URBAN FLOOD REAL-TIME FORECASTING AND MODELLING: A STATE-OF-THE-ART REVIEW

Justine Hénonin[1], Beniamino Russo[2], David Suñer Roqueta[2], Rafael Sanchez-Diezma[3], Nina Donna Sto. Domingo[1], Franz Thomsen[1], Ole Mark[1]

[1]DHI Denmark, Denmark

[2]CLABSA, Spain

[3]HYDS, Spain

(Presenter: J. Hénonin - jsh@dhigroup.com)

Abstract

More than half of the world's natural disasters are floods, affecting millions of people every year. In fact, more than 3 billion people have been affected by floods over the last century, i.e. half of the current world population! Urban floods have long been considered as unpredictable and unavoidable natural disasters. Continuously increasing urbanization has led to an increasing flood risk whereas technological growth has raised various new strategies to predict and face this risk. Most of the urban drainage networks are aging and have been designed to manage a maximum rainfall, or so-called design rainfall, which refers to a design return period (usually 10 to 100 years). Thus, this implies an "accepted" flood risk for a rainfall greater than the design rainfall. But this flood risk can be underestimated considering factors like city growth, flash floods and climate change. Thus, being able to forecast the flood is one of the main issues of integrated flood risk management. Various flood forecasting systems have been developed and used, a lot using a large range of advanced tools and some as part of integrated decision support systems. Runoff and hydraulic models are usually essential elements for such systems, as pre-studying tools or as components of the system. This paper intends to make a review of current urban flood forecasting systems as well as the available modelling technologies, focusing on urban drainage modelling. Different types of urban real time systems are assessed and evaluated to sort out the current state-of-the-art and to give recommendations for future urban flood forecasting systems.

Keywords

Urban flood, real-time forecast, urban drainage modelling, MIKE FLOOD, MIKE URBAN, DIMS, Dashboard Manager

1. INTRODUCTION

Floods are the most threatening natural disaster across the world. Over the past century, major flood events caused the death of almost 7 million people, affected more than 3 billion people and caused damages about 441 billion USD[1].

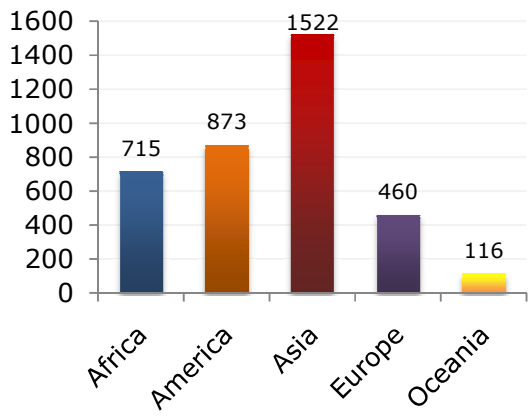

Figure 1 Number of major flood events from 1900 to 2009 (records from EM-DAT)

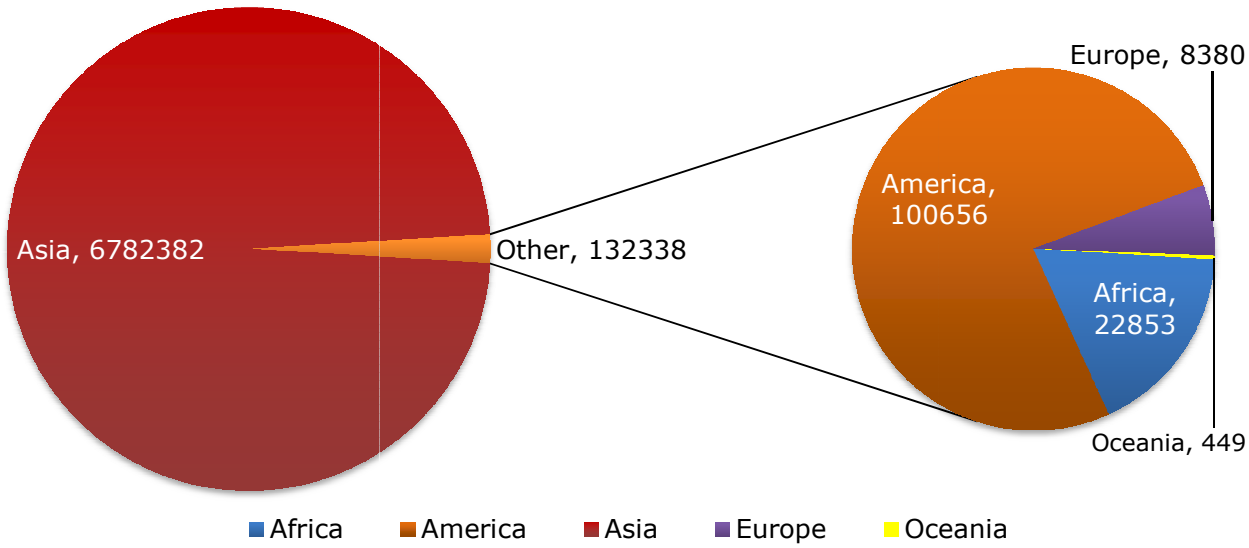

Figure 2 Number of people killed because of flood, per continent (records from EM-DAT)

Flood management strategies usually involve policy, planning and design as well as operational management. Benefits of hydroinformatic tools for such strategies have been proven.

[1] Source: EM-DAT, The OFDA/CRED International Disaster Database, www.em-dat.net

Although a good flood management would take into account both the city development and flood protection measures, full protection against flood is generally impossible. Therefore, real-time flood forecasting and warning systems can be significantly helpful to reduce flood damages.

The second part of this paper gives an overview of the numerical models available for urban flood management, as well as a classification of real-time flood forecasting systems, based on hydroinformatic tools use. The third part intends to make a review of existing real-time urban flood forecasting systems. The main issues of such systems and ongoing research challenges are discussed briefly in the last part.

2. URBAN FLOOD MODELLING AND REAL-TIME FORECASTING: DEFINITIONS

URBAN MODEL CLASSIFICATION

a) Catchment hydrological model

This kind of model is generally based on widely used hydrological equations. The runoff is computed from the rainfall based on the catchment characteristics.

