Water Challenges for a Changing World
Joint Programming Initiative

WaterWorks2014 Cofunded Call
Final Progress Report

Research and Innovation for Developing Technological Solutions and Services for Water Systems

Multi-scale Urban Flood Forecasting (MUFFIN)

This document must be filled in by the project coordinator with the help of the project partners and must be sent to the WaterWorks2014 Follow-up Secretariat by **2019-09-01** (for Consortium MUFFIN).

The WaterWorks2014 Follow-Up Secretariat will ensure distribution to the concerned national funding agencies. The project coordinator is responsible for sending a copy of the report to the partners.

PROJECT TITLE AND ACRONYM

Author(s) of this report (Coordinator): Date of submission: 2019-08-31

Jonas Olsson (coordinator), Lisa van Well (WP leader), Marc Schleiss (WP leader), Søren Thorndahl (WP leader), Teemu Kokkonen, Tero Niemi, Rasmus Nielsen, Jim Hedfors

E-mail: jonas.olsson@smhi.se

Project Website: http://www.muffin-project.eu/

Project code: WaterWorks2014 - MUFFIN

Duration of project: officially 40 months

Start date: 2016-05-01 End date: 2019-08-31

Period covered by this report: 2016-05-01 – 2019-08-31

Title of the Final Technical Report: MUFFIN Technical Report

Authors of the Final Technical Report: same as above authors of this report

Please ensure that you do enclose the Final Technical Report as an Appendix to this report.
If this report cannot be made available publicly in reason to IPR considerations, please provide also a version of the Final Technical Report for dissemination (Public Report).

1. Publishable Summary

(Maximum 1 page)

More and more people live in cities and by 2050 two thirds of the global population is expected to live in a city. Because of this urban migration, cities generally need to densify and expand. The densification often leads to more impermeable surface, such as asphalt and concrete, which increases the risk of flash floods in city centres. The expansion may require that historically flood-prone areas need to be exploited, which increases the flood risk also in suburbs and peripheral parts. In parallel with this trend, climate change is expected to intensify the hydrological cycle and for example lead to heavier rainfall. When combined, these changes are likely to significantly increase the risk of flooding in urban and peri-urban areas. There is an urgent need for research towards better understanding, describing and forecasting urban flood risk under these changes.

Much of the R&D in this context is focused on how to design (and re-design) cities to become more "climate proof", in the sense better prepared to handle the expected future climate, e.g. by so-called "nature-based solutions" like green roofs and open dams for stormwater reduction and delay. This is a long-term planning perspective; to gradually modify the cities. There is also a short-term awareness perspective of adapting to the changes, which has been the focus of the MUFFIN project: the need for better tools for real-time urban flood forecasting and decision support (Early Warning Systems). The earlier we can predict a flood risk situation, the higher is the chance of reducing the negative impacts on society.

In essence, an Early Warning System for urban flooding consists of three components:

1. *Rainfall data*. We need both recent rainfall observations, to know how much water is already in the ground, in pipe systems, etc., and rainfall forecasts, that predict the rainfall over the coming hours and days.
2. *Flood model*. We need a model that translates the rainfall hitting the ground to water flows, both on the surface and underground, and potential flooding, either by the flow exceeding the local drainage capacity or by river overtopping when combined with upstream inflows.
3. *Communication tool*. We need a tool that presents the rainfall data and the output from the flood model to relevant users. The tool must present these things in a way that is meaningful for the user, it must be fast and it must be easy to access and understand.

In MUFFIN, we have worked on all three components. Concerning rainfall data, we have focused especially on rainfall observations by weather radar. We have shown that radar observations of very heavy rainfall are uncertain and that radars with a higher level of detail are preferable. We have explored using citizens' weather stations and flood reports for improved forecasts. Concerning flood model, we have developed and tested a coupled multi-scale system, essentially with one model describing the upstream inflow (large scale) and another model describing the flooding in the city centre (small scale). We have shown that forecasting with a 1-h time step is useful in an urban context, and a national 1-h model is now operational in Sweden. We have explored the possibility to use open data and open software for innovative urban flood forecasting. Concerning communication tool, we have developed a prototype for radar-based rainfall visualization with several new features, e.g. "seamless" integration of observations and forecasts. Furthermore, the multi-scale model has a graphical interface with continuously updated forecasts to support the user.

All work in MUFFIN has aimed at fitting as closely as possible to end-users' requirements. An international end-user workshop was held in the beginning of the project, and the subsequent development and experiments were designed on the basis of the outcome. Through this approach, we hope that the results and products from MUFFIN will have a real impact. The results and products were disseminated at the successful final conference named CITIES, RAIN and RISK, held in Malmö, Sweden, 13-14/6 2019.

Project web site: http://www.muffin-project.eu/

2. Work Performed and Results achieved within the Project

(*Maximum 12 pages*)

a. Scientific and technological progress

- *Did the project achieve its main objectives, milestones and deliverables? Please also describe the ways in which they were reached.*

Five (ambitious) key objectives were listed in the proposal and in the following their degree of accomplishment is assessed:

- *To specify the requirements on urban flood forecasts by different end-user categories*

Well reached through end-user interviews, questionnaires and a joint workshop (Appendix IIa) early in the project as well as continuous interaction between project partners and local end-users (Appendix IIb).

- *To gain knowledge about small-scale rainfall extremes, their space-time characteristics and predictability*

Well reached through Joint Experiment 2 as well substantial amounts of analyses of local rainfall observations and forecasts by the project partners (Appendix I and IIc).

- *To explore the performance limits of high-resolution state-of-the-art urban flood forecasting systems*

Well reached through Joint Experiments 1 and 3 as well as local analysis and modelling (Appendix I and IId).

- *To develop a Pan-European flood forecasting system with a quantified performance in urban areas*

Partially reached through Joint Experiment 3, which combines output from a high-resolution implementation based on the Pan-European model with a local model for improved forecasting. Full Pan-European implementation was not attained, but (*i*) required background knowledge and results were obtained through the Joint Experiments (Appendix 1) and (*ii*) proof-of-concept implementation is on-going in follow-up project PLUPP (Section 2e).

- *To describe the relationship between the scale/accuracy of the forecasting system and the end-user value*

Partially reached through end-user requirements (Appendix IIb), Joint Experiment 2 and local investigations by the partners (Appendix 1) but needs further research.

See further item 2g below.

- *How did the project progress in comparison to the original description and milestones? If not/only partly, please describe the reasons for the possible deviations.*

See previous item. Overall the project progressed (and ended) well according to plan, and all deliverables and milestones were reached, but some deviations are worth mentioning:

- There was an initial delay because different times of approval (and starting dates) between the partners (see also item 13 below), the Consortium Agreement took time to finalize, as did the process of hiring staff.
- We were affected by unexpected malfunctioning of sensors, notably the radar observation sites in the Netherlands (Appendix 1).

- A full Pan-European high-resolution (sub-daily) hydrological model could not be not attained. Its realization was based on assumptions of positive preliminary results from the Joint Experiments, that we needed to await. But (*i*) the experiments got somewhat delayed and (*ii*) the results raised some question marks and need for further investigation. Still, it is very clear that there is value in sub-daily hydrological forecasting on Pan-European level and the work will continue in follow-up project PLUPP (Section 2e).

- *How did the project promote a multidisciplinary approach during its lifetime?*

The project staff was designed to include experts from a rather wide range of disciplines, including meteorology, hydrology, social scientists, IT / web development, mathematics / statistics, Geographical Information Systems, etc. Through the workshops and the conference as well as the Joint Experiments and the prototype development, the different experts have been closely collaborating (rather than working individually).

- *What was the most important result of the project? Please describe why.*

At this point, when the project is just about to be wrapped up, it is difficult to select one result as the "most important". In a year or two we will know which of the results that were most successful, in the sense making most impact, but today this is very difficult to judge.

