagswasser gar nicht mehr bis zur Kanalisation leiten kann die Belastung für das Netz und damit die Überflutungsgefahr gemindert werden. Solche Verfahren sind beispielsweise Infiltrationsanlagen (Mulden, Rigolen, etc.), welche den anfallenden Regenabfluss vor Ort in den Untergrund versickern. Das Einbeziehen dieser Konzepte in die Betrachtung der Stadtentwicklung hilft damit auch positive Auswirkungen zu berücksichtigen, wenn beispielsweise bereits erschlossene und bebaute Gebiete mit diesen Kenntnissen neu entwickelt werden. Dies kann sogar so weit gehen, dass ein klimawandelbedingter Anstieg der Niederschlagsintensität durch dezentrale Regenwasserbehandlung kompensiert werden kann.

Das Projekt „DynAlp" behandelt diese Fragestellungen. Es untersucht, welchen Einfluss Klimawandel auf die für die Siedlungsentwässerung relevanten Niederschlagsereignisse hat, wie sich prognostizierte Bevölkerungsänderungen in der Stadtentwicklung auswirken und was dies für die Leistungsfähigkeit bestehender Entwässerungssysteme bedeutet. Dabei wurde ein Stadtentwicklungsmodell entwickelt und mit einem hydrodynamischen Kanalnetzmodell kombiniert. Niederschlagsdaten unter Berücksichtigung des Klimawandels wurden für verschiedene Emissionsszenarien mittels lokalem statistischem Downscaling für die Simulationen bereitgestellt. Die kombinierten Einflüsse von Klimawandel und Stadtentwicklung auf das Entwässerungssystem, sowie die Wirksamkeit von Anpassungsmaßnahmen, wurden untersucht. Die Ergebnisse werden in einer Web-GIS Umgebung visualisiert um sie in einfacher Weise Entscheidungsträgern und der interessierten Öffentlichkeit zugänglich und verständlich zu machen.

Um die Einflüsse aus Stadtentwicklung und Klimawandel zu untersuchen, wurden hydrodynamische 1D Simulationen des Entwässerungsnetzes gekoppelt mit 2D Simulationen der Oberfläche durchgeführt. Die 2D Simulationen erlauben es Informationen über den Wasserstand auf der Oberfläche im Überflutungsfall zu erhalten und damit detailliertere Aussagen über gefährdete Gebiete und Gebäude zu tätigen. Dazu wurden für den Innenstadtbereich detaillierte Aufnahmen der Gebäude gemacht und ermittelt welcher Wasserstand eine Gefährdung darstellt. Dies ist für jedes Gebäude unterschiedlich und hängt beispielsweise von der Höhe der Bordsteinkante, der Lage von Kellerfenstern und Lichtschächten ab oder ob der Eingang ebenerdig oder über Stufen

erreichbar ist. Durch Verschneiden dieser Gebäudeinformation mit den ermittelten Wasserständen kann die Überflutungsgefahr für jedes Gebäude individuell ermittelt werden.
Aus der Kombination unterschiedlicher Stadtentwicklungsszenarien (unterschiedliche Bevölkerungsprognosen, unterschiedliche Verteilung), unterschiedlicher Klimaszenarien, verschiedener Anpassungsmaßnahmen und unterschiedlicher Wiederkehrzeiten ergibt sich eine Vielzahl (ca. 100.000) unterschiedlicher Simulationen. Diese Simulationsergebnisse werden anschließend statistisch ausgewertet. Um diese Daten aber auch direkt nutzbar zu machen und Entscheidungsträgern sowie der interessierten Öffentlichkeit zugänglich zu machen wurde eine Web-GIS Umgebung erstellt (siehe Abbildung). Über die Auswahl verschiedener Parameter (z.B. Klimaszenario, Stadtentwicklungsszenario, Wiederkehrzeit) werden sofort die entsprechenden Simulationsergebnisse angezeigt.



Visualisierung der Simulationsergebnisse im in einer Weboberfläche

Wenn Anpassungsmaßnahmen für städtische Entwässerungssysteme geplant werden, ist es notwendig Klimawandeleinflüsse und Stadtentwicklung gemeinsam zu Betrachten. Zur Vermeidung falscher Entscheidungen, die sich aufgrund der langen Lebensdauer der Anlagen noch lange auswirken können, sollten Anpassungsmaßnahmen möglichst so geplant werden, dass sie unter einer großen Bandbreite möglicher zukünftiger Entwicklungen zufriedenstellend funktionieren. Gleichzeit kann Anpassung auch eine Chance darstellen die bestehenden System nachhaltiger zu machen. Interessant in diesem Zusammenhang ist vor allem die integrierte Planung der Stadt und ihrer Infrastruktur. Gerade für die Siedlungswasserwirtschaft interessante Anpassungsmaßnahmen durch dezentrale Niederschlagswasserbehandlung (beispielsweise durch Gründächer, Grünflächen zur Versickerung oder Regenwasserspeicherung in Teichen), können gleichzeitig auch andere erwünschte Wirkungen in der Stadt haben (z.B. Verminderung von Hitzeinseln). Gleichzeitig ist es aber auch wichtig, derartige Maßnahmen auf möglich negative (zukünftige) Wirkungen hin zu untersuchen um eine möglichst umfassende Entscheidungsgrundlage in der Anpassungsplanung zu gewährleisten.

2 Executive Summary

Urban drainage systems are important infrastructure facilities in an urban environment. These facilities are essential for human well-being and they are characterized by a very long typical service life of 50 to 100 years (or more). As a result, prospective planning is important for such infrastructure. With changing boundary conditions due to a change in climate, demographics (growing or shrinking cities), behaviour of the population and environmental regulations, adaptation measures might be required.

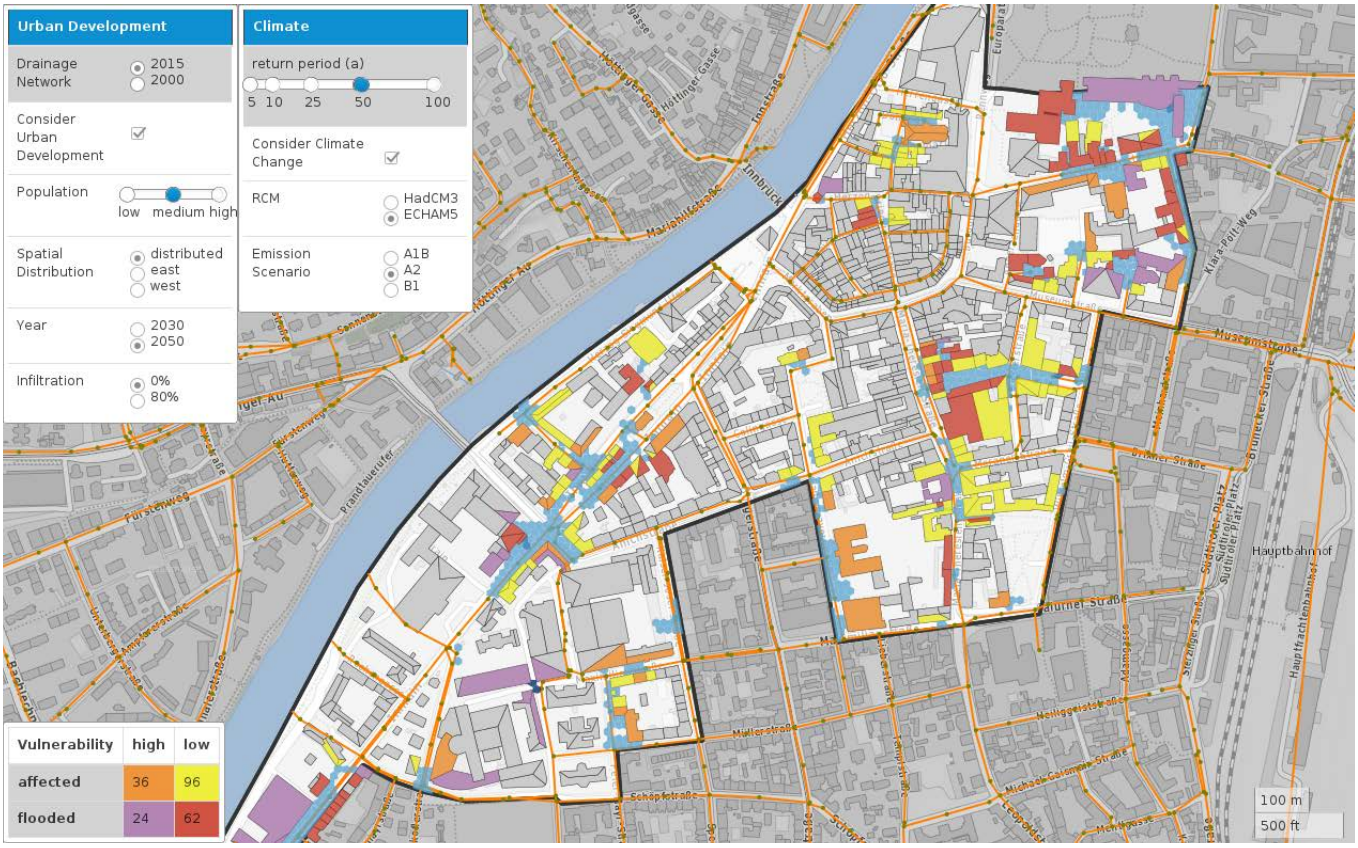
Pavement of the surfaces, along with a possible climate change induced increase of rainfall intensities, is one of key factors accountable for (increased) flooding in urban areas. Consequently higher runoffs have an impact on sewer system performance in terms of higher risk of flooding and decrease of storm water treatment performance. This increase in flood risk causes increases in the risk of property damage and in extreme cases also danger to life and limb. In addition to changes in precipitation due to climatic changes, population growth and urban development, in particular the sealing of surfaces and changes in land use, can lead to an increased pressure on the urban water infrastructure. For example the connection of newly populated areas to the existing sewer system can increase the risk of flooding.

