PROJECT FINAL REPORT

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1 Executive summary

The FP7 Collaborative research on flood resilience in urban areas – CORFU consortium (2010-2014) was made up of seventeen partners from eleven countries, with a €3.5m budget. The overall aim of this project was to enable European and Asian partners to learn from each other through joint investigation, development, implementation and dissemination of strategies that will enable more scientifically sound management of the consequences of urban flooding.

CORFU has brought novel methodologies and models into a *DPSIR (Drivers-Pressures-States-Impacts-Response) framework,* which were implemented in seven case studies – Barcelona in Spain, Beijing in China, Dhaka in Bangladesh, Hamburg in Germany, Mumbai in India, Nice in France and Taipei in Taiwan. Application in the case studies involved variations in focus and level of detail, depending on specific flooding problems, data availability and development scenarios. A parallel study on flood risk management problems in these cities was conducted, which brought about valuable experience in the applicability of modern methods in different conditions. An important lesson was that for both the Asian and European case studies, the DPSIR framework using flood modelling, based on hydrodynamic flood models with the introduced modifications, provides a sound basis for flood damage analysis and the evaluation of mitigation measures.

Key novel *modelling technologies* developed within CORFU include: (i) a Bayesian probabilistic optimisation algorithm for urban growth modelling based on the use historic land cover maps taken from satellite data combined with thematic maps, (ii) a multi-cell approach to urban flood modelling in mega cities that adopts a coarse grid for the global model domain of the whole city and refined grids that are activated only when flooding occurs, (iii) the first health impact model that uses a combination of deterministic hydraulic modelling of transport and mixing of pollutants in flood water to predict their concentrations and the data on human vulnerability through dose-response functions and (iv) a new Flood Resilience Index (FRI), which takes into account different spatial scales from parcel to city scale, by evaluating external and internal requirements for urban functions.

Other original *methodologies* that have been investigated and implemented in CORFU case studies include evaluating the impact of economic growth on development scenarios relevant to flood risk management, a consistent methodology for urban flood modelling, an ARL (Awareness, Relationships and Livelihood) framework and an assessment of flood risk management strategies using maturity levels. New *tools, databases and web-based systems* created in CORFU include new depth-damage curves for all case study cities, an impact assessment tool, a web-based GIS platform with flood and damage modelling results from case studies, a web-based system for real-time flood modelling and a 2D (two-dimensional) tool for simulation of transport and mixing of pollutants in urban flood water. The project also produced new *guidelines* for calibration of urban flood models as well as new national guidelines for design of urban drainage systems in China.

The main dissemination event of CORFU was the *International Conference on Flood Resilience: Experiences in Asia and Europe* held in Exeter on 5-7 September 2013. Project results have also been disseminated at workshops in *all* case study areas and by various other presentations and publications. CORFU is a unique EU-funded action in that it has had a strong impact in Asia, including in countries not associated with this project (e.g. Hong Kong, Japan, Thailand).

This was a collaborative research programme in the sense that investigations always involved both local case study partners and the consortium partners who were focussed on the development of novel methods. Through these interactions the former had opportunities to take up the cutting edge science being developed, and the latter were able to test the new tools on real world problems.

CORFU deliverables and publications are downloadable from the project web site.

2 Summary description of project context and objectives

2.1 Background

Recent years have witnessed a large number of serious flood events around the world that led to thousands of deaths, displacement of millions of people and damage and economic losses that amount to tens of billions of Euros. In addition, projections of future climate changes and of urban growth indicate that flood risks will be exacerbated in many regions. Consequently, governments, policy makers and communities worldwide have been forced to review their flood management strategies and invest more resources in portfolios of structural and non-structural measures. The European Directive on the Assessment and Management of Flood Risks – the Floods Directive (EC, 2007) and the wider EU Flood Action Programme and numerous national programmes call for improved flood forecasting and early warning systems as well as for flood risk mapping.

Significant advances have been made in various elements of flood risk management recently. However, with the emergence of new tools, new links and feedbacks between different approaches (including methods from different disciplines) are also becoming possible. Consequently, new and more challenging requirements are demanded of modern flood risk management strategies, some of which would have been unimaginable until recently due to technological limitations. CORFU aimed to explore these new links by focusing on risk, prevention and management of urban floods. This was done in two general ways, which describe the originally envisaged overall scientific progress:

- Firstly, advances were made in various segments of modelling drivers and pressures, flood forecasting, flood risk analysis and mapping, flood impact assessment and flood risk management.
- Secondly, these models were coupled in a novel way – by envisaging scenarios of relevant drivers: urban development, socio-economic trends and climate change, and quantifying the cost-effectiveness of resilience measures and flood management plans for these scenarios.

The differences in urban flooding problems in Asia and in Europe range from levels of economic development, infrastructure age, social systems and decision-making processes, to seasonality of rainfall, drainage methods and climate change trends. CORFU vision was that this project uses these differences to create synergies that can bring new quality to flood management strategies globally.

2.2 Principles

This research programme has been developed and conducted based on the following principles:

- *Interdisciplinarity* – CORFU research involves a broad range of disciplines relevant to dealing with urban flooding, such as hydrology and hydraulics, urban planning, economics and social sciences, technology and management, and this has been clearly reflected in the composition of research team.
- *Reliance on real-world examples* – the developed methodologies have generic components, but they have been tested and implemented in a series of case studies – we strongly relied on real-world data on infrastructure, meteorological inputs, population and economic parameters and predictions of climate change.
- *Collaboration between Europe and Asia* – we made scientific progress by cross-fertilising the latest technological advances with traditional and emerging approaches to living with floods, including those based on involving socio-economic aspects – this was driven by interactions between European and Asian partners.

- *Emphasis on 'responding'* – the first two elements of EU FP7 Environment research ('understanding' and 'assessing impact' in particular) were part of the programme, though mainly in order to enable more sound focus on the third one – 'responding' including adaptation and resilience measures.
- *Building on both the CORFU team experience and tools as well as on general scientific and technological progress in the field* – we implemented and further developed our own methodologies and tools, with adequate consideration and inclusion of recent advances made by other research teams.
- *Targeted dissemination* – we were interested in presenting our results to the audiences that are relevant for improving resilience to flooding – city and government officials, urban planners and consultants in case study areas, professionals who work in flood risk management and new projects.

2.3 Aims and objectives

The overall aim of CORFU was to enable European and Asian partners to learn from each other through joint investigation, development, implementation and dissemination of short to medium term strategies that will enable more scientifically sound management of the consequences of urban flooding in the future.

The scientific and technical objectives can be summarised as follows:

- *To establish and maintain links with recently completed and ongoing major national and EU research projects related to urban flooding,* with the view of enabling smooth acceptance and further enhancement of methodologies developed in these projects by CORFU and vice versa, aiming at a better use of resources and avoiding duplication of work. Links with major urban flooding related programmes outside EU have also been established and maintained, in order to enable identification of synergies, enhance mutual support and consider the potential for joint dissemination of projects' results through multiparty workshops and conferences. The ultimate objective was to build up relationships with Member States at EU level and with national and regional decision-makers in Asian countries and elsewhere.
- *To determine the interactions between economic and urban growth, societal trends and the urban structure,* which serve as the basis for the development of a DPSIR (drivers-pressures-state-impact-response) logical framework, and to complete this analysis in conjunction with IPCC-based projections of climate change, economic, health and social development, aiming at identifying the future policy areas where the responses to the drivers and pressures can be most effective. Consequently, we aimed to consider all different drivers – economic, social, land use/planning, soil sealing and mitigating practices and climate trends.
- *To enhance methodologies and tools for off-line and real-time flood hazard assessment based on urban flood modelling* by developing missing elements in existing models for system analysis in order to identify consistent procedures for calibration of urban flood models at different scales, having in mind the envisaged technological advances – wider availability of weather radars and on-line rain gauges, increase in computer speed and possibilities for coupling of runoff-sewer-river hydrologic and hydraulic models. The ultimate objective was to develop generic tools for urban flood mitigation plans and test real time urban flood forecast systems, including real time data assimilation and uncertainty estimates that enable evaluation of future impacts of urban growth and climate change on flood probability through scenario studies.

- *To improve, extend and integrate modern methods for flood impact assessment* – the objective was to develop a comprehensive and flexible framework that amalgamates different methodologies for evaluation of various types of damage, such as the assessment of health problems that has been taken to a higher level by a combination of hydraulic modelling of urban floods and quantitative microbial risk assessment. We aimed to enable realistic assessment of vulnerability to urban flooding at different spatial and temporal scales, aiming at quantification of the effectiveness of management strategies and resilient measures in the scenarios context. Additional objective was to study interrelationships between risk perception, level of preparedness and actual responses, distinguishing between impacts on individual and on communities.
- *To assess and enhance existing flood risk management strategies* related to planning and prevention for the minimisation of flood risk, management during flood events including early warning systems, emergency protocols and crisis management and measures to be taken after a flood event, including evaluation of damages, recovery measures and the procedures that allow learning from experience. This approach guarantees comprehensive coverage of the whole flood management cycle. We developed new strategic flood risk assessment strategies by building on CORFU outputs. The ultimate objective was to formulate good practices and good standards that can be implemented nationally in partner countries, thus contributing to development of efficient medium- to long-term strategies and providing adequate measures for improved flood management at relevant levels.
- *To disseminate new approaches and support exploitation of opportunities at local, national and international levels* – the aim was to engender a 'flood resilience' culture through rising awareness of proposed strategies and comprehensive adoption of CORFU methodologies and tools and by engaging policy makers, especially in the case study areas, to share best practice in flood resilient design and planning enabling policy decision making to be positively influenced by new urban flood risk management principles.
- *To co-ordinate the project within a robust organisational framework* that supports collaboration, oversees scientific and societal issues, promotes gender equality, ensures the financial viability of the entire project and ensures good internal and external communication, in full compliance with FP7 guidelines and principles.

2.4 Case studies

This project involved seven case studies in Europe and Asia through which the new strategies have been investigated and enhanced. Comparisons have been made by implementation of new approaches in cities in different socio-economic systems and different climate zones. Particular attention was paid to the careful identification of case studies such that:

- they are major large urban centre with history of flooding,
- flooding problems are linked to different causes and interactions at different scales,
- local flood management systems with different levels of sophistication are in place,
- rich databases with rainfall patterns, urban surfaces and drainage systems exist,
- verified hydrologic and hydraulic models are accessible,
- possibilities for engagement of stakeholders and their interest are present.

As a result of this process, the following cities – three in Europe and four in Asia – have been selected in this project: Barcelona in Spain, Beijing in China, Dhaka in Bangladesh, Hamburg in Germany, Mumbai in India, Nice in France and Taipei in Taiwan. The idea was that some aspects of case study work would be focussed on one or two parts of these cities, whilst other aspects would consider a city as a whole and also take into account regional data where relevant.

Specific issues in the case studies can be outlined as follows:

- Barcelona is prone to flash flooding due to its Mediterranean climate. It is not uncommon for 50% of the annual rainfall to fall in two or three events. The rapid response of the catchment leaves little time for residents to be forewarned. A special focus is placed on the development of real-time flood warning systems based on heavy rainfall alerts. Damages are of particular interest in the Raval District in the city centre.
- Beijing is one of the fastest growing megacities in the world, with a population of nearly 20 million. Although the city's annual rainfall is relatively low (less than 600mm per year), extreme rainfall events do occur, such as in July 2012. A particular problem in Beijing is the vulnerability of the traffic network; many underpasses are prone to flood, and the knock-on disruption can be severe. The focus area is the new satellite town of Yizhuang.
- Dhaka is particularly vulnerable to flooding during the monsoon season. It is also a rapidly growing megacity, and is the most densely populated city on the planet. Its vulnerability is exacerbated by poor housing standards. The lack of services and adequate infrastructure leads to significant sanitary and health problems when flooding occurs. CORFU project looked at all areas at risk of flooding in Dhaka.
- Hamburg case study focused on two catchments. In Wilhemsburg the main problems is storm surges and dike overtopping, where cascading compartments method is the main flood management strategy. Wandse is a small urban catchment with a combination of fluvial and pluvial floods and where strategies are mainly based on the development of green roofs and other SUDS (Sustainable Urban Drainage Systems).
- In 2005, widespread flooding hit Mumbai, when over 940 mm of rainfall was recorded in 24 hours, leading to significant loss of life, economic damage and disruption to services. Like Dhaka, the city is rapidly growing and with significant poverty and large portion occupied by slums. The city elevation at some locations is just one meter above mean sea level. Focus area is the catchment of the Mithi River, in which a vertical flood wall has been constructed.
- Nice is a coastal city with steep mountains in the upstream catchment, hence it is at risk from river flooding, pluvial flooding, flash floods and coastal flooding. The development of the CORFU methodology in this case study was mainly focused on the global assessment of risks of flooding over the full city with a high accuracy and the creation of the Flood Resilience Index from the parcel scale to the city scale.
- Taipei is a densely developed urban area with a number of pumping stations and underground structures. It is at risk of being hit by cyclones. In 2001, Typhoon Nari struck the city, and extreme rainfall (more than 700 mm in 36 hours) caused widespread damage. Typhoons are a regular feature of Taiwan climate, hitting the island three times a year on average. A specific problem is an increasing vulnerability due to Taiwan's aging population.

3 Description of the main S&T results

3.1 Introduction

This report describes the main scientific achievements and advances made in the CORFU project. Rather than focusing on individual case study cities, this report develops a narrative using a DPSIR (Drivers-Pressures-States-Impacts-Response) framework (Djordjević *et al.,* 2011).

- *Drivers* (D) – The social, demographic and economic developments in societies and the corresponding changes in life styles, overall levels of consumption and production patterns.
- Socio-economic drivers lead to environmental *pressures* (P)
- Environmental pressures lead to changes in environmental *state* (S).
- Changes in state are reflected in environmental and socio-economic *impacts* (I).
- Stakeholder gains/losses from impacts lead to *responses* (R) which affect one or several of the components mentioned before.

DPSIR was initially developed by the Organisation for Economic Co-operation and Development and has been used by the United Nations and the European Environmental Agency to relate society and human activities to the environment.

Through the use of a DPSIR modelling framework, it is possible to gauge the effects of drivers, pressures, impacts and responses and as such can assist decision-makers in many steps of the decision process. As a generic concept, it is applicable to the assessment of the causal of the factors and processes contributing to the formation of flood risk and its mitigation.

In the context of flood risk management, *drivers* can include the impact of climate change on the hydrological cycle and extreme rainfall, as well as demographic change and economic growth.

These drivers lead to *pressures* on the environment, which include urban expansion, and therefore the loss of natural drainage systems, and the proliferation of hard surfaces.

These pressures can lead to changes in the environmental *state*, which include increased runoff, sewer overflows, increased flood risk and reduced water quality. In the project, the changes in the state have been largely considered through the use of urban flood models and their application to flood hazard assessment.

Impacts cover the effects that flood risk has on people, on the environment, the economy, and critical infrastructure. These have been considered through flood impact assessment methodologies.

Responses include anything that individuals or groups might do to reduce the risk of flooding, such as take precautionary action, construct structural flood defences, or increase human capacity so that societies are well prepared if and when floods occur.

The DPSIR framework can be represented by a set of models, which were developed and deployed in a sequential order as of the DPSIR framework. By the use of models, the efficiency and effectiveness of different resilient strategies have been evaluated for the case study cities.

The models and their interconnectivity within the CORFU project are depicted in Figure 1 and the overall modelling matrix considering the data exchange and models connectivity is given in Table 1.

