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Considering the Impact of Future Climate Change on the Resilience of a City – Surface Run-Off due to Heavy Storm Events in the City of Wuppertal

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1 ABSTRACT

Environmental events are a big concern when looking at the safety and resilience of a city. This is even more true if climate change scenarios, and thus changed environmental conditions, are taken into account. Within the European FP7 Research Project SUDPLAN (Sustainable Urban Development Planner for Climate Change Adaptation) a Scenario Management System (SMS) is under development. The SMS combines large scale climate change models, downscaled model results and local high resolution simulations with interactive 3-D/4-D visualisations to facilitate the analysis of future climate change effects on city-scale environments.

The system will be applied by four european pilot cities which are part of the consortium: Stockholm, Linz, Prague, and Wuppertal. The project adresses the environmental topics air quality (e.g. temperature, emissions, etc.) and rainfall. In the case of rainfall, major concerns are combined sewage overflow (CSO) and surface run-off due to heavy rainfall events.

Due to the geographical situation of the german city of Wuppertal located in the steep, narrow, long valley of the Wupper river, the main concern regarding climate change impact is uncontrollable, extremely localized run-off from increased heavy, short rainfall events. The potential damage of public infrastructure and of private property is a major concern to the city managers. The potential needs for investments are huge, considering that the city copes with run-off from 350 kilometers of creeks (over 800 creek sections) and 650 kilometers of drainage channel system. To enhance the public awareness for investments due to future risks related to a changed climate, means to transport complex domain specific results into a clear and easy to understand "language" are needed.

In this paper we present the current results of the SUDPLAN project concerning the Wuppertal pilot. We will describe the workflow from the large scale climate model to the 3D/4D visualisation of local high resolution simulation results. We focus on the intuitive and easy to understand presentation of the effects on the resilience and safety of critical public and private infrastructures.

We combine widely used GIS features with highly interactive 3D/4D visualisation in order to provide insight into possible future problems caused by heavy rainfall events. This can be used for the analysis and comparison of simulation results from different climate and planning scenarios by domain experts (i.e. climate modellers) as well as endusers (i.e. urban planners). Moreover, the presented results are also suitable to illustrate and convey the necessity of investments even for non-experts (e.g. city administration, property owners, etc.).

2 INTRODUCTION

Environmental Information and Decision Support Systems (EDSS) are complex information systems containing complex information and performing complex workflows, that may not even be pre-defined (ad-hoc workflows). In general, these systems are composed of a number of highly heterogeneous components and tools solving a complex monitoring, analysis or decision support task. The component structure of such systems cannot really be generalized or even properly defined, because real world applications vary considerably depending on the concrete use of a concrete system. However, certain common elements are present in many systems [1,2] data management and data network components, geomatics components, decision support components, numerical simulation models and others. Even at the level of a single, stand-alone system for one single purpose, integration of data, models, visualization, analysis tools and decision support tools is often a very difficult and costly undertaking. Today's EDSS are very often hard wired ('all-in one systems'), which is not astonishing, as the complexity covered by EDSS is enormous. EDSS have to deal with complex space and time related data and its representation, furthermore they are asked to transfer a multitude of data into easy to understand visualization representation having complex algorithms in the back end – all this before the actual decision support begins.

Due to the lack of standards for data interchange hard-wiring the tools and the data in one monolithic application is still a common practice. This practice makes EDSS expensive and inflexible and this is one of the main reasons why there are not more decision support systems in real use.

In recent years an important trend in environmental informatics has been research and development on environmental information service infrastructures (in the case of geomatics components also called Spatial Data Infrastructures, SDI). The main driver for this research has been the practical need to overcome organizational boundaries in environmental management and to enable linking systems together which are operated by different organizations. In Europe, for instance, the INSPIRE Directive [3] set the goal in 2007 to establish an Infrastructure for Spatial Information in the European Union. The directive obliges member states to make available relevant geographic information for the purpose of formulation, implementation, monitoring and evaluation of Community environmental policymaking and for the citizen. Furthermore, by establishing from the onset cross-sector co-ordination mechanisms, INSPIRE aims at providing access to compatible information across sectors such as environment, transport and agriculture. INSPIRE has become a major driver for research in the area of environmental service infrastructures. This driver has triggered research in FP6 Integrated Projects OASIS [4], ORCHESTRA [5], SANY [6], OSIRIS [7] and other to achieve the overall goal of interoperability.

