Assessing the potential for real-time urban flood forecasting based on a worldwide survey on data availability

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This paper explores the potential for real-time urban flood forecasting based on literature and the results from an online worldwide survey with 176 participants. The survey investigated 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. It was originally assumed that the lack of real-time urban flood forecasting systems is 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 or modellers (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.

Keywords: Data availability, modelling, pluvial flooding, real-time urban flood forecasting, urban flood modelling

Introduction

One of the most significant current discussions in urban flood management is the need for and use of real-time flood forecasting. Researchers have continued to show an increased interest in the performance of urban drainage systems because flood problems will undoubtedly worsen in some parts of the world due to climate change (Willems et al., 2012, E E A, 2012). This is of particular importance because unmodified urban drainage systems will not be able to maintain the same level of flood protection, therefore emphasising the need for effective flood forecasting.

During the last few years, developments in surface flow modelling, and the means of data transfer in real-time in a stable and consistent way, have facilitated realistic research on real-time flood forecasting as a means of mitigating flood impacts. However, a major problem in real-time urban flood forecasting is the lack of practical experience in building such systems. Currently there are very few operational cases and published material on real time urban flood forecasting systems (Henonin et al., in press, Mark et al., 2002, Raymond et al., 2006, Montero et al., 2010) and so potential flood modellers may be unaware of recent progress and the potential of such systems.

One major issue that has dominated the field for many years concerns the computational time required for hydraulic simulations. Despite advances in computing software and hardware, high-resolution modelling still remains a challenge and most people resort to simplified approaches which affect the accuracy of the results. This has been challenged before in the hybrid modelling approach that couples a 1D surface model in areas which are less flood-prone and a 2D surface model in more flood prone areas to the 1D buried drainage network (Simões et al., 2011); and more recently by Chen et al. (2012) in a study demonstrating a multi-layered approach to 2D modelling that can improve the accuracy of a coarse grid model while also shortening the computational time.

Flood forecasting is an important component of flood warning. Flood forecasting involves predictions of water levels and flows at particular locations at a particular time, while flood warning is the task of making use of the flood forecasts to make decisions on whether flood warnings should be issued to the general public. Typically it is the role of the flood modeller or manager to pass on information to the appropriate authorities, which then has the responsible to warn the general public or properties of the impending flood risk (Werner et al., 2005).

So far there has been little research about the potential for real-time urban flood forecasting based on current available resources. This paper describes the work undertaken in order to assess the potential for real-time urban flood forecasting and will attempt to show that flood practitioners can make the simplest of urban flood forecasts based on even the sparsest of data. The main questions addressed in this paper are: a) how widespread is the use of specific data amongst urban water professionals, b) what are some of their perceived challenges, and c) how do they perceive data availability?

The section 0 of the paper will give a brief review of real-time urban flood forecasting and modelling. Section 0 will present how the study was carried out and this is followed by the results in section 0. The following section (section 0) presents a discussion of the results and this is followed by concluding remarks in section 0.

Throughout the paper, the following terms will be used to refer to:

(1) Quantitative Precipitation Forecasts (QPF) – expected amount of precipitation over a specified period of time and specified area. The forecasts can be made through weather radar and weather forecast models or a combination of both.

(2) Numerical Weather Prediction (NWP) forecasts – quantitative precipitation estimates over a specified period of time and specified area provided by numerical weather prediction models (weather forecast models).

(3) Operational data – data that supports the control of flow in the drainage network. This includes but is not limited to pump discharge and location, gate locations etc.

Real-time urban flood forecasting and modelling

The first and perhaps most important thing in forecasting in general is that there must be a need for it. Despite the fact that real-time flood forecasting systems are relatively widespread based on the features involved, they can be classified into three general categories. That is the empirical, pre-simulated and real-time simulation approach. On the former hydrodynamic models are not used, instead it is based on historical account on past events. However the other two approaches makes use of hydrodynamic simulations which are characterised by dimensionality. This section will elaborate on the modelling approaches that can be possibly applied, its selection and application as it relates to data availability as well as the flood forecasting systems categories. This section will also emphasise on uncertainty in flood forecasting.