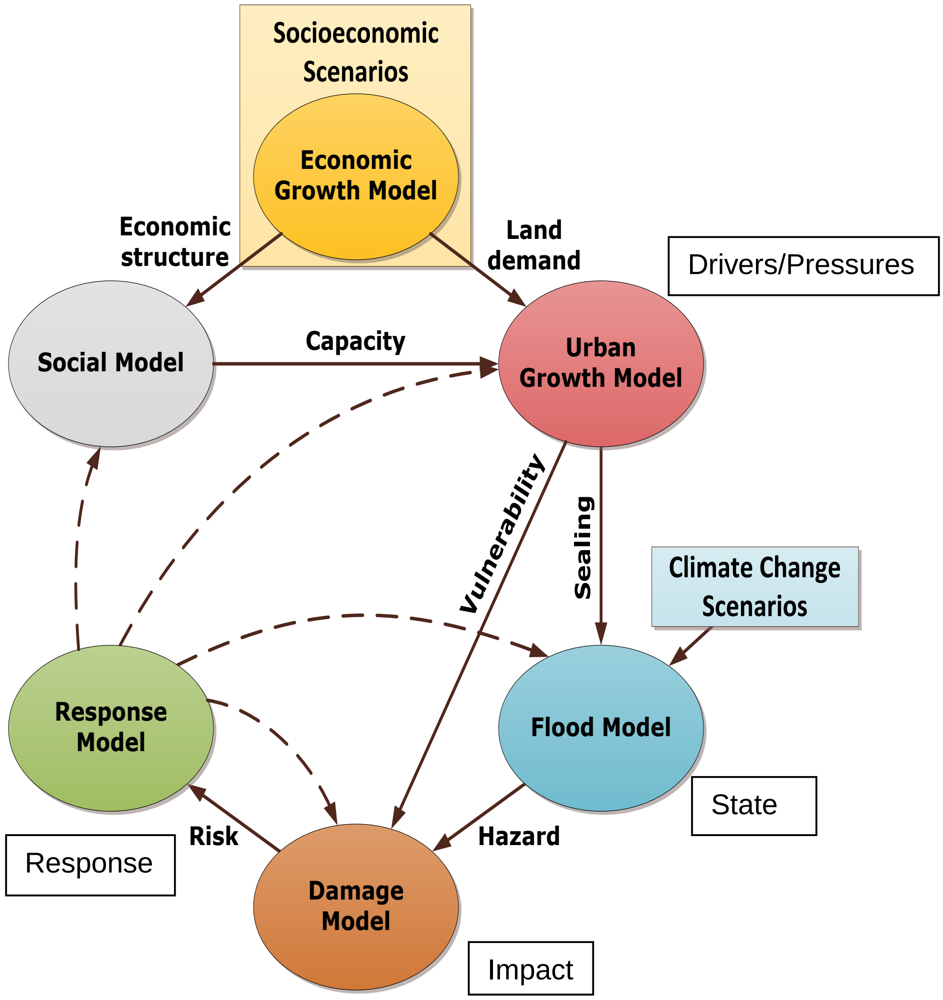


Figure 1. The CORFU modelling loop following the DPSIR framework

Table 1. Modelling matrix indicating model outputs that are taken as inputs by other models

Model output / Model	Social	Economic growth	Urban growth	Flood	Vulnerability	Response
Social				Flood intensity		
Economic growth						
Urban growth						Adaptive measures
Flood			Land cover distribution			Adaptive measures
Vulnerability	Coping capacity	Exposed assets	Land use distribution	Flood intensity		Adaptive measures
Response	Protection motivation	Access/ availability of resources		Flood intensity	Direct/indirect, tangible/intangible damage	Adaptive measures

3.2 Drivers and pressures

Drivers and pressures were considered together in the CORFU project. Five drivers and pressures were considered:

- climate change leading to changes in rainfall,
- population growth,
- economic growth and changes to economic structure,
- urban growth and subsequent changes to impervious surface areas,
- demographic changes (most notably the age distribution).

Not all of these drivers and pressures were considered in every city. To take two examples, urban growth and sprawl was not considered a significant pressure in Barcelona, as the case study was focused on a highly populated highly developed part of the city. In Taiwan, the aging population was considered as a specific pressure which could affect the vulnerability of its inhabitants. Climate change was considered as a significant driver in all cities.

First, a framework was established to develop scenarios to assess the future flood risk. A scenario is one of a plausible set of future conditions.

3.2.1 Scenarios

Shared socio-economic pathways (SSPs) were developed that make common assumptions across the different case study cities. In order to make the CORFU case study cities comparable, these SSPs form the basis for developing regional socio-economic scenarios in each city. Where urban growth is considered to be a significant driver, an urban growth model based on a cellular-automata model has been applied to produce various scenarios. In this way, the scenarios are associated with different future urban configurations. Regional drivers of urbanization have primarily been determined by the statistical analysis of land use changes in the past, and identifying rules that can be applied in the future. Apart from setting the overall growth rate, the influence of the shared pathways is expected to be rather small compared to the regional drivers of urbanization and the urban planning policies in each city. For this reason, the regional drivers and policies are part of the scenario definition and act as additional input parameters to the urban growth models in the form of spatial requirements and constraints.

The socio-economic scenarios are combined with plausible climate futures. Climate futures describe the impact of increasing greenhouse gas emissions on climate variables that have a direct influence on the flood hazard, e.g. changes in extreme precipitation, sea level rise, and storm surge levels. Projections of climate change variables have been conducted using Global Climate Models. Climate impact results for the AR5 Representative Concentration Pathways are not yet available. For this reason, climate futures are based on the results of the 4th IPCC (Nakićenović and Swart, 2000). As the SSPs are mostly driven by regional factors, they can easily be combined with a wide range of possible climate futures. Several key challenges remain. The most important of these will be to downscale the results of global and regional climate models to the relevant city scale. However, the definition of climate futures is not in the scope of this paper. Reference will be made to guidance on the use of climate inputs to urban flood models.

For each case study city, a minimum of three scenarios has been developed, which take into account the future land use, socio-economic pathways, adaptive capacity and the climate futures. These scenarios cover “interesting” aspects in the space of possible urban configurations and future climates. An interesting scenario is either very plausible (i.e. likely) or it has a high impact. One of the scenarios is an extreme scenario based on the high growth pathway. The scenarios did not take into account different climate mitigation policies directly. A certain level of climate mitigation is instead assumed indirectly in the socio-economic pathways by a combination with a specific climate future.

The general framework for the definition of scenarios within CORFU is given in Figure 2 and a more detailed structure of the developed CORFU scenarios addressing different aspects considered such as future land use patterns, socio economic developments, adaptive capacities and climate futures is given in Figure 3.

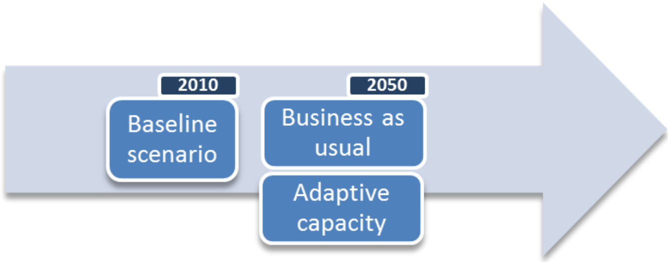


Figure 2. **The general approach to scenarios in CORFU considered for all case study cities**

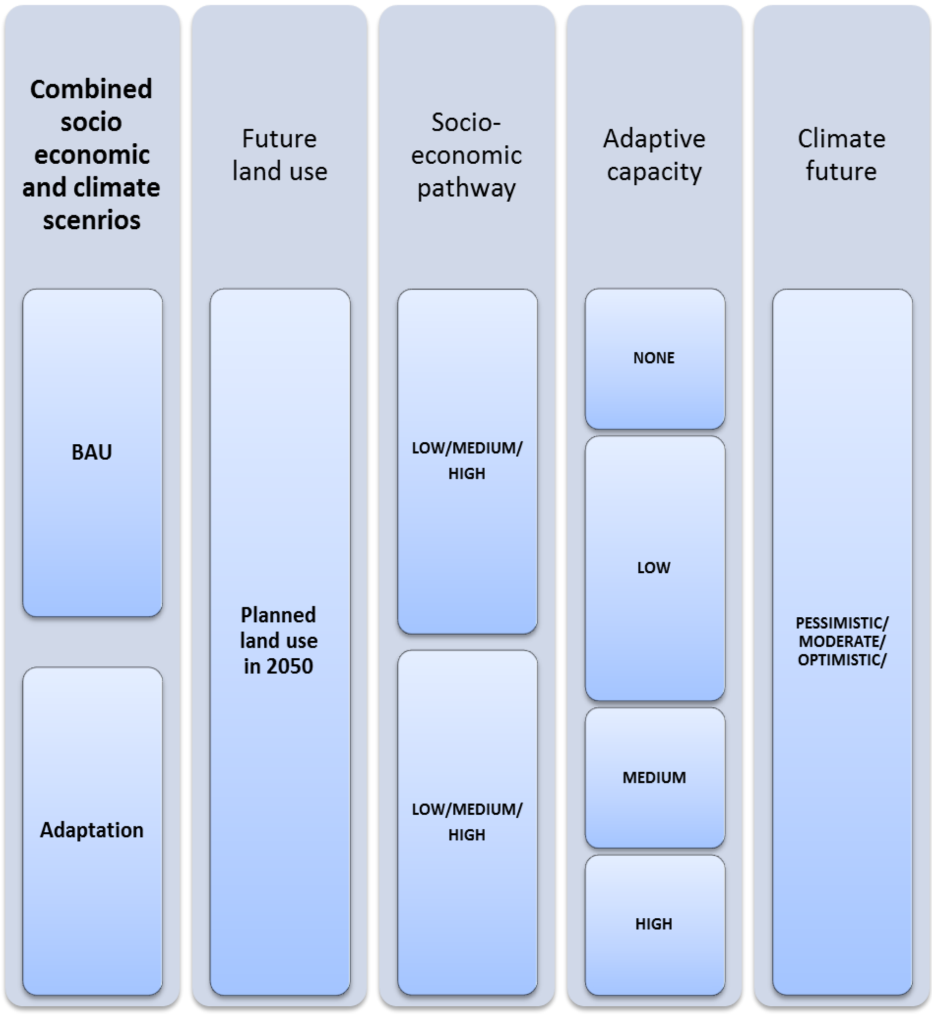


Figure 3. **The structure of the developed CORFU scenarios: it combines different future land use patterns, socio economic developments, adaptive capacities and climate futures**

In the case study cities, *climate change scenarios* were derived from existing studies or reports or are based on the nationally adopted practices, and typically through the use of 'uplift' factors to present day design rainfall scenarios. For example, in the case of Barcelona, rainfall intensities were scaled by a factor of 1.12 for the 10 year return period event, and 1.15 for the 100 year event, for the 2050 event, relative to the current design rainfall intensities.

3.2.2 Economic growth

To produce economic and urban growth scenarios, new sophisticated modelling approaches were have been developed and applied at the case study cities.

Economic growth model has been developed and deployed at the case study cities to understand the overall rate of economic growth for each case study, but also to understand changes to the economic structure (for example, increases in the service sector and decline of manufacturing). A methodology was developed that could be applied to the diverse cities that were considered in the project (Schlitte, 2013). On the one hand, some are in highly developed countries, exhibiting a high level of wealth and relatively low dynamics in terms of population and GDP growth. On the other hand, there are very rapidly growing cities in developing and emerging countries, which are marked by relatively weak institutions and extremely high social inequalities. The cities in highly developed countries of Europe may follow different growth patterns than the highly dynamic cities in the emerging countries of South-East Asia.

A challenge in this modelling has been data limitations, which are more severe in some cities than in others. Therefore, the modelling framework was designed to produce good results based on a minimum amount of data. In any case, long-term economic projections are associated with immense uncertainties. Therefore, it is essential to consider that the scenario results are not to be interpreted as predictions, but as a plausible description of the future.

The overall approach taken in producing future economic growth scenarios was to regionalise national economic development paths. This means starting with high level projections or scenarios of future national economic and population growth paths as a Medium Growth Path, or a "Business-As-Usual" case. At the global level, it assumes a more or less linear growth path of population, while the economic growth rate resembles the long-term average annual growth rate since 1980. Low and High Growth paths were also selected which deviated from this medium "Business-as-usual" case.

The economic and population projections were prepared in two steps:

- Ex-post regression analysis was undertaken to estimate and identify drivers and trends of past regional growth relative to the national growth.
- Projections – these past region trends (identified from ex-post analysis) were applied to projected national trends to produce future regional projections.

The ex-post analysis aims at identifying key drivers and long-term growth trends in order to extrapolate regional growth deviations from the national level. Therefore, we conducted a regression analysis applying panel data structure, thus comprising time-series observations for a cross-section of regions within a country. We emphasised the importance of the local sector composition in regional growth processes by estimating regional employment growth and productivity for each sector separately. Thus, the outcome of the future scenarios for the case study areas depends crucially on the local sector structure. Furthermore, in order to account unobserved local characteristics we estimated region-specific fixed effects controlling idiosyncratic regional characteristics that are invariant over the observed time period. In Step 2, we built scenarios for regional employment, productivity and output (by economic sector) until 2050. Starting point is the most recent ex-post observation in our data set. In order to simulate the development of employment and productivity by sector and the development of working age population, we extrapolated the ex-post development by applying the estimates received in Step 1 in combination with different scenarios for the socio-economic development at the national level. The product of employment and productivity yields the projected level of output in each sector.

In Bangladesh, high growth is associated with less population growth, but a greater share of urban population living in cities. In 2050, although the total population for the high growth situation is less than for the low growth scenario (195m compared to 214m), its urban population is significantly larger (131m compared to 81m). Under the high growth scenario, one would expect greater pressure on Dhaka and its land (Table 2).

Table 2. National scenarios for Bangladesh

	Low growth		Medium growth		High growth	
	2050	Growth rate 2012-2050	2050	Growth rate 2012-2050	2050	Growth rate 2012-2050
GDP (billion US$ 2005 prices)	153	197%	366	612%	506	886%
Population (total, million)	214	44%	194	31%	195	31%
Population (aged 15-64, million)	142	49%	132	39%	131	37%
Share of population in urban areas	38%	36%	52%	84%	67%	138%

Regression analysis on Dhaka has been projected into the future to produce scenarios of population and economic growth. Compared with the national picture, Dhaka's growth (Figure 4) is projected to be faster than the national growth. Between 2010 and 2050, Bangladesh's economy is projected under the medium scenario to be 612%, and over 850% for the high growth path. This is in accord with the idea of a growing economy being associated with a more rapidly growing urban population.

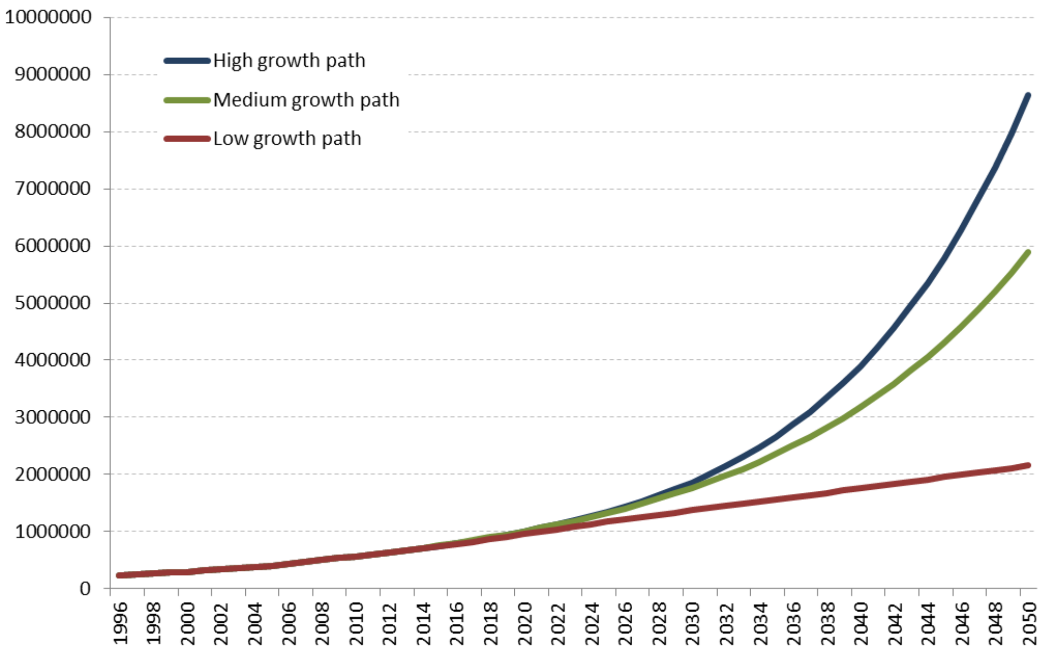


Figure 4. Gross domestic product in Dhaka

3.2.3 Urban growth

Urban growth modelling was conducted using a spatially explicit urban growth modelling framework in which land use and land cover changes (LUCC) are a manifestation of a complex set of drivers, and physical constraints and policies (Veerbeek and Zevenbergen, 2013). We aim to use models in this study to develop consistent projections of urban development scenarios based on the local characteristics, conditions and historic development trends of cities.