Projects funded through other programs contribute to the same goal, for instance SSE [8]. This research has reached a stage where generalized concepts are available, generalized architectures have been published, service specifications have been defined and service implementations become more and more available, in some cases as open source products. At the same time, the use of established industry standards, most notably those of the Open Geospatial Consortium [9], OASIS [10] and the W3C [11], has become a dominant requirement in order to achieve inter-operability amongst systems and stakeholders. More and more customers require systems which they order to comply with these standards, and at the same time the standards evolution also drives some of the technological changes, along with the ongoing research mentioned in the previous paragraphs. A common trend of both research and standards evolution is to compose systems in a loosely-coupled way through a service-oriented architecture (SOA).

These recent developments have dramatically changed the opportunities for EDSS development. The practice of monolithic systems, which integrate data and functionality into one system, built for this purpose only, will be replaced by flexible environments which make use of external resources (data, information and services), and which provide a framework for flexible delivery of functionality to end users. This means that the “software plumbing” (individual integration projects) for each individual EDSS will cease to exist. The vision of next generation EDSS is that of a dynamic composition of services in a SOA.

The dimensioning of urban infrastructure is typically based on a statistical calculation of historical time series data, e.g. to quantify the maximum river runoff during a 100 year period, the most intense rainfall occurring within a similar period or the risk for a combined air pollution and heat wave. The temperature increase, changes in precipitation and air pollution levels – both expressed as yearly totals and as extreme values – and storm frequencies expected to occur during the coming decades will invalidate those historical time series analysis and call for new statistical assessments based on forecasted weather scenarios up to and beyond 2050 [12,13]. There is a need for planning tools which will make it possible for city planners to include such analysis in a simple, early and cost-effective manner. In order to make these EDSS solutions affordable, data integration, integration of models as well as integration of other services must be possible at low cost, in an optimal case in an “on-the-fly” manner. Sustainable cities also require an integrated planning approach. They need to assess some of most important environmental factors in an early stage, in particular for applications like:

- coping with the risk for river flooding and inundations of built-up areas and other developed areas
- maximum rain intensity to be expected over sealed surfaces and for which water runoff systems must be dimensioned
- spatial distribution of air pollution, risk for extreme events and high ambient temperatures in built-up residential and work areas

The sustainability must be assured both during present and for expected future climate scenarios, as simulated by regional climate models (RCM's). Therefore the integration of RCM's into local decisions, and the integration of RCM's with local models, is a crucial factor.

2.1 The SUDPLAN Project

The SUDPLAN project aims at developing an easy-to-use web-based planning, prediction, decision support and training tool, for the use in an urban context, based on a what-if scenario execution environment, which will help to assure population's health, comfort, safety and life quality as well as sustainability of investments in utilities and infrastructures within a changing climate.

This tool is based on an innovative and visionary capacity to link, in an ad-hoc fashion, existing environmental simulation models, information and sensor infrastructures, spatial data infrastructures and climatic scenario information in a service-oriented approach, as part of the Single Information Space in Europe for the Environment (SISE). It will provide end users with 3D modeling and simulation as well as cutting edge highly interactive 3D/4D visualization, including visualisation on real 3D hardware.

The tool includes the SUDPLAN Scenario Management System with three so-called Common Services. The latter will allow downscaling of regional climate change model results to a spatial and temporal scale useful for urban planning in whatever European city. SUDPLAN Common Services include gridded information on present and future extreme rainfall, temperature, river runoff and air pollution.

Vital consequences of climate change are considered in 4 carefully selected urban pilot applications located in Austria, the Czech Republic, Germany and Sweden. The SUDPLAN Scenario Management System with Common Services information will here be used to execute and visualize results from local high resolution models and sensor systems, covering such diverse applications as: a) extreme rainfall episodes causing problems with b) uncontrollable, extremely localized runoff, and c) drainage and sewage systems, d) hazardous air pollution and high ambient temperature episodes causing health risks, e) social dynamics (movement of people) as function of climate change and quality of living.

More information about the SUDPLAN project (including demo applications) can be found on the project website http://www.sudplan.eu.

2.2 Wuppertal Pilot

The city of Wuppertal is located in the steep, narrow, long valley of the Wupper River. The location is so narrow that more than a hundred years ago, the city went in the 3rd dimension for public transport, and built the famous Wuppertal Suspension Line (Figure 1).

Figure 1: Because of the narroness (left) the city of Wuppertal decided to use the 3rd dimension for public transport (right).