The end-user requirements gathered in MUFFIN (Appendix IIb) were important for designing the activities in the project itself (see Section 4 in Appendix 1) and will be important also for designing follow-up activities. The two prototypes developed in MUFFIN (multi-scale rainfall visualization and multi-scale flood forecasting) were developed in collaboration with (and will be further evaluated by) end-users representing different categories. All partners worked closely with local end-users as well as communities, e.g. with citizen observations and tailored model development. Furthermore, we believe that MUFFIN has promoted new understanding and new contacts between different types of end-users, not least through the final conference CITIES, RAIN and RISK. All this end-user interaction clearly helped making MUFFIN more relevant.

Conceivably the findings from the three Joint Experiments will be important and useful for the "urban flooding community" in the on-going "climate proofing" of urbanized areas worldwide.

1. *Hydrodynamic vs. high-resolution hydrological modelling*: The joint efforts to compare the hydrologic and hydraulic models at multiple scales highlighted the differences between the two approaches. There are definitely advantages using the fast hydrological models in high resolution with focus on urban areas – especially for real-time modelling and assessment of warning levels. However, the hydrological models are still not at the level of detail as the hydraulic models with inclusion of the urban drainage systems in terms of predicting flooding. It is needed to explore hybrid or coupled models, as in Joint Experiment 3.
2. *High-intensity rainfall in European operational radar observations*: The European radar data comparison proved the importance of high-resolution precipitation data in terms of estimating heavy flood producing rainfall. The scale dependence found is important for understanding the limitations involved in using radar data for flood risk assessment and the results have implications for the future management and development of radar

observations systems in Europe and elsewhere.

3. *Development of a multi-scale flood forecasting system*: The coupling of the two types of models (hydrological and hydro-dynamic) to one flood warning product shows great potential. The experiment outlines how a large-scale high-resolution multi-basin hydrological model can serve as input to local flood models for early warning in real time. More work is needed to develop this concept into a product that can be applied everywhere, but this experiment has provided a baseline approach for future development.

Some further project highlights include the following:

- The development of an hourly national flood forecasting system for Sweden (Appendix 1) is a significant output from the project, that is used in operational forecasting. This provides a substantial added value especially for flash floods, as compared with the standard daily forecasting system. The Swedish system is used as a "role model" for the on-going development of a high-resolution pan-European model.
- The estimation of "rainfall thresholds" for warning purposes, attained by different approaches in Joint Experiment 1 (based on a "rainfall event catalogue") and locally at TUD (through citizen reports), is another significant output. Meteorological forecasts are becoming gradually better at predicting sub-daily rainfall extremes, and this information is crucial for interpretation and communication.
- The exploration of open data and open software for urban flood forecasting, particularly at Aalto is a significant contribution. Methods have been developed for facilitating urban runoff simulation using spatial datasets characterizing topography and land-cover of urban regions. Such datasets are often openly available and range from more detailed local scales to continental scales having a coarser resolution. MUFFIN also linked open tools to generate nowcasts of rainfall, runoff, and flooding extent in an urban setting.
- The project has generated / will generate a large number of scientific publications and conference contributions (Section 8 below).
- Last but not least, the final conference CITIES, RAIN and RISK (jointly with INXCES project) became a very successful event that must be considered an important result from the project. Directly after the conference there were discussions whether we should make this a recurring event and hopefully that will happen.

b. List of students supported by or affiliated with this consortium

The list is not attached due to GDPR. Please contact Jonas Olsson at SMHI (Jonas.olsson@smhi.se) if you have any questions.

c. List of staff supported by or affiliated with this consortium

The list is not attached due to GDPR. Please contact Jonas Olsson at SMHI (Jonas.olsson@smhi.se) if you have any questions.

d. Mobility of staff and students supported by or affiliated with this consortium

The list is not attached due to GDPR. Please contact Jonas Olsson at SMHI (Jonas.olsson@smhi.se) if you have any questions.

e. Collaboration, coordination, mobility and synergies

- *Please indicate clearly who performed the work.*

See Table 2c above.

- *Describe how effective and active was the collaboration between partners (incl. in-kind partners).*

The project was designed in two phases, with different levels of interaction between the partners:

Phase 1 (~first half): *End-user requirements and partner-specific activities*. In this phase, the main collaboration between partners concerned (i) the preparation and implementation of the End-user workshop held in February 2018 and (ii) the design of the Joint Experiments in phase 2. Otherwise the focus was on observation and model development individually at each partner, in preparation for the second phase.

Phase 2 (~second half): *The Joint Experiments*. Three joint experiments, as far as possible designed based end-user requirements, were performed (see further Appendix I):

1. Hydrodynamic vs. high-resolution hydrological modelling

2. High-intensity rainfall in European operational radar observations

3. Development of a multi-scale flood forecasting system

These experiments involved all project partners and required intense collaboration by frequent communication (mainly e-mail) and monthly all-staff skype meetings as well as physical exchange visits (see Table 2d above). Overall, the collaboration has been sufficiently effective and active to fulfil the objectives of the project.

- *Were the coordination and organisation of the project effective? Please explain.*

In the partners' opinion, coordination and organization have been effective. This was facilitated by the limited size of the consortium, with only four main partners (and one sub-contracted partner). Annual physical meetings were held, as well as regular all-staff skype meetings, more frequent during the second phase of the project.

- *Please describe the mobility of the researchers within the Consortium.*

The mobility within the consortium was relatively limited, although four exchange visits were made (see Table d above) which contributed significantly to the Joint Experiments. Further mobility was desired but turned out difficult to realize, e.g. because of staff changing jobs and leaving the project.

- *How did the project and/or researchers' careers benefit from the mobility within the Consortium?*

The project benefitted substantially from the visits of Rasmus Nielsen and Tero Niemi at SMHI in 2018, when a key part of Experiment 1 was performed as well as detailed planning of Experiment 3. These visits induced a fruitful collaboration between partners. With HYPE being a widely used hydrological model, the HYPE course taken by Rasmus Nielsen and Damian Tyuls as a part of mobility within the project will hopefully be of value in their careers.

Aside from mobility, the participation in the MUFFIN project seems to have been generally advantageous from a career point of view, as all students associated with the project (see Table a above) have now got good jobs.

- *Please indicate coordination and/or synergies with other projects funded in the WaterWorks2014 Cofunded Call or national or international projects funded by Water JPI or other instruments.*

The coordinator initiated a collaboration with the INXCES project, also funded in the WaterWorks2014 Cofunded Call. Key members of the INXCES consortium, including the coordinator, were invited to the MUFFIN All-staff meeting in Delft on 2018-02-06, for discussion and coordination. The idea of a joint final event was born, tentatively to be held in Sweden. Further face-to-face discussion was made when the two coordinators met at the WaterWorks2014 Mid-term Evaluation Meeting and at the conference Nordic Water in Bergen (NO), August 2018. Two Swedish research projects were invited to join the event – *Sustainable Urban Flood Management* and *X-band Radar* – and in late 2018 the dates (13-14 June 2019) and venue (Malmö, SE) were decided. (It may be remarked that Malmö was confirmed as an optimally "climate-friendly" location for a joint final event, requiring the least possible total amount of travelling when considering all partners involved.) The joint final event finally became the international conference CITIES, RAIN and RISK (see Section 5 below), preceded by Climate Café Malmö organized by the INXCES project.

Concerning Sweden, the project has been coordinated with two other research projects funded by the same national FPO (the Swedish Research Council Formas). One is the SPEX (*Small-scale Precipitation Extremes*) project, which has developed the Swedish radar-observations used in MUFFIN. Currently, in the PLUPP (*Pluvial Flooding Support*) project, products and tools based on results from the MUFFIN project are being implemented or put into operational use.

Concerning Denmark, MUFFIN has initiated a closer collaboration between Aalborg University and Aalborg Water Utility Company and the municipality of Aalborg. Currently a proposal for a new development project building on top of the results of MUFFIN has been applied at the VUDP (The Danish water sector's development and demonstration programme). Notification of grant approval will be given in September 2019.