Modelling approaches for simulating floods in urban areas

In urban flood modelling, hydrological processes are commonly separated conceptually from the hydraulics of the drainage system. Two types of models are therefore required: (i) a hydrological model which simulates surface runoff, and (ii) a hydrodynamic model which simulates the flows in pipes, streets and storage of water on the surface. Runoff generated from rain generally starts as overland flow before entering the underground pipe system through manholes or catch-pits/gullies. Runoff computations can be carried out by a standard surface runoff model, e.g. time-area, kinematic wave, linear reservoir and rational method (Price and Vojinović, 2011). Surface runoff is typically computed for each sub-catchment and the resulting hydrograph is used as the input into the hydrodynamic model (Mark et al., 2004).

The hydrodynamic representation of flow is usually characterised by dimensionality: (i) a one-dimensional (1D) model such as a sewer (drainage) and/or surface channel model, or (ii) a two-dimensional (2D) model such as a surface flow model. Alternatively, a combination of approaches may be used known as coupled modelling (Djordjević et al., 1999, Simões et al., 2011).

Typically, the choice of modelling approach depends on the overall purpose of the model and ultimately the desired accuracy. However, in practice the choice depends most importantly on the available data, as data is the limiting factor in the ability to apply accurate models. 1D modelling relies heavily on geometrical data whereas 2D modelling relies heavily on terrain/Lidar data. Coupled approaches will inevitability rely on both data types.

Real-time flood forecasting approaches

According to Henonin et al, (in press) real-time flood forecasting can be classified into three main categories: (i) empirical scenarios, (ii) pre-simulated scenarios, and (iii) real-time simulations.

The *empirical scenario approach* relies on experience and observations of the past. This approach uses knowledge of previous flood events (e.g. accumulated rainfall in one hour, water levels) and establishes threshold levels based on historical accounts. Once these thresholds are exceeded a warning is issued. In the *pre-simulated scenario approach* a scenario catalogue is created covering a range of flood events. As the name suggests, this approach requires some form of hydrological and hydrodynamic simulation. The modelling approach is based on data availability and a library of scenarios is created and stored. In general, this approach uses information about the given rainfall forecast along with a set of rules for selecting the probable scenario. This can be done manually or by an automated system, and based on the results of the selected scenario, a warning is issued. In the *real-time simulation approach,* hydrodynamic simulations are performed in real-time and their results are disseminated to responsible authorities and/or to the public through web services or as a SMS-message on mobile phones. The calibrated hydrological and hydrodynamic simulation model is fed with rainfall information in real-time and the simulations are performed and flood locations are identified. Areas or facilities with greater risk are usually identified in pre-studies and once the water level exceeds a certain threshold (e.g. stair/curb level at train station) at that facility a warning is issued.

Timeliness is paramount for flood forecasting and for that reason flood forecasting systems should be computationally fast. Real-time urban flood forecasting has been progressing in a direction aimed at utilizing physical information about the urban catchment, which strongly affects the computational time required for running simulations. However, the use of physical information is not only important for hydrologic and hydrodynamic computations but from the end user perspective is ideal for visualising the actual flood location.

The absence of a physically-based hydrodynamic model for the empirical scenario approach means that although computational time is not an issue, visualising the actual flood location is not possible. In addition, care should be taken when using this approach when there are significant physical changes in the urban environment (e.g. urbanization). Nevertheless, this approach is suitable for identifying problem areas and in a situation when data and models are limited, it provides an opportunity to make the simplest of “what if” flood forecasts.

Although the pre-simulated approach considers the physical characterises of the urban environment and the computational time may not be an issue because computations have already been performed, and just like the empirical approach, changes in the urban environment pose a continual challenge to urban flood modellers. This approach therefore requires continuous maintenance and updating of the catalogue involving hydrodynamic simulations with recent information about the urban topography which covers a wide range of events.

There are several things to consider for the real-time simulation approach and these include: computational time which depends on the modelling approach, size of the computational grid, and the size of the model area; response time of the catchment; rainfall forecast data source and its lead-time, and real-time model updating for improving the accuracy of the forecast (data assimilation).

However, the benefit of the real-time simulation approach is the advantage to provide a more accurate forecast, regardless of the modelling approach, since the model and the data represent the current state of the system. Rainfall, water levels, and flow rates are key inputs for running the hydrodynamic models. During the rain event, information about these variables is the key point for the success of the flood warning (Beven, 2009).

Each approach has it strength and weaknesses, but it is important to update the catalogue for the success of the approaches.