Due to the geographical situation of the city, the main concern regarding climate change impact is uncontrollable, extremely localized run-off from increased heavy, short rainfall events. For instance, an event in 2007 caused heavy local damage and first went completely unnoticed in the city hall, located only 2 kilometers away, where the sun was shining. The potential damage of public infrastructure and of private property is a major concern to the city managers. The potential needs for investments are huge, considering that the city copes with run-off from 350 kilometers of creeks (over 800 creek sections) and 650 kilometers of drainage channel system. Due to the complex geography, it is completely unpredictable where a heavy rainfall event might occur, and when it occurs it is today unknown whether there will be flood and where it will run off. Due to the huge investments required, it is also not possible to just increase the profile of all, or even only of major parts, of the drainage system. The Wuppertal pilot is therefore concentrated on heavy, short rainfall events and their impact on the infrastructure. The city administration has put a project underway to develop a master plan, during the coming 5 years, which shall identify the most vulnerable areas and shall suggest different localized planning options which are likely to prevent damage and are yet practical to be implemented, including being capable to cope with financial constraints.

3 SUDPLAN SYSTEM OVERVIEW

This section gives an overview of the complete SUDPLAN system and describes the different parts. A system overview is illustrated in Figure 2.

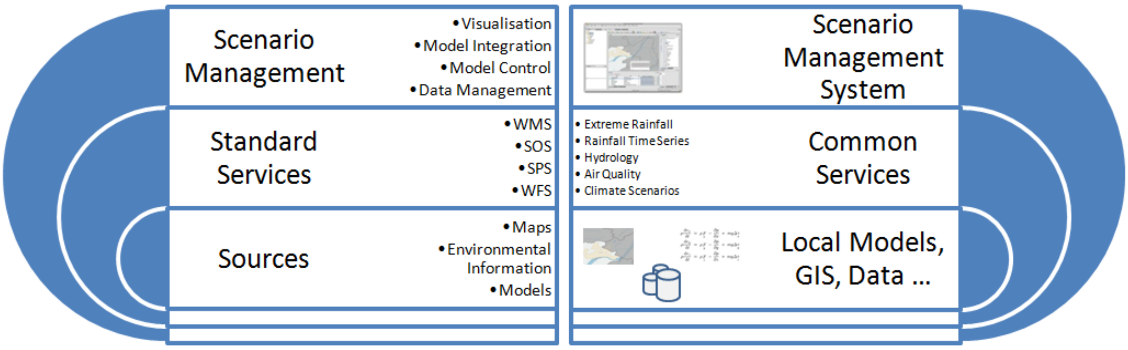

Figure 2: SUDPLAN system overview

3.1 Scenario Management System

The Scenario Management System (SMS) is the platform on which any SUDPLAN Application (or SUDPLAN System) is built. It consists of three distinct Building Blocks described in the following subsections. The SMS can be seen as a generic integration platform that will be able to facilitate climate change induced urban development planning in any city in Europe. The goal to provide a universal, flexible and adaptable planning tool is supported by the separation of the SUDPLAN System into several architectural layers as shown in Figure 2.

The top-level layer, the SUDPLAN Application itself, is the result of an extension, customisation and configuration of the underlying SMS. The SMS comes with everything needed to provide common scenario management tasks including data integration, model management and execution, workflow management, basic and advanced visualisation, and comparison of various temporal and spatial data sets, etc. It therefore relies upon standard services for data access and model management and thus greatly facilitates the task of integrating new models and data sources. Consequently, the same mechanisms used for interfacing the SUDPLAN Common Services with the SMS can be used for local model and data source integration. As shown in Figure 3, several services specified by the Open Geospatial Consortium (OGC) are supported by the SMS: Sensor Planning Service (SPS), Sensor Observation Service (SOS), Web Map Service (WMS) and Web Feature Service (WFS).

It is also possible to develop a custom model integration solution with respect to particular user requirements. The SMS Framework allows both standard and custom integration without the need to change the SMS itself. For this purpose, the SMS Framework exposes an API that enables the developers of a SUDPLAN Application to extend the SMS with their specific functionalities. The four pilot applications of the SUDPLAN project therefore validate not only the general approach of the SMS but also its adaptability/transferability and thus its applicability to any city in Europe.

3.1.1 SMS Framework

The Scenario Management System Framework (GUI shown in Figure 3) is the central component providing common SMS and integration functionality. Together with the Building Blocks for the integration of models through standardized services and for advanced visualisation capabilities it provides the basis for pilot specific implementations and the necessary workflows to support the use of models as a basis for decision making.

The core functionalities provided by the SMS Framework include, for example, support for the management of models, i.e. model execution, result storage, parameterisation and basic model result visualisation (such as 1D time series, and 2D maps).