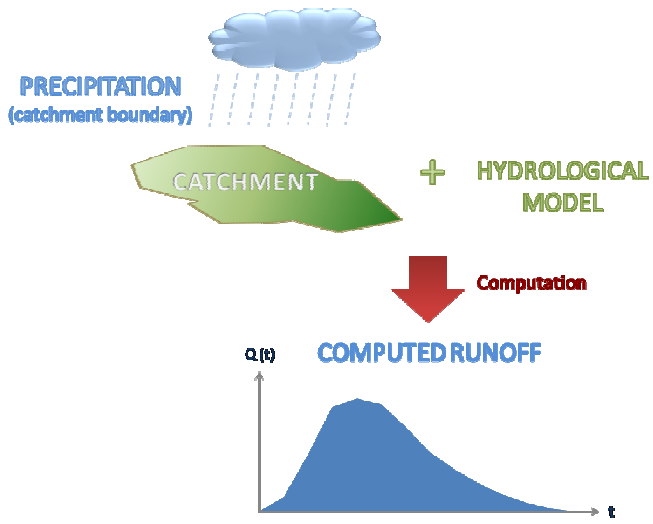

Figure 3 Illustrated Rainfall-Runoff computation (Adapted from MIKE URBAN Collection System Manual - Rainfall-Runoff Modelling with MOUSE: Terms and concepts)

Most of the hydrological models are conceptual models, relying on set of empirical parameters that need to be calibrated from field measurements. The urban surface runoff models don´t allow the user to reproduce the hydrodynamic behavior of the runoff and are basically used as input for a drainage network model.

b) 1D model: Drainage Network 1D model

This kind of model solves the Saint-Venant one-dimensional flow equations to simulate the behavior of the flow within a drainage pipe network, including complex devices such as pumps, gates, weirs, valves… The quality of such models is highly dependent on the quality of the input dataset and calibration. 1D models usually handle both pressurized and free flows. The boundaries for such models are usually the catchment runoff and dry weather flow at the inlets and water levels at the outlets. These models are available in software packages such as MOUSE[2] (DHI, 1986), SWMM[3] (US EPA, 1988), INFOWORKS[4] (Wallingford, 2002) and MIKE URBAN[5] (DHI, 2004), and are widely used by research organizations, consulting companies and local authorities.

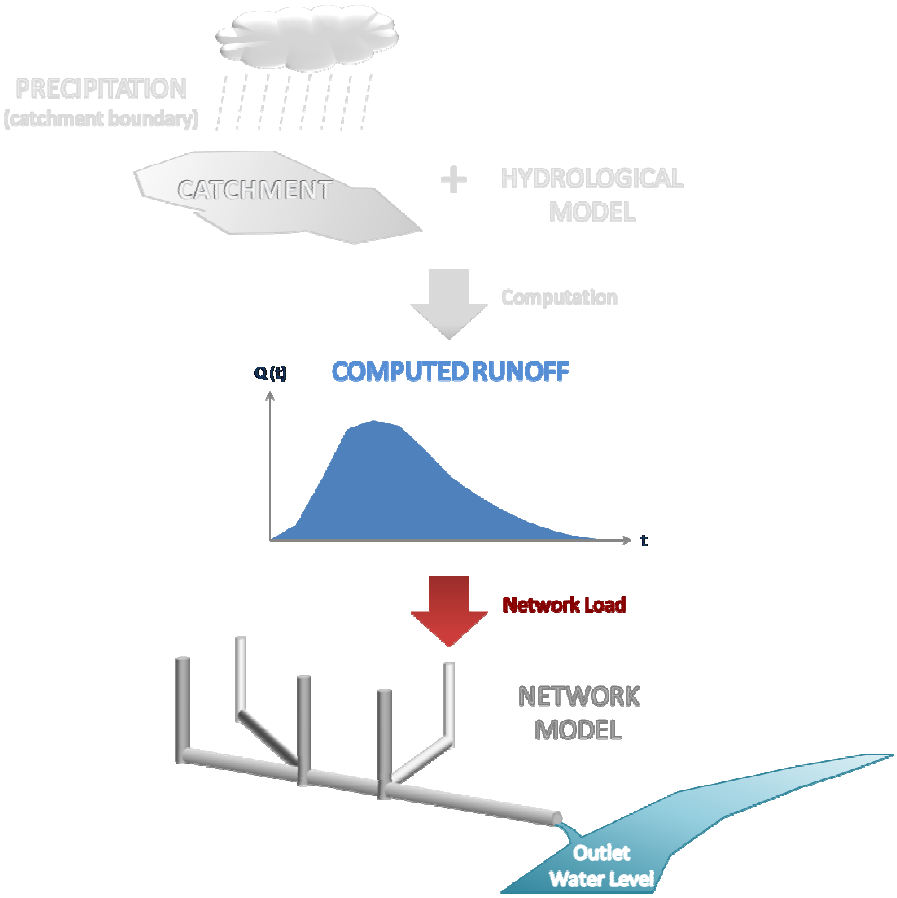

Figure 4 Illustrated 1D Drainage Network computation (Adapted from MIKE URBAN Collection System Manual - Rainfall-Runoff Modelling with MOUSE: Terms and concepts)

[2] MOUSE, http://www.dhigroup.com
[3] SWMM, http://www.epa.gov/ednnrmrl/models/swmm/
[4] INFOWORKS, http://www.mwhsoft.com/
[5] MIKE URBAN, http://mikebydhi.com/

However, such models are not suitable to reproduce the network overflow phenomenon. Indeed 1D model overflow is usually handled through a simplification such as virtual storage on top of the manholes. As this kind of model does not simulate the surface flood routing, plus the water level calculated in the virtual storage is not linked to any realistic behavior of the overflow water, it logically leads to an overestimation of the "flood depth" (Mark et al. (2004), Maksimovic (2000)).

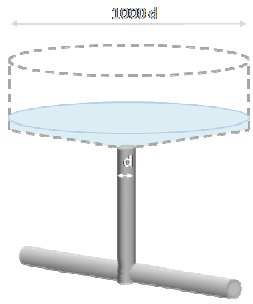

Figure 5 Virtual storage on top of a surcharging manhole (concept from MIKE URBAN and MOUSE Pipe Flow Reference Manual)

c) <u>1D-1D model: Drainage Network 1D model coupled to 1D surface model</u>

This kind of model is actually a coupling between a 1D collection system model and a 1D representation of the surface flow path (usually the streets). This modelling approach is also known as **dual drainage approach** (Djordjević et al. (1999), Stephenson (1987), Wisner et al. (1982)). The computed runoff can be distributed either directly into the drainage system or on the surface network, depending on the local context. The exchange between the two networks is handled through coupling links, usually located at manholes or catch pit.