Concerning the Netherlands, through the experiments in Rotterdam, the Dutch partners have established substantial synergies and opportunities for future collaboration with the JPI Urban Europe project "FloodCitiSense" (https://jpi-urbaneurope.eu/project/floodcitisense/). At the core of this collaboration are the joint experiments and published papers on the use of citizen rainfall and/or flood report data as an alternative way of studying the hydrological response of urban catchments. The Dutch partners have also been collaborating with students and researchers from the H2020 TWIGA project (http://twiga-h2020.eu/) to design and test cheaper rainfall sensors for use in developing countries. This collaboration has led to a joint publication, to be submitted to Atmospheric Measurement Techniques, beginning of September 2019. Reference: "Something fishy going on? Evaluating the Poisson hypothesis for rainfall estimation using intervalometers: first results from an experiment in Tanzania", by Didier de Villiers, Rolf Hut, Marc Schleiss, Marie-Claire ten Veldhuis and Nick van de Giesen.

Concerning Finland, Finnish national funders did not participate in the WaterWorks2014 Cofunded Call and hence MUFFIN activities at the Aalto University were funded by the research grant awarded by the Maa- ja vesitekniikan tuki ry. private foundation.

f. *Infrastructures*

Please describe briefly the infrastructures used in the Project. Has the proposal been based/built on research infrastructures already existing?

The project has to a large extent been built upon an already existing infrastructure in each partner country, but for the Joint Experiments a new infrastructure have been built and data and models have been shared and used across this new infrastructure.

One major category of existing infrastructure used concerns weather radars for precipitation measurement, either single radars or radar networks. In NL, the KNMI radar network has been used, as well as a new micro-rain radar (acquired in MUFFIN) and an X-band high-resolution radar in the city of Rotterdam. In DK a local X-band radar at AAU has been used and in FI data from the FMI network. In SE and a multi-national domain used in Joint Experiment 2, the BALTRAD network was used.

Also local and national rainfall gauge networks have been extensively used. Other types of infrastructure were used e.g. to make flow observations in rivers, to collect citizen reports of flooding and to generate multi-scale weather forecasts (Joint Experiment 3).

Another major category concerns flood models (hydrodynamic or hydrological). Local models in DK, FI and NL were further developed and improved during the project. In SE and Europe, the HYPE model is associated with an extensive technical infrastructure for simulation and forecasting on different scales and over different domains (https://hypeweb.smhi.se/).

g. *Which WaterWorks2014 Call theme/themes were addressed by the project (listed below for your information)? How did the project cover the main aims & objectives of the Call?*

2. Research and Innovation for Developing Technological Solutions and Services for Water Resources Management:

• *Developing smart water technologies based on sensor networks and real-time information systems;*
MUFFIN: e.g. real-time rainfall visualization prototype and exploring citizen observatories.

• *Developing methodologies for adaptive water management, using relevant study cases, scenario development, and uncertainty assessment; and*
MUFFIN: e.g. assessment of radar uncertainty for high-intensity rainfall and development of coupled multi-scale flood forecasting prototype in Aalborg.

• *Setting up innovative decision-making tools.*

MUFFIN: the coupled multi-scale flood forecasting prototype and the rainfall visualization prototype are both examples of innovative decision-making tools.

3. Research and Innovation for Developing Technological Solutions and Services to Mitigate Impacts of Extreme Events (Floods and Droughts) at Catchment Scale:

• *Innovative tools for protection from hydroclimatic extreme events, including nature-based solutions, sensor technology, systems for interpreting and communicating data, and monitoring networks;*

MUFFIN: high-resolution forecasting tools, such the coupled multi-scale flood forecasting prototype and the (catchment-based) rainfall visualization prototype, are key components of impact mitigation and climate adaptation to extreme events at catchment scale.

• *Developing technological, and/or managerial and/or integrated risk management solutions to urban floods and droughts.*

MUFFIN: everything produced in the project can be considered components of risk management solutions to urban floods.

h. Has the consortium developed or implemented any kind of knowledge hub tool? If yes, which one (i.e. specific working groups, platforms, citizen science initiative)?

We are somewhat uncertain about the definition of a "knowledge hub tool", but some output from the project that may belong to that category include:

- The project significantly contributed to improving the citizen flood observatory in Rotterdam. It also created a working group on citizen rainfall observation comprised of researchers from TU Delft and KNMI.

- The rainfall early warning and visualization tool (tentatively called "Rainvis"; Appendix 1) is being complemented with a manual that is supposed to have the function of a "knowledge hub" with respect to observation and forecasting of extreme rainfall.

- The flood warning system in Aalborg which is joint effort between SMHI and Aalborg University will continue after the end of the MUFFIN project. The knowledge will be distributed through demonstration and visualization to Aalborg Municipality and other end-users and stakeholders in the Danish water industry.

i. Do you have any particular suggestion for further R&I development in your field? Please take into account the SRIA of the Water JPI.

From the point of view of MUFFIN, the following SRIA themes are of particular significance and relevance:

Subtheme 1.3. Managing the effects of hydro-climatic extreme events

1.3.2. Developing innovative (or improved) tools for adaptation to hydro-climatic extreme events, especially floods (link with 2.2.1)

1.3.3. Improving water management to mitigate the harmful impacts of extreme events (extreme weather events, impaired water quality) (link with 2.2.1)

Subtheme 2.2. Minimising risks associated with water infrastructures and natural hazards

2.2.1. Progressing towards flood-proof cities (from small settlements to large suburban areas) (link with 1.3.2, 1.3.3, 3.1.1, 5.2.1)
Subtheme 4.2. Reducing soil and water pollution
Subtheme 5.1. Enabling sustainable management of water resources
5.1.1. Promoting water RDI infrastructures for a better understanding of hydrological processes on different scales
5.1.2. Promoting adaptive water management for global change

Ideas and recommendations from MUFFIN include the following aspects, that we think keep needing more attention:

- Sub-daily rainfall extremes and their consequences. Which durations are critical in different (types of) basins, for which (types of) hazards and for which (types of) end-users? How reliable/accurate are historical estimates of short-duration extreme (Intensity-Duration-Frequency) statistics and how will they change in the future? How can we establish a better connection between rainfall generating mechanisms at different scales and different types of impacts on society?
- Real-time management aspects. How do we develop and design the types of efficient Early Warning Systems that are needed to adapt to a warmer climate with more intense rainfall extremes? How can we best post-process, interpret and communicate probabilistic high-resolution hydro-meteorological ensemble forecasts to end-users and decision makers? How do we integrate observational products from different sensors as well as different impact models for optimal performance and end-user value?
- Long-term planning and adaptation. How can current procedures for design of rainfall/water-related infrastructure be developed in order to meet the needs of a fully "climate proof" city? What added value can be attained from harmonization of practices and procedures at EU level? How do we best support end-users and decision makers with tools for designing and assessing the performance of adaptation measures?

Furthermore, there is a clear need for an improved methodology to produce urban flooding assessments, both nowcasts and design event simulations, for susceptible urban regions. MUFFIN started exploring 1) the potential of openly available land-cover data covering large areas in urban flow simulations; 2) the performance of national scale weather radar data in describing high intensity precipitation events; and 3) combining open computational tools in establishing a nowcasting model chain from precipitation nowcasting to urban flow and flooding assessment. Given the potentially increasing prevalence of high impact storm event due to the projected climate change, research in resource efficient tool chains exploiting readily available wide coverage spatial data along with open source hydrometeorological models will aid in tackling the adverse effects caused by excess water in urban regions.

3. Table of Deliverables

Please indicate whether the planned deliverables were completed, delayed or readjusted. Please explain any changes, difficulties encountered and new solutions adopted. Please add/suppress fields if necessary, in the table below.