The choice of a particular approach

The most accurate way to forecast the future is by using a lot of information. Very often, much focus is on making the most accurate forecast; while in some instances (e.g. where data is sparse) it makes sense to consider making a forecast and accepting that there is an inherent uncertainty associated with the forecast. In many respects, the issue we need to address in flood forecasting is recognising and accepting that it is always uncertain, but provides valuable information to end users such as decision makers, planners, public etc.

Typically the choice of a particular flood forecasting approach is based on the desired accuracy, forecast horizon, degree of complexity required, cost of producing the forecast, technological capacity and finally the available data. Each approach for flood forecasting has its advantages and disadvantages, but data constraints, technological capacity and the desired level of accuracy will ultimately determine the approach that can be implemented. While more effort in flood forecasting may cause increased cost due to data collection and analysis, less forecasting activity may result in increased damages and possibly loss of revenue depending on the severity of the flood event. Therefore, a balanced should be maintained in the flood forecasting effort and the desired forecast accuracy, or in other words, the tolerable level of uncertainty.

The roles that each data type plays based on the classification scheme presented in Henonin et al, (in press) as well as what role that different modelling approaches play in each scheme are summarized in Table 1

[Table 1 near here]

Methodology

Survey Development

A literature review was carried out to ascertain the current state of real-time pluvial flood forecasting for urban areas. The study revealed that presently there are very few published cases and that in order to accurately forecast floods in urban areas, data of high spatial and temporal resolution is required (Schilling, 1991, Mark et al., 2004, Berne et al., 2004). It was assumed that there are very few cases because of the lack of relevant data for urban flood management; herein referred to as data of suitable resolution and length for fulfilling the objective. For a better understanding of the issues that dominate the field of urban flood management, a survey was designed to determine the existence of data for urban flood management and the perceived challenges and constraints in data acquisition, to evaluate the prospects for real-time flood forecasting.

The questions from the survey were focused on evaluating the resolutions, sources and applications of the relevant data for urban flood management. The accessibility of data in real-time was also addressed. Some questions were related to the limitations of the available data as well as how practitioners perceived data availability. Background characteristics, such as nationality, profession, years of experience as well as type of organisation were collected.

The research design of this study was descriptive and inferential as it aimed to explore relationships for assessing the potential for urban flood modelling and management based on the quality, quantity and accessibility of data. The survey contained 20 closed ended questions each with sub-questions and 1 open ended question. Most of the closed ended questions were multiple response questions. The data was captured using the Bristol Online Survey system (Bristol Online Surveys).

Participants

A frequent impediment for conducting large scale internet based surveys is the lack of a registry for specific populations. However, globally urban flood practitioners exist in very small numbers and fortunately for this study a few mailing lists (e-mail address) are available which makes it possible to permit generalization. To achieve this, convenience samples were obtained from two representative target groups which were invited to participate.

- *Scientific community:* Urban drainage mailing list (IWA, 2012) as well as participants who submitted an abstract to the 9th Urban Drainage Modelling Conference (UDM) held in Belgrade in 2012 (University of Begrade, 2012).
- *Consulting community:* DHI's MikeUrban client mailing list. Although it only covers one product it is representative for this community

A pre-survey was sent to a representative sample of 30 urban flood practitioners to see if they understood and responded well to the format of the questions. The test sample included participants from both the scientific and consulting community. The improved survey was then sent to approximately 250 urban flood professionals. Participants were also asked to share the survey with whom they may have found it relevant. The survey was also publicized on various social media sites (e.g. LinkedIn) and was open to anyone with an interest in the area.

Data analysis

Data analysis was performed using a statistical analysis package known as PASW (Premier Analytical Software) Statistics (IBM, 2010). Since most of the questions were multiple responses, a multiple response frequency procedure was adopted. This is demonstrated in Table 2 with the total percentage under organisations being more than 100, due to overlapping between the categories of organizations that were selected.

Results

There was a huge spread in the demographics of the data collected. There were 176 completed responses and the characteristics of the participants are presented in Table 2. The response rate for the survey was 70.4%.

[Table 2 near here]

What are their experiences with data?

Of the 176 participants who completed the questionnaire, the majority (90.9%) indicated they have used rainfall data from rain gauges with a minority (39.8%) having used radar data (Figure 1). More than 1/3 of the participants have used terrain, land use, water and flow rates, drainage network and rain gauge data. Fewer persons have used operational data (50.0%) and QPF (49.4%).