One possibility for adaptation to such changes is to disconnect paved urban areas from drainage systems to implement on-site treatment as stormwater infiltration facilities. Infiltration might help to address current problems but might not fully compensate for increased runoff. To respond to the changes, continuous adaptation of the infrastructure is necessary by combining different technological solutions (e.g. on-site treatment, increase of pipe-sizes etc.). To reduce costs, adaptation of pipe networks should reasonably occur in line with the regular renewal/rehabilitation of aging infrastructure. Hence dynamic adaptation is crucial to maintain the drainage system operational.

The project ‘Dynamic Adaptation of Urban Water Infrastructure for a Sustainable City Development in an Alpine Environment (DynAlp)‘ focuses on city development and the potential impact of climate change on the adaptation and development of urban water infrastructure and addresses the aspect of pluvial flooding. 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.

An urban development model has been developed and coupled with a hydrodynamic drainage network model. Precipitation data has been generated by using statistical downscaling and taking various IPCC emission scenarios into account. The combined effects of climate change and urban development on the drainage system and the efficiency of adaptation measures have been examined. The results are visualised in a Web GIS environment to provide it in a simple manner for decision makers and the broad public. To investigate the effects of urban development and climate change, hydrodynamic 1D simulations of the drainage network were coupled with 2D simulations of the surface. The 2D simulations allow detailed information about the water level on the surface in case of flooding events. This gives the opportunity to analyse flood risk for different areas in the city. For this purpose detailed data collection of the buildings in the 2D area (downtown) was necessary in order to collect the information with which water level water is entering a building (depending on elevation of entrances, windows, etc.). By intersecting this building information with the determined water levels, the flood risk for each building can be determined individually.

The combination of different urban development scenarios (different population projections, different spatial distribution), different climate scenarios, various adaptation measures and different return periods results in a large number (about 100,000) of different simulations. These simulation results are statistically evaluated. In order to make these data directly usable and available to decision-makers and the interested public a Web-GIS environment was created (see figure). The corresponding simulation results are displayed according to the users selection of various parameters (climate emission scenario, urban development scenario, return period, etc.).



Visualisation of the simulation results in a web interface

If adaptation measures for urban drainage systems are planned, it is necessary to regard both, impact of climate change and impact of urban development together. To avoid wrong decisions and consider uncertainties in future development in the planning process, adaptation measures should be planned in a way that they are sufficiently working under a wide range of different scenarios. This is especially necessary due to the long service life of the urban drainage networks.

At the same time required adaptation can also be an opportunity to make the existing systems more sustainable and environmental friendly. Therefor also an integrated planning of the city and its infrastructure is important. Apart from the perspective of urban water management, adaptation through decentralized stormwater treatment (for example, green roofs, green areas for infiltration and rainwater storage in ponds) can also increase human well-being and liveability.

3 Background and Motivation

Urban drainage networks are essential for human and ecosystem well-being. They are characterized by a long design life expectancy of six or more centuries (Tscheikner-Gratl et al. 2014). At the same time these systems are facing manifold and far-reaching challenges. With constantly changing boundary conditions due to population change including demographic changes, growing and shrinking cities (United Nations 2014), changes in behaviour and regulations and also changes in climatic conditions anticipatory planning is important for such infrastructure (Rauch & Kleidorfer 2014). Apart from its main purpose to remove waste water from households, environmental tasks and prevention from urban flooding move into focus (CEN 2008). Urban flooding events as a consequence of heavy rainfall events are cause an increasing number of damages which requires provident planning for the future. Sealing of the surfaces along with a possible increase of rainfall intensities due to climate change, are the key factors accountable for increased flooding in urban areas and additional pressure on existing drainage structures (Semadeni-Davies et al. 2008; Butler et al. 2007; Grum et al. 2006). Apart from a higher flood risk higher runoffs lead to a decrease in storm water treatment performance (Ashley et al. 2005).

To fulfil all these requirements we are using infrastructure which as planned and designed a century ago and since has been extended and modified. To respond early and flexibly to changes in the boundary conditions continuous adaptation of the network is essential to minimize flood risk, negative impacts on the environment and reduce adaptation costs (Kleidorfer et al. 2009; Tscheikner-Gratl et al. 2014). Dynamic adaptation is one possibility to maintain a functional and cost-effective drainage system (Urich & Rauch 2014).

The project 'Dynamic Adaptation of Urban Water Infrastructure for a Sustainable City Development in an Alpine Environment (DynAlp)' focuses on city development and the potential impact of climate change on the adaptation and development of urban water infrastructure and addresses the aspect of pluvial flooding. 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.

The goal in the project is the integration of climate change, urbanization and the assessment of the performance of the sewer network in a strategic planning framework. To address challenges like urban flooding and environmental disturbances the design and construction of urban water infrastructure has to be performed in a predictive way. As upcoming conditions are highly uncertain, the design has to be as flexible as possible.

4 Project Content and Results

The project was organized in 9 work packages (WP) (including WP1 for project management and WP9 for dissemination). The objective of WP 02 – Climate change assessment and WP 03 – Assessment of urban development was to provide precipitation data under future climate conditions and scenarios of city development as input for WP 05 – Performance assessment. Therein hydrodynamic simulations of the drainage network of a case study were conducted to analyse the performance of the system under different future conditions. The required computational framework was developed in WP4. The results are water levels for different return periods and different future conditions (approximately 100.000 simulations). These water levels are intersected with risk levels for individual buildings in an investigation area in WP 06 – Vulnerability and risk assessment. Those risk levels are water levels at which the water begins to cause damages in the buildings. They depend for example on the elevation of entrances or windows. Based on these results in WP 07 – Development and analysis of adaptation strategies different adaptation strategies were tested. Consequently in WP 08 – Visualization a WEB-GIS environment was developed to visualize simulation results for stakeholders.

Impact of Climate Change on precipitation data

Downscaling results from the reference period 1971-2000 were compared to station observations from eight stations in the study area. The time series produced by the statistical downscaling reproduce the characteristics of daily and hourly precipitation measured by the rain gauge stations. The results are satisfying both for mean and extreme precipitation. While the evaluation over the whole year shows similar results from the HadCM3 and the Echam5 driven simulations, the effect of the driving GCM can be seen in the differences between the winter and summer precipitation. The Echam5 driven run is closer to observations especially for winter and mean summer precipitation.
A quantile-quantile plot of hourly precipitation from station observations against simulations is shown in Figure 1. Original hourly values from the RCM simulations are plotted in comparison to the downscaling results. While the quantiles of downscaled hourly precipitation are almost on the shaded line denoting equal distributions, the original hourly precipitation values are below the line for all extreme precipitation sums.
While the quantiles of downscaled precipitation are almost equally distributed as the observed quantiles the original RCM values clearly come from a different distribution with lower extremes. This result is partly due to the characteristic of the RCM values as grid point means in comparison to point values from stations and illustrates the additional effect of the statistical downscaling procedure.

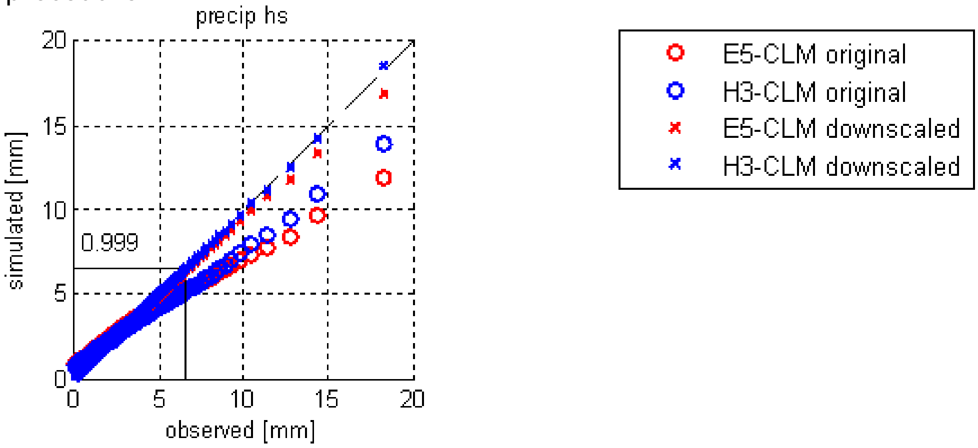


Figure 1: Quantile-quantile plot of hourly precipitation from simulations against station observations in the period 1971-2000. Original hourly values from the Echam5-CLM and HadCM3-CLM simulations are shown (circles) as well as the results after the statistical downscaling (daggers). In addition the 99.9% quantile of observed hourly precipitation is indicated.

Trends of extreme precipitation heights for sub-daily events with durations from 5 min – 1 d were derived based on the downscaled time series. All scenario runs show an increase of the ensemble mean extreme precipitation from the period 1971-2000 to 2021-2050. Changes of the ensemble mean precipitation heights for the return period 5 years are listed in Table 1. Bold letters denote statistically significant changes at the confidence level 95%. Resulting trends for other return periods are similar: within ±3% compared to the values in Table 1
Altogether three of the four model projections indicate a significant future increase of sub-daily extreme precipitation which is relevant to consider for urban hydrology.

Table 1: Relative changes of extreme precipitation sums from 1971-2000 to 2021-2050. The statistical return period is 5 years. Bold letters denote statistically significant changes.

5 year return period	E5-CLM A1B	H3-CLM A1B	E5-CLM B1	E5-CLM A2
15 min	**+ 7 %**	+ 3 %	**+ 19 %**	**+ 18 %**
30 min	**+ 8 %**	+ 4 %	**+ 21 %**	**+ 20 %**
1 h	**+ 8 %**	+ 4 %	**+ 23 %**	**+ 20 %**
3 h	+ 4 %	+ 3 %	**+ 12 %**	**+ 13 %**

Urban Development

In Table 2 the results of the different urban development scenarios are show exemplary for the development years 2030 and 2050. Understandably the changes in effective impervious area increase with an increasing population (A-C), but as can be seen there a significant difference between throughout the spatial scenarios. This can be explained by different causes: varying parcel sizes and building heights. Especially spatial scenario 'east' differs with maximum building heights up to 18 stories from the 'distributed' and 'west', where building sizes reach maximum of 6 to 7 stories. Consequently, this means increased space consumption. An example of a simulated development of a free area within the city can be seen in Figure 2.