Deliverable name	Lead partner (country)	Date delivered (dd/mm/yyyy)	Comments (e.g. changes, difficulties encountered and new solutions adopted)
WP1			
D1.1 Final report (this document, with appendices)	SMHI (SE)	01/09/2019	
WP2			
D2.1 End-user Requirement Specification Report: (a) Dedicated Workshop Report (Appendix IIa) (b) Draft End-user Requirement Specification Report (see D2.3 below)	SGI (SE)	30/05/2018	Report synthesizing results from all end-user activities: Workshop, on-line survey and telephone interviews
D2.2 GIS analysis and prototype application	SGI (SE)	13/06/2019	First launch for prototype of cloudburst observation and forecast visualization tool
D2.3 Final End-user Report (Appendix IIb)	SGI (SE)	30/08/2019	Final End-user Requirement Specification Report, updated with an assessment of the extent to which, and how, MUFFIN has been able to meet the needs elaborated in D2.1.
WP3			
D3.1 Observational data for flood model development and calibration	TUD (NL)	31/05/2019 (and on several occasions before that)	Different observational data were used from the start of the project and updated when needed
D3.2 Meteorological hindcasts for flood model simulation	SMHI (SE)	31/05/2019	As Joint experiment 3 became somewhat delayed, D3.2 was postponed accordingly

Deliverable name	Lead partner (country)	Date delivered (dd/mm/yyyy)	Comments (e.g. changes, difficulties encountered and new solutions adopted)
D3.3 Report on hydro-meteorological forcing in the project (Appendix IIc)	TUD (NL)	13/03/2018	
D3.4 Final observational data bases	TUD (NL)	01/09/2019	Most data are restricted access and stored locally but some are open (see Section 8).
WP4			
D4.1 Report of flood model development in the project (Appendix IId)	AAU (DK)	15/01/2018	
D4.2 Report of the results from the multi-scale experiments	AAU (DK)	01/09/2019	Included in the MUFFIN technical report (Appendix 1) and scientific papers of Joint Experiments 1, 2 and 3.
D4.3 Material for end-user feedback	AAU (DK)	13/06/2019	Presented for end-users in the "Creative Hut" @ CITIES, RAIN and RISK conference 13-14, 2019 in Malmö (MUFFIN Final Seminar).

4. Consortium Meetings, conferences, workshops, training courses, organization of events and other events attended

Please fill in the table below (add/suppress fields as necessary).

N°	Name of event	Date	Location	Attending partners / Participants (typology of stakeholders invited)	Purpose
1	Core group project kick-off	2016-05-04	Stockholm (SE)	SMHI, SGI, AAU, AALTO, TUD (i.e. all)	Initial planning
2	Water JPI Kick-off Meeting	2016-05-18	Rome (IT)	SMHI	WaterWorks 2014 Kick-off
3	All-Staff meeting	2016-11-24	Aalborg (DK)	SMHI, SGI, AAU, AALTO,	Project meeting

				TUD (i.e. all)	
4	Advisory Board meeting	2016-11-25	Aalborg (DK)	SMHI, SGI, AAU, AALTO, TUD (i.e. all) + Advisory Board (five members)	Collect Advisory Board feedback on project planning and progress
5	End-user workshop	2017-02-28	Video (skype)	SMHI, SGI, AAU, AALTO, TUD (i.e. all) + 26 end-users (see Appendix IIa)	Collect end-user requirements and feedback on project activities
6	HYPE course	2017-09-04/06	Norrköping (SE)	SMHI, AAU	Learning the HYPE model
7	All-Staff meeting	2018-02-06	Delft (NL)	SMHI, SGI, AAU, AALTO, TUD (i.e. all) + members from the INXCES project	Project meeting, coordination with INXCES project
8	Advisory Board meeting	2018-02-06	Delft (NL)	SMHI, SGI, AAU, AALTO, TUD (i.e. all) + Advisory Board (five members)	Collect Advisory Board feedback on project planning and progress
9	Water JPI Mid-term Meeting	2018-05-08	Larnaca (CY)	SMHI	Mid-term presentation and feedback from evaluation panel
10	WP4 meeting	2018-09-06/07	Norrköping (SE)	SMHI, AAU, AALTO	WP4 meeting on Joint experiments 1 and 3
11	All-Staff meeting	2019-06-12	Malmö (SE)	SMHI, SGI, AAU, AALTO, TUD (i.e. all)	Project meeting + preparations for CITIES, RAIN and RISK
12	CITIES, RAIN and RISK	2019-06-12/13	Malmö (SE)	SMHI, SGI, AAU, AALTO, TUD (i.e. all) + INXCES partners + around 120 participants	Final seminar, informal Advisory Board meeting
13	Advisory Board meeting	Sep 2019	Video (skype)	SMHI, SGI, AAU, AALTO, TUD (i.e. all) + Adv. Board	Collect Advisory Board feedback on project outcome
14	Planning and progress meeting	2016-2019 (~25 times)	Video (skype)	SMHI, SGI, AAU, AALTO, TUD; all or sub-sets	Joint discussion on planning and progress
15	Water JPI Final Evaluation Meeting	2019-10-09/10	Athens (GR)	SMHI	Final presentation and feedback from evaluation panel

5. Stakeholder Engagement

Maximum 2 pages

What has been the added value of the stakeholders' engagement to the project's results?

WP2 on "End-user value", for which the Swedish Geotechnical Institute (SGI) has been responsible, had the goal to optimize the process and outputs of the project with respect to practical value for relevant end-user categories. This is to ensure that the flood forecasting meets the specific and concrete needs of the urban users and can be integrated into their existing organizational structures and current use of forecasting.

The MUFFIN advisory group, consisting of one representative from each of the four countries, and a mix of researchers, water authorities and regional and national authorities, was present during most of the project meetings. The group provided active input and quality assurance into how the project results could respond to the needs of both practitioners and academics.

To further specify the end-user value, SGI used a three-prong or triangulation method to understand the needs and requirements of the MUFFIN end-users. After drawing up a list of the relevant stakeholders and end-users in Sweden, Denmark, Finland and the Netherlands, these three methods consisted of 1) an international video Workshop in February of 2017, 2) an End-user survey administered in December 2017 and 3) in-depth telephone interviews with end-users in November 2017- February 2018.

The final conference CITIES, RAIN and RISK provided an opportunity to bring together both end-users and Advisory Board members involved in the project, as well as potential new end-users and stakeholders.

The figure below shows the number, percentage and categories of stakeholder and end-users involved in each of the common MUFFIN events and WP2 tasks. Local and regional stakeholders were also involved in each of the case studies and joint experiments.

Number (and percentage) of stakeholders and end-users involved in MUFFIN events

Event	*Consultants*	*Researchers*	*Local, regional and national authorities*	*Water managers/ technicians*	*Other*	*Total*
International video workshop	6 (15)	17 (42)	12 (30)	3 (8)	2 (5)	40 (100)
On-line survey	6 (24)	1 (4)	17* (68)		1 (4)	25 (100)
Telephone interviews			2 (67)	1 (33)		3 (100)
Final Conference "Cities, Rain and Risk"**	23 (19)	35 (28)	28 (23)	27 (22)	10 (8)	123 (100)

* In the on-line survey, water managers and technicians were included in catetories "Local, regional and national authorities"
** Registered participants

While the number of stakeholders was not necessarily high, they were specifically identified by the project team as those who could benefit from the project, and those who were willing to actively provide input for the project team. Thus, many of those who were involved in the events and tasks were active all through the project life. This added value to the project, as their identified needs for data and forecasts were used by the project team within the case studies and joint experiment.

End-users are had differing needs and conditions. The project team relied on end-user involvement to help understand how they currently used rainfall and flood observations and forecasts in their work, and which limitations they experienced in using these. Information was also gathered on which spatial levels data was were most useful. Unsurprisingly, local end-users were most interested in rainfall and flood observation and forecasts at a local level, while researchers tended to find the pan-European level forecasts interesting. MUFFIN could not provide a one-size-fits all solution to the problems of urban flooding, but stakeholder and end-user engagement provided added value to the project, by helping to ensure that project results fit the specific needs of the case study areas and could add value to helping communities deal with the risks of flooding and extreme precipitation.