The models used in the CORFU are based on Cellular Automata based models. These are regular grids, where each cell has a number of potential states (i.e. LULC classes). In an urban growth model, these cells can represent rural or natural areas (e.g. forest, barren land, etc.) as well as built-up areas containing various levels of densification. Rules need to be devised to determine the probabilities of cells changing from one state to another. Once these transition rules have been determined, they can be applied to create projections of future states.

The modelling of urban growth therefore required two stages. The first stage was to use historic land cover maps, usually derived from satellite data, to explore changes in land cover and urban density. These are combined with 'thematic maps' which can include information on factors such as the topography, slopes, distance to main roads, and distance to economic hubs such as central business districts. The data sets included in the analysis are chosen by the modeller. These maps are used in a 'Weight of Evidence' approach which applies a Bayesian probabilistic optimisation algorithm to determine the importance of different factors and the transition rules. Once these rules are obtained, they are then validated by applying the rules to project urban growth from some time in the past to project the present situation, and then these 'projections of the present' are compared with the observed changes. A genetic algorithm driven calibration minimizes the differences between projected and observed changes.

In the CORFU case study cities, simulation of past land cover transitions and comparison to observed historic land cover changes resulted in accuracy levels of over 80% at a spatial resolution of about 150 metres. The model is relatively robust against classification errors in the land cover data used for 'training' the model as well as to a limited training cycle during the automated calibration and validation method. The second stage in urban growth modelling is to apply these transition rules to project future states from the present situation. 'Business-as-usual' scenarios were developed by simply extending the observed rules from the recent history until 2050. This was done for the cities of Beijing, Dhaka, Mumbai and Hamburg until 2050, using 5 year increments.

Furthermore, for the Dhaka case study alternative scenarios have been developed, by applying low and high population growth projections. The outcomes for the different case studies show a variety of spatial trends. A common factor is that all four cities are expected to develop rapidly, causing substantial densification (Beijing), suburbanization (East of Mumbai) as well as development of neighbouring towns. The outcomes have been post-processed to increase the expressiveness and characterisation of the different land cover classes and observed spatial patterns. Figure 5 shows a business-as-usual projection for Dhaka from 2005 to 2060. Urban expansion can be classified in three categories: infill where undeveloped land within a city is built upon, extension where the city sprawls to neighbouring areas, and leapfrogging where urban growth occurs some distance away from the existing urban area. Satellite towns are an example of this type of development.

This urban growth has been converted into figures for the percentage cover of impervious areas for the case study cities. The results for Beijing, Dhaka, Mumbai and Hamburg are shown below in Figure 6. In Nice, Barcelona and Taipei, urban growth is not considered to be significant driver, and these are therefore omitted from the analysis.

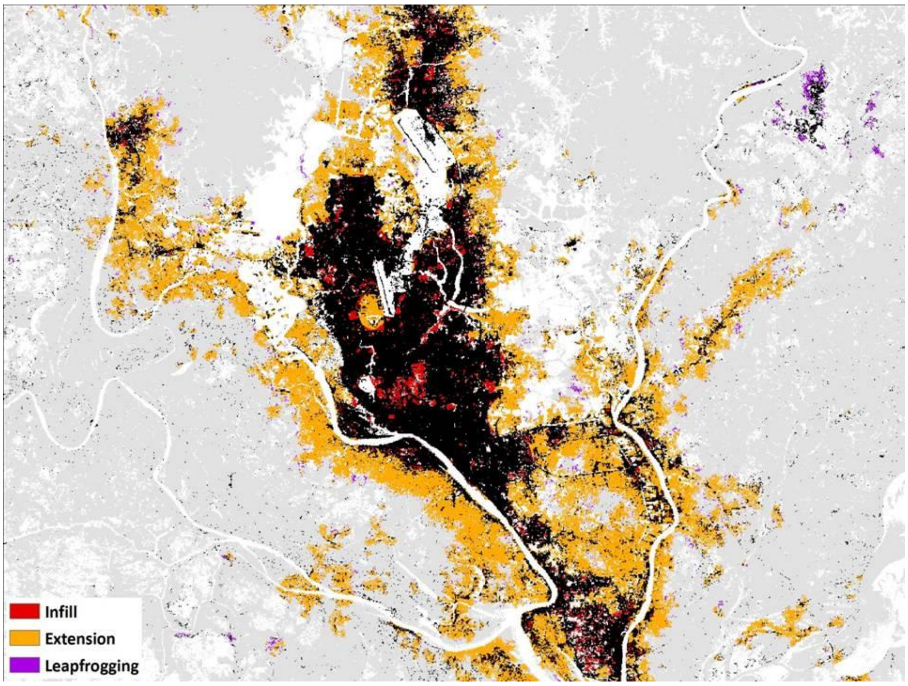


Figure 5. **Business-as-usual urban growth scenario for Dhaka (2005-2060)**

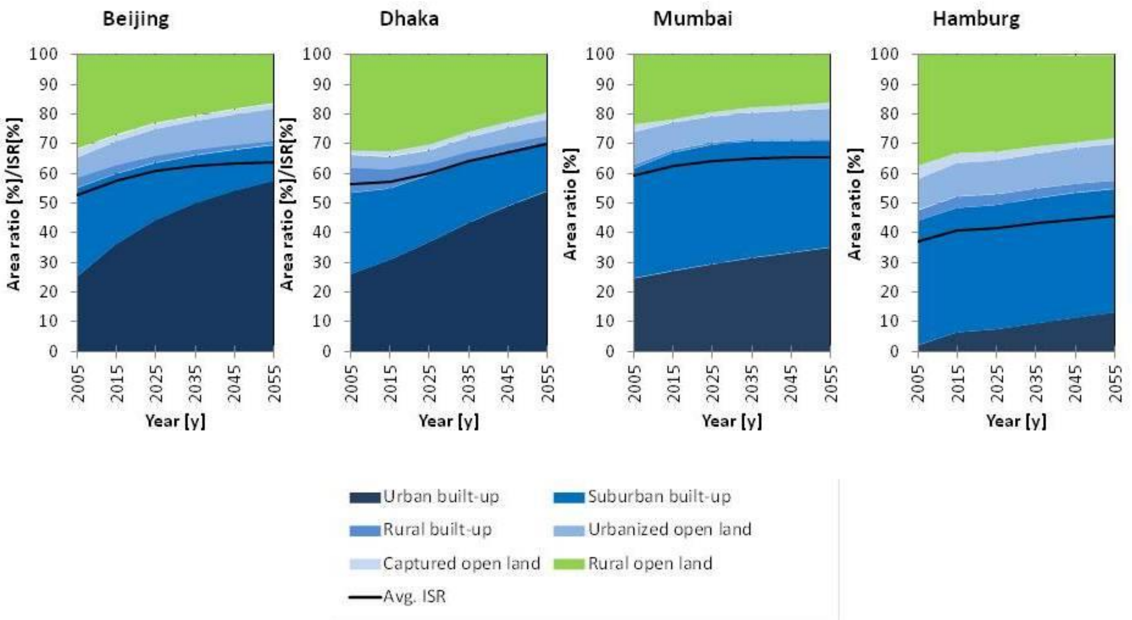


Figure 6. **Proportion of impervious cover for four cities**

3.3 Urban flood modelling

3.3.1 The philosophy behind the urban flood modelling carried out in CORFU

The philosophy behind the urban flood modelling carried out in CORFU was that the flood modelling in all case studies should be based on the same principles i.e. the flood modelling should be consistent, sufficiently accurate and robust. It was decided to go for 1D (one-dimensional) deterministic hydrodynamic model for the description of flows in sewer, urban drainage system and rivers, whereas the surface flooding was decided to be modelled by 2D deterministic hydrodynamic models. The full dynamic interaction between the sewer/urban drainage system/river and the surface flow is then described through a dynamic coupling between the two modelling systems.

It was realized that this decision challenged the perception that such hydroinformatic models could be too difficult to use in developing countries such as Bangladesh and India. No top down decision was made on which specific software should be used for each case study, so during the CORFU project the case studies have implemented a series of hydraulic models for a wide range of applications. The DHI MIKE URBAN and MIKE FLOOD models (Andersen *et al.,* 2004) have been applied to flood modelling in Beijing, Dhaka, Hamburg, Nice, Mumbai and Taipei, whereas the Innovyze InfoWorks model was adopted for the Barcelona case study.

3.3.2 State-of-the-art and a consistent methodology for urban flood modelling

A review was carried out at the beginning of the CORFU project in order to write-up a consistent methodology for the modelling of urban flooding. The-state-of-the art review of urban flood modelling revealed that there was a gap in the suite of urban flood models. None of the urban flood models available at the beginning of CORFU could simulate flooding for a mega city, such as Beijing or Dhaka city. Simulating an entire mega city is needed because during floods the surface water does not necessarily flow in the same direction as the drainage system i.e. it would be wrong to break down the city area down into smaller models that follow the drainage system, as flood water will flow according to the surface topography rather than along the drainage system. Hence, in order to describe the flooding correctly all of the city must be simulated in one go – and after such a simulation localized flood areas can be identified together with the associated drainage systems. As a response to this need a multi-cell urban flood model was developed within CORFU (Hénonin *et al.,* 2013). The multi-cell model adopts a coarse grid for the global model domain of the whole city and a number of refined grids are activated, only when flooding occurs. This kind of simulation provides a quick overview assessment for a large region such as a mega city, which allows a more efficient use of computing resources in hydraulic modelling.

The need for an urban flood model simulation of a whole mega city was highlighted on 21 July 2012, when large parts of Beijing were seriously flooded which caused 57 casualties. The multi-cell model was then setup for Beijing City (area more than 1000 km^2) and the model demonstrated it applicability as it was set-up and it reproduce the observed flood location (Figure 7).

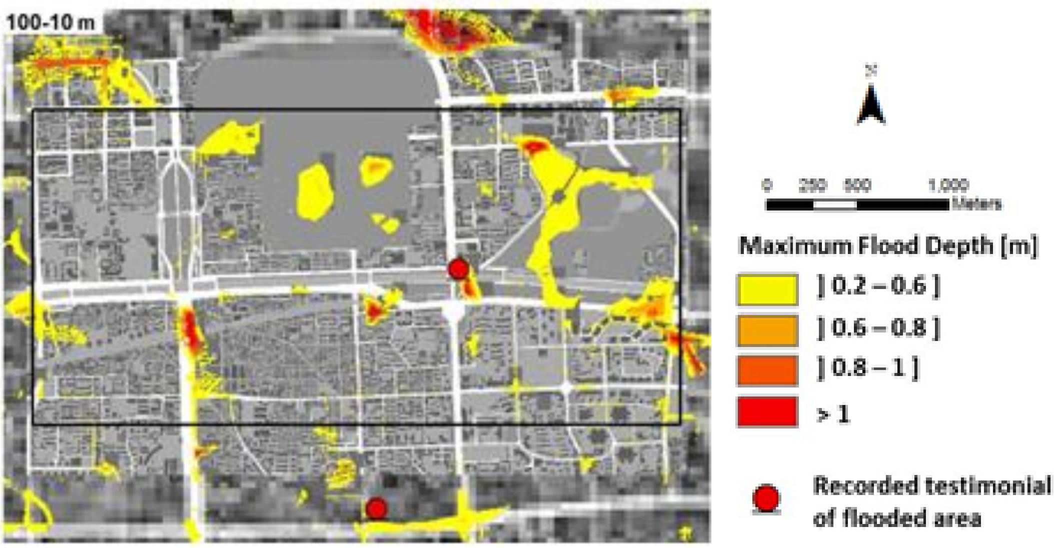
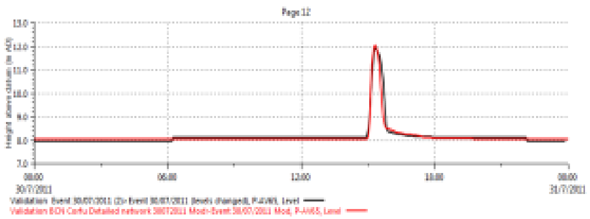


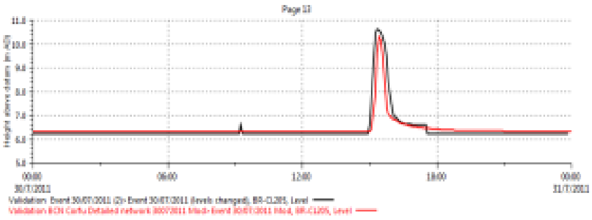
Figure 7. A zoom into the flood map produced for all of Beijing showing flood testimonials (the red spots) and flood depths modelled by the multi-cell model

3.3.3 Calibration of urban flood models

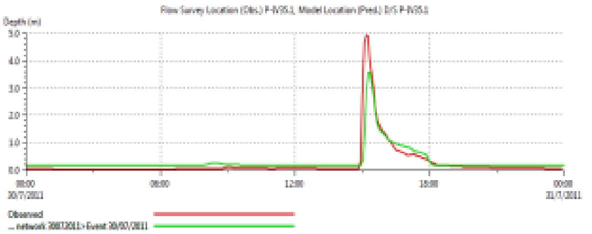
In the past calibration of urban flood model was not described in detail. Calibration guidelines existed for urban sewer and drainage systems running with free surface flow – or running pressurized, whereas nothing existed for calibration and validation of such models for flood events. Guidelines for calibration of urban flood models have been produced during the CORFU project and applied successfully to the Barcelona case study, where the calibration of the 1D/2D flood model was carried out (Russo *et al.,* 2014). Firstly, the pipe flow model was calibrated (Figure 8) and secondly, the flood model was calibrated and compared to real life flood observations (Figure 9).