Table 2. Scenario definition for the urban development model

Scenario		Population	Change in effective impervious area (ha)	
Population	Spatial	Projection	2030	2050
A	1: distributed	135,000	31.91	49.46
	2: east		21.44	27.93
	3: west		18.93	30.74
B	1: distributed	145,000	46.61	69.35
	2: east		27.83	36.66
	3: west		28.01	44.79
C	1: distributed	165,000	50.5	84.98
	2: east		32.31	44.68
	3: west		36.06	60.13

Starting from the 9 base scenarios (population and spatial) several variations of urban development results have been generated using the model built in Monte Carlo Markov Chain module in addition with infiltration scenarios for newly developed areas.

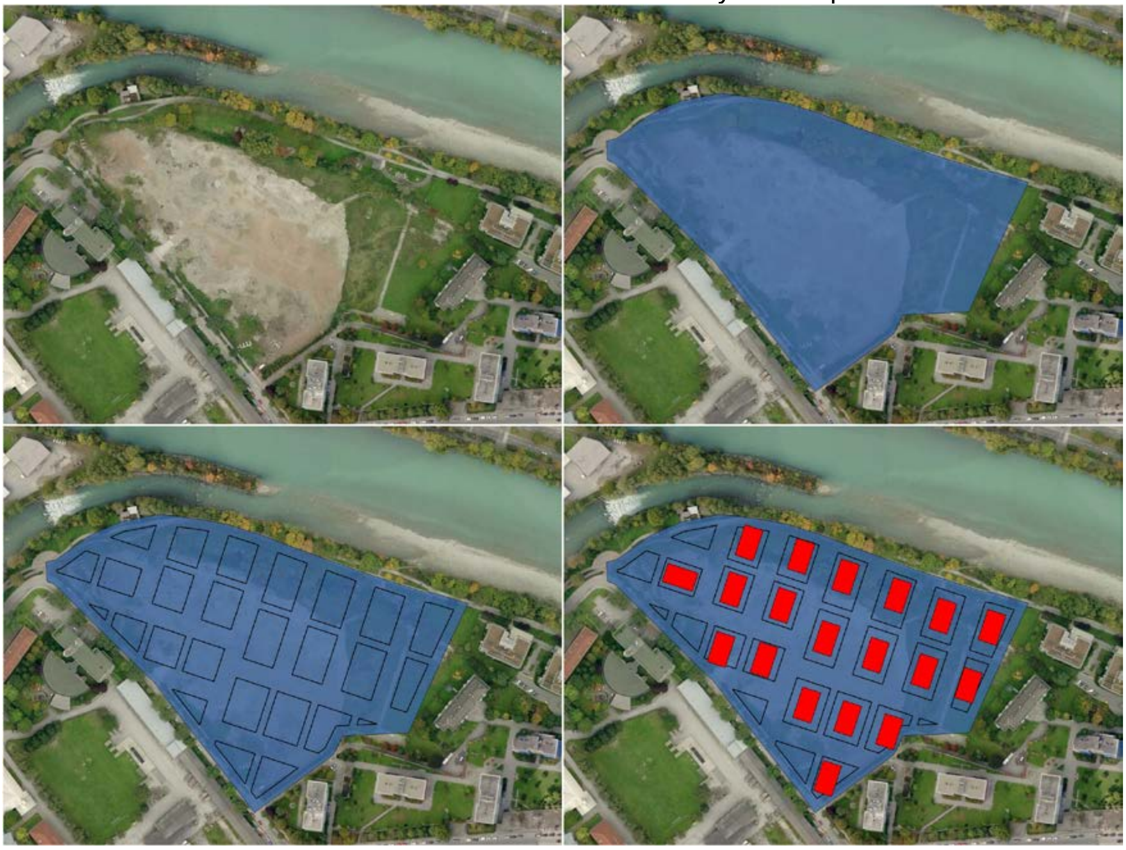


Figure 2. Example for the development of a free area (top left) from selection of the block (top right), parcelling of the block (down left) to the generation of buildings (down right)

Hydrodynamic simulations

In Figure 3 the ration in relation to the base network, base year and without climate change influences have been visualized. On the x-Axis the flooding volume, on the y-Axis the CSO (combined sewer overflow, combined sewer systems are designed to overflow occasionally and discharge excess wastewater directly to nearby streams, rivers, or other water bodies) volume, the colour varies with climate – emission scenario, shape with development year. As can be seen there are significant differences in CSO volume and flooding volume between different climate–emission scenarios and as expected with not as significant differences for the original data without a climate factor, as well as E5-A1B.

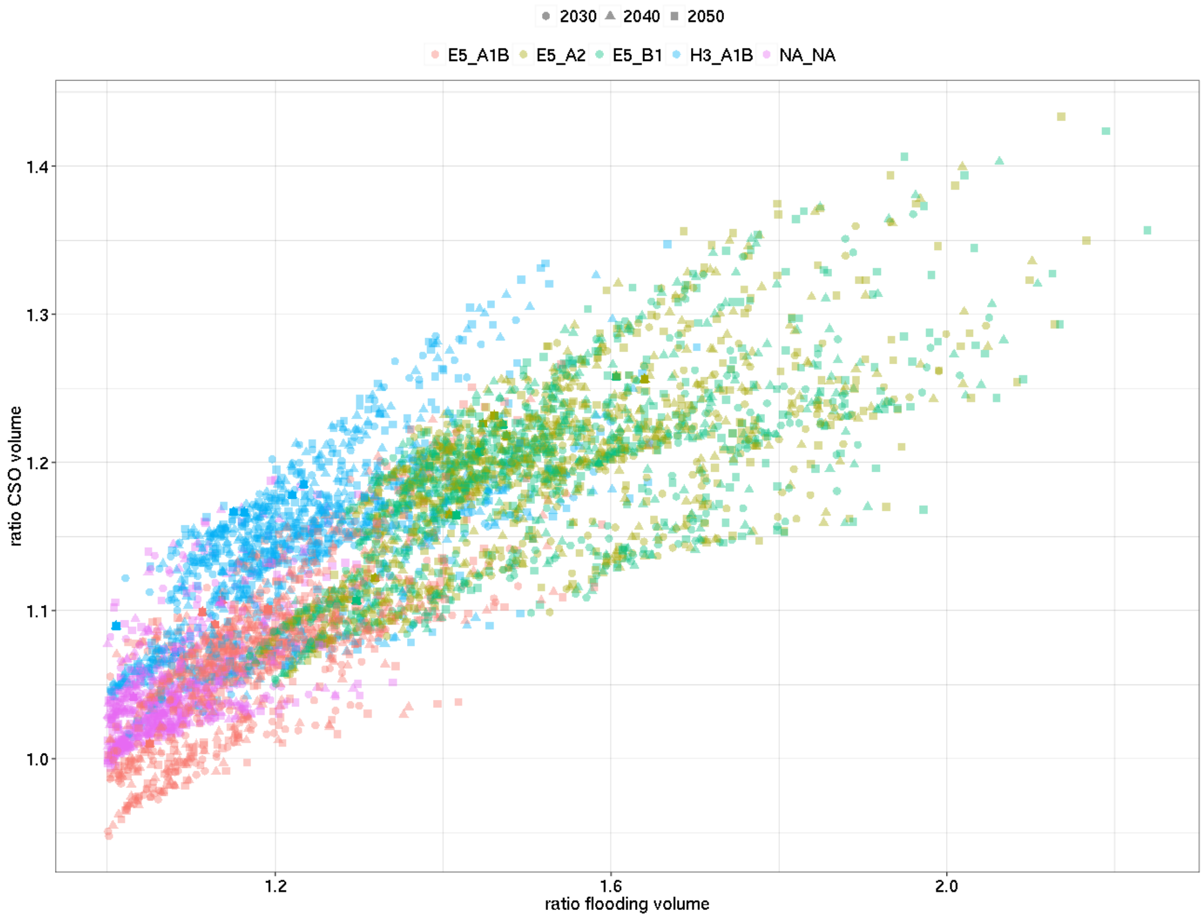


Figure 3. Ratio of flood volume and CSO volume in relation to the base scenario for all simulations

Risk, Visualization and Adaptation

To quantify the collective risk of a scenario a simple and pragmatic approach is introduced. Each object is assigned with a value according to its specific risk: low (yellow), medium (orange), high (red) and very high (violet). The cumulative sum of all specific risk values results in a dimensionless quantity, which allows to compare the flood risks of different scenarios. All buildings were designated with the specific risks according to the risk matrix. An example is shown in Figure 4. As can be seen the 'old' network without influences urban development or climate change shows several buildings flooded (left). The situation worsens if additional areas are connected to the system and an rainfall intensifies (middle).from It can clearly be seen that the adaptation measures of the local operating company (IKB) are sound and can cope with extreme long term trends in the future (right). A screenshot of the Web GIS user interface can be seen in Figure 5. The results of all scenarios computed can be visualized by the user through selection of the parameters shown. Also a statistics about affected and flooded buildings is shown according to the vulnerability.