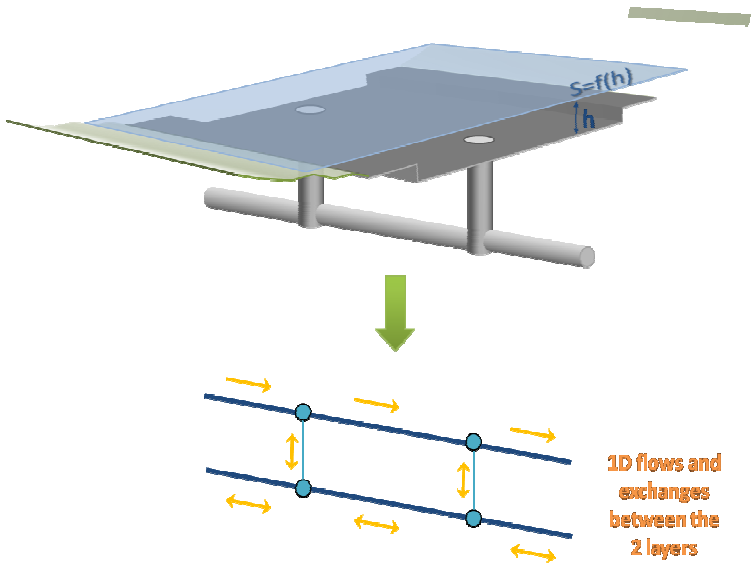

Figure 6 Example of 1D-1D modelling principle

Besides the proper modelling of the collection system, this approach has two main issues:

- The setup of the relationship between the two networks – the flow exchange should be bi-directional through most of the coupling links, to represents both the surface flow catch by the drainage system and the overflow back from the drainage system to the surface. Plus, these coupling links should take into account the intake capacity of the drainage system to ensure that the amount of water flowing from the street into the drainage system is realistic.

- The proper representation of the surface network – the 1D surface model usually consists in a 1D hydrodynamic flow model of the streets with a storage function to handle the surface flooding out of the streets (Mark et al. (2004)). Thus, the development of this model involves a large amount of data with detailed GIS dataset including high-resolution DEM (Digital Elevation Model) or DTM (Digital Terrain Model) plus streets and buildings data. The preprocessing and verification of both the surface flow paths and storage functions have to be done carefully and can be particularly time consuming, although automatic GIS procedures can be used (Maksimović et al. (2001), Mark et al. (2004), Boonya-aroonnet et al. (2007)).

Various studies have shown that 1D surface modelling seems suitable to reproduce the flow in street channels. But the surface hydrodynamic flow cannot be reduced to only flow in streets, i.e. channel flow, and it becomes obviously more complex to represent when it comes to flow in street crossings or outside streets.

d) <u>1D-2D model: Drainage Network 1D model coupled to 2D surface model</u>

This kind of coupled modelling has been used in a number of studies and is now available in commercial software packages such as INFOWORKS[6] (Wallingford, 2006) and MIKE FLOOD[7] (DHI, 2005). The flow in collection system is still modeled in 1D but the surface flow is computed with a 2D engine solving the Saint-Venant 2-dimensional flow equations. The 2D model is used to reproduce accurately the urban surface topography, including buildings, ponds, various structures, etc. The hydrodynamic flow computation with the 2D surface model allows calculations such as flow velocities with 2-directions components. The surface water level is no longer calculated from an interpolation formula but the result of 2D modelling of the flow behavior.

[6] http://www.mwhsoft.com/
[7] http://mikebydhi.com/

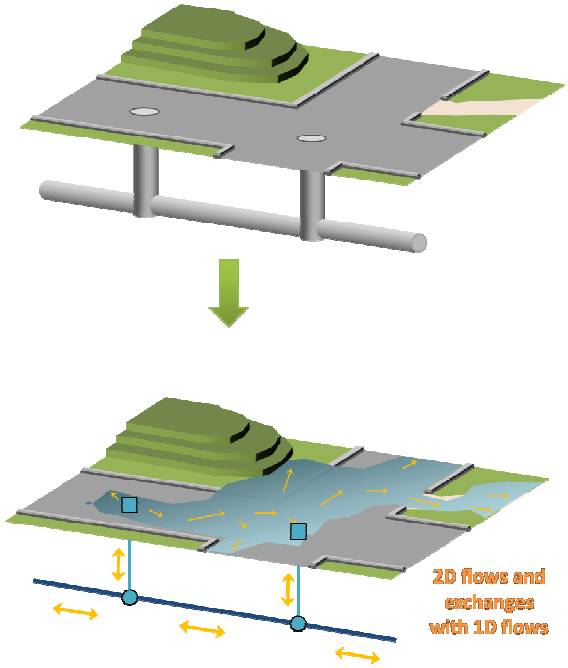

Figure 7 Example of 1D-2D modelling principle

The exchanges between the collection system and the surface are still handled through coupling links as for the 1D-1D coupling, but the nodes of the collection system network are connected to cells of the 2D surface model. Thus, an issue of such 1D-2D models is the accuracy and resolution of the 2D surface model. Indeed, the accuracy of the 2D model is highly dependent of the input data resolution, i.e. topographic data resolution (density & elevation, buildings shapes…). Then, the resolution of the 2D model has to be suitable for a proper representation of the city, i.e. fine enough to take into account the main structures influencing the flow such as buildings and roads. The recommended grid size for urban 2D surface model is usually 1m to 5m (Mark et al. (2004), Prodanovic et al. (1998)). Actually, GIS pretreatments are usually required to ensure that the main topographic features will be properly taken into account into the 2D model.

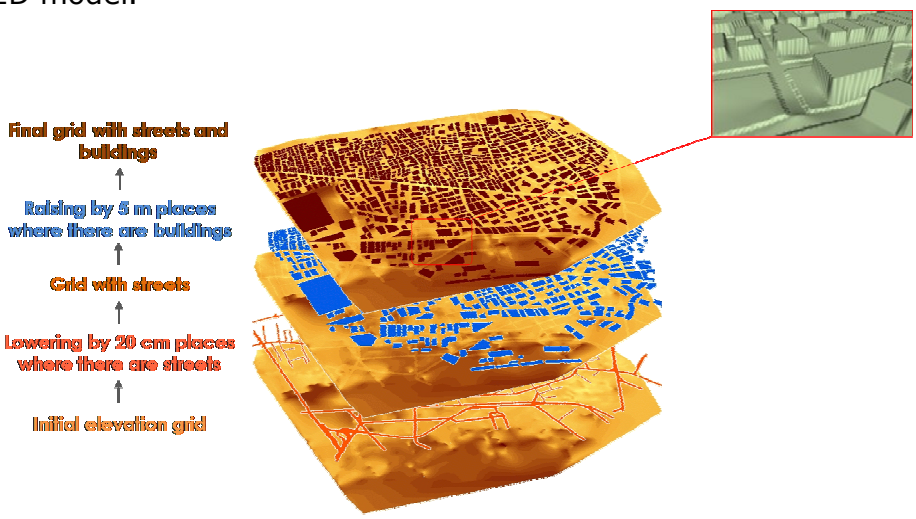

Figure 8 Example of GIS pretreatment to process a grid for a 2D model

Although 2D models are far more realistic than 1D models to represent the surface flow behavior, 1D-2D models still require more computation time than 1D-1D models Thus, 1D-2D models are currently use for off-line applications only while 1D and 1D-1D models can be used online for real-time forecast applications. Some ongoing research projects are investigating the feasibility of 1D-2D online models use for real-time applications, focusing on model enhancements methods to reduce computation time.