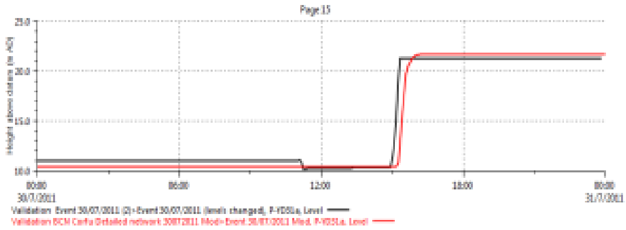
Manhole P-V65



Manhole BR-CL205



Pipe P-IV35.1



Urgell storage tank

Figure 8. Modelling results for the calibration and validation of the pipe system model

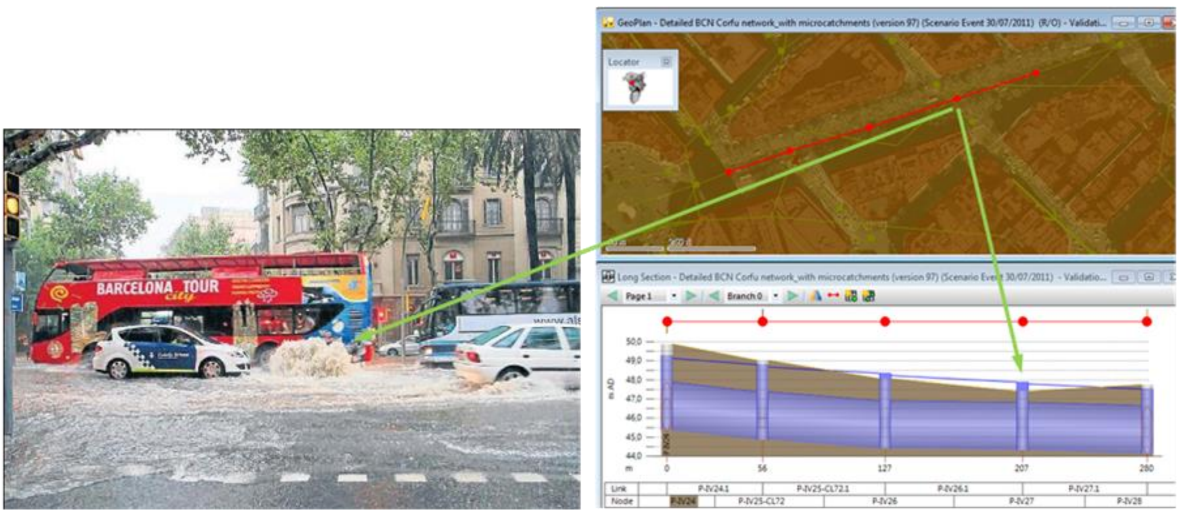


Figure 9. Validation results for the flood model in Barcelona. Location: crossroad between Diagonal Avenue and Casanova Street. Comparison between the profile showing surcharged pipes provided by modelling software and a photo taken during the event of 30 July 2011

3.3.4 Visualization and sharing of flood model results

Flood assessment studies involve the production of flood maps for presenting results to be used as a basis for making decisions ranging from general planning to taking action and more detailed decisions selecting particular mitigation measures to be implemented. Maps are also used for sharing information within institutions during project execution. In CORFU flood maps are also essential for sharing and providing information for activities such as: flood damage assessment, evaluation of flood mitigation measures, etc. Hence, the CORFU flood mapping activities were supported and enhanced by having a central site for dissemination and sharing of maps that is easily accessible not only to those from within CORFU but also from outside. Thus, a GIS-based mapping application was developed to support urban flood assessment activities in the project. The aim was to provide, especially for the CORFU partners and stakeholders in the various case study areas, a tool that they can use to study and understand urban flooding as well as the potential impacts of climate change on flood risk in their areas. The application was put together using ESRI's ArcGIS Online – a cloud-based mapping platform that allows creation, sharing and publication of maps and geo-spatial data online – http://dhigroup.maps.arcgis.com/home/index.html (username = CORFU, password = Rhubarb2014). Figure 10 shows two maps from this data base.

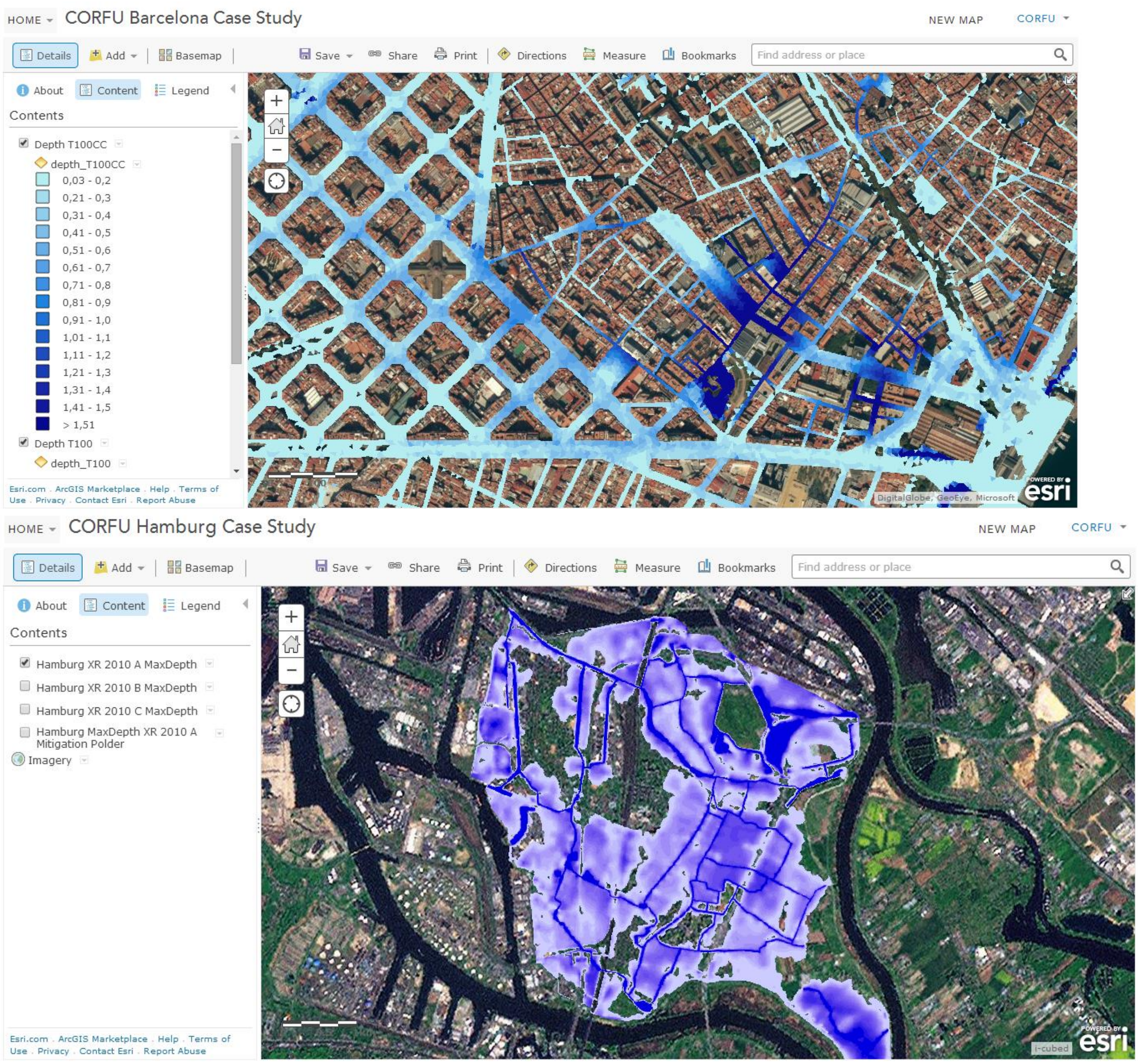


Figure 10. Examples of flood maps created and accessible through the GIS mapping application: Barcelona case study (top) and Hamburg case study (bottom)

3.3.5 Simulation of impacts from climate change and urban growth on flood hazards

The impacts from climate change on flood probability in the seven CORFU case study areas was computed, i.e. the development scenarios defined for the case cities were used. First, the flooding under current conditions has been outlined for the baseline scenarios. Based on the climate change analyses, new flood maps were prepared for the cities, in order to determine the probability and intensity of flooding. Urban growth and urbanization changes and increases the runoff in cities. The main point was that urban growth variables should be represented in the flood models. Hence, a new methodology was developed in order to model the impacts of urban growth on flooding. The urban growth variables were identified and represented as conceptual and physically-based components for the flood modelling. An example of simulated urban growth and subsequent changes in flooding can be seen in Figures 11 and 12.

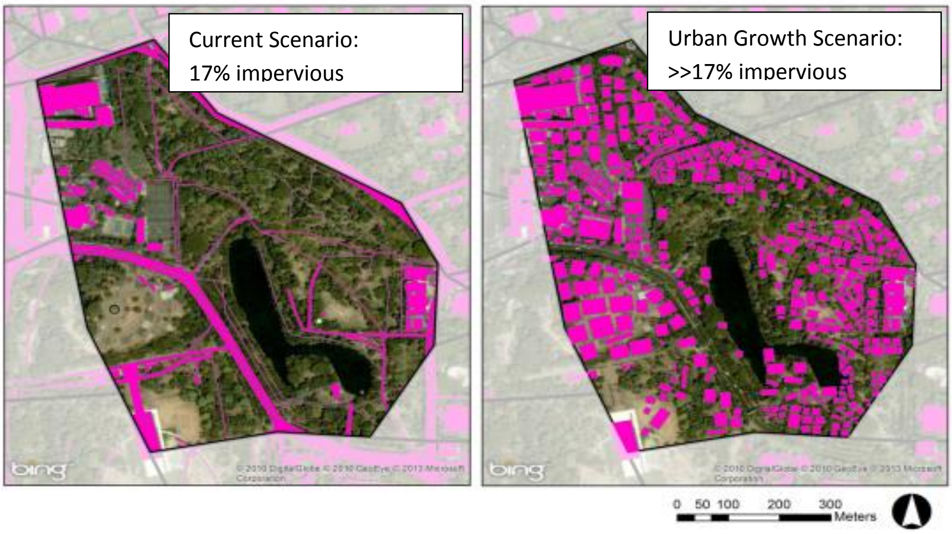


Figure 11. Built-up areas in a catchment for present (left) and future urban growth (right) scenario

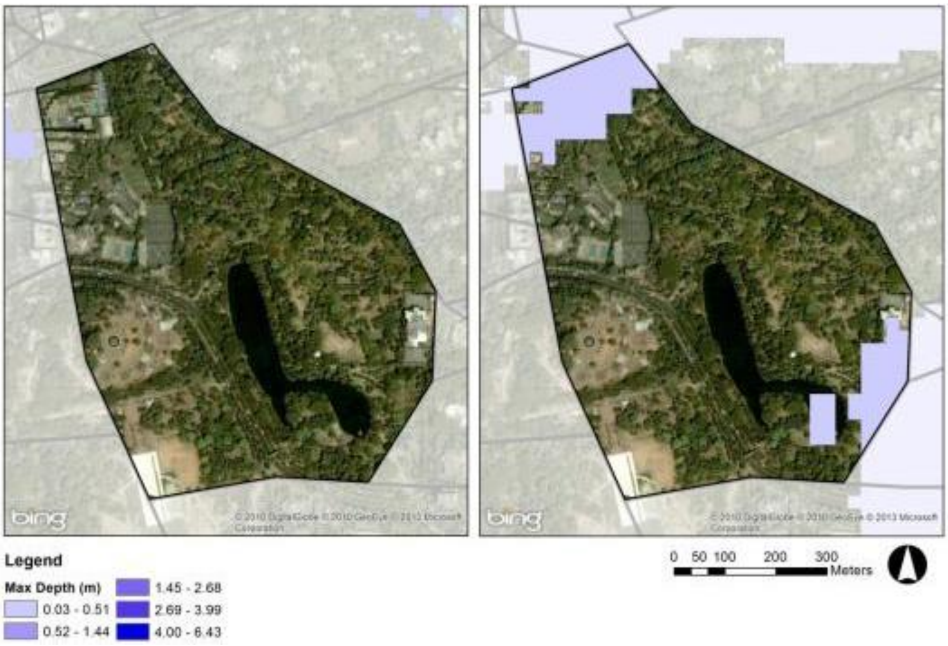


Figure 12. Simulated maximum flooding for current (left) and urban growth (right) scenarios

3.3.6 Real-time forecasting

All urban drainage networks are designed to manage a certain design rainfall. This implies an accepted flood risk for any greater rainfall event. This risk is often underestimated as factors like city growth and climate change are ignored. Even major structural changes cannot guarantee that urban drainage networks would cope with all future rain events. Thus, being able to forecast urban flooding in real-time is one of the main issues of integrated flood risk management and for reduction of flood damages.

At the beginning of the CORFU project the state-of-the-art within real-time forecasting of urban flooding was analysed (Hénonin *et al.,* 2012). The review gave an overview of the current available options for pluvial flood modelling in urban areas, ranging from very fast and empirical and simplistic correlations based on rain measurements – over basic estimations with 1D urban drainage model to detailed flood process representation with 1D-2D hydrodynamic coupled models. Each type of modelling solution was described with pros and cons regarding urban flood analysis.

Further, the potential for real-time urban flood forecasting was explored based on literature and the results from an online worldwide survey with 176 participants. The survey analysed the use of data in urban flood management as well as the perceived challenges in data acquisition and its principal constraints in urban flood modelling (René *et al.,* 2014). It was originally assumed that the lack of real-time urban flood forecasting systems was related to the lack of relevant data. Contrary to this assumption, the study found that a significant number of the participants have used some kind of data and that a possible explanation for so few cases is that urban flood managers and practitioners may not be aware they have the means to make a pluvial flood forecast. This paper highlights that urban flood practitioners can make a flood forecast with the resources currently available.

In CORFU an aim was to setup, test and evaluate state-of-the-art real time urban flood forecast systems for a smaller high tech city and for an Asian mega city. A real time system was setup for the city of Barcelona. It can be seen at: http://www.hydswicast.com/wicast.php/en_US/login/FloodAlert (login: corfu, password: rhubarb). The real time system in Barcelona has demonstrated that it is possible to develop an early warning support system that combines forecasted radar data with a detailed 1D-2D complex model of Barcelona that provides 2 hour forecasted hazard maps in 15 minutes computational time.

A real time system was also setup for Dhaka City. It turned out that the traditional 1D/2D urban flood models are too slow to compute flood forecasts in real time in mega cities. Hence two modelling frameworks for faster urban flood simulation have been developed – a multi-cell framework, which was tested in Beijing and a diffusive wave modelling approach was developed and tested for Dhaka. The diffusive model (*Hénonin et al.,* 2014) uses simplified shallow water equations to improve modelling efficiency without sacrificing the accuracy significantly. Both new modelling approaches have by the end of the projects been setup for Dhaka and at present they both produce flood forecasts. The real time forecasts of rainfall and urban flooding can be seen at:
http://flooddev.dhigroup.com//DashboardEngine.aspx?DashboardID=FLOOD_Dhaka\\Forecast_STORM
http://flooddev.dhigroup.com//DashboardEngine.aspx?DashboardID=FLOOD_Dhaka\\Forecast_Model
The setup of the two real time systems for Dhaka has demonstrated that it technically it is possible to develop an early warning support system for any city around the World based on a numerical weather prediction model, which in real time feeds data to an urban flooding model. Finally, a framework for probabilistic flood forecasts have been developed and reported in scientific papers. Next step after the CORFU project will be to apply and evaluate the probabilistic flood forecasts in real time urban flood forecast systems.

3.4 Impact assessment

The CORFU project developed a flood damage assessment framework to evaluate various impacts of flooding. This framework was based on known principles and methodologies (Hammond et al., 2014), and the original tools for calculating direct damage on buildings in mega cities have been developed as well as original methodologies for some specific impacts.

3.4.1 Depth-damage curves for case study cities

To calculate the direct damage to buildings, knowledge of the relationships between the hazard and the damage for various building types with different uses is required. All CORFU case study cities have established their own locally relevant flood depth-damage curves (DDCs) for different building types. This work began by using curves that were available in the literature, but where they were either absent or insufficient, field surveys were conducted to collect information, or a tool known as as FloReTo was used (Manojlovic *et al.,* 2010). This latter tool allows users to develop flood damage functions by combining information on the building materials and the typical contents.

Establishment of locally relevant DDC-s is a major legacy of CORFU because these up-to-date curves are now available for future projects. An example of depth-damage curves is shown in Figure 13.