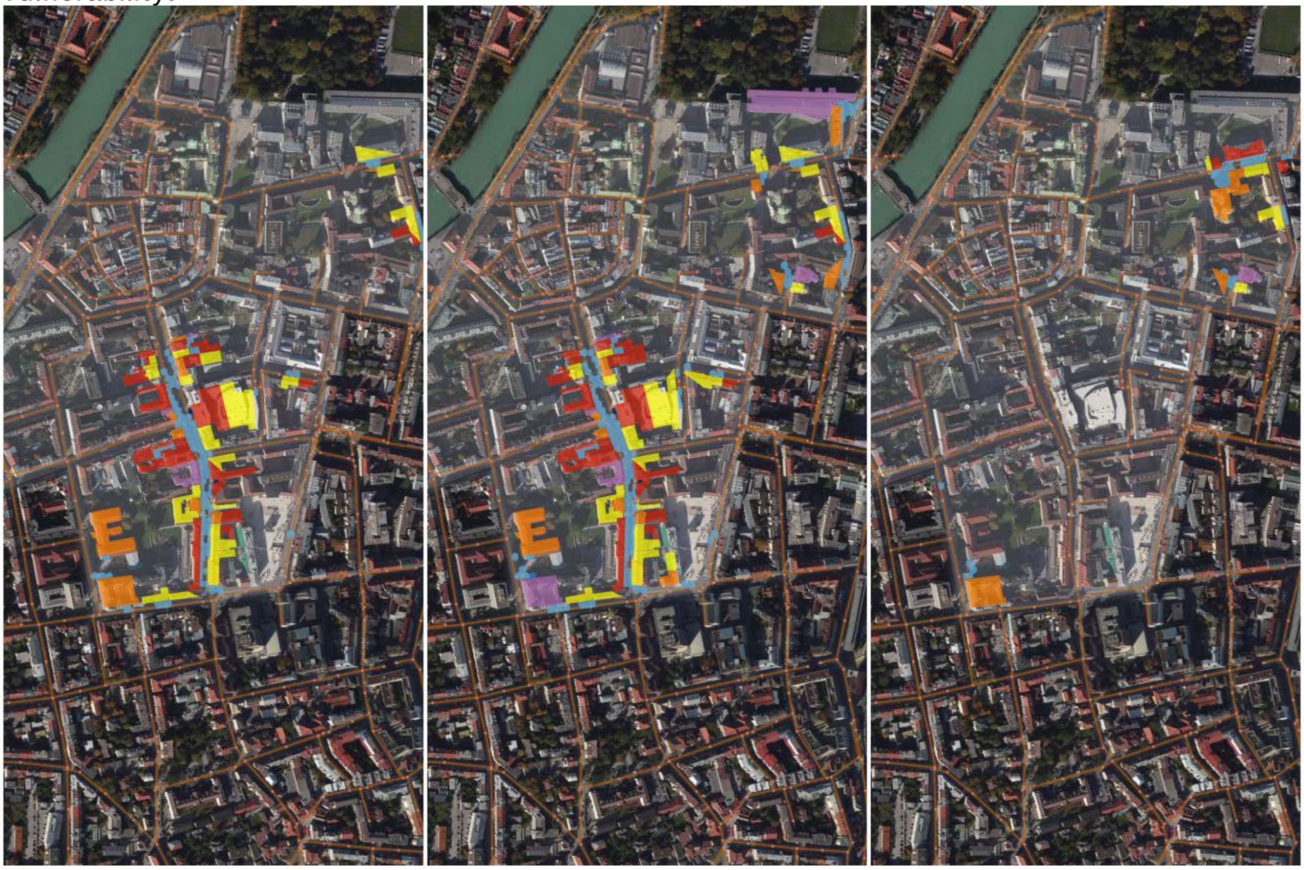


Figure 4. Risk map for buildings for an annuality of 5; left: as-is situation with the 'old' network; middle: UD scenario West with high population increase - year 2050, RCM model HadCAM3, emission scenario A1B using the 'old' network; right: same as middle but with the 'new', adapted, network

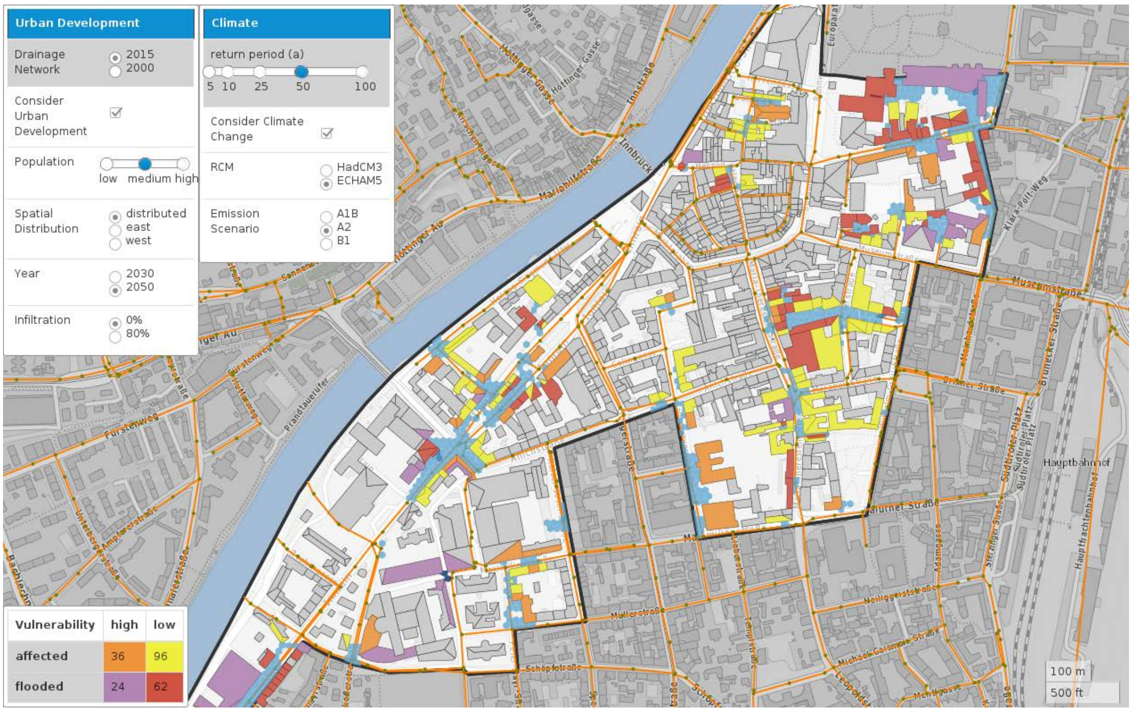


Figure 5. Screenshot of the fully functional Web-GIS applications with all results selectable by the user, including statistics about buildings and a viewer for details about junctions and conduits

5 Conclusions and Recommendations

Climate change analysis

The derived trends result from a superposition of mean climatic trends and regional climate variability. As differences between the greenhouse gas emission scenarios are relatively small compared to regional climate variability until the middle of the 21th century it is no contradiction that the Echam5-CLM run with the lower emission scenario B1 shows higher precipitation trends compared to the projection with the higher emission scenario A1B. In addition to climate variability and scenario uncertainties the derived trends are affected by uncertainties due to potential model deficiencies from the driving global climate model and the regional climate model. We do not expect that the four scenario runs span the full range of uncertainty; however, with the relative small scenario uncertainties for the near future we assume that the results are a good indicator for mean changes which can be expected in the study region until 2050.
The hydrodynamic simulations using distributed rainfall data have shown that for the event of July, 2010 the amount of precipitation is underestimated if using only rain gage data. Depending on the chosen data set (rain gages, INCA, radar) the event presents itself differently. Whilst only using rain gage data it is not possible to detect the whole extend and spatial structure of the event and consequently in a under- or overestimation of the amount of precipitation. Additionally the spatial-temporal rainfall events used not only change the total sums of precipitation on urban fabric, but also changes systems behaviour. If the travel direction of the storm cell and the flow direction of the sewer system coincide, actual runoff in the conduits and new inflow from the surface superpose, consequently resulting in higher peaks and ultimately in water leaving the system other than the predetermined path.

Urban development assessment

The newly developed methodology is suited for the comparison of growth scenarios for cities and urban regions. In general a calibration and validation is necessary, but these costly and time-consuming steps may not reduce or eliminate future uncertainties. To test the robustness of the urban drainage system it is therefore crucial to allow a manifold of sub scenarios to be automatically created. The values from these stochastic variations superpose the simulation parameters of the same head-scenario. Despite all uncertainties the urban development results allow for an analysis of tendencies as without the spatial analysis of population change an ample analysis of weaknesses in the urban drainage network is not possible. Based on this the generation of dozens or even hundreds of possible future developments is possible.

Dynamic Processes

This project proves that a combined and dynamic processing of climate change / distributed rainfall data and the modelling of the urban fabric is crucial for a thorough analysis of the existing sewer system to identify possible flooding nodes even years before the a problem may occur. Especially within the Alpine Case Study provided input parameters for the models are likely to change rapidly over time. As with the framework created within this project the simulation steps are to be repeated easily with changing boundary conditions (both climate change and urban development) this project is kept as dynamic as possible.

Risk and Visualization

The DynAlp approach generates a high-dimensional simulation parameter space. The resulting data sets that cannot be evaluated manually and cannot be communicated to an outside audience without proper processing. An insightful analysis of the dynamic processes and determination of the significant correlations in time and space had to be done and the results must be presented to allow the contents to be viewed showing the full potential of the project. The water depth calculated by the hydrodynamic model is used to classify buildings as affected or flooded. Furthermore, the affected and flooded buildings are distinguished into non-critical and critical (details see Figure 5).
The evaluation of adaptation strategies and its visualization enables the preparation of commented vulnerability and risk maps as a decision support system for planning, adaptation and mitigation strategies. Also the visualization can be used to illustrate the uncertainties arising from modelling future scenarios, to strengthen the attention of the decision makers.
To realize such a visualization system modern and flexible methods and tools must be utilized. All data is managed in geo data bases. The package for the decision support system is based on GIS technics. To visualize the contrast between the big picture of the challenge and the detail problems, a fast switch between different scales must be possible. A fast interactive user interface was created for the visualization of the map based information as well as for the statistical time based plots and results. To ensure easy access for all groups the visualization interface is web based. The access can be granted for all audience or regulated by group or even individual user.