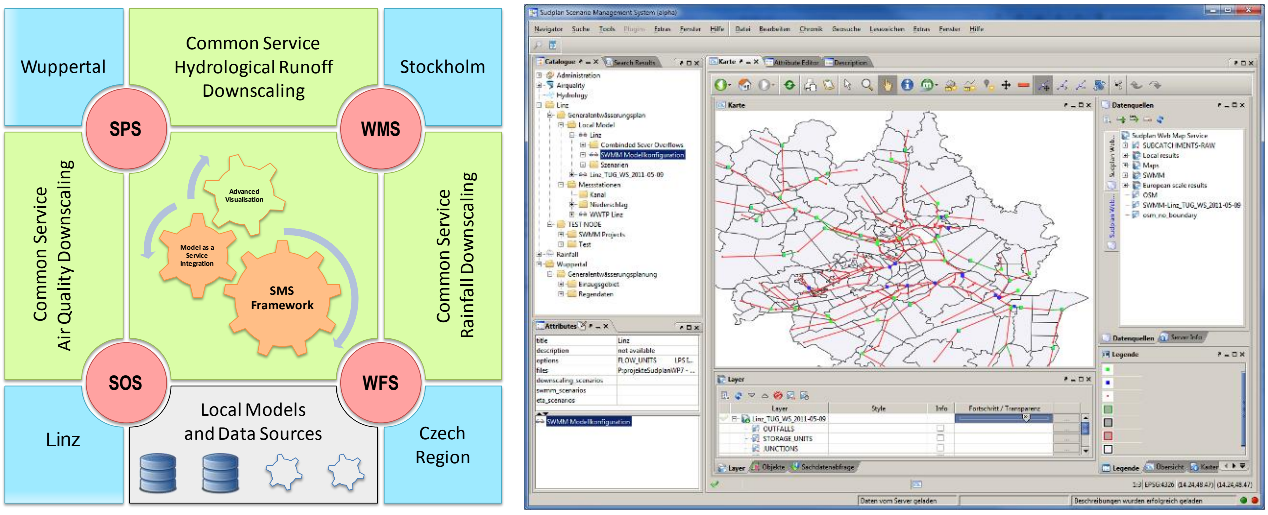

Figure 3: OGC Services Integration and SUDPLAN SMS GUI

3.1.2 Model as a Service

This building block of the SMS provides the means to control model implementations and access model results, including both SUDPLAN Common Services and local pilot specific models, via standardised web services. The selected standards are members of the OGC SWE [14] family, specifically SOS (Sensor Observation Service) and SPS (Sensor Planning Service), which are used for model result access and model control. This part of the SMS can be used to access the corresponding common service (section 3.3) as well as to encapsulate local models.

3.1.3 Advanced Visualisation

Using this building block facilitates the user of the SUDPLAN SMS the mean to interact and navigate with a virtual globe (based on NASA’s World Wind SDK). Furthermore, the advanced visualisation component handles the visualization of data as well as simulation results in a geographical three-dimensional context. Moreover, the advanced visualization component provides a visualisation wizard called VisWiz. VisWiz enables the user to choose a suitable visualization technique for a data set. Even if the user is not familiar with visualisation techniques in general the intuitive VisWiz component provides the mean to visualize the data in 3D.

3.2 Climate Scenarios

Climate scenarios depict the resulting climate evolution over time, as simulated by global (GCMs) and regional (RCMs) climate models. Climate scenarios are products of certain emission scenarios that reflect different economic growth and emission mitigation agreements.

SUDPLAN uses available climate scenarios according to IPCC directed activities preparing for AR4 and currently for AR5 (through the CMIP5 coordinated model intercomparison, see http://cmip-pcmdi.llnl.gov/cmip5). SUDPLAN uses regionally downscaled (over Europe) results from some well reputed global models. Currently SUDPLAN includes the following climate scenarios downscaled by SMHI’s RCA3 model:

- ECHAM5 (Roeckner et al., 2006; version: initialization 3), using A1B emission scenario
- HADCM3 (Gordon et al., 2000; version: climate sensitivity Q0), using A1B emission scenario

At the end of the project, an extended scenario ensemble will be available. Especially for rainfall downscaling, it is likely to also include the following scenarios:

- ECHAM5 (Roeckner et al., 2006; version: initialization 1), using A1B emission scenario
- ECHAM5 (Roeckner et al., 2006; version: initialization 2), using A1B emission scenario
- ECHAM4 (Roeckner et al., 1996), using A2 emission scenario
- ECHAM4 (Roeckner et al., 1996), using B2 emission scenario

3.3 Common Services

Common Services are the climate downscaling services for rainfall, river flooding and air quality, developed in the SUDPLAN project and accessed through the SUDPLAN platform (Scenario Management System).