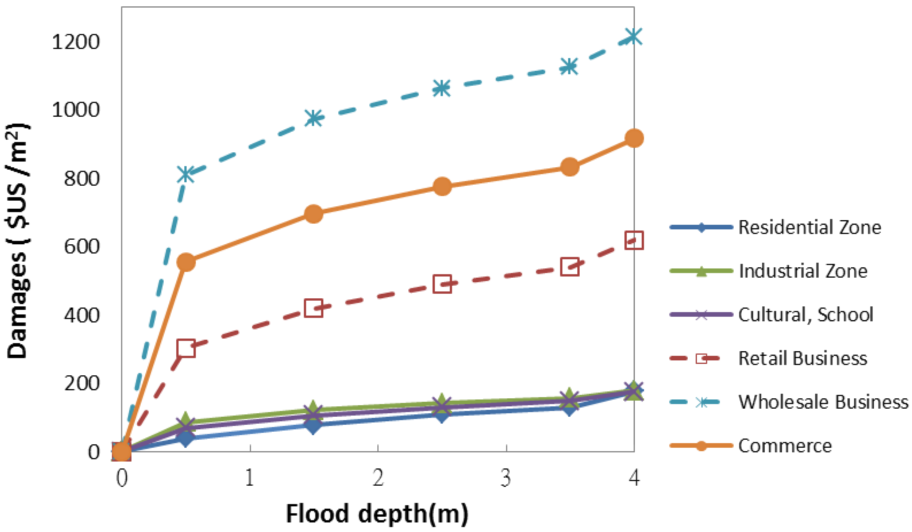


Figure 13. Depth damage curves for buildings in different zones in Taipei

3.4.2 Impact assessment tool

Direct damage to buildings was then computed by overlaying flood maps (for particular rainfall events) with building information maps, and linking them through damage curves. When summed over the area, the flood damage for a single event, under a particular scenario of climate change and socio-economic conditions, with or without mitigation measures, can be estimated. By doing this for several events of different likelihoods, the Expected Annual Damage (EAD) can be calculated. This figure is a key statistic that can be used in the analysis of the costs and benefits of implementing different resilience strategies.

In order to be able to do this in a consistent manner for all seven CORFU case studies, a GIS-based flood damage assessment tool was developed, which computes the flood impact at various spatial scales, using different data formats and resolutions, and a wide range of scenarios of growth and measures (Chen et al, 2014). This was challenging because of the large number of buildings involved (over 200,000 in some case studies), and due to the fact that different flood models used in the project use different types of computation grid (either regular grid or unstructured mesh) and treat water in building in different ways. This tool can be applied to calculate flood damage, with only a minimum amount of training. The tool has been shown to evaluate the flood damage efficiently across all the case studies, including some of the very complex situation found in some mega cities in Asia, with detailed analysis for individual buildings. The tool can read the simulation results from flood models either directly or to use mesh information to calculate the flood damage. An example of the tool's application is given in Figures 14 and 15.

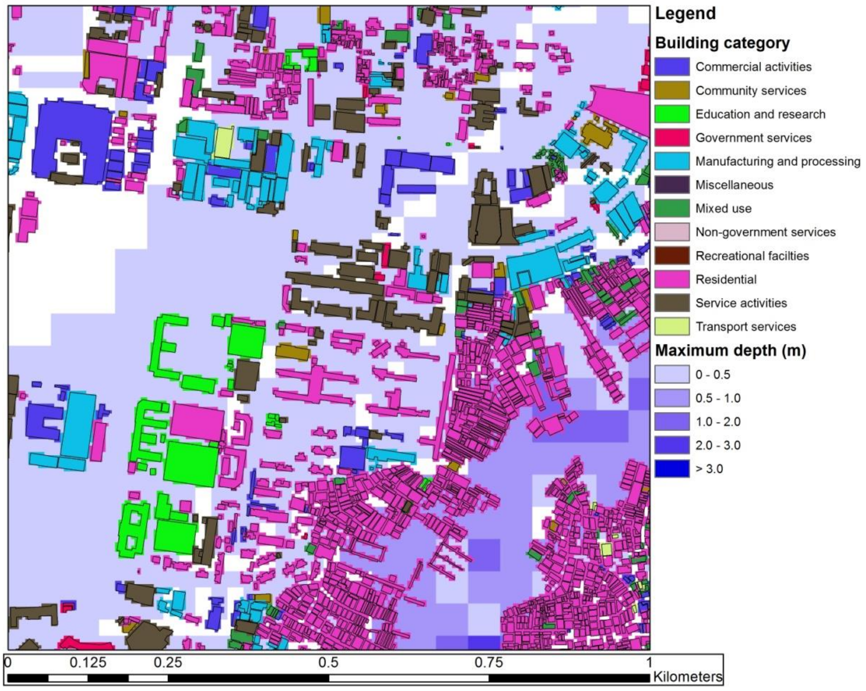


Figure 14. Flood map of central Dhaka with building classifications

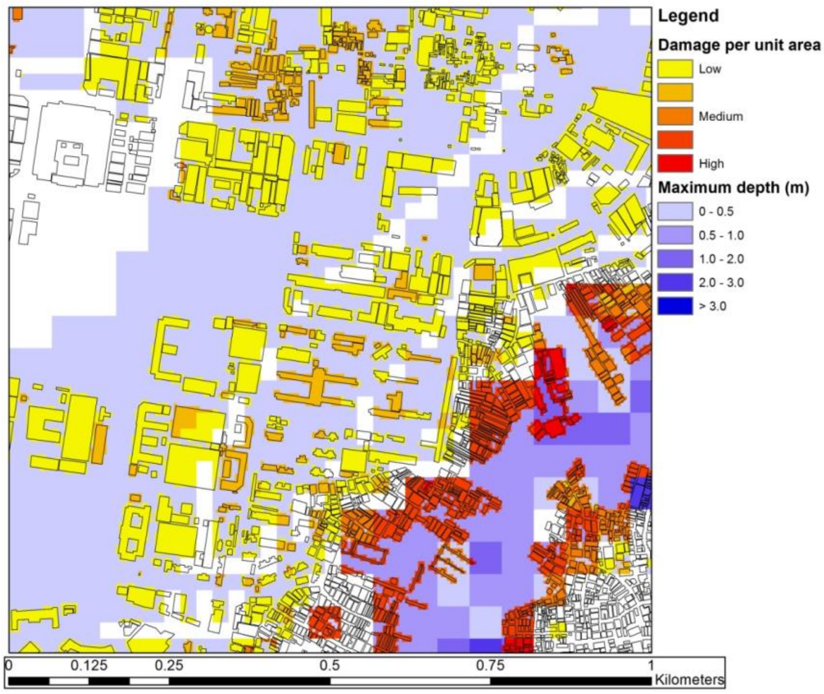


Figure 15. Damage per unit building for Central Dhaka

In this process, there is no real building information for the new urbanised area in the far future. Therefore, the damage assessment would rely on the urban growth projections. The CORFU damage assessment tool can associate the building uses data with the projected land cover classes from an urban growth model such that the depth-damage curves for building uses can be translated into curves for land cover classes. That way, with the new curves and the projections of future urban growth scenarios, the tool can evaluate the flood damage in the future.

For the cost-effectiveness or the cost-benefit analysis, simulations of events with different probabilities would be essential. Instead of estimating the damage for individual events one-by-one, the tool can assess a pre-set series of events and calculate the expected annual damage in one go.

3.4.3 Input/Output models

In the Hamburg case study, attention was given to the indirect costs of flooding, which occur through knock-on effects on the wider economy. These costs vary in time and result from complex relationships between different businesses. A modelling framework, known as Input-Output modelling was developed to estimate these indirect costs. This framework considers the economy as a complex system of interlinked sectors with flows of inputs and outputs between them and total demands for goods and services. This modelling framework can represent how changes to one sector can adversely affect other sectors, as well as the speed of recovery. This approach was applied to assess the effects of a simulated flood event in Wilhelmsburg in Hamburg, and it was found that the total cost of flooding could be significantly higher than the direct costs alone, and it could take up to two years for the economy to recover.

3.4.4 Health impacts

In combined sewer systems, where sewage (domestic, commercial and industrial) combines with storm water and surcharges onto the surface, people are potentially exposed to water that contains a range of pathogens that can cause a number of diseases like cholera and diarrhoea. Although this problem can arise in any urban environment, it is particularly severe in cities where high population density is combined with inadequate drainage systems and monsoon rains. In Dhaka, the probability of contracting cholera can be as high as 1/1000 (and higher for diarrhoea) during critical periods.

A particularly novel and exciting part of the CORFU project has been the development of an original methodology for assessing the health impacts of flooding. We developed what is believed to be the first model that uses a combination of deterministic hydraulic modelling of flooding and transport and mixing of pollutants in flood water that can simulate concentrations of pathogens (Figure 16), on the one hand, and, on the other hand, data on human vulnerability through dose-response functions. This approach enables estimation of the risk of contracting cholera for several relatively homogeneous social categories, e.g. adults in middle-class areas and children in slum areas.

The framework to estimate these impacts was adapted from the process for Quantitative Microbial Risk Assessment (QMRA). This methodology consists of four steps: a) hazard identification, b) hazard characterisation (or dose-response assessment), c) exposure assessment, d) risk characterisation.

In order to calibrate the model, data was taken from literature reviews and field measurements. The CORFU team worked with the International Centre for Diarrhoeal Disease Research, Bangladesh to take samples of surface water during dry weather and during flooding conditions at various locations around Dhaka. The novel modelling approach defines a consistent framework for analysing the health risks in association with urban flooding. The risk of contracting cholera was estimated for three locations in Dhaka, and these results were found to be close agreement with the overall incidence of severe cholera in Dhaka (Mark et al, 2014).

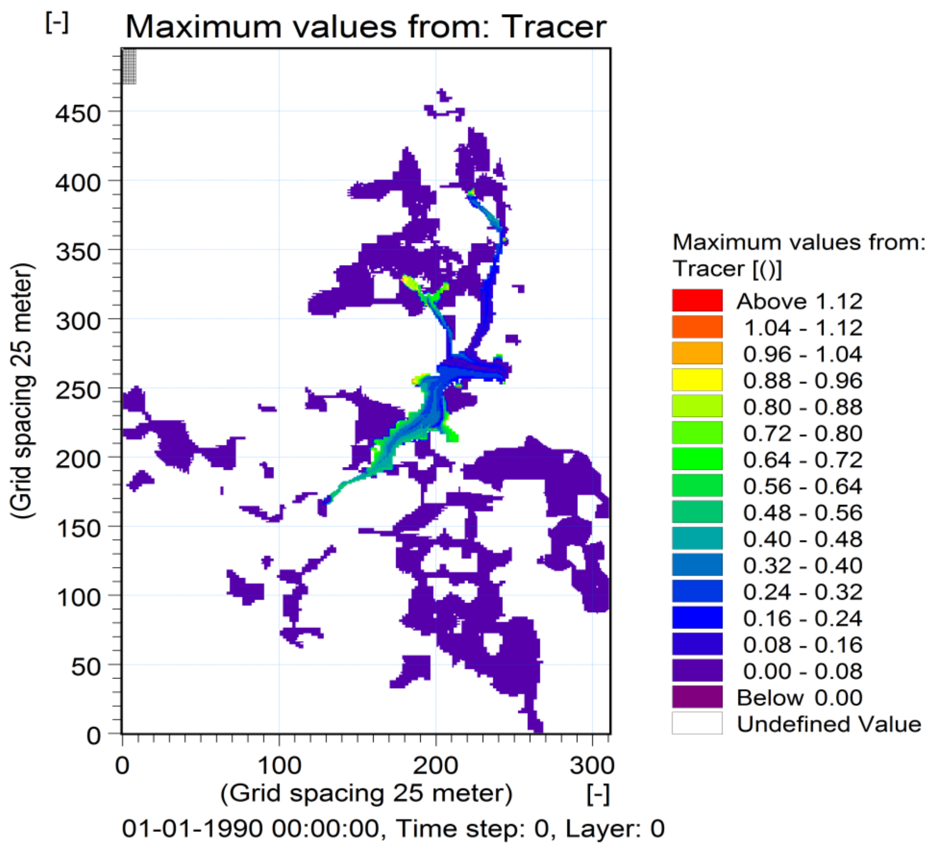


Figure 16. Simulated pollution for the flood in Dhaka in September 2004. The map shows the dilution factor of wastewater concentration in flood water

Other flood impacts that were specifically considered only in some CORFU case studies include the safety of pedestrians on the street during flooding, for which laboratory experiments have been conducted in Barcelona to investigate the flow conditions that may put humans in danger.

3.5 Social capacity

3.5.1 Investigations of the protection motivation

Grothmann and Reusswig (2006) utilised Protection Motivation Theory (PMT) to assess the pathway between perception of flood risk (threat appraisal), assessment of response options (coping appraisal) and adoption of flood protective (preparedness) measures in the city of Cologne (Germany). Utilising this PMT framework, investigations of the protection motivation in the case studies of Hamburg (Wilhelmsburg) and Dhaka (Badda) were carried out. As to be expected the frequency of flood events in the case studies had a big influence on the flood experience of the communities researched. Flood experience in turn affected their perceptions of the risk, perceptions on need to and ability to prepare and cope with potential flood risks, and therefore, their protection motivation. As such a low protection motivation was found in Hamburg, where the last big flood experience was in 1962 and a high protection motivation was found in Dhaka, where flooding occurs on an annual basis. PMT analysis and determination of protection motivation provided a good indicator of the likelihood that local communities will have adopted hazard adaptations to help limit potential flood damages.

3.5.2 Awareness, Relationships and Livelihood (ARL) framework

In order to enable coping capacity to be included in the flood damage estimates being carried out in the CORFU case studies, three primary variables representing the cornerstones to coping capacity were identified: Awareness, Relationships and Livelihood.

Awareness is the collective social (or individual) cognisance that a community (or individual) has of the flood risk they are exposed to and the strategies for preparing or mitigating for potential flood events. Three secondary variables were identified for awareness: experience, education and environmental clues. Relationships represent the key links and interactions that exist between individuals, communities and government agents that create avenues of co-operation and communication in the event of a flood event. Three secondary variables were identified for the assessment of relationships in the case studies: kin & friendship networks, community networks, and formal networks. Livelihood is seen as the means by which (or ability to) individuals or communities obtain the resources that sustain their daily existences in the event of a flood and/or disaster. The three assessment secondary variables identified were: resources (livelihood assets), flexibility and health.

With these primary and secondary variables an assessment framework was developed in order to assess or gain understanding around coping capacity in the different CORFU cities. This framework was then termed the ARL Framework because of its three primary variables (Awareness, Relationships and Livelihood). The assessment part of this framework is qualitative and utilises key questions developed around important aspects of the various secondary variables, to assess the strength and efficiency of the secondary and primary variables. A scoring scale was constructed around the five-point scale that Twigg (2009) developed to indicate the milestone levels towards the creation of a 'culture of safety'. The Hyogo Framework for Action has put forward the 'culture of safety' ideal as a goal in resilience efforts. A score scale ranging from 1-5 where 1 represents a low level of capacity or level 1 in Twigg's scale, and 5 representing a high level of capacity or communities with strong aspects of safety culture towards flooding (i.e. Level 5).

Field trips of two months and three months durations were taken in Hamburg and Dhaka, respectively. During these trips interviews and observations were made in vulnerable areas and with vulnerable communities. In addition the investigations were carried out to determine key literature and policy around the issue of flood risk perception and coping capacity in these case studies.