Further Steps

A follow up project of DynAlp will be submitted to the 8th Call of the Austrian Climate Research Program in September 2015. This project will investigate consequences of adaption.
It is necessary to investigate which effects adaptation strategies have and if a 2nd order adaptation is required. The analyses of consequences of adaptation shall investigate both positive and negative effects. Positive effects of decentralized stormwater treatment are for example increased amenity due to positive effects of green infrastructure on the urban micro-climate or improved groundwater balance as on-site infiltration is closer to the natural water cycle. A positive effect of classical technical measures (increase of pipe diameters) is passive rehabilitation of aging water infrastructure which is currently seen as one of the main challenges for the next decades. Negative effects of decentralized stormwater treatment are for example increased complexity of

responsibility, management and maintenance of these systems (they are often built on private ground), unknown service life, consumption of land in usually densely populated expensive areas, etc.
It is important to understand both positive and negative 2nd order consequences to choose the best adaptation measure (or optimal combinations), to evaluate true life-cycle adaptation costs (which can be higher or lower as direct costs), to avoid unexpected follow-up costs and to prepare – if feasible – for adaptation by implementing 2nd order adaptation measures. Such 2nd order measures can be technical but also organizational (e.g., implementation of monitoring and maintenance departments for decentralized systems) or legal (e.g. required adaptation of guidelines or standards).
Furthermore it is important to make sure, that missing 2nd order adaptation or missing knowledge / experience does not contradict the transition to more resilient, sustainable and flexible systems. As people's tolerance for the urban water system to fail is very low and the experience with decentralized systems is limited, today many municipalities' first choice is still the traditional pipe system. Furthermore, there are many ongoing questions in relation to hybrid infrastructure, for example about long-term performance, the institutional structures to guarantee maintenance and inspection or a lack of technical guidelines. Additionally decentralized solutions much more than central systems require the involvement of citizens and community groups (as they are often most effective on private ground or on public land that already had other uses)

A further step is taking the methods developed during the project to another case study in Austria, or even further to countries with even more imminent and greater expected changes both in terms of climate change and urban development.

C) Projektdetails

6 Methodology

Climate Change

Sub-daily extreme precipitation mainly occurs in the summer season as a consequence of strong convection often related to thunderstorms. For urban hydrology heavy rain events with high precipitation intensities and short durations up to one hour are specifically relevant. The atmospheric processes which are involved in the formation of these rain events have too small spatial and temporal scales to be represented by dynamical climate models. Therefore, in order to assess the effects of climate change on sub-daily heavy precipitation regional climate projections cannot directly be used. However, theoretical considerations based on the Clausius-Clapeyron Equation indicate an increase of convective heavy precipitation with rising temperatures. In this project we use a statistical downscaling method to transfer data from regional climate projections on smaller scales and make it usable for analysis of sub-daily heavy precipitation. The statistical downscaling method is based on statistical relations between different scales which are derived from observations.

First step is a data comparison and statistical analysis of observation data in the study region. Based on the results an empirical statistical downscaling method is designed. The resulting method is a combination of the quantile mapping method (Piani et al. 2010) and the analogue method (Zorita & von Storch 1999).

A number of observation datasets have been received and analysed for the study region. The data includes

- Weather station data from three sources (ZAMG, ehyd, IKB) including continuous precipitation measurements from rain gauges with a time step of 5 – 10 min.
- the Alpine precipitation grid dataset EUR04M-APGD by MeteoSuisse (Isotta et al. 2014)
- INCA analysis grid data from 2002-2012 by ZAMG.

Regional climate projections have been produced for Austria within the ACRP project reclip:century by AIT, Wegener Center, Boku and ZAMG (Loibl et al. 2011) The regional climate simulations are calculated on a 10 x 10 km² grid with the model CLM driven by two global climate models (GCMs): Echam5 and HadCM3. The data consists of two 20th century runs and four scenario runs based on the greenhouse-gas emission scenarios: A1B, A2 and B1. A comparison of the reclip:century projections to a greater ensemble of RCMs from the ENSEMBLES project shows that the reclip:century temperature trends are in the mean range of the ensemble, partly covering the ensemble spread (Loibl et al. 2011). In this project we use the reference period 1971-2000 and the future period 2021-2050 from the reclip:century runs to evaluate climatic trends in the study region. The precipitation regime in Innsbruck and the surrounding area is substantially determined by the Alpine topography and the flow direction. Yearly precipitation sums in the close vicinity of Innsbruck (Patscherkofel and Birkkarspitze) are significantly higher than yearly precipitation sums in the city area (Figure 7).

When comparing the mean yearly precipitation sum from the INCA reanalysis data on a 1 x 1 km² grid compared to the EUR04M-APGD precipitation data on a 5 x 5 km² grid (Figure 8) the effect of the spatial resolution is distinct. While the structures of the main valleys are still clearly visible a number of smaller valleys and structures cannot be detected on the larger grid. On the 10 x 10 km² grid of the reclip:century simulations this effect is even more pronounced and e.g. the different precipitation regimes in Innsbruck and on the Patscherkofel and Birkkarspitze cannot be resolved.

An extreme value analysis of the precipitation time-series from eight rain gauge stations in the study region was done according to DWA (2012). The data periods from the different stations are not identical: for each station the longest available measurement period between 1971 and 2012 is used, at least 15 years. Results are displayed in Figure 9 for the return period 5 years.

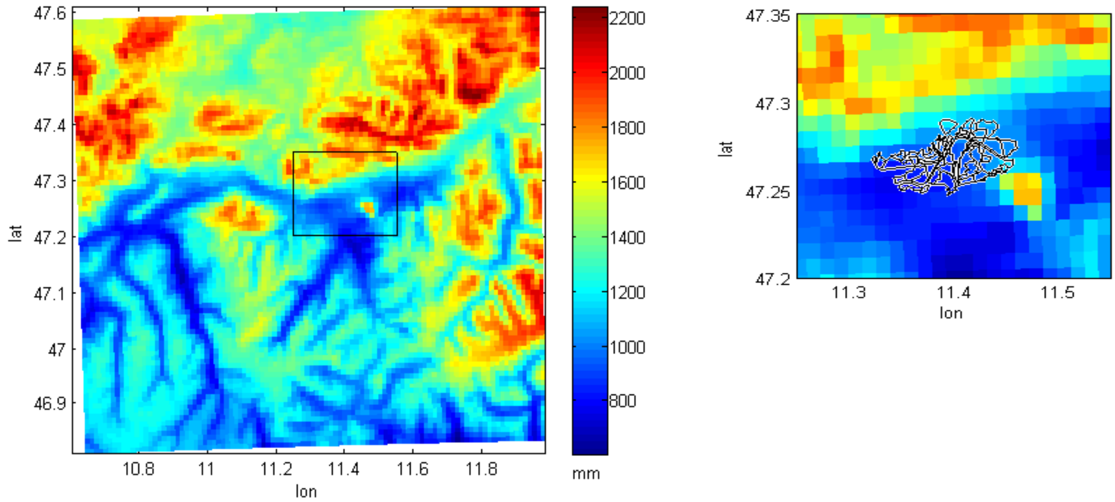


Figure 6: Mean yearly precipitation sum from the INCA reanalysis data in the period 2003-2008 of the study region (left) and the section of Innsbruck city (right). The grid resolution is 1 x 1 km².

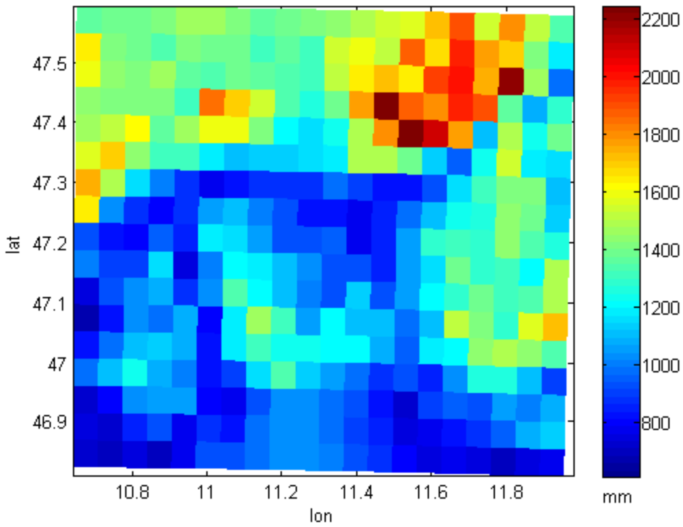


Figure 7: Mean yearly precipitation sum from EUR04M-APGD in the period 2003-2008, grid resolution is 5 x 5 km².

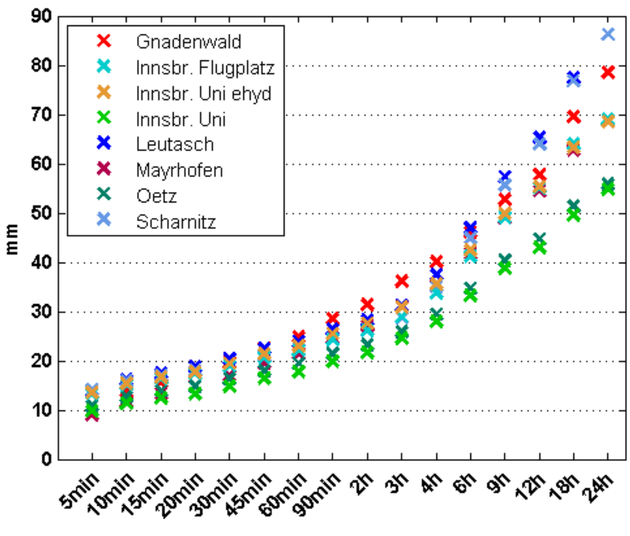


Figure 8: Statistical extreme precipitation of station observations in the study region for durations from 5 min to 24 h, return period 5 years. Time periods are the longest available measurement periods for each station – at least 15 years – between 1971 and 2012.

For the development of an appropriate statistical downscaling procedure the special requirements of urban hydrology of the case-study Innsbruck were considered. Urban water systems are in particular sensitive to extreme and flash-flood events. So the focus was on adequately representing sub-daily extreme precipitation. An overview of the downscaling procedure is given in Figure 10.