[Figure 1 near here]

Real-time data access

61.4% of those who took part in the survey reported they have access to rainfall data in real-time (Figure 2). In addition, less than half of the participants have access to water levels and flow rates in real time with even fewer reporting having real-time access to weather radar data.

[Figure 2 near here]

What are people actually doing with the data?

The majority of the participants used the data for research (Figure 3). Most are using rain gauge data in general when compared to the other data types. However, considering flood forecasting, more participants are using rain gauge data (42.6%) as well as drainage network data (39.2%), flow or water levels data (35.2%) and terrain data (37.5%).

[Figure 3 near here]

An even smaller percentage of the participants are using the data for real-time control. Real-time control was presented as an option because it gives an indication of the percentage of participants who have the infrastructure for real-time data access (e.g. SCADA).

When asked about software, 68.8% of the participants are using some kind of modelling software with the majority of those participants using commercial packages (72.7%). Fewer of those 121 participants (30.6%, 31.4% and 32.2%) are using university owned, open source or in house packages respectively.

What are their perceptions on data availability?

A little more than half of the participants (59.1%) felt they had difficulty getting data while the remaining 40.9% did not have any difficulty acquiring data. Their reasons for each case are highlighted in Table 3 and Table 4:

[Table 3 near here]

[Table 4 near here]

Perceived challenges in urban flood modelling

The perceived challenges in urban flood modelling were obtained by categorizing the participants responses based on the themes that emerged from the survey. The key themes were summarized and the top 10 challenges collated and presented in decreasing order.

(1) Cost of data acquisition

(2) Limited ability to calibrate and validate models

(3) Copyright bureaucracy

(4) Data Resolution

(5) Limited information on assets (e.g. location and geometry of pipes and drains, weirs, pumps sizes etc.)

(6) Dealing with uncertainty in historical data

(7) Inability to implement statistical models due to short time series

(8) Unavailability of data in real-time

(9) Urban topography is constantly changing

(10) Lack of urban flood forecasting cases published in the literature

Discussion

Contrary to expectations, this study found that over half of the participants *had* used all the different data types except for weather radar which only 39.8% had used (Figure 1), and more than 2/3 (68.8%) are using some kind of modelling software. The observed difference in the use of weather radar compared to rain gauge data is not surprising because the application of weather radar in urban hydrology may still not be so common for reasons stated in Einfalt et al, (2004).

Another important finding was that less than half of the participants have real time data access to water levels, flow rates and QPF except for rain gauge data with more than half of the participants (61.4%) (Figure 2) indicating they have real time access. One anticipated finding in terms of real time data access was that there would not be many participants with access to weather radar data and numerical weather prediction forecast in real-time merely because very few are currently using it and it is only recently used in urban flood modelling (Liguori et al., 2012). Comparing the frequency of real-time access of water levels and flow rates data to that of rain gauge data (Figure 2), the results suggests that it seems a lot easier to get real-time access to rain gauge data than flow rates and water level data.

The most interesting finding was that most participants are using the data for research followed by flood forecasting (Figure 3) although it is less than half in both cases. This result *may* be explained by the fact that most of the respondents were from universities (Table 2). Other possible reasons why the respondents are not using the data for flood forecsating *may* include:

- Lack of interest in issuing a real-time urban flood forecast – However, the increase in the frequency of flooding in some areas (E E A, 2012) and the added urgency to address urban flooding (CORFU, 2012)) does not confirm a lack of interest as an explanation.
- Lack of awareness that a real-time urban flood forecast can actually be issued – Real-time urban flood forecasting is not trivial; if more work is published in scientific journals which can be used as reference and motivation, perhaps there would be more cases.
- Ongoing doubts about the quality and quantity of the data for urban flood modelling – Strong evidence is provided in the results under section 0 as one of the main challenges in urban flood management. Findings on data resolution suggest that only a small percentage of the participants who have used the different types of data have used data of fine resolution, for example: 25% of the participants used terrain data of resolution less than 2.0m, 13.1% used rainfall data from rain gauge of 1 minute resolution: 3.4% of the participants used radar data with grid cell coverage of 100m etc. The percentage with fine resolution data is much less than the percentage doing flood forecasting, therefore suggesting that fine resolution data is not necessary in all cases, it depends ultimately on the desired level of accuracy.