Results show that neither case study achieved a score higher than 3 for any of their primary variables, which indicates that in both cities mitigation measures are required to strengthen the coping capacity vulnerable communities have to flooding. It is concluded that neither city can be truly seen as more resilient than the other, although given the high experience levels in Dhaka, local communities have a much high understanding of what is involved and what can happen then in Hamburg. However, in both cities there are clear areas that require mitigation action in order to enable local communities to cope with flooding and minimize damage. The ARL Framework have to be adapted based on cultural contexts, but at the present provides a useful tool, by which to assess coping capacity of urban communities vulnerable to flooding, and identify areas in which mitigation actions are required to improve coping capacity.

3.6 Flood risk management strategies

The ambition of CORFU was to elaborate and develop new concepts that could be used in order to enrich and improve flood management strategies in urban environments. The application of the developed methods and tools on various Asian and European case studies was used as a validation exercise that has successfully demonstrated the universality of the developed concepts.

3.6.1 Definition of urban systems and scales

One of the major challenges was to address the complexity of urban environments and to integrate such complexity in a new methodology able to generate efficient flood management strategy. The starting point is the definition of a city and the chosen option was to use the functional analysis. A city is the spatial expression of a system based on functional actions, processes and operations that must be performed in order to achieve addressed outputs. Performing activities such as transportation of people, assets, food, providing residential areas, energy supplies to residential areas, etc. are some of addressed outputs that urban systems have to achieve. Looking at a city at different spatial scales increases the ability to assess flooding issues. The smallest "unit" of an urban system is represented by an individual parcel. A group of parcels surrounded by streets represent a block. The third level of organization represents a district (group of blocks or administrative unit) and the final organization ring is the city itself (Batica, Gourbesville 2011) (Figure 17).

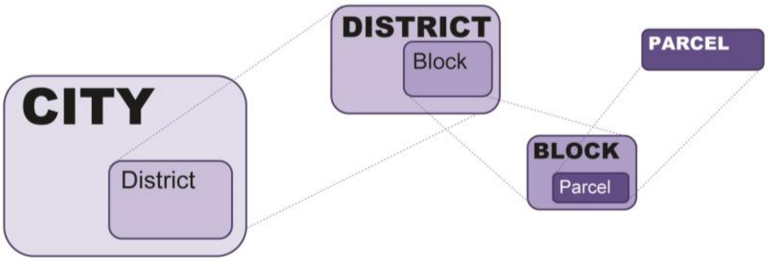


Figure 17. City system represented through scales (city, district, block and parcel)

Urban functions of a city are defined as components with their spatial extensions that urban system need to provide as fundamental needs to residents. Eight main urban functions have been identified and represent the answer to the residents' needs. These are: *housing, education, food supply, working, safety and governance, health, leisure and tourism, religious areas.*

Connectivity between physical components hosting the various functions is done through services. Services in the city give functionality to urban features (e.g. the function of a house is to provide space for living). Graphically urban functions and services are presented in Figure 18. The urban functions are components, and services are presented as fluxes in an urban system.

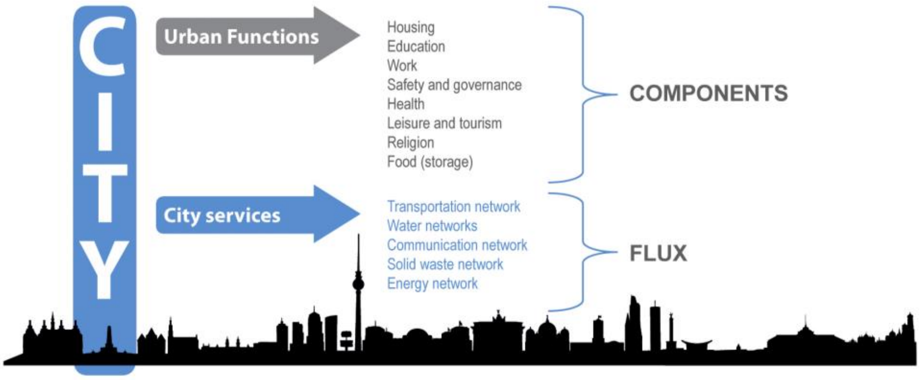


Figure 18. Mapping of the city according to urban functions and services

Strategic urban functions include: power stations, water treatment plants, control centre of public transport, waste water treatment plants, fire fighting stations and hospitals. The failure of strategic urban functions triggers major problems for society and the economy. The spatial identification of vital functions and services allows initiating the process of flood management strategy development.

3.6.2 Assessing flood risk management – maturity levels

The approach to assess defined strategies and evaluate the efficiency of associated measures and actions in case studies was based on the *maturity level* concept, which is being utilized increasingly to map out logical ways to improve an organization's services. Maturity refers to the degree that an organization consistently carries out processes that are documented, managed, measured, controlled and continuously improved (CMMIProduct Team, 2002). This means that is possible to 'measure' the level of coordination, integration and implementation of existing frameworks. The method is based on evaluation of maturity of an individual flood risk management framework and view towards full integration and implementation within urban system. The principle is to compare elements in the different frameworks with a reference level which characterizes the complexity and the efficiency of the implemented flood risk management strategy or measure. Maturity levels are determined according to reference levels. Five different levels of maturity have been defined:

- The first one is an ad-hoc where there is little risk perception. The actions are taken in an informal way. The implementation of flood risk management strategies is not assessed for the informal maturity level. Actions are taken without institutional coordination.
- Second level of maturity is basic. Here the knowledge is present but just for a specific event. Procedures within flood management cycle are starting to be identified. The risk is known just for the particular events. The reliance on knowledge of individuals is high. The actions taken to manage the risk have low institutional coordination.
- Initial maturity represents implemented flood risk management policies where institutional coordination is present. The coordination is under city governance level. Flood insurance schemes are available as well as flood maps.
- Coordinated maturity level represents a state where flood risks have been fully identified. Flood risk management policy and procedures integrate best practice. FRM tools and templates are available to stakeholders. FRM implementation plan exists with highly applied capacity building of human resources. Insurance schemes exist and if there is a need real time system.
- The fifth level of maturity converges to resilience. On this level the best practice is not just a part of FRM framework but it is also fully integrated. The attitude of learning from past events is dominant. The flood risk management framework is addressing main problems.

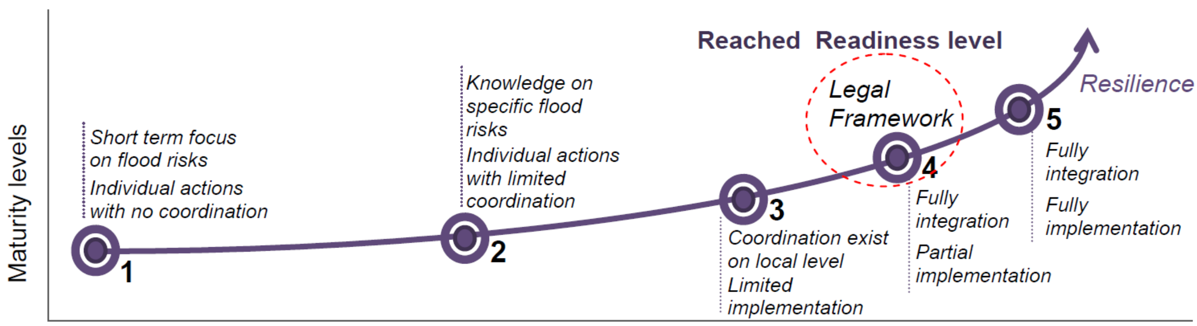


Figure 19. Theoretical curve for different maturity levels

The maturity level of flood risk management frameworks in CORFU case study cities varied. Figure 20 reflects the situation observed in each location and provides a global overview on the development of flood management strategies.

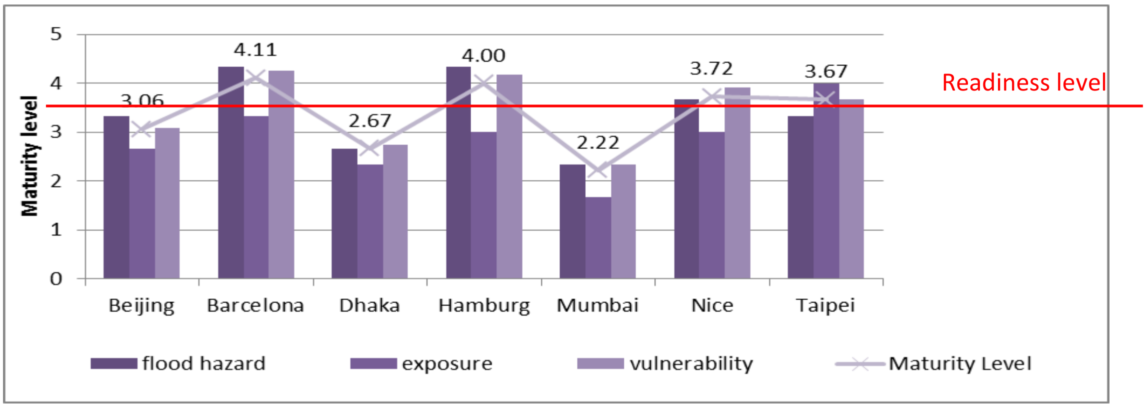


Figure 20. Maturity level assessment for CORFU case study cities

3.6.3 Assessing resilience – flood resilience index (FRI)

One of the key objectives was to establish a methodology for assessing the resilience dimension of each urban system regarding floods issues. The selected approach was to develop the Flood Resilience Index (FRI), which is represented as a level of flood resilience assessment in analysed area and for certain flood characteristics. The proposed methodology is set to take into account different spatial scales: from parcel to city scale. The assessment of flood resilience on parcel scale is taking into account implementation of all measures that are protecting a 'house from water' or provide minimized damages and rapid retrieve of flood waters in cases when water is in the house. This is done with evaluation of external and internal requirements for the urban function. In this way the Flood Resilience Index (FRI) is adapted to the parcel scale. FRI evaluation for the city and district and block scale takes into account five dimensions: natural, physical, economic, social and institutional.

The Flood Resilience Index appears as a central element for defining the flood management strategy because it allows evaluating the various options that could be proposed according to the issues related to urban development/planning (including city regeneration) or to climate change scenarios.

Each building or parcel can be associated with one of the defined urban functions and connected to services that are mainly defined as external dependencies. The main purpose of the FRI is to investigate "if the particular function is operational during and after the flood?". The flood resilience on building level is expressed as a function of external requirements (energy, water, waste, communication, transport) and internal requirements (food availability, occupation of urban function, access to the urban function) and weights defined during evaluation. Different levels of functioning during and after flooding processes indicate a different level of flood resilience. In this context the set of two requirements stands as an adequate instrument to measure a functionality of urban function. Setting up availability level with respect to different flooding conditions there are sufficient data to measure flood resilience for urban function. Different levels of availability are marked from 0 where the requirement is not provided to 5 where the requirement is fully provided. Guidance for weights is set to respond to different flood characteristics and provide users to set the relevance and importance to requirements for particular flood event. The weights are set based on the environmental and cost benefit criteria. This is a subjective characteristic of the methodology.

The FRI represents overall flood resilience for different scales of urban systems. The assessment of FRI on the parcel and block scale is focused on the building while for the bigger scales the evaluation of FRI is done through five dimensions describing physical and social attributes of urban systems (Figure 21). Evaluation of whether the urban community is able to accept certain disturbance and recover from it was done after the reassessment of FRI, after the implementation of the measures.

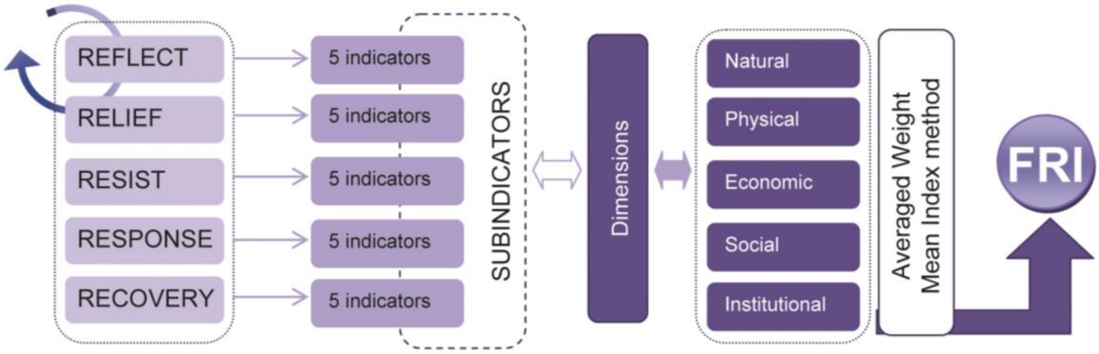


Figure 21. Schematic presentation of FRI evaluation of city/district scale

The construction of a rating scale with weights for all variables was done using weighted indexes. Aggregate Weighted Mean Index or AWMI (for each dimension) was calculated with the Weighted Mean Index (WMI) method (Shaw and IEDM Team, 2009). The calculated averaged WMI of one dimension is the Flood Resilience Index for that dimension. Rating scales have assigned numbers 1, 2, 3, 4, 5 corresponding to *very low, low, medium, and high* respectively.

The application of the developed methodology has been realised at various scale: from parcel to city and for various scenarios taking into account urban development and climate change issues. The application was successful at the various locations and have provided clear added value within the process of flood management strategy development.

The evaluation of FRI on property scale is done for the whole Nice case study. The whole urban system is mapped with eight urban functions and city services. For each urban function the FRI is evaluated (evaluation of external and internal requirements) with respect to produced flood map and presented using GIS. Figure 22 shows the mapping of FRI for each urban function.

Figure 22. FRI mapping at parcel scale, Nice case study

The evaluation process for the flood resilience assessment on block scale takes into account the dominant urban function for the chosen block scale. The chosen block shown in Figure 23 is located in old part of case study. For the dominant urban function the external and internal requirements are evaluated for the particular flood characteristics. The values are presented in Figure 24.

Figure 23. Chosen block in the old city in Nice

FRI evaluation on city scale focuses on five dimensions of urban system: (i) natural, (ii) physical, (iii) economic, (iv) social and (v) institutional. The presented evaluation follow the present scenario with existing land use and present economic, social and institutional condition – BAU scenario (Figure 24 left). The result of FRI evaluation at city scale (Figure 24 right) has five dimension indices (one for each dimension). This way of evaluation and presentation provide a fast and efficient procedure for mapping the gaps in existing structure of urban systems. By locating the gaps in each dimension the way towards increase of flood resilience levels is more efficient.

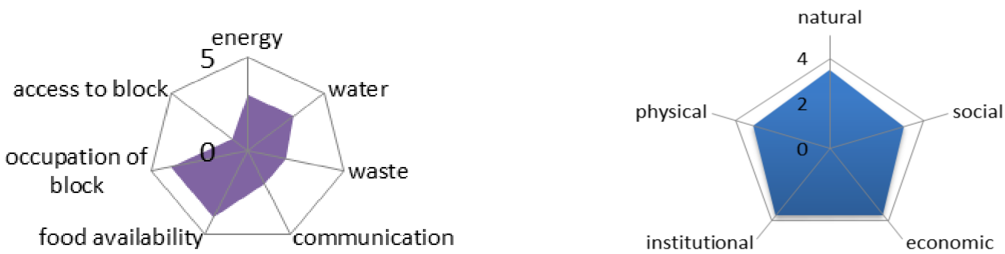


Figure 24. FRI at the block scale (left); FRI at the city scale (right)

3.7 Concluding remarks

This section has presented the main scientific and technological results through highlights from various strands of research and with a selection of illustrative examples from all seven case studies. This is a small cross-section of key results, details of which are given in project deliverables (with cumulative length of over 2,500 pages, downloadable from www.corfu7.eu/results).

Novel *modelling technologies* developed within CORFU include the urban growth model, the multi-cell approach to flood modelling in mega cities, real-time forecasting systems and the health impact model.