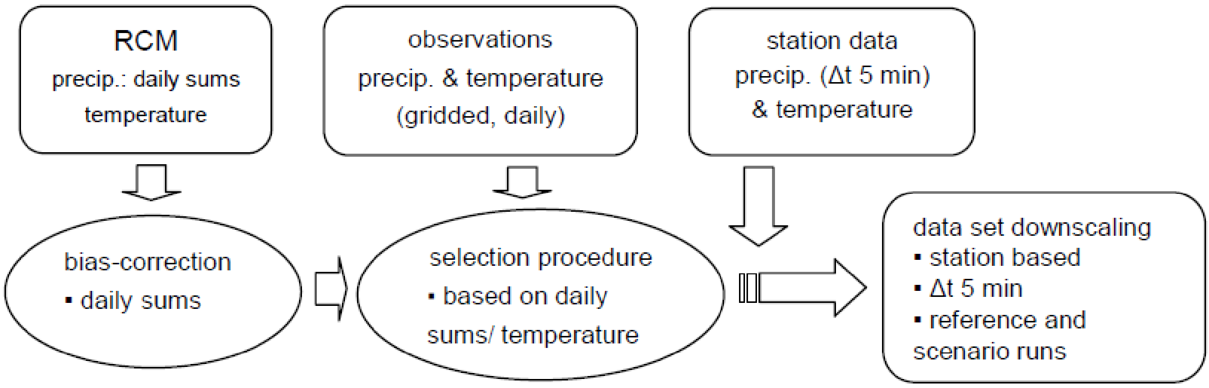
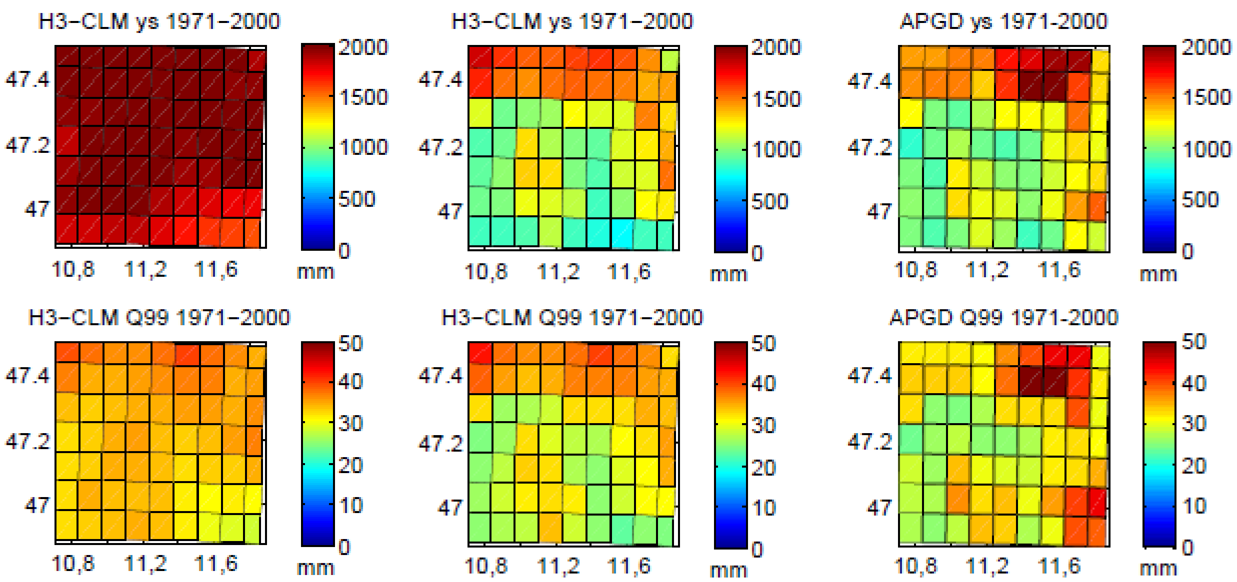


Figure 9: Downscaling procedure overview

Data from regional climate models often show systematic differences in comparison to observations. A systematic and time-independent model error is called bias. The results show a bias in the simulated daily precipitation from both Echam5-CLM and HadCM3-CLM. Therefore as a first step, a two-dimensional bias correction of model daily precipitation and temperature was carried out using gridded data of precipitation (EUR04M-APGD, upscaled to the model grid) and daily mean temperatures from weather stations. The bias-correction was done based on the quantile mapping method (Piani et al. 2010) with the difference of using empirical CDFs from both observations and model data (Themeßl et al. 2012).
Figure 11 shows the spatial effect of the bias-correction on yearly mean precipitation and the 99% quantile of daily precipitation in the study area. The original model precipitation from HadCM3-CLM and Echam5-CLM (left column) shows almost no spatial structures both for mean precipitation and the 99% quantile. The bias-corrected precipitation (middle) shows the basic precipitation patterns within the region. Observations from EUR04M-APGD (right column) have the most detailed spatial structures.



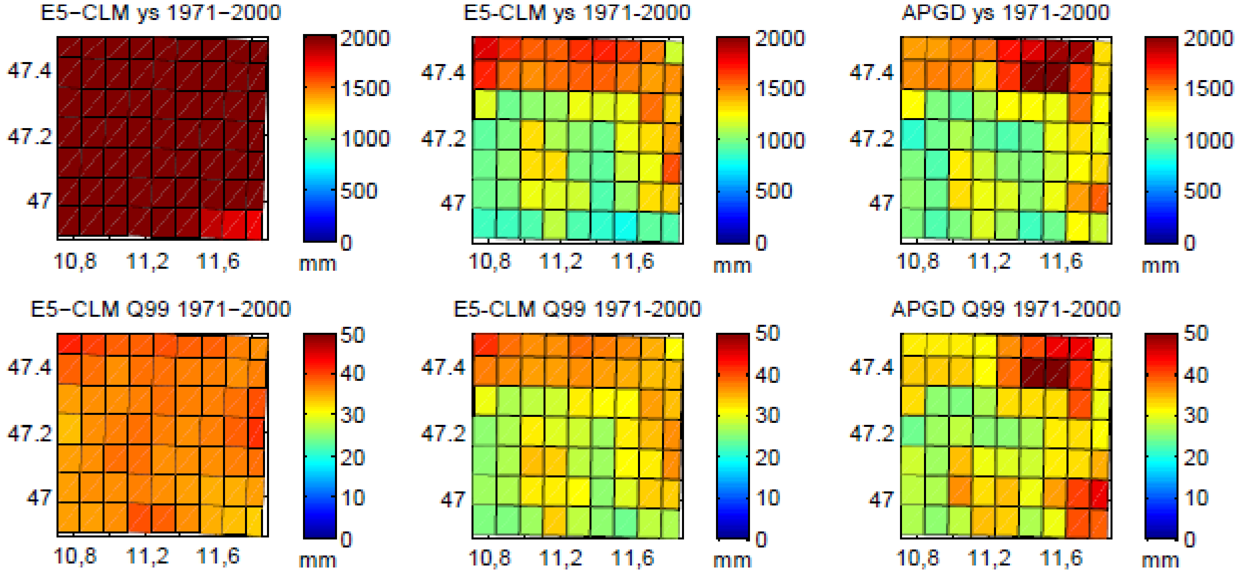


Figure 10: Precipitation in the study region from the original simulations HadCM3-CLM and Echam5-CLM (left), the bias-corrected model precipitation (middle) and EUR04M-APGD observations (right). Displayed are the mean yearly sum (years) from 1971-2000 and the 99% quantile of daily values (Q99) from 1971-2000.

In the next step a statistical downscaling procedure was conducted. The aim of statistical downscaling is to produce temporally and spatially higher resolved values compared to the original model resolution. For this purpose statistical relations between different scales are used which are derived from observations. Here we use an empirical statistical downscaling method based on the analogue method (Zorita & von Storch 1999).
The rain gauge measurements from the selected day are used to build the new downscaled precipitation time series. Hence the new time series is constructed from daily sections of station data and takes over the temporal resolution (5 min) and spatial resolution (point scale) of the measurements. Temporal relations of the new time series are consistent during one day but not over several days. As we are mainly interested in precipitation events shorter than 3 hours we assume that the effect of the daily sections on the temporal relation is negligible.
In order to enlarge the database and find a sufficient number of similar days also for precipitation extremes, station data was not only taken from the three Innsbruck rain gauge stations but also from five stations in the surrounding area. In consequence the resulting time series cannot be interpreted as a local result for Innsbruck but as data from a hypothetic rain gauge which is located somewhere within the study region.
To account for the random effect in the selection procedure downscaling ensembles are produced based on the RCM time-series of 21 grid points in the study region for each projection of the RCM. The resulting ensemble is used to calculate the regional average values of extreme precipitation and precipitation trends.

Urban Development

Several urban development simulation frameworks exist but often don't allow for easy integration of successive models or are simply too costly to be run by small communities or infrastructure planning offices (Wegener, 2004). The level of detail of the obtained results from such models is usually not required or of little benefit in the context of urban water management. Others may be simplistic and give the possibility for succeeding models, but do not offer the automatic generation of a street layout in newly developed areas.
Conventional planning and management practices undergo a paradigm shift towards approaches which integrated and coupled with urban development including the assessment of social changes

(Hans de Haan & Rotmans 2011; Bach et al. 2013). Deterministic planning guidelines and practices are fixed to a narrow band of scenarios being considered. But especially in times of rapid and certain changes a shift towards more flexible designs and the analysis of multiple options is imminent (Zhang & Babovic 2012). By estimating population growth and taking into account spatial conditions it is possible to take all urban development possibilities into account generating several scenarios within the given boundaries.

Connecting the newly developed areas to the drainage system leads to higher surface runoff and consequently higher runoff peaks in the network. The runoff peaks might lead to a higher risk in flooding and additionally to a decrease in storm water treatment, meaning the release of untreated contaminants to the receiving water (Semadeni-Davies et al. 2008; Astaraie-Imani et al. 2012). Especially runoffs from paved roads or roofs are rich in heavy metals which enter and accumulate in the environment and potentially leads to a violation of regulations (Kleidorfer & Rauch 2011). Furthermore issues with water quality as a consequence of city growth might occur (Roesner 1999).

The urban development model uses the DynaMind Framework as a basis to run the dynamic modelling cycle (Mikovits et al. 2014) and illustrated in Figure 12. The model itself is designed to run with minimal data needs which are presented in Table 3. CITY represents the city centre with appended population information, GRAVITY are attraction points which are used to calculate the priority of development, SUPERBLOCK the parishes of the city, CITYBLOCK subdivisions of a parish (street network. After the data input the development cycle is started, creating parcels, buildings and distributing population on the basis of ‘gravity nodes’ (Mikovits et al. 2015).