As discussed in Section 4 of the Technical Report (Appendix I) as well as in the End-user Requirement Specification Report (Appendix IIb), the Joint Experiments carried out in MUFFIN were designed to take the end-users' needs into account as far as possible. This, we believe, has made the experiments more practically relevant and this is thus a very clear example of added value provided by stakeholders' engagement.

Has the consortium allowed further exchanges of practices, procedures or technologies among different groups of stakeholders (i.e. researchers, public or private sector, end users)? If yes, how? Please indicate if through dissemination and exploitation plan, business plan or specific meetings at local/international level.

Exchange of practices, procedures or technologies among different groups of stakeholders was a key objective of the final conference CITIES, RAIN and RISK in Malmö June 13-14, 2019. The main means of achieving this objective was the so-called "creative hut", a dedicated room with PCs and screens for live demonstration and hands-on testing of the different prototypes developed in the project. Very lively and engaged discussions took place between the researchers/developers and the various end-users and stakeholders attending the conference (see e.g. the short conference video: http://www.muffin-project.eu/wp-content/uploads/2019/08/CRR_NY_med_ratt_lank.mp4).

Further exchange took place during the end-user workshop in February 2018 (Appendix IIa) as well as through collaboration with the INXCES project.

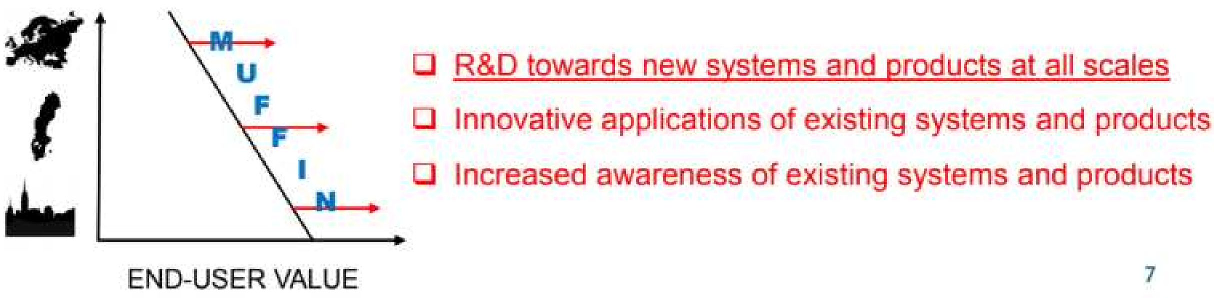
6. Impact Statement

Maximum 2 pages

Are the main impacts achieved?

As a background, here is a summary of Section 2.1 (*Impact of the proposal*) in the project proposal and a key figure from the proposal:

"*The project aims at developing and refining innovative tools for reducing the urban impacts of extreme precipitation, including sensor technology, systems for interpreting and communicating data, and monitoring networks that will contribute to improved integrated risk management solutions to urban floods. The important social scientific component of the project will ensure that all development are closely responding to the needs of the wide range of end-user categories included in the project, e.g. national authorities, local water managers and private companies (e.g. consultants and insurance companies). The main benefits of the project will be better early warning as well as emergency response in urban flooding events, which in turn will reduce the risk of flood-related negative impacts on e.g. infrastructure and communications, human safety and environmental resources.*"



Overall we think it is fair to say that the main impacts, as formulated above, have been achieved. A single project cannot solve everything but it can take steps in the right direction. MUFFIN has had a strong foundation in the end-users' requirements. The end-users and stakeholders did consider MUFFIN to be very ambitious, but acknowledged this ambition and the intention to drive technology forward through the different steps taken and developments made, both jointly and by partners individually. They also stated that better tools with higher accuracy within meteorological and hydrological forecasting and modelling are needed, and if good tools exist, end-users will find a way to use them in municipal and regional planning.

The key point in MUFFIN has been the multi-scale perspective on urban flood forecasting and how observations and models of different extension and resolution, individually or combined, can assist end-users and decision makers. Obviously, everyone wants as local and as accurate information as possible, and the limits of that "ideal situation" has been explored in MUFFIN, mainly through individual developments by the partners but also to some extent in the Joint Experiments (especially nr. 3). In practice, however, few cities have the capacity and resources to set up the local Early Warning Systems required to reach the ideal situation, but need to rely on more generalized and larger-scale (but available) information. This was the general starting point of the Joint Experiments, aiming at exploring the value of this information in the case studies. The results were interesting and valuable but ambiguous, with both positive and negative components. There is a clear added value in the developments made on both rainfall observation/forecasting and flood modelling, but also remaining limitations and uncertainties that need further attention.

Please describe any other (also unexpected) impacts the project has generated/will probably generate in the future. What kind of impact do you anticipate from the project outcomes in five years?

It is difficult to speculate on a specific time horizon, but conceivable future development and impacts based on MUFFIN output include the following:
- *Weather radar development*. Although still uncertain, quantitative precipitation estimates from radars are reaching a level of accuracy useful for flood modelling and forecasting. Fast progress is expected in the coming years towards even better accuracy and, higher/multi-scale resolution.
- *Other sources of rainfall observations*. For example, in MUFFIN we have looked at on-line private weather stations, which can provide an added value in many situations. Rainfall estimation from microwave links is another example. Development of integrated products will take place.
- *Open data, software and tools*. The trend towards increasing "openness" will continue, providing new information to society and opening up new possibilities for innovative development.
- *Rainfall-based urban flood warnings*. "Sharper" meteorological forecasts in combination with new knowledge on urban flood impacts of rainfall extremes will improve urban flood warnings.
- *High-resolution hydrological modelling and forecasting*. A national sub-daily hydrological forecasting system is already operational in Sweden and will be followed by similar development elsewhere.
- *Coupled multi-scale forecasting systems*. Integrated forecasting systems such as the one developed in Aalborg (Joint Experiment 3) will be further explored and implemented.
- *Tailored end-user and stakeholder support*. Last but certainly not least, we hope that the web-based user-friendly prototypes developed in MUFFIN will inspire other efforts in the same direction.

Where do the results of the project impact (e.g. industry, end users, policy, etc.)?

The stakeholders involved in the project were divided into the following categories, which illustrate where the project results are likely to have an impact:
- Local / regional / national water authorities
- Water organisations
- Emergency services
- Consultants / private companies
- Academics

Have the partners identified exploitable results?

We have merged this question with Section 11 below.

Has intellectual property protection been considered?

Not in any formal or explicit way.

7. Knowledge Output Transfer

For each of the Knowledge Output arising from the project, please complete the following table.

We sent the following mail to the WaterWorks2014 secretariat on 2019-08-14 but as we have not received any reply by the time of submission we have left this section empty. We will be happy to update the report with this section later, if needed, when we have received a reply.

"Just a question on Section 7 in the report template, "Knowledge Output Transfer". We find the description/definition of "knowledge outputs" a bit difficult to interpret: "…that is, those non-deliverables, milestones or 'grey knowledge' areas that were not expected and are not included in the list of publications". Thus, here we should only list results/output that were not expected? In the MUFFIN project we had, I think, a quite clear project plan from the beginning, that we have more or less followed. And we have produced a number of outputs in the different categories listed under "knowledge type". But essentially all of them must be viewed as planned/expected, and thus they are not "knowledge output" as defined here(?). We may be able to find some unexpected results but nothing of particular significance and we may even have to leave Section 7 empty. Grateful if you can confirm this interpretation."