Let us first explore how many of the participants can actually make a flood forecast based on the empirical approach. It is not straightforward to say that, since 61.4% indicated they have real-time access to rainfall information from a rain gauge (Figure 2); then 61.4% should potentially be able to make an urban flood forecast based on the empirical scenario. Similarly it cannot be said that the percent having access to radar data (27.3%) (Figure 2) in real-time should potentially be able to make a forecast based on any of the approaches. In fact there are several factors which would influence the type of forecast that can be issued.

The main difficulty in using rain-gauge information is that it provides information about the past. The location of the rain gauge relative to the catchment as well as the size of the catchment will determine if it is possible to issue a real-time flood forecast based on rain gauge information. In general, if the response time from the time the information is received (lead-time) is less than the time of concentration of the catchment (runoff time), then the reliance on rain gauge information would be obsolete. Therefore, in order to say how many can issue a forecast based on the empirical approach, topological information which would give an indication of time of concentration as well as the size of the catchment is required. Other information such as location of rain gauge, as well as a historical records of past flood events in the form of reports, witness accounts of the events etc. would be required.

It would be much too optimistic to think that the use of QPF either from radar or NWP model would increase the number of cases who do flood forecasting using QPF; considering that the mere purpose would be to extend the lead-time. The high level of uncertainty which is usually associated with QPF is the reason why its use is not so widespread (René et al., in press, Anagnostou et al., 1999).

The choice between weather radar and NWP forecasts depends on the desired level of accuracy and the desired forecast horizon. Weather radar provides high quality precipitation forecasts (nowcasts) for a lead time of a couple of hours, but if a longer lead-time is desired, other sources of information are required, such as NWP forecasts (Lin et al., 2004). NWP models will also provide data for short lead-times but the quality is not the same as radar nowcasts. The data needs to be evaluated to see if it is fit for purpose.

Aside from radar, the World Wide Web is a substantial source of information. Everyone who has access to the internet can potentially get access to QPF for instance from NWP (www.yr.no). Although NWP forecasts has its limitations (Best, 2005), it is still a valuable source. Based on this assumption, urban flood practitioners can make a flood forecast based on the empirical scenario regardless of the catchment size, location of rain gauge etc. However there is always a tradeoff between the accepted accuracy and damage reduction cost, but this source provides the best possible information about the future when other more reliable rainfall sources are not available. Generally, most online sources of any kind of information are a rough approximation. More refined data usually costs a lot of money to produce and compile.

Having access to more information introduces some sophistication in urban flood forecasting. Rather than a simple forecast based on rainfall forecast and information of historical events (empirical scenario) another potential means of urban flood forecasting would involve running simple or extremely detailed computationally intensive simulations which is currently within the grasp of the urban flood practitioners. The simplest of models would be a 1D or 2D model. 1D modelling has been the conventional approach to urban flood modelling particularly because pipe systems were designed for the collection and disposal of storm and waste water in urban environments. More recently, because of urban growth and climate change and thus the increased frequency of floods in some places, the urban surface is now considered to have a dual purpose, one of which is to channel water out of the urban area. For that reason, using a 2D terrain model in an urban environment is appropriate for urban flood modeling (Gourbesville, 2009).

Recent advances in the ability to obtain low cost terrain data can account for why 79.0% of the participants have access to terrain data. Despite this access, only 47.1% (which is 37.5% of the participants) are using it for flood forecasting (Figure 3). The most probable explanations as to why so few are using terrain data for flood forecasting *may* be because they are probably not interested in making a flood forecasts or they *are* not sure how to handle the storage or the carrying capacity of the pipe system. In the latter case, if the design capacity of the urban drainage system is known in equivalent rainfall, the closest approximation would be to subtract it from the rainfall input for the event being modelled. In effect, the pipe system is seen as storage and its rainfall equivalent to its storage capacity that is removed prior to running the simulation of the event. In that way, the carrying capacity of the drainage system is almost accounted for. This approach is an approximation but is useful when additional information about the pipe system is not known.

