WP3 OUTPUTS

1. Selection and 'implementation' of pilot locations across the 4 partner countries:

A total of 12 pilot sites located in the 4 participating countries were selected for testing the rainfall monitoring and processing techniques, as well as the urban pluvial flood modelling and forecasting methodologies developed as part of the project. Pilot catchments were selected based on data availability and in such a way that a variety of urban hydrological conditions were covered. At each of these locations rainfall and runoff were monitored (using a range of sensors) and urban pluvial flood models were implemented. Information about the pilot locations, including general characteristics of each catchment, as well as data and models available/implemented for each of them, can be found under the **PILOT SITES** tab.

2. Review document on urban pluvial flood models: current theory and practice

At the beginning of the project a review document was produced which provides an overview of the state-of-the-art of urban pluvial flood models, including a description of their inputs and components and approaches for modelling these. This document served as 'road map' for the implementation of models throughout the project (WP3). The document also includes a brief description of the type of models implemented at each of the pilot locations of the RainGain project. Click here to access this document.

3. Tools and recommendations for urban pluvial flooding simulation, model building and catchment analysis:

Throughout the RainGain project a number of tools were developed, tested and / or used to model storm water flows and pluvial flooding in urban areas. Along the way, recommendations for handling specific modelling aspects were made.

3.1. Urban pluvial flooding simulation tools:

Depending on the modelling software most commonly used at each partner country, on the data that were available and on the purpose of the modelling exercise (e.g. whether it is for urban planning or real time applications, such as flood forecasting and warning), different simulation tools and modelling approaches were adopted for each pilot location. Some of the adopted software tools were commercial ones, developed by companies external to the project and widely used by urban hydrologists around the world, whereas others were research tools developed by project partners. The use of different simulation tools enabled comparison and allowed drawing conclusions regarding the suitability, advantages and disadvantages.

The software simulation tools used within the project include the following:

- **InfoWorks CS** and **InfoWorks ICM**: commercial tool developed by Innovyze. Used in the UK and Belgian pilot sites.
- **Sobek**: commercial tool developed by Deltares. Used in the Dutch pilot sites.
- **Canoe**: commercial tool developed by Artelia in collaboration with a group of French institutions. Used in the French pilot sites.
- **MultiHydro:** research tool developed by ENPC partners. Used in the French and Dutch pilot sites.

A brief description of each of these tools and of the modelling approaches implemented as part of the project can be found in this document.

3.2. Model building and analysis tools and recommended practices:

A range of tools and recommendations to aid the analysis of urban catchments and the implementation of urban storm water drainage models were developed, documented and tested within the project.

Click on the links below to access additional information and/or documentation of each of the tools.

- **Fractal tools for analysis of urban catchments:** these tools can be used to analyse geometric features of different aspects of urban catchments, including sewer layout and land use distribution. They were developed by partners from ENPC during the RainGain project. **Additional information (will be available soon):** Tutorial kit

- **Automatic Overland Flow Delineation (AOFD) tool:** this is a GIS (Geographic Information Systems) tool which, based upon a digital elevation model (DEM) of the study area, generates a 1-dimensional (1D) flow model of the urban surface. In this 1D model the urban surface is discretised as a set of storage nodes (representing ponds) and conduits (representing streets and other pathways through which surface runoff flows. As compared to 2D models of the urban surface, 1D models are significantly faster, thus being suitable of real-time applications. However, 1D models have some limitations, including poor visualisation of flood simulation results and inability to handle flows in flat areas. This tool was initially developed by Imperial College London partners as part of a previous research project (Maksimovic et al., 2009). During the RainGain project this tool was further improved and a detailed tutorial was developed. **Additional information:** Overview of the AOFD tool; User manual. To obtain a copy of this tool (i.e. an executable file) and test data, please contact Prof. Cedo Maksimovic (c.maksimovic@imperial.ac.uk) or Dr Ana Mijic (ana.mijic@imperial.ac.uk).

- **General recommendations for dealing with open channels and other small surface features in urban pluvial flood simulations:** Recent developments in urban drainage simulation tools include the seamless integration of classical 1 dimensional (1D) models of the sewer network with 2-dimensional (2D) models of the urban surface which enable a more realistic and accurate representation of the urban drainage system, both during and after the occurrence of intense rainfall. Given the growing risk of urban pluvial flooding as well as increasing drives to make urban drainage systems ever more sustainable, it is important that small surface elements are modelled sufficiently accurately, as these play a critical role in the management of overland flows, which in turn affects the overall performance of the drainage system.