8. List of Publications produced by the Project - Open Access

International	Peer-reviewed journals	Published: 1. Niemi, T.J., Warsta, L., Taka, M., Hickman, B., Pulkkinen, S., Krebs, G., Moisseev, D.N., Koivusalo, H., Kokkonen, T. (2017) Applicability of open rainfall data to event-scale urban rainfall-runoff modelling, Journal of Hydrology, 547:143-155, https://doi.org/10.1016/j.jhydrol.2017.01.056 2. Olsson, J., Bengtsson, L., Pers, B.C., Berg, P., Pechlivanidis, I., and H. Körnich (2017) Distance-dependent depth-duration analysis in high-resolution hydro-meteorological ensemble forecasting: a case study in Malmö, Sweden. Environ. Model. Softw., 93:381-397, open access, https://doi.org/10.1016/j.envsoft.2017.03.025 3. Tuyls, D.M., Thorndahl, S., Rasmussen, M.R. (2018.) Return period assessment of urban pluvial floods through modelling of rainfall-flood response. Journal of Hydroinformatics 20(4):829-845, open access, https://doi.org/10.2166/hydro.2018.133 4. Kokkonen. T., Warsta. L., Niemi. T.J., Taka. M., Sillanpää. N., Pusa. M., Kesäniemi, O., Salo, H., Koivusalo, H. (2019) Impact of alternative land cover descriptions on urban hydrological model simulations. Urban Water Journal, 16(2):103-113, open access, https://doi.org/10.1080/1573062X.2019.1634742 5. Niemi. T., Kokkonen. T., Sillanpää. N., Setälä. H., Koivusalo. H. (2019) Automated Urban Rainfall–Runoff Model Generation with Detailed Land Cover and Flow Routing, Journal of Hydrologic Engineering, 24(5), https://doi.org/10.1061/(ASCE)HE.1943-5584.0001784 6. Tanouchi, H., Olsson, J., Lindström, G., Kawamura, A., and H. Amaguchi (2019) Improving urban runoff in multi-basin hydrological simulation by the HYPE model using EEA Urban Atlas: a case study in the Sege River Basin, Sweden, Hydrology, 6(1), 28, open access, https://doi.org/10.3390/hydrology6010028 7. Xin T., ten Veldhuis, M.-C., Schleiss, M., Bouwens, C.and van de Giesen, N. (2019) Critical rainfall thresholds for urban pluvial flooding inferred from citizen observations, Science of the total Environment, 689:258-268, https://doi.org/10.1016/j.scitotenv.2019.06.355 Submitted: 8. Schleiss, M., Olsson, J., Berg, P., Niemi, T., Kokkonen, T., Thorndahl, S., Nielsen, R., Nielsen, J. E., Bozhinova, D., and Pulkkinen, S. (2019) The accuracy of weather radar in heavy rain: a comparative study for Denmark, the Netherlands, Finland and Sweden, Hydrol. Earth Syst. Sci. Discuss., open access, https://doi.org/10.5194/hess-2019-427 9. Nielsen, R.V., Thorndahl, S. (2019) Sensitivity Analysis of an

		Integrated Urban Flood Model, Journal of Environmental Management, submitted. In preparation: 10. Nielsen, R. Niemi, T., Thorndahl, S., Hundecha, Y., Schleiss, M., Kokkonen, T., Olsson, J. (2019) Hydrological vs. Hydrodynamic Modelling – A Comparative Study in Aalborg and Helsinki, manuscript in preparation. 11. Nielsen, R. Thorndahl, S., Hundecha, Y., Olsson, J. (2019) Large-scale and local flood modelling – Overcoming drawbacks of both domains by combining strengths, manuscript in preparation. 12. Olsson, J., Berg, P., Simonsson, L. (2019) Spatial properties of short-duration rainfall extremes in Sweden, manuscript in preparation. 13. Reinoso-Rondinel, R. and Schleiss, M. (2019) Improved rainfall estimates for X- and C-Band weather radars based on raindrop size distribution retrievals from a micro-rain radar, manuscript in preparation. 14. Schleiss, M., ten Veldhuis, M. C., Hutten, R., Schoester, J., de Vos, L. and Leijnse, H. (2019) The potential of citizen weather stations for urban rainfall monitoring - a case study for Rotterdam, mansucript in preparation 15. Van Well, L., Hedfors, J., Olsson, J. (2019) Identifying end-user needs: Lessons from stakeholder involvement in Multi-scale urban flood forecasting, manuscript in preparation.
	Books or chapters in books	n/a
	Communications (presentations, posters)	Presentations: 1. Olsson, J. (2016) Development of a high-resolution flood forecasting system in Sweden, invited talk at WMO RAVI Hydrological Forum 2016, 20 September, Oslo, Norway. 2. Banks, R. F. (2017), Comparison of two WRF single moment microphysics schemes during an August 2015 convective event, 2017 GRS Poster Day, April 2017, TU Delft. 3. Banks, R. F., Basu, S., Schleiss, M., and Russchenberg, H. (2017), Towards real-time high-resolution precipitation forecasts for the city of Rotterdam, 2017 European Conference on Severe Storms, 18-22 September 2017, Pula, Croatia. 4. Ivarsson C.-L., Olsson, J., Pers, B.C., Hundecha, Y. and J. Andersson (2017) High-resolution ensemble flood forecasting: a case study in Höje Å, Sweden, 15th International Conference on Environmental Science And Technology, 31 August - 2 September, Rhodes, Greece. 5. Murla, D., Nielsen, R.V., Thorndahl. S.: Extreme event statistics of urban pluvial floods – return period assessment and rainfall variability

		impacts. Extended abstract submitted to the 14th International Conference on Urban Drainage, Prague, 10-15 September 2017. 6. Nielsen, R.V., Thorndahl, S. Low-cost remotely sensed environmental monitoring network. Extended abstract submitted to the 14th International Conference on Urban Drainage, Prague, 10-15 September 2017. 7.Olsson, J., Berg, P., Norin, L., and L. Simonsson (2017) Hydrological applications of a high-resolution gauge-adjusted radar precipitation data base for Sweden, International Symposium on Weather Radar and Hydrology, 10-13 April, Seoul, South Korea. 8. Schleiss, M. (2017), Probabilistic radar nowcasting based on time nuggets, 38th Conference on Radar Meteorology, August 2017, Chicago, United States 9. Ten Veldhuis, M.-C. and Schleiss, M. (2017), High-resolution Hydro-meteorological observations in the city of Rotterdam: a Summer Experiment, 14th International Conference on Urban Drainage, September 2017, Prague, Czech Republic 10. Nielsen, R., & Thorndahl, S. L. (2018). Sensitivity Analysis of an Integrated Urban Flood Model International Conference on Urban Drainage Modelling - Palermo, Italy 11. Olsson, J., Hundecha, Y., Rosberg, J., and A. Johansson (2018) High-resolution hydrological prediction in urbanized areas, Nordic Water, 13-15 August, Bergen, Norway. 12. Olsson, J., Pers, C., Bengtsson, L., Pechlivanidis, I., Berg, P., and H. Körnich (2018) Dealing with rainfall location uncertainty in flood forecasting: a distance-dependent depth-duration approach, EGU General Assembly, 8-13 April, Vienna, Austria. 13. Schleiss, M., 2018: "A new multiplicative random cascade model for downscaling intermittent rainfall fields", 10th European Conference on Radar in Meteorology and Hydrology, 1-6 July, 2018, Wageningen, the Netherlands 14. Thorndahl, S. L., Tuyls, D. M., Nielsen, R., Schleiss, M., & Olsson, J. (2018). Influence of Flood Water Contribution from Multiple Sources in Extreme Event Statistics of Urban Flooding. International Conference on Urban Drainage Modelling - Palermo, Italy 15. Kokkonen, T., Niemi, T.J. (2019) Urban rainfall-runoff nowcasting with open data and open tools, CITIES, RAIN and RISK, 13-14 June, Malmö, Sweden 16. Nielsen, R., Niemi, T., Thorndahl, S., Hundecha, Y. Kokkonen, T., Olsson, J, Schleiss, M. Hydrodynamic vs. hydrological modelling: a comparative study in Aalborg and Helsinki (2019) CITIES, RAIN and RISK, 13-14 June, Malmö, Sweden 17. Nielsen, R., Hundecha, Y., Johansson, A., Thorndahl, S., Olsson, J. A web-based visualization prototype of urban flood forecasts from a multi-scale hydrologic-hydrodynamic flood forecasting system in Aalborg, Denmark (2019) CITIES, RAIN and RISK, 13-14 June, Malmö, Sweden