Perceptions

Some other issues emerging from this finding relating specifically to data quality and quantity are based on an understanding of the experiences and perceptions of those who took part in the survey. One unanticipated finding was that a significant percentage (40.9%) of the participants did not have difficulty getting data with the majority (Table 3) saying it was because a client paid or provided the data or the data was available at the office. It is not surprising that the majority who did not have problems got the data from their office or were provided or paid by the client. It is interesting to note that in real life implementations, data are considered to be a necessity and the cost for data acquisition is usually small compared to the consultancy and construction costs.

There are also several possible reasons why 59.1% had difficulty finding data (Table 4). As can be seen from the table, the most common (43.8%) reason is that the data has not been measured in the first place. Adding to the problem is the increasing evidence (Table 4) that in some instances the data is measured but is not easily available. This is not limited to the cost of purchasing the data, technological incapacity, organizational policies, reliability etc.   These are common problems which demands more focus to mitigate risks in urban environments.

The principal constraints for urban flood modelling and management as perceived by the participants are the cost for data acquisition, limited ability to calibrate and validate models, copyright bureaucracy and so on (Refer to Section 0). All hydrological and hydrodynamic applications require data, and acquiring (measuring) data in some instances can be prohibitive. For research, the cost of data is generally perceived to be high, but as previously mentioned cost for data acquisition is usually not an issue in real life implementations. As a result, data procurement should not be assessed in isolation but rather relative to the damage reduction costs.

Model calibration and validation has been the most important modelling issue for some time (Beven, 2009, Refsgaard et al., 2005) and the importance of tying this to real-time urban flood forecasting continues to challenge many urban flood practitioners. The credibility of the predictive skill of the model ultimately depends on rigorous model calibration and validation when datasets are available. Otherwise, a sensitivity analysis on the impact of flood from impervious area and roughness is required. This is essential to reduce uncertainty and to increase the user confidence in the predictive ability of the model, which makes the application of the model more effective.

It has been argued by Refsgaard et al, (2005) that although limitations in data may affect the reliability of the model, it is not the main reason for poor modelling results. They argued that the inadequate use of guidelines and quality assurance procedures and improper interaction between the client and the modeller is the dominant reason for poor results, therefore suggesting that there is potential in the resources at our disposal.

Data resolution has an effect on the predictability of the model. Generally, finer resolution data better represents the reality and is usually considered much better. However, it is not necessarily the case as it all depends on how precise the results from the computational procedures should be. Fine resolution data have their own constraints and may not necessarily be ideal for all applications. Coarser resolution data can be used in some instances and may be considered fit for the purpose. On the other hand, most research applications (such as climate change impact studies) would require finer resolution data since it is important to determine the impact, particularly because it may have huge implications.

Another challenge which has been an issue for some time is the subject of uncertainty (Beven, 2009, Pappenberger and Beven, 2006). Uncertainty in data has been the main limitation to the development of accurate flood modelling, in particular, land use data, sewer system data and DEM (Djordjević et al., 2013) and accuracy in historical rainfall records, especially when modelling floods for long return periods. As emphasised by one of the respondents, "*Statistically you need over 100 years of flow data to derive 100 year flows with high confidence*". It is of course correct the more data the smaller the uncertainty of estimation of extreme events. However, use of statistical models allows quantification of the uncertainty related to the available sample (sampling uncertainty), which is important for the decision making. It is also important to consider not only the uncertainties in the input datasets but also the uncertainties in flood forecasting per se (outputs).

In order to get access to data in real-time, the data must be available through high speed devices. However, it is not so difficult to get access to data in real-time because of ease of access of internet connections in areas of interest for data collection. While this may have been a problem on the river basin scale, in an urban setting internet connection should not be an issue, even in the most remote settings. Nevertheless, at the river basin scale progress has been made in the collection of real-time data from remote hydrological monitoring stations

(Keoduangsine and Goodwin, 2012).Existence of real-time information systems is more of a problem than internet access which is paramount for real-time data access.

The only phenomenon that presents a challenge to urban flood managers is that of urbanization. Urbanization results in demographic changes which bring about unprecedented changes in land use which constantly needs updating. The constant change means that models should be constantly updated which results in significant cost.

Despite all the challenges and constraints outlined by the participants in the survey that are discussed above, the authors have identified what they believe are the main barriers that affect the ability to issue an urban flood forecast and these are summarised in Table 5.

[Table 5 near here]

Conclusions

This paper has given an account of the possible reasons why real-time urban flood forecasting systems are not so widespread, based on a world-wide survey. In this investigation, the aim was to assess the potential for real-time urban flood forecasting based on specific data for urban flood management currently at our disposal.