URBAN FLOOD REAL-TIME FORECAST SYSTEMS CLASSIFICATION

Each system should be based on a rainfall forecast. The rainfall information can come from a national weather forecast system, a rain gauges network and local radar.

A) **Real-time flood forecast based only on rainfall information & empirical scenarios**: uses only a rainfall forecast as input for empirical scenario selection. The scenarios are based on historical events recordings and key people knowledge (network knowledge, emergency services experience…). This system is "simple" regarding the technology involved but the data assessment is a key issue to define proper scenarios. This kind of "system" can be difficult to update (not a continuous process) and faces a risk of loss of knowledge and know-how.

B) **Real-time flood forecast based on rainfall information and pre-simulated scenarios:** uses a rainfall forecast as input for simulated scenario selection. The scenarios are based on a pre-study project involving data recovering and treatment, and hydraulic simulations. Various modelling strategies and levels can be used depending on the available tools and on the kind of flood. The different types of urban flood models are described later in the paper. The accuracy of the simulated scenarios depends on both the model(s) and the input data quality (including calibration data). The main issues for this kind of system are the update of the scenarios in case of major change in the hydraulic network and the proper setup for scenarios: the "warning levels" have to be selected carefully so that the scenario catalog will cover the whole range of flood events. Thus, the possible climate change effects should be taken into account, at least through a scenario update schedule.

C) **Real-time flood forecast based on real-time data assimilation**: uses a rainfall forecast as input for an online modelling system. This kind of system is based on real-time modelling to forecast the behavior of the runoff. The simulation system usually involves a hydrological model connected to a 1D hydraulic model representing the drainage network. Warnings are issued when network overflow is forecasted. Additional historical database storage can be done for off-line simulations and data assessment. The main issues for such systems are the forecast accuracy (depending on the rainfall forecast system, on the model calibration…), the update of the model in case of major change and the whole system maintenance. Besides, automatic and continuous calibration process should be considered to ensure the accuracy of the forecast.

D) **<u>Real-time flood forecast with active feedback to the drainage system operation</u>**: in addition to the previously described online modelling forecast system, this type of system involves automatic & remote control of the actual network controllable devices based on the model forecast. Remote sensors are a key technology for such systems. The main issue (in addition to the issues for the previous type) is the proper setup of the automatic procedures to ensure that the controlled system will behave efficiently (i.e. to avoid overflows) and safely (i.e. not worst than without control).

Whatever the kind of forecasting system, it has to be sustainable and ergonomic. The end-user must have easy access and understanding to the forecast.

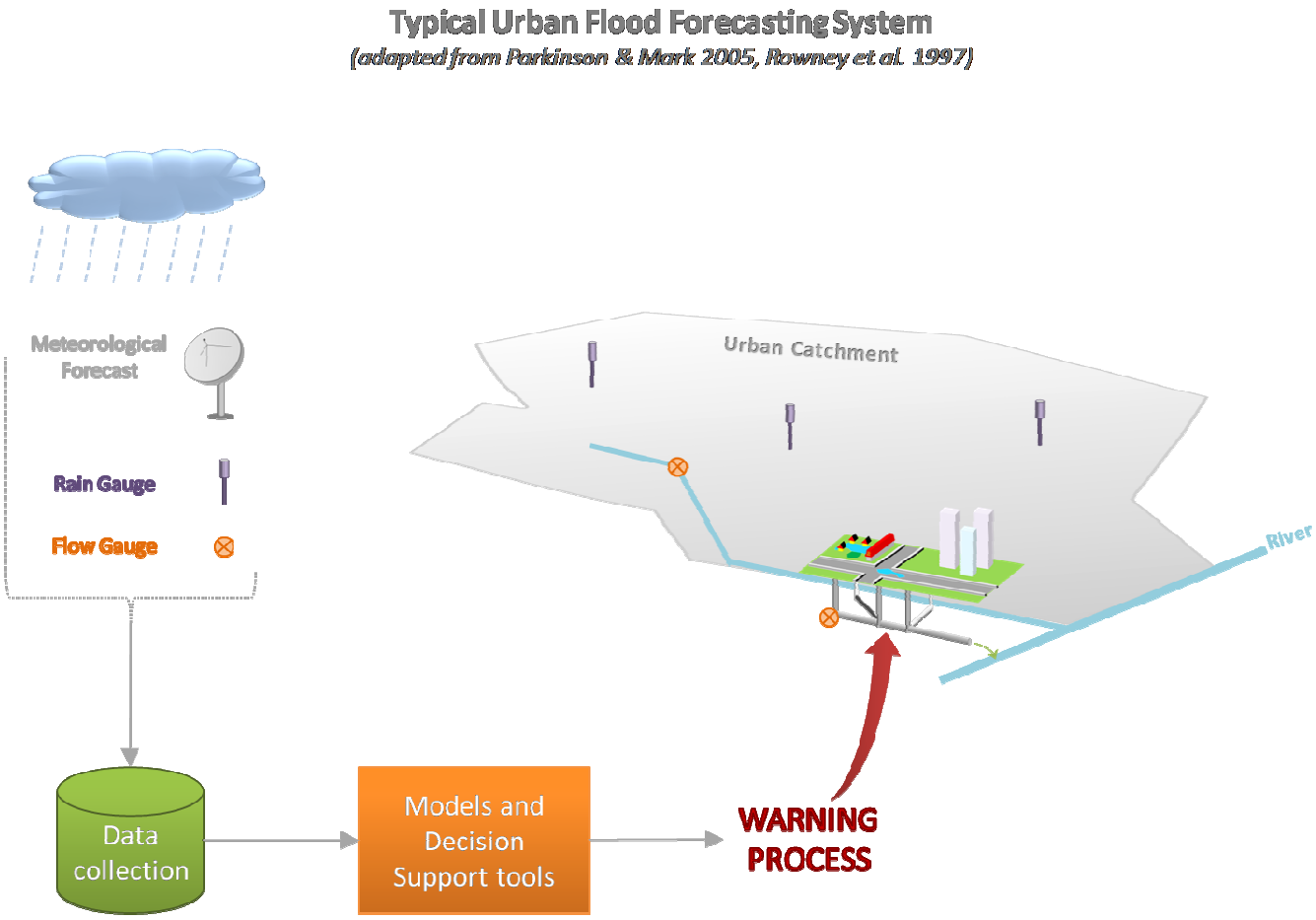

Figure 9 Typical Urban Flood Forecasting System (adapted from Parkinson & Mark 2005, Rowney et al. 1997)

3. A REVIEW OF EXISTING URBAN FLOOD FORECAST SYSTEMS

Hvidovre (Denmark): real-time flood warning using high-resolution radar [Type B]

The municipality of Hvidovre is a southwest suburb of Copenhagen, Denmark.