		18. Niemi TJ, Krebs G, Kokkonen T. Automated Approach for Rainfall-Runoff Model Generation. In: Mannina G, editor, New Trends in Urban Drainage Modelling: UDM 2018. 2019. (Green Energy and Technology). https://doi.org/10.1007/978-3-319-99867-1_103 19. Olsson, J. (2019) Real-time high-resolution cloudburst visualization prototype, CITIES, RAIN and RISK, 13-14 June, Malmö, Sweden 20. Schleiss, M., Olsson, J., Berg, P., Niemi, T., Kokkonen, T., Thorndahl, S., Nielsen, R., 2019: "Can we trust radar?", Cities, rain and risk, 13-14 June, 2019, Malmö, Sweden 21. Schleiss, M. (2019) Relationship between rainfall and pluvial flooding in Rotterdam based on citizen reports, CITIES, RAIN and RISK, 13-14 June, Malmö, Sweden 22. Schleiss et al., 2019: "The accuracy of operational radar in times of heavy rain – a comparative study for Denmark, the Netherlands, Finland and Sweden, 39th International Conference on Radar Meteorology, 16-20 September, 019, Nara, Japan 23. Schleiss, M. (2019) Can we trust the radar? High-intensity rainfall in operational radar observations, CITIES, RAIN and RISK, 13-14 June, Malmö, Sweden 24. Ten Veldhuis, M.C., Schleiss, M., Hutten, R., Schoester, J., Xin, T. and de Vos, L., 2019: "Rainfall maps from networks of citizen weather stations for urban rainfall information", MOXXI (Measurements and Observations in the 21st century), New York, March 11-13, 2019 25. Thorndahl, S., Ahm, M., Nielsen, R., Andersen, C.B, Nielsen, J.E., Rasmussen, M.R. (2019) Use of weather radar in the water sector in Denmark; what can we learn? CITIES, RAIN and RISK, 13-14 June, Malmö, Sweden 26. Thorndahl, S., Nielsen, R Multi-purpose urban water management in a complex urban basin (2019) CITIES, RAIN and RISK, 13-14 June, Malmö, Sweden 27. Xin T., ten Veldhuis, M.-C., Schleiss, M., Bouwens, C.and van de Giesen, N., 2019: "Critical rainfall thresholds for urban pluvial flooding inferred from citizen observations" Cities, risk and rain, 13-14 June, Malmö, Sweden Posters: 1. Murla, D.T, Thorndahl, S. (2017) Urban flood return period assessment through rainfall-flood response modelling. European Geosciences Union General Assembly 2017, Vienne, Austria. 2. Murla, D., Nielsen, R., Thorndahl, S. Extreme event statistics of urban pluvial floods –Return period assessment and rainfall variability impacts. Abstract from the International Conference on Urban Drainage, Prague 10-15 September 2017. 3. Nielsen, R., Thorndahl, S. (2017) Low-cost remotely sensed environmental monitoring stations, 14 th IWA/IAHR International

		Conference on Urban Drainage, Prague, Czech Republic. 4. Van Well, L. (2017) The Needs-Knowledge Gap: Geotechnical Risk in Swedish Planning Processes Poster profiling stakeholder engagement in several SGI projects, including MUFFIN at 3rd European Climate Change Adaptation Conference: Our Climate Ready Future Glasgow 5th-9th June 2017. 5. Xin et al., EGU2019-4890: “Critical rainfall thresholds for urban pluvial flooding inferred from citizen observatories”, European Geophysical Union, 7-12 April, 2019, Vienna.
National (separate lists for each nationality)	Peer-reviewed journals	Sweden: 1. Ivarsson, C.-L., Olsson, J., Pers, C., and Y. Hundecha (2017) High-resolution ensemble flood forecasting: a case study in Höje Å, Sweden, J. Water Manag. Res. (VATTEN), 73, 85-92.
	Books or chapters in books	n/a
	Communications (presentations, posters)	Sweden: 1. Olsson., J. (2016) Improved short-term forecasts of cloudbursts using radar and mobile masts, invited talk at Modelling for Climate Adaptation, 9 November, Lund, Sweden (in Swedish). 2. Olsson, J. (2017) Multi-scale urban flood forecasting (MUFFIN): from local tailored systems to a Pan-European service, poster at Hydrologidagarna, 16-17 March, University of Gothenburg, Sweden. 3. Van Well, Lisa ”Implementering genom brukarmedverkan – co-creation, living labs och dialog” Presentation for Vetenskapsrådets nätverk för FoU-myndigheter, 18 oktober 2018. Finland: 4. Niemi, T. (2016) Presentation at the ‘Dean’s Circle’ event (http://www.aalto.fi/en/current/news/2016-11-17-007/) of the Aalto University School of Engineering (Nov 16, 2016) 5. Kokkonen, T., Niemi, T.J. (2017) Improved precipitation information for hydrological problem solving - focus on open data and simulation, Open radar seminar, Finnish Meteorological Institute, Helsinki, Finland, Jan 17, 2017. Invited presentation. 6. Niemi, T. (2018) Recent weather radar related activities in Aalto Water Engineering research group. Presentation at Open radar seminar, Finnish Meteorological Institute, Helsinki, Finland, Aug 28, 2018. Invited presentation. 7. Niemi, T. (2018) Weather Radar in Hydrology: Why, How & What – A Hydrologist’s Perspective. Invited talk at “Vaisala Weather Radar Meteorology Workshop”, Vaisala, Vantaa, Finland, 30.10.2018. The Netherlands:

		8. Banks, R. and Basu, S. (2017), High-resolution rainfall forecasting with the WRF model: a first trial, Joint meeting TU Delft – municipality of Rotterdam, 15th February 2017 9. Bouwens, C. (2017), Flooding observations in Rotterdam: mapping of flood-prone locations, flood vulnerability, dominant failure mechanisms, Joint meeting TU Delft – municipality of Rotterdam, 15th February 2017 10. Hill, J. (2017), Investigating the Efficiency of Sustainable Urban Drainage System Implementation on a City, Joint meeting TU Delft – municipality of Rotterdam, 15th February 2017 11. Krietemeyer, A. (2017), Low-cost gNSS receivers for the retrieval of precipitable water vapor spatial variability, Joint meeting TU Delft – municipality of Rotterdam, 15th February 2017 12. Mulder, M. (2017), The effect of the imperviousness on the hydrological response time for the sewer districts of Rotterdam, Joint meeting TU Delft – municipality of Rotterdam, 15th February 2017 13. Schleiss, M. (2017), MUFFIN – Multi-scale Urban Flood Forecasting, Joint meeting TU Delft – municipality of Rotterdam, 2017-02-15 2017 14. Ten Veldhuis, M.-C. (2017), High-resolution rainfall observation for enhanced urban flood risk management, Joint meeting TU Delft – municipality of Rotterdam, 15th February 2017
Dissemination initiatives	Popularisation articles	1. Article in Swedish newspaper Expressen: https://www.expressen.se/premium/nyheter/regnhotet-mot-sverige-i-klimatkrisens-spar/ 2. Article in Swedish newspaper Helsingborgs Dagblad
	Popularisation conferences	n/a
	Project Website	http://www.muffin-project.eu/
	Others	1. Final conference CITIES, RAIN and RISK http://www.trippus.se/web/presentation/web.aspx?evid=h1aB/JwWkXwmoKpp1KcNog==&ecid=gFkckIQrOuYmM80IqAzl2w==&ln=eng&view=category&template=Desktop 2. Web prototypes: Rainfall visualizaton: http://hypewebapp.smhi.se/skyfall/, Multi-scale forecasting: http://rasmusvn.com/malmo_viz/index.html 3. De Beus, E., Low Power Weather Sensors – Bringing Open Sensor technologies together, https://www.lpw-sensors.eu/ (website)

9. Open Data

Maximum 1 page

Please list all the Data (Reports) that have been submitted to the OpenWaterJPI Interface.