Common Services allow a common urban downscaling functionality for all European cities, based on how relevant environmental factors will evolve according to different climate scenarios. The application of Common Services for downscaling of environmental factors in a new city is simple and requires a minimum of local data. The results are communicated through open standards. The following environmental factors are possible to downscale within selected climate scenarios:

- Rainfall intensity, frequency and duration, with consequences for urban storm water flooding and sewer system capacities
- Hydrological conditions in terms of river runoff and soil moisture, with consequences for river flooding, surface water resources and farming conditions
- Air quality with consequences for city population health and life quality

3.4 Local Models, Data Sources and Services

Local models, data sources and services already existing within a city's infrastructure can be easily incorporated in the SUDPLAN application through standard services provided by the SMS (section 3.1). In addition the SMS Framework exposes an API to easily extend the application according to the users needs.

4 WUPPERTAL USE CASE

The city of Wuppertal, a town with approximately 350,000 residents, is the biggest town in Germany that is situated in hill country (from 98 to 353 m above mean sea level). It is located in the steep, narrow, and long valley of the Wupper river. There are several creeks on both sides of this valley that open into the storm water sewage system before they finally end in the Wupper. During a heavy rainfall event the city's storm water sewage system is quickly blocked by those swollen creeks causing the precipitation to runoff on the surface. The storm water run-off may thereby affect valuable public infrastructure and private property. This is a major concern to the city managers. Due to the complex geography it is completely unpredictable where a heavy rainfall event might occur and therefore unknown whether there will be flooding and where it will runoff.

Figure 4: Damage due to uncontrolled storm water run-off.

Up to now the mid- and long-term planning of the storm water sewage system has been accomplished with iterative model runs of a hydrological model (for the creeks) and a hydrodynamical model (for the sewage system). This planning process is called 'Generalentwässerungsplanung' (GEP), what could be translated as 'General Drainage Strategy'. Wuppertal's first main objective is to expand the GEP: the modelling of surface run-off after heavy rainfall events should be integrated into the process. To achieve this goal, a hydrodynamical model should be used to detect the critical spots (high risk of flooding plus valuable and vulnerable facilities).

Wuppertal's second main objective is to mitigate the risk of flooding for the detected critical spots. The traditional strategies to achieve this are either the enlargement of the profiles of the sewage system or the construction of retention basins. Given these two options the potential needs for investments would be immense, considering that the city copes with water run-off from 350 kilometres of creeks (over 800 creek sections) and 650 kilometres of sewage channel system. An alternative and much more cost-efficient strategy is to look for localised planning options which are likely to prevent damage. Examples for such structural measures are the alteration of street profiles by means of higher road kerbs or the installation of stationary (or mobile) walls. Wuppertal's third main objective is to find the most cost-efficient measures for the flood risk mitigation for each critical spot. These measures shall give a higher probability to prevent damage and should yet be practical to implement, including being capable to cope with the ever growing financial constraints of the city. Please see [15, 16] for more information on Flood risk management.

The fourth main objective is to provide the responsible planners and hydrological modellers in Wuppertal with a tool that enables them to simulate a multitude of modelling experiments with the model component for the surface run-off, both to detect the critical spots and to simulate the effects of different structural measures at the critical spots. The tool should be able to store the parameters and results of such a model run and to visualise the results. The SUDPLAN project provides such a tool – the Scenario Management System (SMS).

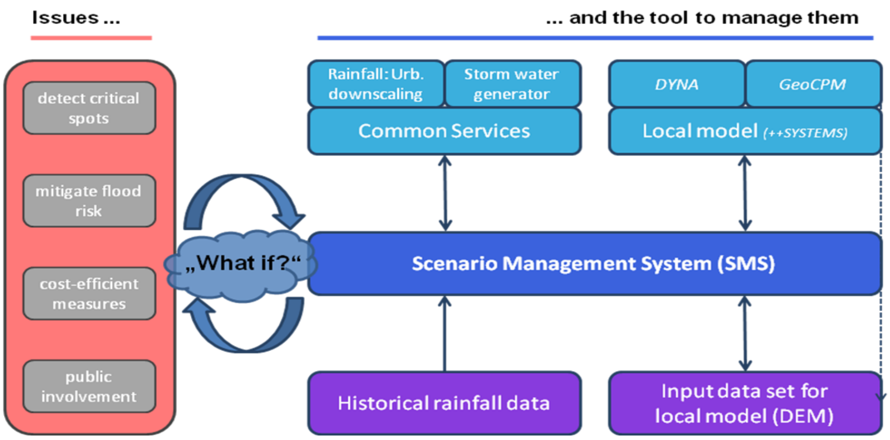

Figure 5: Wuppertal objectives and tools used for solving.