During summer 2008, a real-time online warning system has been setup to provide information on the risk of basement flooding. The system is based on local area weather radar (LAWR)[8] rainfall forecast and on hydrological book-keeping model for 22 urban catchments. The high resolution radar pictures are retrieved every 5 minutes to produce and update a forecast for the next hour. This forecast is used by the Decision Support System (DSS) together with historical data to calculate the accumulated rainfall for each sub-catchment and to issue a warning if any of the pre-defined critical levels is exceeded. The Hvidovre citizens can be either warned automatically by the DSS, by SMS and/or e-mail, or access to the current status information through a webpage developed with Dashboard Manager[9].

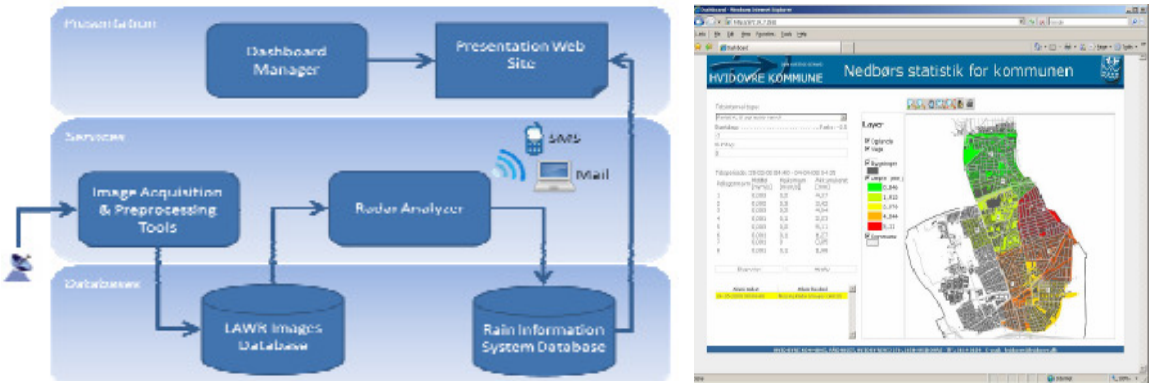

Figure 10 Hvidovre Flood Warning System Architecture and Webpage (from N.E. Jensen and L. Pedersen)

One of the main issues for such a system is the radar proper setup, including location, data validation and calibration. The radar has to be installed where it can get clear pictures, avoiding as much as possible clutter impacts, so a top position is usually required. In Hvidovre, it has been installed on the roof of a fire station, which has been proved to be not the best location due to perturbations from the fire brigade exercises requiring switch off of the radar.

This system has been kept "simple" (even though based on high tech tools) on purpose as an intermediate solution during the drainage system modernization plan, which is expected to take several years. Besides warning people as long as the drainage system is insufficient, this system is also used to collect experience and knowledge to enhance the flood management strategies.

[8] Local Area Weather Radar (LAWR), X-band radar from DHI, www.dhigroup.com
[9] Dashboard Manager, DHI Solution Software, www.dhigroup.com

Nîmes (France): urban flood warning using weather forecast and real-time hydrological models [type B-C]

Nîmes is a city of about 150 000 people in Southern France. Like most of the Mediterranean cities from Spain to Italy, Nîmes experiences heavy rainfall due to extreme storm events during autumn. In combination with surrounding karsts catchments with temporary river beds, steep slopes and high density urbanization, this makes Nîmes particularly exposed to flash flood risk. Indeed, Nîmes has experienced major floods along its history, the last but not the least in October 1988, September 2002 and September 2005. The October 3rd 1988 flood is used as a reference as one of the most catastrophic flood event in Nîmes, and even one of the most catastrophic flood event in France, with 45000 victims and 10 deaths plus damages of more than 600 million Euros. More than 14 million m^3 flowed through the urban area, with a flow discharge similar to the Seine River (France) at some places. Since then, the Nîmes municipality has initiated a new flood management plan "Nîmes Cadereau"[10] including a flood forecast and warning system: ESPADA (Evaluation et Suivi des Pluies en Agglomération pour Devancer l´Alerte).

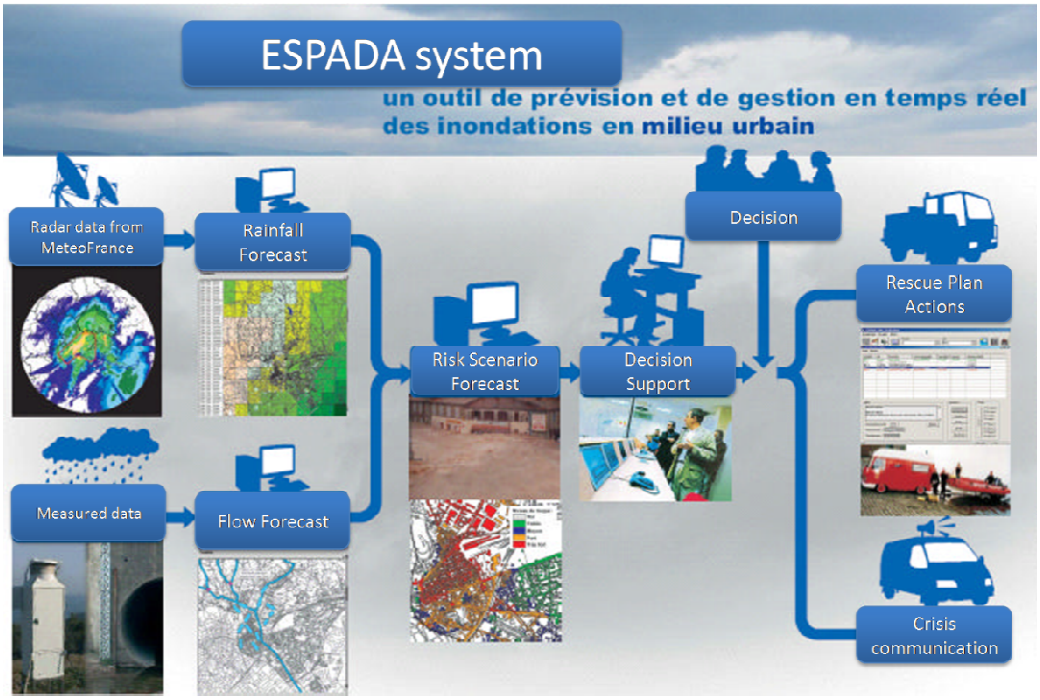

Figure 11 ESPADA System architecture (from Raymond et al.)