Table 3. Input data needs for the DynAlp-urbandevel model. M stands for mandatory, O means optional

	View	Shape Type	Attributes				
			Development Year	Area Type	Inhabitants	Height	Mass
mandatory	CITY	Point			M		
	GRAVITY	Point					M
	SUPERBLOCK	Polygon	O	O		O	
optional	CITYBLOCK	Polygon					
	BUILDING	Polygon			M	M	

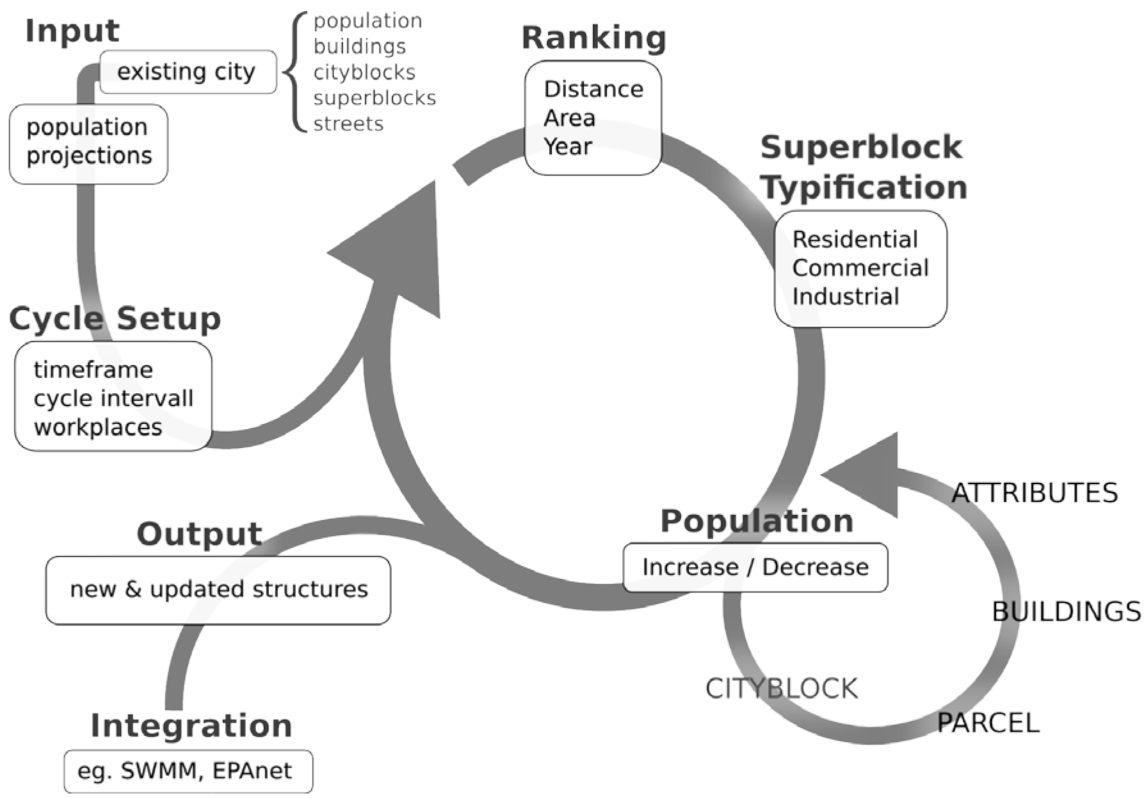


Figure 11. Dynamic Urban Development Cycle

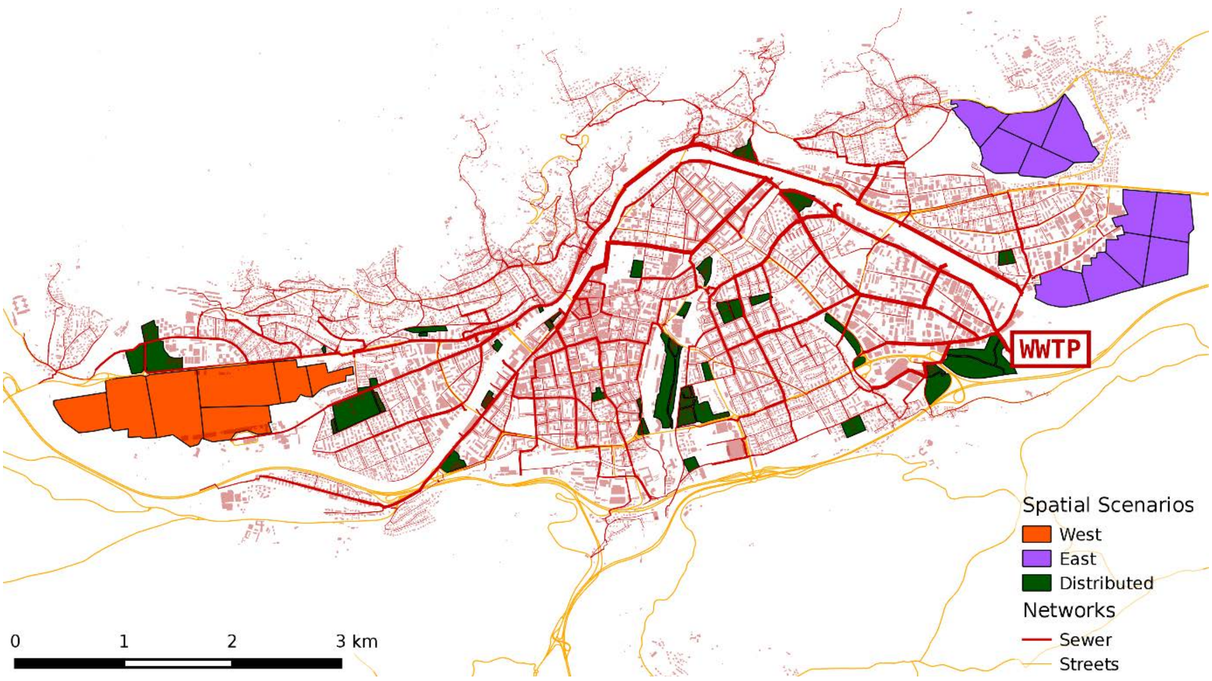


Figure 12. Development Scenarios for the city of Innsbruck

It has been shown that calibration of land use - and urban development models is only partially possible and also a portability of calibration practices is difficult (Silva & Clarke 2002; Akin et al. 2014). As urban growth or decline is subject to many influences (economic situation, immigration, emigration, etc.), a reliable prediction is hardly possible. Especially when we are looking into a small spatial scale, subjective decisions of urban planners and city stakeholders highly influence the future urban fabric. While reproduction of past urban change is possible, reliable and exact

future predictions are highly improbable. Therefor a scenario analysis of urban development is the best way to cope with uncertainties of future situations.
Three different population growth scenarios (increase to 135,000, 145,000 and 165.000 inhabitants respectively) were chosen (see Figure 13) in combination with three different spatial development scenarios as can be seen in Table 4 (Hanika 2010). This results in a total of six scenarios tested. As the table shows, scenario A resembles the projected population increase whereas scenario B doubles the increase of 10,000 to 20,000. Scenario 1: distributed uses small, discontinuous available areas throughout the city. Scenario 2: east focuses on large areas in the east of the city north of the river. Scenario 3: west concentrates on the area of the airport which is simply removed and its space used for development.

Table 4. Scenario definition for the urban development model

Scenario		Population Projection	Spatial Description
Population	Spatial		
A	1: distributed 2: east 3: west	135,000	Fractions throughout the city the north eastern rims of the city at the area of the ‘former’ airport
B	1: distributed 2: east 3: west	145,000	Fractions throughout the city the north eastern rims of the city at the area of the ‘former’ airport
C	1: distributed 2: east 3: west	165,000	Fractions throughout the city the north eastern rims of the city at the area of the ‘former’ airport

Hydrodynamic Simulations

The simulation framework DynaMind (Urich et al. 2012), a scientific workflow engine with focus on dynamics, is used to read input data from external modules (WP 2) or used to implement the module itself (WP 3). In the case of urban development the implementation within the framework has been accomplished. Simulation components within the framework have been adapted and/or written by scratch to fulfil the needs for this project. For simulation and the performance analysis subsequent scripts written in Python or R have been programmed.
To assess the performance of the sewer system the data provided by the previous work packages was used in a hydrodynamic model of the drainage network of the city of Innsbruck. To further be able to assess possible adaptation measures three version of the model have been used. One originating from 2005 (Möderl 2009), a second an extended version of this model, the other one generated during this project with data provided by the local operating company (IKB). This give the possibility to analyse the effects of roughly 10 years of network change and adaptation. Especially the comparison of the old and new network under the influence of possible future conditions can give an interesting insight on adaptation measures.
The performance of the system is assessed by means of ponded (flooding) volume leaving the system and CSO discharge. These overall performance indicators were chosen because they can be used the express system-wide performance. In addition to the purely 1D model of the sewer network a 1D-2D model of the inner city has been created. The purpose of such a model is to get detailed information about flooding events in urban areas. Not only in terms of volume leaving the sewer system, but information about flood paths and depth and is necessary to assess the risk of flooding for buildings and other structures. At the same time this increases the difficulty in creating the model and computational time (Leandro et al. 2009).
In total about 100.000 hydrodynamic simulations have been processed. The configuration of the variations can be examined in Table 5. Apart from the listed variations, numerous simulations outside the standard scheme have been done, e.g. with long term rainfall files and parking lots used as retention volumes.

Table 5. Combinations in climate and urban development used for the hydrodynamic simulations

	Number	Description
1D / 2D	2	1D and 2D simulations
Network	3	Original, Extended, New
Population	3	Low, medium, high
Spatial	3	Distributed, East, West
Year	5	Base year, 2020, 2030, 2040, 2050
Infiltration	3	0%, 40%, 80%
Variant	3	MCMC variations
Climate & Emission	5	Past, E5-A1B, E5-A2, E5-B1, H3-A1B
Annuality	8	3, 5, 10, 20, 25, 33, 50, 100
Total Variations	97200	

Risk, Visualization and Adaptation

Potential urban flooding risk hot-spots were identified in the city centre. Those include the area of the hospital, several University buildings and the historic centre of Innsbruck. Hence a detail study area was delineated, which encloses the above mentioned hot-spots (Figure 5). Those hot-spots were chosen as there is either a high vulnerability level (hospital) or a high hazard level (historic centre). Passageways through buildings were located and verified on site using OSM data in combination with surveys. The widths of the passages were estimated and subsequently implemented in the building shape file by cutting the respective polygons. In order to assure applicability in the whole municipality of Innsbruck the procedure to analyse vulnerability must be widely standardized. Hence all buildings were classified into 27 different object classes depending on their predominant function. In respect to vulnerability it was distinguished between four different (qualitative) classes, i.e. low, medium, high and very high (Table 6).

