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Improving Surface Water Flood Mapping: Estimating Local Drainage Rates

User Guidance – SC120020/3

Environment Agency

Contents

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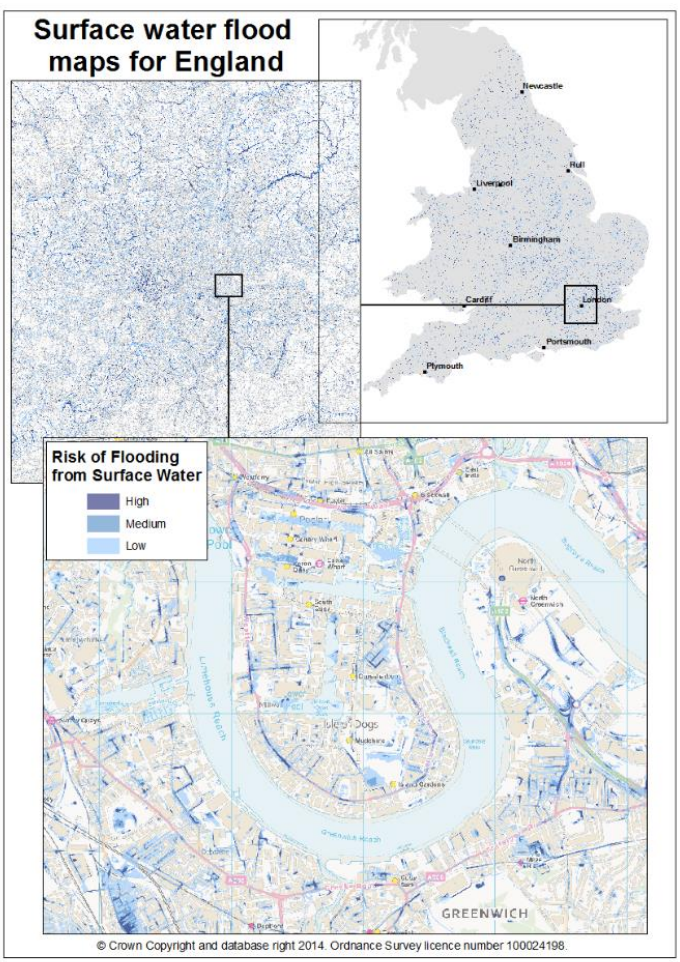
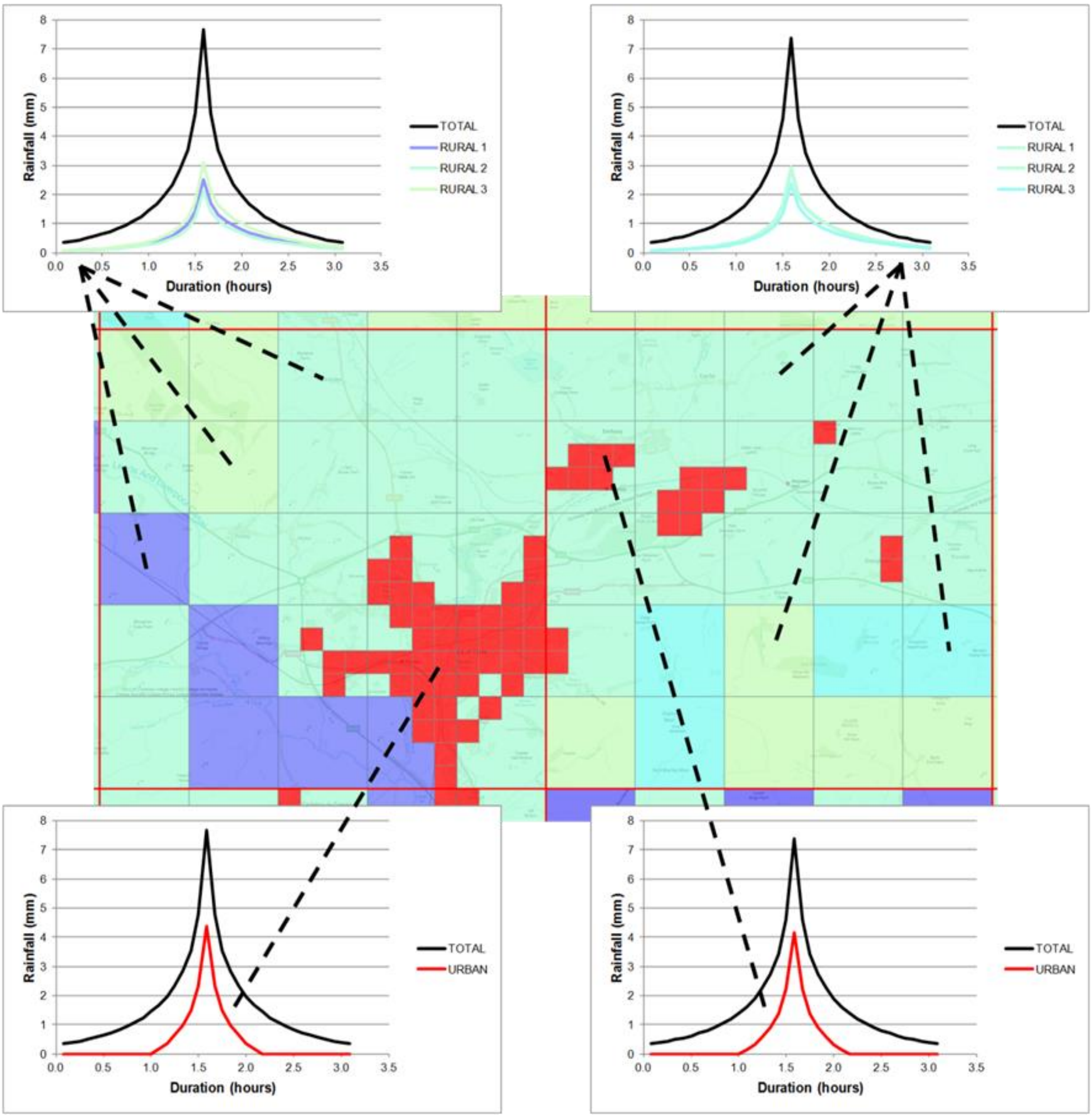
1. Introduction