New *tools, databases and web-based systems* created in CORFU include the impact assessment tool, original depth-damage curves for all case study cities, a web-based GIS platform with flood and damage modelling results from case studies, web-based systems for real-time flood modelling and the 2D tool for simulation of transport and mixing of pollutants in urban flood water.

Methodologies that have been investigated and implemented in an original manner in CORFU case studies include looking at the impact of economic growth on development scenarios relevant for flood risk management, consistent methodology for urban flood modelling, an ARL framework, assessment of flood risk management strategies using maturity levels and assessing system resilience through a new flood resilience index.

Common for all outputs presented here was that they brought novel methodologies and models into the DPSIR framework, which was then implemented in the case studies. Application to case studies involved variations in scale, focus and level of detail, depending on specific flooding problems, data availability and the adopted development scenarios. That has demonstrated the generic nature of the developed concepts, which enables upscaling from more detailed scales to the city scale.

The key lesson learned from the simulations carried out in CORFU case studies are that advanced modelling of urban flooding is feasible anywhere and can provide a sound basis for the consistent analysis of flood damages and mitigation measures:

- The work done in Barcelona, Hamburg and Nice involved various applications with high resolution data that was already available at the project kick off (e.g. Helmers *et al.,* 2014; Russo *et al.,* 2014).
- On the other hand, the Dhaka case demonstrated that the Bangladeshi partner could progress modelling and analyses as far as the European partners could and beyond, even though Dhaka is a fast growing mega city in the developing world where comprehensive data sets were not available at the start of the project (Mark *et al.,* 2014).
- In Beijing, data confidentiality was an issue and CORFU staff had to be physically present in Beijing in order be able to work on that case study, i.e. no data related to urban flooding could be sent to project partners outside China. However, this case study showed how good research can make significant impact – as the very convincing CORFU results from Beijing were instrumental in changing the Chinese national guidelines for urban flood management (General Office of the State Council of the People's Republic of China, 2013).
- The Mumbai case study did not get very far in terms of urban flood modelling, flood damage analyses and testing of mitigation measures. This case study implemented traditional river modelling well, but when it came to urban flood modelling local authorities declined to make the existing data and terrain models available. Hence, flood risk assessment there was mainly based on expert judgment rather than on state-of-the-art urban flood models.
- The Taipei case study proved that an associated partner – just by having access to the tools and reports and by participating in project meetings – can successfully make use of the CORFU research and reach the same high level of urban flood analysis as in other cities.

CORFU was a collaborative research programme in the sense that investigations always involved both local case study partners and the consortium partners who were focussed on the development of novel methods. Through these interactions the former had opportunities to take up the cutting edge science, and the latter were able to test the new tools on the real world problems. This process was highly beneficial for European and Asian partners and ultimately has led to the improvement of flood resilience and flood risk management practices in case study areas and beyond.

3.8 Future research and the way forward

The lessons learned and the recommended actions on how to improve resilience in urban areas can serve as a road map for administrations and responsible authorities at different levels in both Europe and Asia. Also, the activities triggered and conducted in CORFU in Dhaka can be taken as a motivation for other cities in the developing world with limited budgets, to aspire to use up-to-date methods and tools to improve their flood resilience.

A challenge within urban flooding is the documentation of the flood extent after a flood. During CORFU, photos and videos records from local spots were made in some cities and that provided very good data for verification of models at specific locations (this was particularly effective in Barcelona). In addition, the use of satellite images was investigated to capture full extent of floods in cities. This was not successful because either satellite images were not produced during the flood, or because the pictures only showed clouds covering urban areas. In order to move forward with observation of urban flooding it is suggested to test the use of low-flying drones to shoot geo-referenced images of floods or to enhance a new generation of satellites which can map water surfaces through clouds.

CORFU demonstrated that the linkages between urban growth and its potential effects on urban flooding provide a powerful tool for urban planners to plan sustainable growth of cities. At present, some of the predictions of economic growth are not directly taken into account in the predictions of urban growth. Hence the urban growth models could be improved by stronger links with economic development models, to provide better estimates of growth and subsequent urban flooding.

During CORFU several real-time urban flood forecast systems were developed, but only few minor relevant floods took place, therefore the material for evaluating the performance of these systems is still sparse. The real-time systems developed in CORFU will be maintained and experiences will be gathered, hence forming a science base for evaluation and further development of these systems.

CORFU research has opened new avenues in two specific subjects. The health impact model could be further enhanced by testing and by combining modelling of mixing of pollutants from sewer overflows in urban areas with population data, Monte-Carlo simulation and looking at measures to reduce unwanted effects. Impacts of flooding on traffic could be further studied by coupling dynamic flood maps with micro simulation of traffic and analysing economic losses, off-line and in real time. We should also know more about mapping of other indirect and intangible damages.

Another area where CORFU has identified a research need that should be addressed in the consequent research initiatives is better integration of social aspects and models with the hydrodynamic and impact assessment modelling tools. This obstacle is likely to be overcome by utilizing the agent based modelling technology that enables combinations of heterogeneous agents i.e. elements of the urban environment. Future research should also be directed towards the holistic approaches focusing on complex interactions within the DPSIR framework.

The Flood Resilience Index is now used by different professionals in their daily activities related to urban planning and urban development, which has generated a growing interest from architects in the resilience concept and its integration in urban design. This concept has also attracted interest from various international bodies including the World Meteorological Organisation (WMO) who are considering endorsing the tool and promoting it internationally. The development of the urban resilience concept could be extended to other natural hazards and integrated with specific dimensions of the five main services within cities – water, energy, transport, waste management, communication networks and transportation.

4 Potential impact, main dissemination activities and exploitation of results

4.1 CORFU impact

4.1.1 Innovation

Key innovations introduced by the CORFU project can be summarised as follows:

- A novel approach to modelling of *urban growth* – a Bayesian probabilistic optimisation algorithm based on the use historic land cover maps taken from satellite data combined with thematic maps that include information on factors such as the topography, slopes, proximity to main roads and distance to economic hubs such as central business districts.
- A new *multi-cell approach* to simulation of urban flooding in mega cities with typical catchment size of 1,000km^2, which adopts a coarse grid for the global model domain of the whole city and refined grids are activated only when flooding occurs, thus enabling sufficiently efficient simulation of urban flooding on a large scale.
- The first *health impact model* that uses a combination of deterministic hydraulic modelling of transport and mixing of pollutants in flood water to predict their concentrations, and the data on human vulnerability through dose-response functions, enabling estimation of the risk of contracting diarrhoea and cholera for different social categories.
- A new *Flood Resilience Index* (FRI) represented as a level of flood resilience assessment in an analysed area and for certain flood characteristics, which takes into account different spatial scales from parcel to city scale, by evaluating external and internal requirements for urban functions.
- A *parallel study* of flood risk management problems in seven big cities in different climatic and socio-economic systems, through a consistent application of the DPSIR framework, which – in addition to the above highlighted novel methodologies – brought about valuable experience in the applicability of modern methods in different conditions.

These innovations that were combined within CORFU enabled scientific progress that will lead to further developments in various subject areas, on the one hand, and on the other hand, have led to improvements in flood management practices in case study cities.

4.1.2 Contribution to standards

The biggest single impact of CORFU in terms of redefinition of standards is the Guidelines for design of urban drainage systems and flood management in China, which were brought about as a direct consequence of our research. This document – which is now an official design guideline in that country – has huge financial implications having in mind the rate of development of new cities in China. A small change in the return period of the design storm brings big increase in investment levels, and big saving in potential flood damage.

Parallel to that, urban flood modelling practice in China has improved dramatically compared to the pre-CORFU period when state-of-the-art urban flood modelling was rare. As a direct consequence of the influence of CORFU, a significant number of professional flood modelling software licences have been acquired by various institutions – consultancies, planning institutes and universities – which led to a step change in design standards and all related studies.

4.1.3 Contribution to policy at local level

At the core of CORFU was the aim to address and involve local key stakeholders (also referred to as end users) in the case study cities. The conducted end-user workshops in all case study cities can be understood as an initial step to place the CORFU outcomes at the relevant institutions and policy makers in the case study cities.

The Final Workshop in Barcelona gathered more than 80 delegates, mainly end users and local policy makers, who intensively discussed the potential of the CORFU methods, tools and results to be adopted by the local policies and to be embedded in the day-to-day business of the responsible agencies. Also, the post workshop dissemination activities through the end users dissemination channels and the consequent discussions indicated a strong interest of the local responsible authorities to make the CORFU outcomes operational. In particular it relates to the real time forecasting system Flood Alert (developed by an SME partner HYDS).

In Hamburg the responsible authorities for flood protection and the climate change adaptation were the major key stakeholders involved, which enabled CORFU a direct access to the policy makers at the city level. CORFU took place concurrently with a range of national and local projects related to the climate change adaptation (e.g. KLIMZUG-Nord), which is likely to generate a higher leverage effect on the policy makers.

Also, the advances in the development of the KALYPSO modelling platform implemented in CORFU, lead to its higher acceptance in the responsible Agency, which has used the tool for the production of flood maps in the sense of the EC Floods Directive for the small watercourses in the city of Hamburg.

The method developed to assess the flood resilience of a system utilising the flood resilience index (FRI) has been of major interest for the local authorities in the Nice case study area, who contemplate to deploy the developed method to a range of other hazards and problems.

As a general rule, the development and release of local policies have timelines that exceed the lifetimes of research projects and require a range of legal activities and internal and external iterations of expert judgment procedures. In particular, this practice applies to the European countries. Consequently, the practical implementation of CORFU outcomes into the local policy is hardly achievable during the project lifetime. The accomplishment of CORFU is however perceived in the adoption of the methods, tools and results by the responsible agencies, which in the next phase can be included in the policy documents and standards.

At the CORFU workshop in Dhaka, Mr Muhammad Nazrul Islam, MP, State Minister for Water Resources pointed out the potential impact of CORFU research on better planning of urbanisation and lower densification as key areas that could improve flood management in Dhaka, along with decentralization of facilities.

4.1.4 Contribution to policy at national level

At the CORFU workshop in Beijing, Mrs. Yanjin Cao from the Ministry of House & Urban-Rural Development emphasised the impact of CORFU on recent trends in policies on planning related to urban flooding from the aspect of central government, including the promotion of policies and technical guidelines that have been recently released. CORFU demonstrated an impact to the policy in China by contributing to the guidelines for design of urban drainage systems and flood management at the national level.

4.1.5 Contribution to policy at European level

Within the European Union, the overarching policy mechanism for flood risk management is the Floods Directive (EC, 2007). The Directive requires Member States to assess if water courses and coast lines are at risk from flooding, to map the flood extent, and assets and humans at risk in these areas, and to take adequate and coordinated measures to reduce these flood risks. The Floods Directive should be implemented in conjunction with the Water Framework Directive, which requires member states to develop River Basin Managements plans to ensure good ecological status. The Floods Directive has two key requirements, and the CORFU project was able to provide guidance on how these could be achieved:

- the preparation of flood hazard and risk mapping (Article 6),
- preparation of flood risk management plans (Article 7).

First, to support the requirements of Article 6, a consistent framework was developed for the analysis of urban flood modelling and flood hazard mapping. This framework made allowances for the availability of data, the nature of the investigation, the scale of the study site, and the human, financial, and technical resources available. This was supplemented by guidance on the development of procedures for the calibration of urban flood models.

This framework allowed the production of flood hazard and risk maps for all seven case study cities, covering floods with low, medium, and high probabilities, as required by the Floods Directive. One key advance is the development of methods to model flood risk for entire mega-cities, using a multi-cell technique. This was highlighted on 21 July 2012, when large parts of Beijing were seriously flooded, causing 57 casualties. The multi-cell model was applied in Beijing (area more than 1000km^2), and it was able to reproduce the observed flood extents (Hénonin et al, 2013).

Flood hazard maps have been produced for all case study cities, to cover floods with low, medium, and high probabilities, as required by the Floods Directive.

Article 6 stipulates that flood risk maps should show the potential adverse consequences of flooding, including those on “human health and life, the environment, cultural heritage, economic activity and infrastructure associated with floods”. The CORFU project has led to advances in the way these consequences are modelled:

- The state-of-the-art in flood impact assessment was reviewed, and a model was developed. In many of these cities, information was collected for the very first time on the exposure of assets and the damage that could be expected (through the development of flood damage functions). The methodology used here can be transferred to other locations.
- A GIS-based flood impact assessment tool was developed and applied in all case study cities. The key advantages of this tool are its ease of use, and its flexibility, as it can work with different data formats on range of scales. This tool was used in all the case study cities, to produce flood damage estimates.
- An innovative development is the assessment of the health impacts of flooding, that follow from human contact with flood water contaminated with pathogens. A hydro-dynamic model was developed and applied in Dhaka. This work was bolstered by the collection of water quality data at several sites (Mark et al, 2014).
- Improvements in the visualization of flood hazard maps was made through the development of an open GIS-based flood risk mapping tool for stakeholders. Flood hazard maps for all of the case study cities are available on line, and viewers can ‘swipe’ between the existing

state, and possible future states with and without mitigation measures. This will aid stakeholder engagement who will be consulted on the development of adaptation strategies and risk mitigation measures (Article 10 (2)).

The Floods Directive requires that Member States produce flood risk management plans at the river basin level. These plans should "address all aspects of flood risk management focusing on prevention, protection, preparedness, including flood forecasts and early warning systems … Flood risk management plans may also include the promotion of sustainable land use practices". Furthermore, these flood management plans should "take into account relevant aspects such as costs and benefits" (Article 7, Paragraph 3).

CORFU explored the potential future risks that may occur due to the climate change (Article 7, (14)), considering the plausible climate futures when developing future scenarios in the case study cities. For the case study areas, a set of measures formulated in different adaptation strategies, focusing on prevention, protection and preparedness have been developed. The proposed adaptation strategies or flood risk management plans have been analysed in their efficiency and cost effectiveness.

The CORFU project investigated the potential for real-time warning systems to be used in the cities. In Barcelona and Dhaka, such systems have been developed and implemented.

Apart from implementing the elements of the Floods Directive, CORFU went beyond its requirements, which can be reflected in the following aspects:

- In addition to the aspects of climate change, which is explicitly stated in the Directive, CORFU demonstrated that other drivers of future development such as urban and economic growth can have a considerable impact on the future flood hazards and risks and as such should be more prominently included in the policy.
- The relevance of addressing different dimensions of resilience, that go beyond the economic ones (i.e. cost benefit analysis), has been demonstrated at both the European and Asian case study cities. In that sense, any resilient planning for future should include a wider scope rather than merely addressing costs and direct/economic benefits, which should be anchored in the supranational policies.
- The conducted work in the case study cities undoubtedly demonstrated that the rainfall combined with the limitation of the drainage network capacity represents one of the major flood sources in the urban areas. However, it is not reflected in the Floods Directive (Article 2), even stating that the flood typologies to be considered in the Directive 'may exclude floods from sewerage systems: *"'flood' means the temporary covering by water of land not normally covered by water. This shall include floods from rivers, mountain torrents, Mediterranean ephemeral water courses, and floods from the sea in coastal areas, and may exclude floods from sewerage systems"*

The relevance of this flood typology has also been acknowledged by a number of responsible Agencies (e.g. in Copenhagen, Barcelona or Hamburg), which can be considered for the revision of the Directive. In that sense, CORFU addressed the EU policy makers to put stronger emphasis and accommodate the above mentioned aspects in the supranational policies. Also, as CORFU developed the methods and tools to support the implementation of the Floods Directive (e.g. for flood hazard mapping or damage assessment), the obtained results can give the indications or new insights in the required resources or know-how to implement the Directive at different levels.

The impacts of our project on policy are also elaborated in CORFU Science-Policy Briefs.