The study has shown that data for urban flood management is more widespread than is generally perceived. Only 59.1% of the 176 participants have actually had difficulty acquiring data. It was also shown that most participants were actually using the data for research followed by flood forecasting. Although it was only a small percentage, the most interesting comment from some participants is that they see the lack of published cases as a challenge in urban flood forecasting. These finding suggests that, although not confirmed, urban flood practitioners may not know that they can make a very simple forecast, though with increased uncertainty based only on rainfall forecast and information of past flood events when software and models and finer resolution data are not available. The conclusion is drawn from the fact that generally people tend to get motivated when practical examples of cases to associate to, are available, which usually appear in publications.

The evidence from the study suggests that there *may* be more cases as urban flood practitioners become more aware of what *can* be done. In conclusion, the present study provides a state-of-the –art view of current real time flood forecasting, highlights the perceived challenges, and most importantly indicates what the authors believe to be the real challenges that hinder the progress of real-time urban flood forecasting.

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Table 1: Role of different data type in each real-time flood forecasting scheme

	Component	**Empirical scenario**	**Pre-simulated scenario**	**Real-time simulations**
Historical Data	Rain gauge	Used to set threshold level	Input for development of the scenario catalogue	Used for model building (e.g. model calibration)
	Network	-	Flow conveyance in sewer and storm water systems	Flow conveyance in sewer and storm water systems
	Water levels and flow rates	Used to set threshold level	Used for model calibration and validation	Used for model calibration and validation (offline)
	Terrain	-	Flow conveyance for 2D overland model	Flow conveyance for 2D overland model
	Land Use	-	Used in model development	Used in model development
	Operational Data	-	Used in model development	Used in model development
	Radar	Used to set threshold level	input for development of the scenario catalogue	Used for model building
Real-time Data	QPF (NWP and radar)	Used for scenario selection when threshold level is exceed	Used for scenario selection	Used as input for online hydraulic simulations
	Rain gauge	Used for scenario selection when threshold level is exceed	Used for scenario selection	Input
	Flow rates	Used for scenario selection when threshold level is exceed	Used for scenario selection	May be used in data assimilation for model updating
	Water levels	Used for scenario selection when threshold level is exceed	Used for scenario selection	May be used in data assimilation for model updating
Models	1D, 2D, 1D/1D, 1D/2D, 1D/1D-2D	-	Used for hydraulic simulations for creating scenario catalogue	Used for performing computations online (in real-time)

Table 2: Background characteristics of participants

Profession	**%**	**Organisation**	**%**	**Experience**	**%**
Hydraulic Engineer	28.4	Governmental	17.0	< 1 year	4.0
Hydrologist	12.5	Private	31.8	1-4 years	29.0
Civil Engineer	35.2	University	44.3	5-10 years	25.6
Environmental	2.8	Research	22.7	> 10 years	40.9
Researcher	1.7	Other	2.3		
GIS/Remote sensing	2.8				

Hydroinformatician	6.8		
Other	9.7		
Total	100%	118.2%	100%

Table 3: Percentage of participants with different perceptions on why they had no difficulty in obtaining data

Reasons for not having difficulty in obtaining data	%
Client provided or paid for data collection	23.3
Data was available at the office	21.6
I had access to technology that enabled easy transfer	15.3
I knew someone who could have obtained the data for me	10.8
I knew someone at the office where the data was available	7.4

Table 4: Percentage of participants with different perceptions on why they had difficulty in obtaining data

Reasons for having difficulty in obtaining data	%
Not been measured in the first place	43.8
Measured but considered not to be reliable enough for exchange	22.7
Measured but collecting organization policy is to keep data confidential	21.0
Measured but there are legal restrictions including intellectual property rights	21.0
Measured but not in a format that enables exchange	14.2
Measured but is prohibitively expensive	14.2
Measured but too expensive to download	13.6
Measured but perceived not to be important to others	11.9
Measured and are suitable for exchange and the technology exists but lack of capacity to implement it	5.1
Measured and are suitable for exchange and the technology exists but is not reliable	5.1
Measured and are suitable for exchange but the technology for transfer does not exist	3.4