Table 6. Vulnerability matrix for all 27 object classes (1: low, 2: medium, 3: high, 4: very high)

object class	**vulnerability**			
	0-25cm	>25-50cm	>50-100cm	>100cm
accommodation	1	2	3	4
administration	1	2	3	4
airport	2	3	4	4
bank and insurance	1	2	3	4
care home and facility	2	3	4	4
child care	3	3	4	4
cultural institution	2	2	3	4
doctor	2	3	3	4
emergency response organization	2	3	4	4
event and exhibition building	1	2	3	4
fire brigade	1	2	3	4
gastronomy	1	2	3	4
hospital	2	3	4	4
housing	1	2	3	4
industry	2	3	3	4
museum	2	3	4	4
other	1	2	3	4
pharmacy	2	3	4	4
religious facility	1	2	3	4
research/university	1	2	3	4
retail and wholesale	2	3	3	4
school	1	2	3	4

sensible electrical infrastructure	3	3	4	4
service	1	2	3	4
service station	2	3	3	4
sports and recreational facility	1	2	3	4
train station	2	3	4	4

The specific risk of an object is obtained by combining the levels of hazard and vulnerability. In analogy to hazard matrices, risk matrices are also widespread tools in risk analysis. The development of a risk matrix was a major task within this work package (Figure 14).

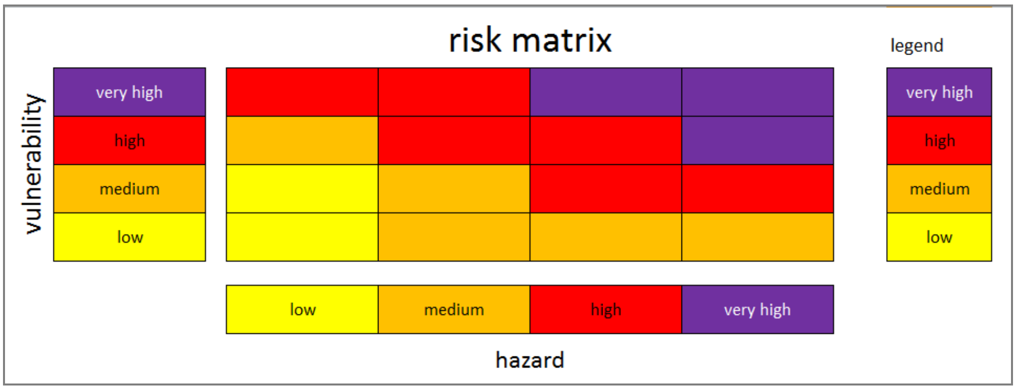


Figure 13: Risk matrix

The stock of elements consists of the assets in the study area. In the present study this refers to the urban fabric, the buildings of Innsbruck. No monetary values are considered in the study. Thus, the damage potential assessed is of semi-quantitative nature, depending on the main function of an object. Further, the stock of elements is spatially combined with the hazard map. Hence, the objects affected by a specific event can be identified as the element at risk and visualized.

The next step is to link the spatially distributed inundation depths to the vulnerability of the individual buildings exposed to the hazard. According to the vulnerability matrix one vulnerability class is assigned to each building for a specific scenario depending on the maximal inundation depth contacting the building. Is the maximal inundation depth lower than the critical z-value the respective building is not sustaining damage and thus, not considered any further. The result is a spatial distribution of vulnerability and can be depicted in a vulnerability map. Within this project a natural-scientific approach with respect to risk analysis was conducted (Huttenlau & Stötter 2011). Thereby risk is understood as a function of hazard, elements at risk and vulnerability and reflects the expected negative consequences induced by a hazard.

Due to the detailed iterative model process, a huge amount of complex cross-linked data has been created. It produces several million resulting data sets that cannot be evaluated manually by the project members and even more cannot be comprehended by outside audience. Thus profound analysis of the dynamic processes and determination of the significant correlations in time and space must be done and the results must be presented in a perspicuous way to obtain the full potential of the project. To order, organize and display the results in a valuable form a state of–the-art GIS based visualization with advanced statistical processing was developed. It is capable to create suitable interactive result maps and images that any audience can use (e.g. decision makers, scientists, technicians or for public use). In order to raise awareness, preparedness and to build up preventive adaptation and coping capacities, the visualization system supports target group oriented presentation of risk potentials.

To realize such a visualization system modern and flexible methods and tools must be utilized. All data is managed in geo data bases. The package for the decision support system is based on GIS technics. To visualize the contrast between the big picture of the challenge and the detail problems, a fast switch between different scales must be possible. A fast interactive user interface was created for the visualization of the map based information as well as for the statistical time

based plots and results. To ensure easy access for all groups the visualization interface is web based. The access can be granted for all audience or regulated by group or even individual user.
Due to the mainly spatial nature of the task the literature study and the following evaluation motivated a GIS based system as the most suitable solution. The evaluation also has shown that the Web Map Service (WMS) and corresponding services of the Open Geospatial Consortium (OGC) with a PostGIS/Geoserver data base are the most suitable technic for a scenario based spatial and temporal representation of the expected results in favour of a desktop GIS based solution. On client side a highly flexible Leaflet based visualization interface was build. To obtain fully interactive 2D plots Dygraph library was utilized.
All visualization methods have been adapted for urban infrastructure. All map results are created as GIS layers to be presented in Leaflet inside the user's web browser. To generate a seamless integration of 2D map data and time variant data curves, all maps are interactive, all visible model nodes can be selected and the time behaviour can be displayed. As in the map display all time line plots are scalable in two dimensions again to allow the comparison between the whole picture and the details.

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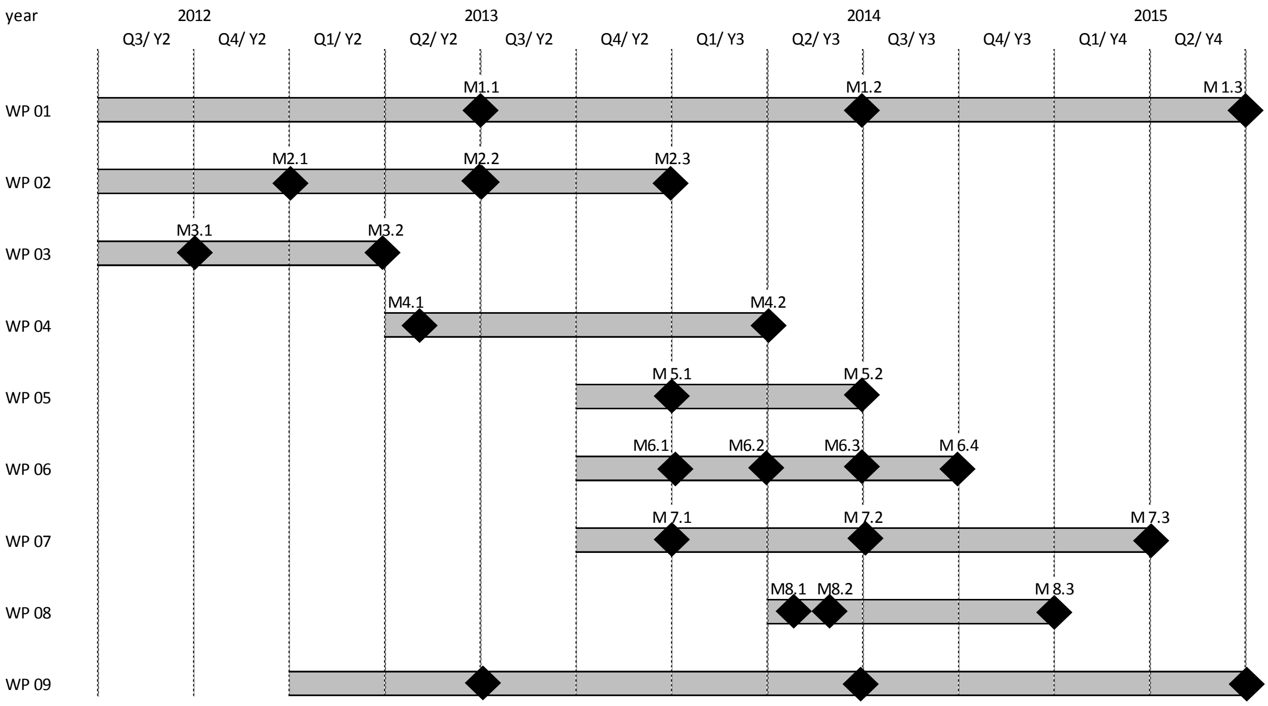
7 Work- and Time schedule



WP 01: Administration
WP 02: Climate change assessment
WP 03: Assessment of urban development
WP 04: Development of computational framework
WP 05: Performance assessment
WP 06: Vulnerability and Risk assessment
WP 07: Development and analysis of adaptation strategies
WP 08: Visualisation
WP 09: Dissemination

8 Publication and Dissemination

Scheduled Publications

Christian Mikovits, Wolfgang Rauch, Manfred Kleidorfer. Importance of scenario analysis in urban development for urban water infrastructure planning and management. In: *Environment and Planning B: Planning and Design*, ***Under Review***

Manfred Kleidorfer, Christian Mikovits, Alrun Jasper-Tönnies, Matthias Huttenlau, Thomas Einfalt, Martin Schöpf, Heiko Kinzel, Wolfgang Rauch Impact of climate change on performance of combined sewer systems. In: Environmental Modelling and Software, ***In Preparation***

Journal

Christian Mikovits, Alrun Jasper-Tönnies, Thomas Einfalt, Matthias Huttenlau, Wolfgang Rauch, Manfred Kleidorfer. Klimawandel, Stadtentwicklung und urbane Wasserinfrastrukturplanung - Risiken und Möglichkeiten. In: Österreichische Wasser- und Abfallwirtschaft. Springer; 2015 http://dx.doi.org/10.1007/s00506-015-0233-z

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