The ESPADA system is based on a local rainfall forecast using both a radar forecast (1 km2 resolution) and a measurement network of 10 rain gauges and 11 water level measurements. The data is sent every 15 minutes to the central system where it is used as input for rainfall-runoff models to forecast the flow expected in the urban areas with an update every 30 minutes. Based on the forecasted flow, a scenario is selected among 44 pre-existing scenarios. The 44 scenarios are based on flood risk maps established during a pre-study involving field survey and

[10] http://www.nimes.fr/index.php?id=936

hydraulic study plus 2D modelling of one of the sub-catchments. Each scenario is linked to a warning level with a total of 4 levels, from alertness (level 1) to global flooding with risk for people (level 4). Depending on the forecast and so on the selected scenario, a warning level is issued to launch the proper set of actions (prevention plan, automatic phone calls…).

An issue of such system is the scenario catalog sustainability. Indeed, each scenario should be updated with an additional hydraulic study whenever a major change of the system occurs. Besides, one difference with a real-time hydraulic model is that the scenario catalog is not automatically assessed with the collected real-time data.

Bangkok (Thailand): flood forecast system using real-time urban drainage modelling [Type C]

Bangkok is the capital and largest city of Thailand, with more than 9 million inhabitants. Lying about 2m above sea level on swamps located at the lower basin of the Chao Phraya River, with a tropical climate including monsoon season, Bangkok is a natural floodplain. With a high population density and fast urbanization, this makes Bangkok exposed to an extremely high flood risk.

In 2002, a rainfall and flood forecast system has been developed in Bangkok within a research project conducted by the Asian Institute of Technology (AIT, Thailand) and DHI (Denmark). The first objective was to provide reliable rainfall and flood forecast based on both radar and rain-gauges network.

The rainfall forecast has been based on a weather radar (Thai Meteorological Department, TMD) located in the downtown area as well as a network of 47 rain-gauges (Bangkok Metropolitan Administration, BMA).

The urban drainage of down-town part of Bangkok is modeled with a two-layer 1D-1D model describing the streets and pipe systems and their interaction. This model has been built with MOUSE[2] and connected to the real-time rainfall forecast, which is used as input, through a DIMS[11] real-time database. The use of this online model allowed to extend the forecast to the future behavior of the drainage system, including the expected flood extent in the model area.

[11] DIMS, DHI Solution Software, www.dhigroup.com

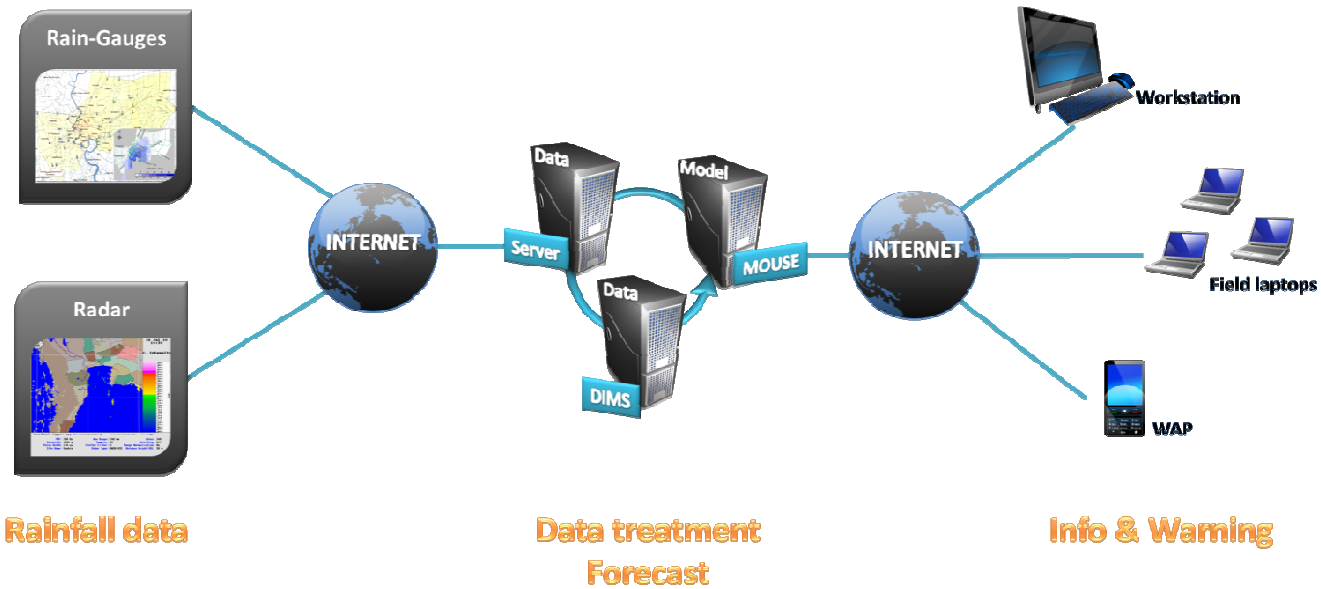

Figure 12 Layout of the Bangkok Rainfall and Flood Forecast system at AIT (adapted from Mark et Al. 2002)

A flood risk warning can be issued via internet and WAP mobile phones. An interesting point of this Bangkok system is that the warning is not only based on the results from the model but also on the local experience as for type A system. Indeed, based on past floods experience, it is considered that if the accumulated rain is more than 60 mm within an hour then flooding can occur in Bangkok. This criterion has been implemented in the system as a warning level so that warnings are sent automatically to BMA officers whenever it is exceeded. Of course, a warning is also sent whenever a flood is forecasted by the hydrodynamic model.

Barcelona (Spain): flash flood forecasting system based on radar and network real-time model [Type C]

Barcelona is one of the most densely populated cities in Europe, with more than 1.6 million people just for the city itself and more than 28000 inhabitants per km^2 in half of the city. Barcelona is located in the northeast coast of Spain and has a Mediterranean climate including heavy storms period from August to November with flash flood risk.