Table 5: Challenges that may hinder the use of forecasting systems

Approach	Challenge
Empirical scenario	• Lack of information on past flood events (no observations) • Urbanization which may affect flood locations • Uncertainty in rainfall input
Pre-simulated scenario	• The rules for scenario selection are not adequate • Catalogue does not contain a wide range for scenario selection • Model calibration and validation • Uncertainty in rainfall input • Real-time data access
Real-time simulation scenario	• Model calibration and validation • Uncertainty in rainfall input • Lack of data, technology and human resources • Real-time data access

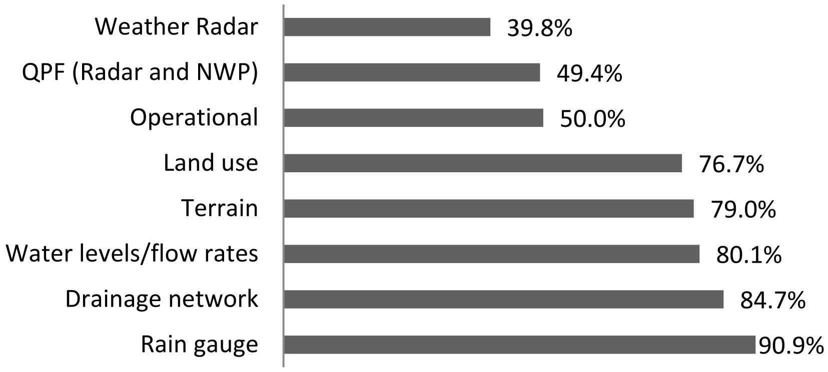


Figure 1: Percentage of participants who have used the relevant data

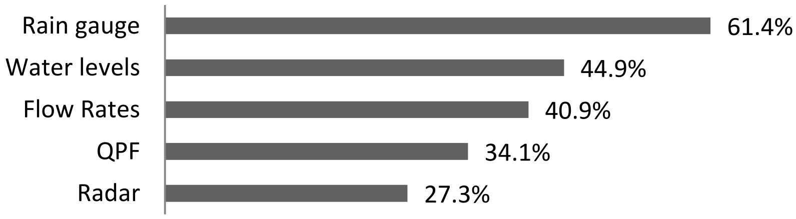
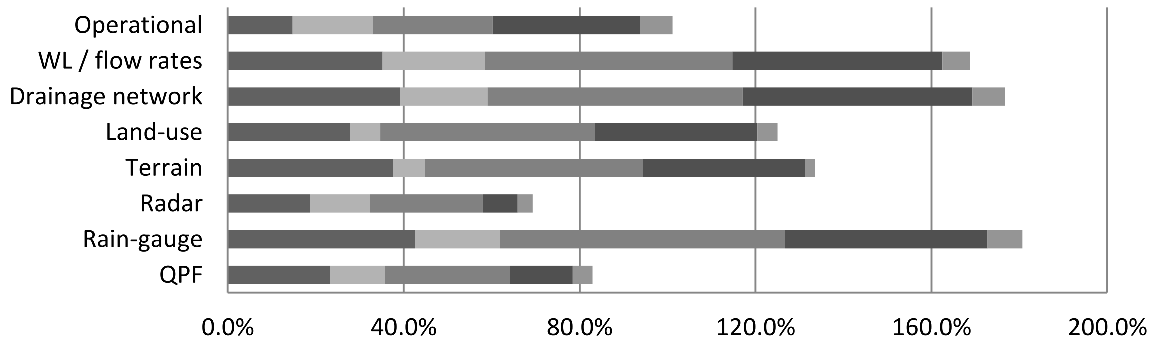


Figure 2: Percentage of participants with real-time data access



	QPF	Rain-gauge	Radar	Terrain	Land-use	Drainage network	WL / flow rates	Operational
Flood forecasting	23.3%	42.6%	18.8%	37.5%	27.8%	39.2%	35.2%	14.8%
Real-time control	12.5%	19.3%	13.6%	7.4%	6.8%	19.9%	23.3%	18.2%
Research	28.4%	64.8%	25.6%	49.4%	48.9%	58.0%	56.3%	27.3%
Design	14.2%	46.0%	8.0%	36.9%	36.9%	52.3%	47.7%	33.5%
Other	4.5%	8.0%	3.4%	2.3%	4.5%	7.4%	6.3%	7.4%

Figure 3: Data applications