  Different tools will use different approaches to represent such surface elements, but all are based on the availability of digital elevation models (DEMs). Whereas ten years ago the typical average grid size of DEMs was anything between 2-5 m, recent LIDAR technology has made it possible to create models with a density of around 15 – 20 points per m² (or a corresponding grid size of about 0.25 m).

  High resolution DEMs create new opportunities for fully integrating small surface elements, such as road ditches and small trenches, into the 2D model of the rest of the surface, which includes roads, fields, parks, etc. This was not possible using traditional (coarser) DEMs, as their resolution was often coarser than the size of the small surface features. When this was the case (and it may still be in given areas), a better approach may be to model the small surface features in 1D and embed them into the 2D model of the surface. The approach that is adopted to model such elements needs to be carefully selected by the modeller, based upon the resolution and quality of the available data, the simulation tools available to him/her, and the purpose of the modelling exercise.

- **General recommendations for dealing with buildings in 2-dimensional (2D) urban flood simulations:** Similar as for the widespread availability of high resolution digital elevation models (DEMs), it is now common to have very detailed GIS background layers of buildings in urban environments. Although this information is very important for 2D flood simulations (given that buildings somehow are "obstacles" for the flood propagation), its high level of detail can turn out to be quite challenging for numerical calculations.

  Vector layers of buildings often have a very high point (vertex) density to make sure that even the most complex shapes and corners are well represented. However, in creating a 2D calculation mesh this can become problematic because the alignment of the mesh with the buildings can cause the mesh to become incredibly complex both in terms of geometry and of number of mesh elements required to cover the buildings' contours. This can result in exponentially increased simulation times.

It is therefore important that building layers are as much as possible cleaned and simplified (however without losing the essential details) before using them in a 2D model. A number of GIS routines exist which can be used for this purpose (e.g. SimplyPy QGIS plugin), although they may be refined and tailored for specific purposes. It is important to conduct sensitivity tests when using such tools, so as to ensure that a desired level of simplification is achieved, while preserving essential topological and geometrical features.

4. Urban storm water drainage modelling results:

Making use of the urban storm water drainage models that were implemented during the project, as well as of the high resolution rainfall estimates that were collected and post-processed, a number of tests were conducted mainly around two topics:

(1) Evaluation of urban storm water modelling approaches, including comparison of fully-distributed vs. semi-distributed models, detailed analysis of model resolution and evaluation of model nesting approaches, amongst others.

(2) Analysis of the impact of rainfall input resolution on urban drainage modelling outputs and consequent identification of rainfall resolution requirements for urban hydrological applications.

These tests involved several pilot locations, making the results robust and enabling drawing general conclusions and useful recommendations for urban hydrologists. The results of these tests have been summarised in a number of reports and scientific publications; the main reports/outputs are listed below. For a full list of publications, please visit our publications webpage.

- Ochoa-Rodriguez et al. (2015). Impact of spatial and temporal resolution of rainfall inputs on urban hydrodynamic modelling outputs: A multi-catchment investigation. Journal of Hydrology (In Press).

- Bruni et al. (2015). On the sensitivity of urban hydrodynamic modelling to rainfall spatial and temporal resolution. Hydrology and Earth System Sciences, 19 (2), 691-709.

- Gires et al. (2014). Impacts of small scale rainfall variability in urban areas: a case study with 1D and 1D/2D hydrological models in a multifractal framework. Urban Water Journal, 47(4).

- Pina et al. (2014). Semi-distributed or fully distributed rainfall-runoff models for urban pluvial flood modelling? In 13th International Conference on Urban Drainage, Sarawak, Malaysia. [**Additional material:** Poster presented at RainGain Final Conference 2015]

- Ichiba et al. (2015). High resolution modeling in urban hydrology: comparison between two modeling approaches and their sensitivity to high rainfall variability. In Proceedings of European Geoscience Union General Assembly 2015 (Vol. 17, EGU2015-14103-1, 2015). [**Additional material:** Poster presented at RainGain Final Conference 2015]

- Murla & Willems. (2015). Nested 1D-2D approach for urban surface flood modelling. In Proceedings of European Geoscience Union General Assembly 2015 (Vol. 17, EGU2015-7162-1, 2015), Vienna, Austria. [**Additional material:** Poster presented at RainGain Final Conference 2015Poster]

Some of the main lessons learned from these tests were the following:

- One size does not fit all! The type of urban drainage (flood) model to be used depends on:
    - Purpose (e.g. CSO reduction? flood visualisation? Real-time / off-line applications?)
    - Data availability: surface data, sewer data & rainfall data

- Available computer power

- There is a strong interaction between the temporal and spatial resolution of rainfall inputs and urban drainage models. Disparity between these (e.g. very fine spatial resolution with relatively coarse temporal resolution; very high resolution urban drainage model forced with relatively coarse resolution rainfall data) may lead to significant loss of information and to ill-posed models.