The Barcelona urban drainage managing company (CLABSA), in collaboration with HYDS, has developed a flood forecast system called HIDROMET. This system has been implemented and tested in the Riera Blanca catchment, South-West of Barcelona. The elevation of this catchment ranges from 180 m to sea level. It covers 9.61 km^2 for 150 000 inhabitants.

The rainfall information comes from both a 1 km^2 resolution radar and 7 rain gauges. The rainfall is forecasted for the next 2 hours. The radar data is calibrated with the rain gauge dataset. The system also includes data from 10 water level sensors. The time step for radar data acquisition is 6 min while it is 5 min for gauges and sensors data.

The rainfall forecast is used as input for a MOUSE[2] model of the drainage system, including 280 nodes, 300 links and 73 sub-catchments. The real-time and forecast application of the model has been tested off-line, with simulations run every 5 min. Comparison of off-line predictions with real measurements have proved that such model can work successfully online for overflow forecasting.

Automatic on-screen and on-call warnings can be issued at every level of the system, from exceeded threshold in the rainfall forecast or water level sensors to overflow simulation in the drainage model, or even failure of any item of the forecast system. The phone call alert application ATTELNET has been developed by CLABSA as a stand-alone tool to adapt to various kinds of alert systems.

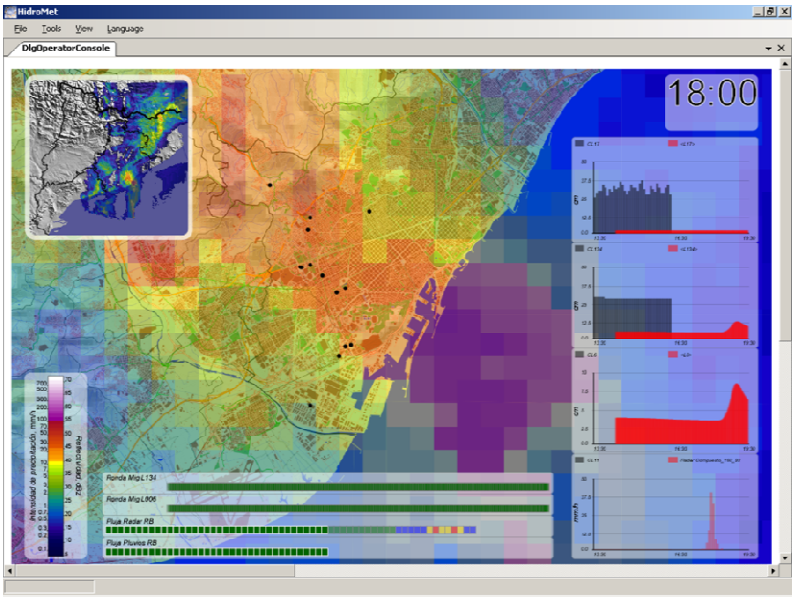

Figure 13 HIDROMET operation main screen with forecast prediction

(Source: CLABSA)

The real-time system has been implemented and tested from June 2008 to December 2008, showing good and reliable results for light rainfall and heavy but non-convective rainfall. Although the forecast reliability is reduced in case of heavy convective rainfall[12] to an optimal prediction of 30 min, the system is now operational since January 2009.

[12] Connected to strong vertical airflow with short-term heavy storms

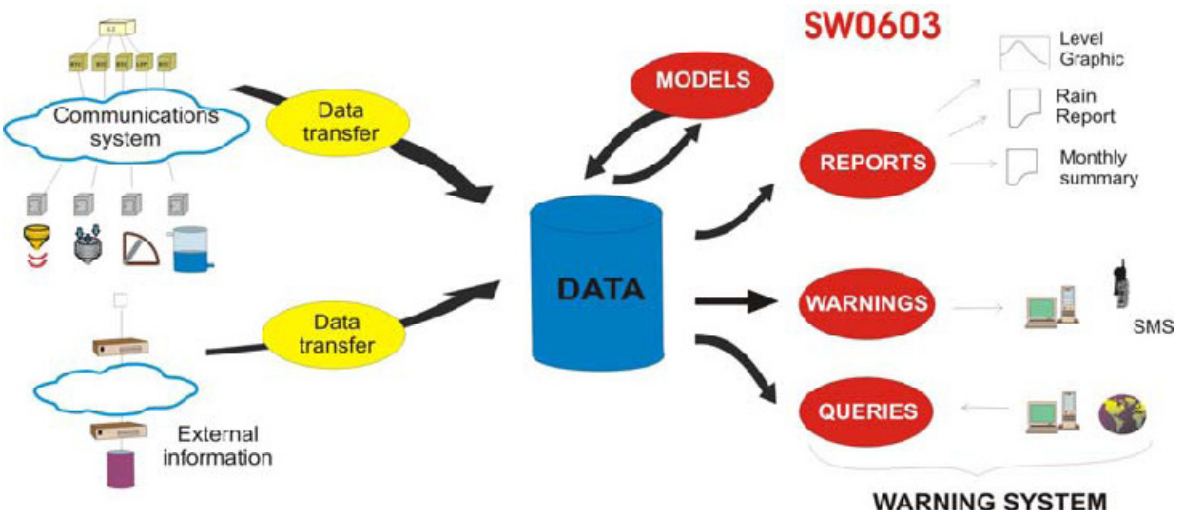

Figure 14 HIDROMET system description (from Montero et Al. 2010)

The Barcelona case underlines the importance of the input data reliability and quality, and particularly of the rainfall forecast. Besides, when it comes to flash floods caused by heavy convective rainfall, the ability of the weather forecast system to detect and predict such event is a major issue, leading to the need of future improvements in forecasting methodologies for this type of rain events.

4. ISSUES, ONGOING AND FURTHER PERSPECTIVES

Issues for such real-time flood forecast systems are as numerous as the variety of systems. Besides, these systems have usually to be tailored for each case. However, some global issues and challenges can be put into perspective.

Rainfall data and weather forecast quality

The quality of the weather forecast has a major influence on the quality of a flood forecast system. It is generally accepted that a rain gauge network is not able to provide a proper weather forecast. However, a wide and well used rain gauge network is valuable to provide calibration and validation data and can even be used to setup rough warning levels. When it comes to weather forecast, the main technology used is the radar forecasting, with a resolution which can range from national to local forecast. A national forecast is usually not suitable for a local forecast system as it does not take into account the spatial distribution of the rain at a local level. However, it can also be used to setup a rough warning level. Among others, some issues using local radar are:

- Radar location: it has to be sustainable and set properly to allow the widest view possible, avoiding as much as possible the ground clutter phenomenon.