5 WUPPERTAL WORKFLOW

In this section we present the current results of the SUDPLAN project concerning the Wuppertal objectives. We describe the workflow from the large scale climate model to the visualisation of local high resolution simulation results.

Figure 5 depicts the objectives which need to be solved and the tools which are involved on the application side. All these components are incorporated within the SUDPLAN application. The general component chain used in the Wuppertal pilot is shown in Figure 6.

After selecting a climate model the Common Services for rainfall are used to project historic rain data into the future based on the chosen climate scenario. This information is then combined with input data for the local model (DEM, simulation preferences, etc.) which can be edited within the SUDPLAN SMS. After running the local models for the sewer network and the surface run-off the data can be visualized either in the 2D GIS component or with the 3D visualisation component.

In the following subsection the different steps of the workflow are briefly described and depicted with screen shots of the SUDPLAN application.

5.1 Select/Inspect Climate Scenarios (European Scale)

To get a first overview of the available climate scenarios the user can simply drag and drop the scenario from the repository onto the map component of the SUDPLAN application (Figure 7 left). By using a time slider the different time steps of the results can be inspected. To get further information for a specific geospatial position/city the user can query the map to show the time series information for the selected point (Figure 7 right)

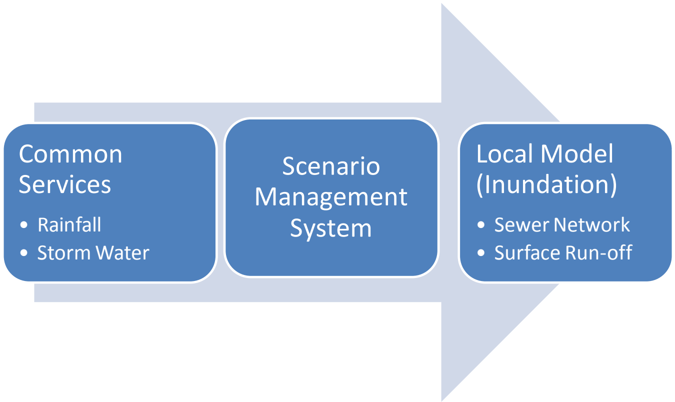

Figure 6: Wuppertal pilot component chain

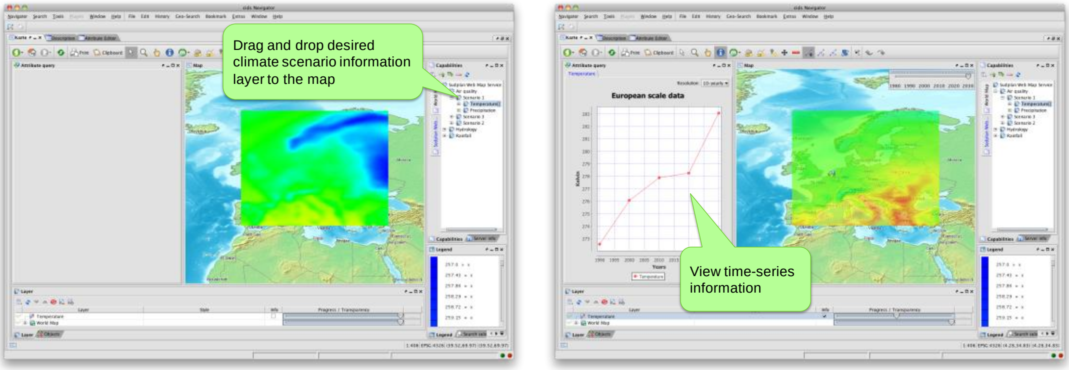

Figure 7: Inspecting a climate scenario on the European scale.

5.2 Urban Rainfall downscaling using historical time series

To downscale the selected climate scenario to the urban level using the SUDPLAN common services the user needs to provide historical rainfall data. This can be provided either as IDF curves or measured rainfall time series. In this use case historical rainfall time series are available and incorporated as local data in the SUDPLAN application.