- Fully-distributed models are generally desirable (over semi-distributed models), as they provide a more realistic representation of urban runoff processes and allow better visualisation of results. These models are particularly desirable in areas in which runoff ponding (before it reaches the sewer system) is a relevant flooding mechanism. Current tendency is in fact towards the use of fully distributed models. However:

    - Runtimes of fully-distributed models are still problematic. Options for overcoming this include use of nested and hybrid models, and making best use of available computational power.

    - Fully distributed models require far more detailed data for their implementation and forcing. Such data are not always available and are often hard to process. When detailed data are not available for model building, semi-distributed models may be a better option.

- The temporal resolution of rainfall inputs showed to have a stronger impact on urban drainage modelling outputs, as compared to the spatial resolution. In terms of urban drainage model sensitivity, results suggest that rainfall inputs with temporal resolutions below 5 min are required for urban hydrology, whereas spatial resolution of ~500 m – 1 km may suffice (for drainage areas > 1 ha). However, from an atmospheric / meteorological perspective, measuring rainfall at high temporal and spatial resolution can lead to improved accuracy and better understanding of the microphysics of the atmosphere, which in turn can translate into improved rainfall forecasts.

5. Methodologies for Real-Time modelling of urban storm water models:

In order to conduct real-time simulations of urban storm water models, it is necessary to automatically link rainfall inputs to hydrological/hydraulic models, and to other data sources (e.g. water depth monitor data). Moreover, it is important to have interfaces which enable effective visualisation of results. Several alternatives/tools exist to perform these functions. Some of them correspond to "in-house" linkage of input data and models which are developed for a specific application (e.g. Vieux et al. (2005), Achleitner et al. (2009), Coors et al. (2012)), whereas others use existing open shell systems which allow managing and integration of time-series data (including rainfall inputs, runoff records, etc.) and modelling processes (e.g. Delft-FEWS (Deltares, 2008), UrbanFlood Common Information Space (Balis et al., 2011), FloodWorks (Innovyze, 2005), InfoWorks ICM Live (Innovyze, 2013)).

During the RainGain project, two approaches for automatic linkage of rainfall inputs to urban drainage models and subsequent real-time simulations were tested and documented. Click on the links below to access additional information about these approaches.

- **Delft-FEWS Platform:** Delft-FEWS provides an open shell system for managing forecasting processes and/or handling time series data. It was developed by Deltares and is freely available. It incorporates a wide range of general data handling utilities, while providing an open interface to any external models. It has a modular structure which makes it flexible and highly configurable, thus allowing its effective use in simple as well as complex systems. The Delft-FEWS system was developed using Java, but is fully configurable through open XML (Extensible Markup Language) formatted configuration files. Moreover, it can either be deployed in a stand-alone, manually driven environment, or in a fully automated distributed client-server environment. For the RainGain Project the standalone setup was considered more appropriate. A full customisation was completed for the Cranbrook pilot catchment (UK), whereas basic customisations were implemented for pilot locations in other countries. During the project two **tutorial sessions** were held whereby participants were instructed in (1) Basic customisation of the platform including definition of locations and filters and import and visualisation of telemetry data; (2) Handling of spatial data and connection of external algorithms to the DELFT-FEWS platform. The training material developed for these tutorial sessions, including instructions as well as customised configuration files, can be downloaded from the following links. **Additional information:** Overview of the Delft-FEWS platform; Delft-FEWS customisation for RainGain pilot locations; Delft-FEWS RainGain Customised Tutorial 1 (locations, import and visualisation of telemetry); Delft-FEWS RainGain Customised Tutorial 2 (Handling of spatial data and connection of external algorithms). In order to obtain Delft-FEWS installation files the reader must contact Deltares directly.

- **InfoWorks ICM Live:** As an extension of the (proprietary) InfoWorks ICM software suite, ICM Live enables real time simulation (including forecasting) of urban drainage systems. All input data streams (e.g. real-time rainfall data from gauges and/or radars, real-time observations of flows and depths, forecasted rainfall data) can be loaded and configured within the familiar ICM user interface. These are then linked to urban drainage models, implemented in InfoWorks ICM. Model results can be processed and viewed in real-time according to user defined criteria and can be used for generating alerts and warnings. A basic configuration was tested by Aquafin for the Herent catchment (BE). Awaiting a fully operational integration of forecast models that were developed in the framework of the Raingain project, the simulations are currently limited to hindcast mode. **Additional information (will be available soon):** Presentation of the Aquafin ICM Live implementation.