- Resolution of the radar grid: it has to fit the resolution needed for the forecast, especially when the spatial distribution of the rainfall is an issue. However, high resolution radar have usually a smaller range (e.g. from 20

km to 60 km for a X-band radar with a 100x100 m to 500x500 m resolution). Therefore, a local radar network could be needed for bigger cities. Combination of micro-scale radar with meso and macro-scale radar is probably the current optimal solution to get the best of each kind of radar and weather forecast. Thus ongoing research projects such as Storm and Wastewater Informatics (SWI, granted by Danish Council for Strategic Research, Commission on Energy and Environment programme) are investigating nested radar forecast potentialities.

- Quality of the radar data: the radar data information has to be tested against various rainfall conditions before operational use. A rain gauge network is generally used to calibrate and validate radar data, although rain gauge measurements have to be used carefully (Pedersen et al., 2010, Jatho et al., 2009, Jensen and Pedersen, 2005). Besides flow measurements at catchment outlets and drainage network inlets are certainly useful to enhance and validate the rainfall-runoff estimation from both radar and hydrological models, although huge uncertainties remain and are connected to all rainfall data source (radar, rain-gauges as well as flow gauges). However, the use of radar data in un-gauged catchment is one of the current challenges for hydrological modelling.

- Quality of the weather forecast model: as it is this model which allows to extrapolate the future evolution of the rain within the radar grid. Errors in this model will propagate among the system. Uncertainty and confidence range should be computed and given for each forecast time range (short term to long term forecast).

Hydraulic models quality

The quality of any hydraulic model to be used in a flood forecast system is an obvious requirement. Of course, such model has to be tested and validated against real events before any operational use. Although some of the following points could seem obvious, it is probably useful to underline it:

- Update and calibration schedule: the ability of the model to predict the flow through the drainage system will be sustainable only if the model is properly updated and calibrated each time a major change occurs. Continuous and automatic calibration is certainly an adding value to ensure the quality of the model results. Actually, network automatic measurements are required to validate on-line model, especially when it deals with complex drainage networks involving real-time controlled features.

- Model resolution and computation time: again, it has to fit with the resolution and response speed needed for the forecast. If the forecast is needed at street level, then a detailed model would be needed, but a macro-model could be sufficient for a forecast at sub-catchment level. Of course, a 1D-2D model would be far more realistic to forecast the surface flood behavior but it is usually not suitable for real-time systems as it still requires much more computation time than 1D or 1D-1D models. The use of online

1D-2D fast and reliable models could be one the challenges for next flood forecast systems.

- Hydrological cycle representation: most of the current forecast systems rely on conceptual rainfall-runoff models that do not take into account the whole hydrological process. The resolution of the sub-catchment definition is then an important parameter to reproduce the main processes including rainfall heterogeneity. The proper distribution of the runoff flow among the drainage system is another issue as the sewer system does not catch all of it. Other processes such as interaction between pipe systems and groundwater are usually not taken into account due to lack of data. Hydrodynamic hydrological 2D models could be an adding value to better represent the full urban water cycle although lack of data and computation time issues still remain.

Forecast and warning quality

Among the weather forecast and hydraulic model quality, each forecast and warning system faces some of the main issues listed below:

- Warning levels setup: the setup of proper warning levels is an important process to ensure the sustainability of any warning system. If the alert thresholds are defined too low, a warning could be issued while actually no flood would occur. On the other hand, too high thresholds would give a too late alert. Although it seems obvious, this is a critical issue as too many wrong warnings will make users losing trust in the forecast reliability and would even end to the resignation of the whole system.

- System time steps: at every level of the system, the time steps have to fit with the forecast speed needs as it would be nonsense to issue a forecast slower than the flood. As example, a once or twice-a-day forecast would not be suitable for flash floods or small urban catchments but could be sufficient for a very slow response catchment. Flash flood forecast and warning would require fast and high frequency forecast that constraint each item of the system.

- Errors and uncertainties: error propagation and uncertainties should be estimated at every level of the system to evaluate the reliability of the forecast and thus take informed decisions. Besides the error and uncertainty calculations, the use and level of such information is still a challenge, particularly when it comes to public information. What kind of uncertainty information can be delivered, and for what kind of user, are questions that are still to address in further research and applications.

- Warning content and communication: even the best forecast quality is useless if the system does not communicate the proper information to the right people. Forecast and alert information have to be understandable at every level of use, from operational staff to public through decision makers. The alert system has to rely on sustainable media and the content has to fit

with each user needs. Communication, information level and interactivity are one of the main challenges of ongoing and future forecast systems. The educational potential of a flood forecast system should be also taken into account in the communication part. Such system can be a useful tool to help people to accept a reasonable flood risk and thus living with floods.

While different modelling strategies can be applied to study urban flooding and the capacity of a drainage system to handle the flood, the more realistic method to represent the surface flow and interactions with the sewer system is the dynamic coupling of the 1D sewer network model with a 2D surface model, so-called 1D-2D coupling. However, the such model is still computationally too much demanding to be suitable for real-time applications. Therefore, 1D-1D, 1D or even only simple hydrological models are still used for real-time flood forecasting. The use of such model can lead to a classification of urban flood forecast systems such as:

- "Empirical" forecast system built without any model application [Type A]
- "Scenario based" forecast system built considering previous modelling study [Type B]
- "Real-time model based" forecast system using online model simulations as real-time data assimilation for flood prediction [Type C]
- "Automatic feedback control" forecast system including active feedback and automatic control of the drainage system based on real-time data and simulation results [Type D]

Although the technology is or could be available in most of the countries, advanced real-time urban flood forecasting systems are still rare. Of course such systems are not needed everywhere, but could be certainly of use in most of the cases. While flexibility is a key issue to ensure that a system could be adapted to several cases, global guidelines could be provided to build suitable flood forecast systems as well as proper flood management. This is one of the objectives of CORFU[13] (COllaborative Research on Flood resilience in Urban areas), interdisciplinary and international project within the EU 7th Framework Programme. The CORFU team will look at advanced and novel strategies to provide adequate measures for improved flood management in cities, studying and taking advantage of differences in urban flooding problems between Asia and Europe. This 4-year collaborative research will cross-fertilized the latest technological advances with traditional and emerging approaches to living with floods. Among the six work packages (WP) of the CORFU project, DHI is leading the WP2 for assessment and enhancement of methodologies and tools for off-line and real-time flood hazard assessment based on urban flood modelling. Among expected outputs, WP2 should provide guidelines and tools to help flood managers to choose the right tools and systems depending on their own urban flood problems.

[13] http://www.corfu-fp7.eu/

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