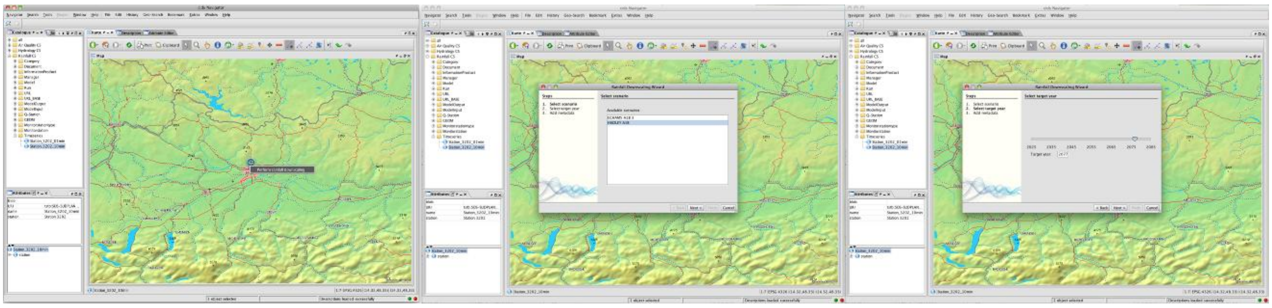

Figure 8: Using the SUDPLAN Common Services to downscale a selected RCM to a specific city using historic rainfall time series.

The user can simply drop the desired rainfall time series from the repository onto the map component. The downscaling is started by selecting the representation of the time series on the map. The user is guided through the process by a simple wizard where he can choose the climate scenario and the desired forecast period/year (Figure 8).

The historical rainfall data and selected preferences will automatically be uploaded to the Common Services and after the downscaling is finished the user is presented with the new (future) rainfall time series based on the chosen climate scenario which he can then compare to the original historical data (Figure 9).

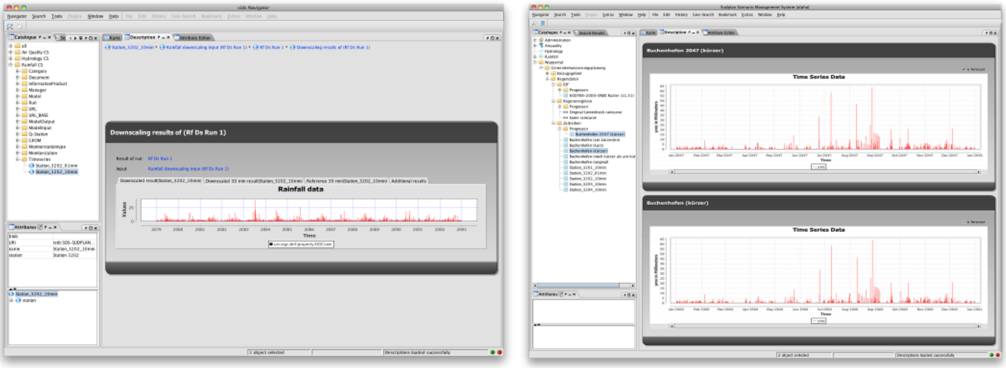

Figure 9: Rainfall downscaling result (left) and comparison of historical and future rainfall time series (right).

5.3 Running the local model

To run the local run-off model the user first selects the area of interest and a predefined configuration (GeoCPM input data, DEM, etc.). The user can inspect the data and if he wants to simulate a effects of a mitigation measure optionally manipulate the underlying DEM, e.g. raise predefined breaklines (road kerbs), etc. (Figure 10).

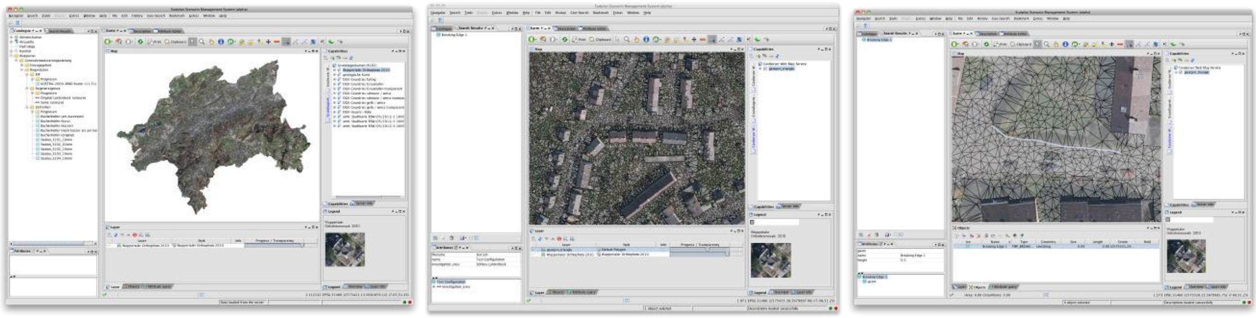

Figure 10: Selecting and manipulating the base data for the local model.