4.1.6 Impact on industry

CORFU consortium involved a number of industrial or private partners, who benefited from this project through extending their product portfolios and their presence worldwide. Also, as CORFU involved a range of end users, the industrial partners were able to get a direct access and create a better understanding of their needs, requirements or problems. The CORFU industrial partners performed the following enhancements of the existing portfolios:

Table 3. Enhancement of portfolios in CORFU industrial partner institutions

CORFU partner	Enhancement of portfolios
Dura Vermeer (Industry)	Ready to use urban growth model (applied in five CORFU case study cities, form Europe and Asia); technology now taken forward in the Delta project in Asia.
HYDS (SME)	Real time forecasting system – improving the existing portfolio of commercialized solutions (Flood Alert), now being implemented more broadly in Spain.
DHI (research/consulting institution, developer of commercial software)	The DHI modelling tools have been used in most of the case study cities, which was a strong incentive to further improve and develop these tools, and led to wider acceptance of these tools, in particular in China and Bangladesh. New developments partly driven by CORFU include: • the multi-cell model implemented in Beijing, • the 2D pollutant transport and mixing model, first implemented in Dhaka, • web-based GIS platform visualizing the case study results that can be further exploited (free access), • on-line real-time warning systems.
HWWI	In the past HWWI was focused on studying of regional economic growth and the economics of climate change in Germany and Europe. CORFU expanded their work on several countries in Asia.

4.1.7 Educating the next generation of flood professionals

CORFU provided an ideal vehicle for the training of young researchers, which will ensure the project's impact in the community of flood professionals, both in industry and in academia.

- Twelve PhD students from CORFU partner institutions (half of them from industry) have worked on PhD dissertations, which are at various stages of completion. In some cases, the PhD work has fed directly into the project – students have worked on case studies and their results have been included in deliverables. In other cases, students have worked on the CORFU project in conjunction with separate but linked research projects, and their PhD work has been supported and supplemented by their CORFU experiences. The PhD research has covered a range of disciplines, including work from the social sciences on risk perception, as well as research from engineering on flood modelling and flood forecasting. In line with the wider goals of supporting equal opportunities, the gender balance among PhD students has been representative – the majority of students are female.

- Several MSc theses have been completed at partner institutions, throughout the project, also covering a range of disciplines.
- A number of people have gone through various software training. DHI has been particularly active, and has hosted training courses for researchers from the University of Exeter, Institute of Water Modelling, the Beijing Municipal Institute of City Planning and Design, and the University of Nice-Sophia-Antipolis, among others.
- Young professionals have progressed into more senior roles, either within the same organization, or by accepting positions at new institutions.
- The early-career researchers have benefited from working on CORFU in innumerable ways, and they have gained more ability and confidence. These positive experiences include attending international conferences, workshops, summer schools, and engaging actively in the international research community.

4.2 Dissemination activities

4.2.1 International Conference on Flood Resilience: Experiences in Asia and Europe

The main dissemination event of CORFU was the International Conference on Flood Resilience: Experiences in Asia and Europe held in Exeter on 5-7 September 2013 (www.ICFR2013.org). The aim of this event was to gather professionals from various disciplines to present and discuss the latest research advances and practices in the development and implementation of resilience measures and flood management plans. The focus on cities in Asia and Europe was motivated by the approach applied within our project, consequently the idea was to have as many CORFU researchers as possible to present our results, but at the same time to invite various other colleagues who work in this area.

We had a well-balanced conference programme that encompassed a range of technical and non-technical topics and disciplines related to flood management, a range of professionals – researchers, engineers, social scientists, consultants, urban planners, government agencies staff, relief workers, software developers and others, young people at the start of their career as well as senior decision makers, a broad geographical representation of projects and participants and recently completed, ongoing and future actions.

One of the keynote speakers was Dr Ole Mark, who presented selected research highlights from CORFU. The welcome address was delivered by Professor Sir Steve Smith, the Vice-Chancellor of the University of Exeter. Other keynotes lectures included Taiwan's Interior Minister Dr Hong-Yuan Lee who talked about the Taiwan experience in governance of climate change and aggravated natural disasters; Professor Annegret Thieken from the University of Potsdam who talked about flood insurance and resilience; Dr Royol Chitradon, the Director of the Hydro and Agro Informatics Institute in Bangkok who talked about flood management in Thailand; and Martin Fairley, Research Director at ACO Technologies plc who talked about resilient technologies from manufacturer's perspective.

The conference was attended by 202 delegates from 33 countries, including 50 delegates from 10 Asian countries. The Proceedings book of extended (2-page) summaries of papers was published, along with the e-proceedings on pen drive that contained full papers (Butler *et al.,* 2013). Out of the total of 131 selected papers, 25 were from the CORFU project. Discussions during conference sessions where our papers were presented were very useful and were taken into account in the final phases of the project.

ICFR had a healthy gender balance. A significant proportion of female delegates were allocated to senior roles, as members of the Scientific Committee, invited keynote speakers, session chairs and moderators.

ICFR was an exceptionally successful and well supported event that presented the EU FP7-funded research in the best possible way. The feedback we received from many delegates was extremely positive.

4.2.2 Special Issue of the Journal of Flood Risk Management

In the run-up to the CORFU conference, the Editor-in Chief of the Journal of Flood Risk Management invited ICFR co-chairs Professors Slobodan Djordjević and David Butler to guest-edit a Special Issue on Urban Flood Resilience, which would have papers based on best presentations from ICFR. Following a careful selection process, seven papers (including five CORFU papers) were chosen and invited to revise and submit their paper. At the time of writing of this report these papers were still being reviewed. It is envisaged that this special issue will be completed and published by November 2014.

4.2.3 CORFU workshops

We had initial workshops in all case study areas in the first year of the project, which were used to give local stakeholders a chance to steer the research, and to give researchers an opportunity to see the sites, learn about specific problems and to get to know relevant people.

Dissemination workshops were held in all case study areas at the end of the project (in period May-June 2014). Most of these were very well attended, included high-level participants (ministers and other relevant officials), city officials, local consultants and researchers and other stakeholders. These events were widely reported in local media and attracted a lot of attention. Presentations were given about CORFU as a whole and about results from particular case studies. Discussions and conclusions were taken forward and incorporated in final reports.

4.2.4 Resilience – the CORFU movie

ICFR and CORFU case study workshops had a special feature – "Resilience", a stunning 25-minute documentary filmed in CORFU case study areas and some other flood prone major cities. This film comprehensively – and at times in a dramatic manner – presented the issues related to flood resilience in Asian cities, and the working atmosphere at few CORFU meetings. The production is still under discussion with several potential partners and therefore the film is not yet in the public domain.

4.2.5 Keynote lectures

CORFU partners gave keynote lectures and invited talks at numerous national and international events, including countries and events that are not associated with CORFU, such as Hong-Kong, Japan, Singapore and Thailand (in Asia), Bosnia, Estonia, Italy and Switzerland (in Europe) and the USA. In that respect CORFU is a unique EU-funded project that has had a particularly strong impact in Asia. This impact will continue to be felt after the end of the project, for example CORFU coordinator will be an invited speaker at the *3rd International Conference on Climate Change (ICCC2014): Building Resilience in Asia's Major Cities* (http://iccc.hk/) that will be held in Hong Kong in November 2014.

4.2.6 Publications

Full list of publications is provided elsewhere. Usual publication routes were used including journal papers, conference proceedings and authorised interviews.

4.3 Exploitation of results

4.3.1 Economic and urban growth and climate change scenarios

Development scenarios formulated within CORFU – that include results of modelling of economic and urban growth combined with plausible climate futures – are available for future analysis in case study cities and are already being used in some places.

4.3.2 Calibration guidelines

The guidelines for calibration of urban flood models – to our best knowledge – are so far a unique document of that kind. It is generic (not related to CORFU case study areas, though some examples are from the project) and as such will be of interest to flood modellers worldwide.

4.3.3 Real-time forecasting systems

Web-based real-time forecasting systems in Barcelona and Dhaka will continue to live after the project, and have great potential to be updated and improved. Similar approaches are already under development in other regions.

4.3.4 New depth-damage curves

One of the major practical contributions of CORFU was the creation of locally relevant depth-damage curves, which had not existed at the start of our project. That is a legacy that will be in use for years to come and will significantly contribute to the quality of any future developments in case study cities.

4.3.5 Health impact model

The initial results of the CORFU health impact work in Dhaka were very encouraging. These may be exploited in a follow-up project entitled "Evidence based prevention of waterborne diarrhoeal diseases in urban areas" proposed by the team of eight institutions from Bangladesh, Denmark, the Netherlands, UK and USA (including three CORFU partners). Funding for this project is being sought from the Bill and Melinda Gates Foundation and from other sources. The CORFU health impact model will also be implemented in other cities.

4.3.6 Other follow-up projects and initiatives

Six partners from the CORFU consortium teamed up with a group of researchers from fifteen other institutions to form a consortium for the FP7 four-year PEARL (Preparing for extreme and rare events in coastal regions) project that started in 2014. This project will directly exploit it take further some of the tools and findings of CORFU.

CORFU has been associated with the Global flooding partnership and contributed to its workshop held in 2014.

The outcomes of CORFU in particular the work related to the impact assessment is currently being integrated and aligned with the Flood Damage Assessment Working Group initiated by Politecnico di Milano (the Politechnic University of Milano), which counts a number of leading researchers in the field of impact analysis and assessment (i.e. JRC, University of Potsdam, Oxford Brookes University). The Group has an objective to make an impact on the European guidelines and policies related to the damage assessment and data collection, which could be formulated in a white paper document as a result of the meetings in Milano (January, 2013) and Bastia Umbra (April, 2014).

4.3.7 Web-based resources

- CORFU deliverables can be downloaded from the project web site, which also provides links to published papers, Science-Policy Briefs and other project resources.
- A selection of flood and damage modelling results produced within CORFU is available on the open-GIS system described in section 3.3.4 of this report, where the web address, username and password are provided.
- The real time rainfall and flooding forecast systems in Barcelona and Dhaka are described in section 3.3.6 of this report, where web their web addresses are provided.
- CORFU presentations at the International Conference on Flood Resilience can be downloaded from the ICFR web site (section 4.2.1).

5 Project web site

The CORFU web site is www.corfu7.eu. During the life of the project it was used as a communication tool and as a depository of various documents. At the end of the project all deliverables and all project publications are placed there and are now publicly available to download. The web site will remain active for at least five years after the project finished. Papers that will be published after the end of the project will also be uploaded to the project web site

References

Selected CORFU publications

Batica J. and Gourbesville P. (2011). Methodology for Flood Resilience Index development, *34th IAHR Congress,* Brisbane, Australia.

Butler D., Chen A. S., Djordjević S. and Hammond, M. J., Eds. (2013). *Urban Flood Resilience, Extended Summaries of the International Conference on Flood Resilience: Experiences in Asia and Europe,* University of Exeter, Exeter.

Chen A. S., Hammond, M. J., Djordjević S., Butler D., Khan, D. and Veerbeek, W. (2014). From hazard to impact: the CORFU flood damage assessment tools, *Urban Environmental Modelling Software,* submitted.

Djordjević S., Butler D., Gourbesville P., Mark O. and Pasche E. (2011). New policies to deal with climate change and other drivers impacting on resilience to flooding in urban areas: the CORFU approach, *Environmental Science & Policy,* 14(7), 864-873.

Hammond M. J., Birkholz S., Jeffrey P., Chen A. S. and Manojlovic N. (2014). Exploring the potential relationships between Protection Motivation Theory and Flood Hazard Modelling to improve understanding of private mitigation measures: transcending disciplinary borders, under preparation, to be submitted to *Global Environmental Change*.

Hammond M. J., Chen A. S., Djordjević S., Butler D. and Mark, O. (2014). Urban flood impact assessment: A state-of-the-art, *Urban Water Journal,* http://dx.doi.org/10.1080/1573062X.2013.857421.

Helmers S., Kurzbach S., Manojlovic N. and Palmaricciotti G. (2014). Multiple linked SUDS in hydrological modelling for urban drainage and flood management, *Journal of Flood Risk Management,* submitted.

Hénonin J., Russo B., Mark O. and Gourbesville P. (2012). Real-time urban flood forecasting and modelling – a state of the art, *Journal of Hydroinformatics,* 15(3), 717-736.

Hénonin J., Ma H., Yang Z. Y., Hartnack J., Havnø K., Gourbesville P. and Mark O. (2013). Citywide multi-grid urban flood modelling: the July 2012 flood in Beijing. *Urban Water Journal,* http://dx.doi.org/10.1080/1573062X.2013.851710.

Hénonin J., Khan D., Chen A., Hartnack J., Gourbesville P. and Mark O. (2014). A flood forecast system for Dhaka city based on faster flood simulations with new diffusive wave approach, *Journal of Hydroinformatics,* submitted.

Manojlovic N., Antanaskovic D. and Pasche E. (2010). Multiscale flood risk assessment with physically based damage modelling tools, *9th International Conference on Hydroinformatics,* Tianjin, China.

Mark O., Jørgensen C., Hammond M., Khan D., Tjener R., Erichsen A., Helwigh B. and Albretchsen H.-J. (2014). A new methodology for modelling of health risk from urban flooding exemplified by cholera – case Dhaka, Bangladesh, *Journal of Flood Risk Management,* submitted.

René J.-R., Djordjević S., Butler D., Madsen H. and Mark O. (2014). Assessing the potential for real-time urban flood forecasting based on a worldwide survey on data availability, *Urban Water Journal,* 11(7), 573-583.

Russo B., Suñer D., Velasco M. and Djordjević S. (2014). A calibrated 1D/2D coupled model to analyze the hydraulic behaviour of the Raval district in Barcelona during heavy storm events, *Journal of Hydroinformatics,* submitted.

Schlitte F. (2013). Scenarios for long-term economic city growth – models and results from selected CORFU case studies, *International Conference on Flood Resilience: Experiences in Asia and Europe,* Ed. by D. Butler *et al.,* Exeter, United Kingdom.

Veerbeek W. and Zevenbergen C. (2013). Developing business-as-usual scenarios for the urban growth of 4 Asian megacities, *International Conference on Flood Resilience: Experiences in Asia and Europe,* Ed. by D. Butler *et al.,* Exeter, United Kingdom.

Other literature

Andersen H. S., Tamašauskas H. and Mark O. (2004). The Full Urban Water Cycle – Modeling with MIKE URBAN, *7th International Conference on Urban Drainage Modelling,* Dresden, Germany.

CMMI Product Team, (2002). *Capability Maturity Model Integration (CMMI) Version 1.1,* Carnegie Mellon Software Engineering Institute, Pittsburgh.

EC (2007). *Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks,* Brussels. URL: http://ec.europa.eu/environment/water/flood_risk/key_docs.htm

General Office of the State Council of the People's Republic of China (2013), *Notification on the Enhancements of the Construction of Urban Drainage and Urban Flooding-protective Facilities,* No 23.

Grothmann T. and Reusswig F. (2006). People at risk of flooding: why some residents take precautionary action while others do not, *Natural Hazards,* 38, 101-120.

Nakićenović N., and Swart R. Eds. (2000). *Special Report on Emissions Scenarios: A special report of Working Group III of the Intergovernmental Panel on Climate Change.* Cambridge University Press, URL: http://www.grida.no/publications/other/ipcc%5Fsr/?src=/climate/ipcc/emission.

Shaw R. and IEDM Team (2009). *Climate Disaster Resilience: Focus on Coastal Urban Cities in Asia,* URL: http://www.unescap.org/idd/events/2009_EGM-DRR/Japan-Rajib-Shaw-CLIMATE-DISASTER-RESILIENCE.pdf.

Twigg, J. (2009). Characteristics of a disaster-resilient communit, Aon Benfield UCL Hazard Research Centre, URL: www.abuhrc.org/research/dsm/Pages/project_view.aspx?project=13.