1. Description of the purpose of the project (se http://www.muffin-project.eu/muffin-outlook/)

2. Link to the webpage of the project: http://www.muffin-project.eu/

3. Deliverable 3.3: Muffin_D3.3.pdf

4. Deliverable 4.1: Muffin_D4.1.pdf

5. Link to and description of the rainfall visualization prototype: http://hypewebapp-tst.smhi.se/skyfall/

6. Link to and description of the Aalborg multi-scale urban flood forecasting prototype: http://rasmusvn.com/malmo_viz/index.html

7. Metadata of radar and gauge data for the top 50 events that were used during the radar-gauge intercomparisons in Joint Experiment 2 (Schleiss et al., 2019; see Appendix 1).

8. Link to the webpage of the final conference CITIES, RAIN and RISK: http://www.trippus.se/web/presentation/web.aspx?evid=h1aB/JwWkXwmoKpp1KcNog==&ecid=gFkcklQrOuYmM80lqAzl2w==&ln=eng&view=category&template=Desktop

9. Link to abstract booklet of the final conference CITIES, RAIN and RISK: http://www.muffin-project.eu/wp-content/uploads/2019/06/Cities_Rain-and-Risk_Abstracts-Booklet.pdf

10. Link to video from the final conference CITIES, RAIN and RISK: http://www.muffin-project.eu/wp-content/uploads/2019/08/CRR_NY_med_ratt_lank.mp4

11. Deliverable 2.3: End-user Requirement Specification Report.pdf

12. Workshop Report.pdf

13. List of publications

14. Deliverable 1.1: Water JPI Final Progress Report

15. WaterJPI Technical Report

10. Continuation strategy

Maximum 1 page

Is the collaboration between Consortium partners expected to continue after the funding period? If yes, please describe how.

First of all, after the ending of the project, the different partners will continue to collaborate on publishing the results of the MUFFIN project in scientific journals during autumn 2019.

On a longer time horizon, there is currently no specific plan on continuing with the same consortium but it is most likely that some of the consortium partners will join forces again and apply for new joint research funding. Discussions related to specific calls are already on-going.

We expect further collaboration across the Danish-Swedish border. In Denmark, the developed flood warning will with further development be implemented in real-time operation in collaboration with SMHI and national partners. Furthermore, partly as a result of the MUFFIN project, high-resolution (X-band) radars are being set up in southern Sweden. The intention is to combine with radars on the Danish side for "cross-border" high-resolution rainfall estimation and nowcasting.

11. Innovation Potential

Maximum 1 page

Please describe any results with innovation potential arising from the implantation of the project

In the Netherlands, several follow up projects exploiting the results of MUFFIN are expected to take place in the coming years (2020-2025). Within the framework of the Ruisdael observatory (http://ruisdael-observatory.nl/), several new rainfall sensors will be purchased to improve the measurement and prediction of heavy rain in urban environments. Central to this new research-line is the question whether state-of-the-art machine learning combined with high-resolution data from weather radars, in-situ observations and numerical weather models can be used to design a new generation of flood forecasting system capable of identifying precursors of heavy rain and warn cities of imminent danger well before the threats becomes obvious. The practical challenges of this follow-up project will be to provide accurate, computationally-efficient and cost-effective rainfall forecasting methods that stakeholders can act upon to make decisions. The new scientific challenges will be to deal with the different sources of uncertainty that are inherent to measuring, modelling and forecasting precipitation at such small scales but also to find a balance between the timeliness, detail, accuracy and reliability of forecasts needed for decision making. The results and insight obtained within MUFFIN (in particular the work on radar uncertainty and citizen rainfall/flood reports) are expected to play a key role in this process.

The unique joint dataset radar rainfall dataset developed in MUFFIN can be further exploited to investigate spatial/temporal variability of heavy rainfall and to further develop insights into differences between national and research based radar rainfall products at multiple scales. There is a large currently untested potential of applying the dataset as inputs to hydrological models, which will provide insights into the application of the data in real time operation for flood warning.

The development of fast hydrological models (HYPE) with increased detail for urban areas can easily be converted (unlike the more detailed hydraulic models) to cover other European locations. This will contribute to the ability to produce flood warnings at an overall level in multiple locations.

From the MUFFIN results, there is a potential for further innovation of a real time flood-warning framework into commercial operation. MUFFIN have proved the possibilities and highlighted the challenges. A potential commercial operation can be developed using the MUFFIN framework as a starting point.

Resource efficient tool chains exploiting readily available wide coverage spatial data along with open source hydrometeorological models open possibilities for local actors to produce urban runoff design event simulations and nowcasts that traditionally have been accessible almost exclusively to national hydrometeorological institutes. The open availability of powerful forecasting tools and high resolution real time meteorological data can lead to wider, locally tailored exploitation of such tools and data in tackling the adverse effects caused by excess water in urban regions. MUFFIN has demonstrated the use of an open source nowcasting toolchain from precipitation forecasting to urban runoff and flood extent simulations, and explored the usability and limitations of land-cover datasets of varying spatial resolutions and coverage.

12. Administrative & financial aspects / Budget use

Maximum 2 pages

Please describe in general terms how the available funding was used for the implementation of the project and identify any administrative/financial aspects that occur during the project lifetime.
For example, did any of the partners find difficulties related to the grant agreement, the availability of funds at national level or other similar issues not specifically related to the technical part of the project?

The project budget was divided into four categories:

- Personnel (~79% of total funding)
- Subcontracting: SGI for end-user communication (~4%)
- Equipment: sensors (microrain radar, rain gauges, disdrometers, soil moisture sensors, flow gauges) and computers at AAU and TUD (~4%)
- Other: travelling for Advisory Board members, final conference (CITIES, RAIN and RISK), open access publication, conference participation (~13%)

The funding has been used overall in line with the budget and national payments have worked out well.

Concerning the participation of Aalto University, the funding was granted by a foundation as Finnish national funders did not participate in the WaterWorks2014 Water JPI programme. The funding was spent on the salary of a post-doctoral researcher and for travelling costs.

In the following some comments related to management and administration are listed.

- The start of the project was rather confusing as there was no clear decision communicated by Water JPI and the national decisions were communicated at different times, in different ways. According to instructions, the project had to start before all partners had received their decisions. The fact that the terms differ between partners, e.g. the time period during which the funding may be spent, makes things complicated. Some more harmonization between the national FPOs would be helpful.
- The processing time of getting an extension of the project in order for the partners to end the project at the same time was unacceptably long. As we understand it, the national FPO was supposed to await decision by Water JPI, but as this decision was substantially delayed the procedure became a bit frustrating.
- The Consortium Agreement process took a long time, as it often does. The general DESCA template (for Horizon 2020) was suggested, but as the Water JPI consortia are generally smaller it may be considered to make another, even more simplified template tailored for Water JPI projects.
- Overall the intended project members were able to perform their intended work, but TUD encountered some problems as two Post-Docs hired for the project quit rather soon after they were hired, for different reasons.
- It would have been helpful if the template for the Final Progress Report had been provided earlier. Now we received it just before the summer holiday season, with a deadline to submit it just after the summer holiday season, which created some complexity concerning the timely gathering of partners' input.

Appendix I: Technical Report

The Technical Report should include all the technical and scientific work and results of the project. It is in free format and should not exceed 15 pages. Please note that this information will be made available to the Follow-up Group Members. If this report cannot be made available publicly in reason to IPR considerations, please provide also a version of the Final Technical Report for dissemination (Public Report).

Appendix II: Deliverables

Please submit all Deliverables as described in the proposal.

See Section 3 in this report.

IIa Workshop Report

IIb End-user Requirement Specification Report

IIc Hydro-meteorological Forcing Report

IId Flood Model Development Report

IIe Abstract Booklet from CITIES, RAIN and RISK (Final Seminar)

IIf Mid-term Progress Report