The external simulation is integrated in the SUDPLAN application through the provided API and can be started directly from within application. The user is provided with the estimated time to run the simulation and after finishing an overview of the simulation results is given (Figure 11). The simulation result is automatically added to the local repository and can be used for further inspection and visualisation.

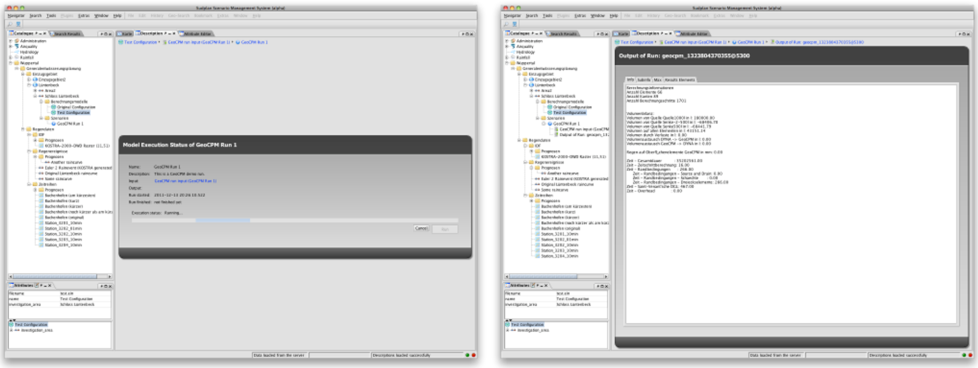

Figure 11: Running the external local model and result overview.

5.4 Visualise the results of the local model

The simulation results can be visualised either in the 2D map or with the 3D visualisation component. The results can be easily combined with additional existing data like building information, traffic data, etc. When using the 3D visualisation component the user is able to animate the model results inspect the water levels at certain important points of interest over time. In addition multivariate data can be shown with different information visualisation techniques to get a better understanding of the impact of the flooding event or the mitigation measures used for this simulation run.

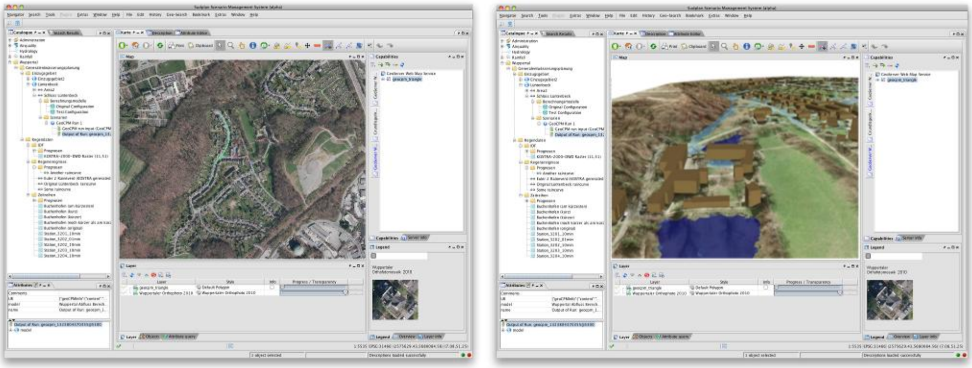

Figure 12: 2D and 3D visualisation of local model simulation results.

6 CONCLUSION

In this paper we gave an overview of the SUDPLAN system which is currently being developed within the EU FP7 project SUDPLAN and presented details about the Wuppertal pilot which is concerned with the mitigation of the impact of heavy storm water events considering future climate change.

We presented the objectives and use case for the City of Wuppertal and described the workflow from selecting a climate scenario, downscaling this scenario to the urban scale, running the local simulation model to visualizing the simulation results, which is all combined within the SUDPLAN application.

7 FUTURE WORK

The SUDPLAN project is now in the third year of development. After developing and integrating the basic building blocks and first pilot extensions we will now focus on specialised solutions for the different pilot cities and use cases. The project status and results can be followed on the project website (http://www.sudplan.eu).

8 ACKNOWLEDGEMENTS

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