- The Risk of Flooding From Surface Water (RoFSW) is published by the Environment Agency online. It can also be downloaded from data.gov.uk. The underlying modelling is available to Lead Local Flood Authorities (LLFAs) on request.
- LLFAs and other (flood) Risk Management Authorities (RMAs) can use the RoFSW to see which communities are vulnerable to surface water flooding and the likely extent of any impact which might occur in severe weather.
- The data covers all of England and therefore the underlying model required simplification, especially when representing the conveyance capacity of urban drainage systems.
- As a simplifying measure the modelling underlying RoFSW generally assumes a default urban drainage capacity (modelled as a ‘drainage rate’ of 12 mm/hr) in built-up areas, although some local variants were applied on the request of LLFAs.
- The purpose of this guidance is to provide approaches to assign locally accurate drainage capacity values or ‘drainage rates’ to check or update the national mapping. Section 2 (Process Overview) guides the reader through the steps to take.
- It also provides guidance on using RoFSW to test sensitivity of the maps to changes in drainage such as under climate change or new flood risk management measures.
- This guidance is supplemented by a full Evidence Report and spreadsheet tools that are published on the Environment Agency Research and Development website (references: SC120020/R, SC120020/S, SC120020/1, SC120020/2).



2. How drainage rates are applied in RoFSW



- In urban areas (shown in red on the map), total rainfall is modified to represent net rainfall allowing for what is stored and conveyed in drainage systems.
- The standard assumption is that the drainage system ‘removes’ rainfall at a rate equivalent to 12 mm/hr.
- Other hydrological losses are applied in rural areas (shown in blue and green on the map).

3. Why change my drainage rate?

Small changes to the drainage rate can have a big effect on the RoFSW[1]. Changing the drainage rate could help to improve the map in a local area. It could also be used to explore different drainage scenarios to support future planning. Some example scenarios representing different user needs are presented below.

Amend the modelled drainage rate for my local area

Flood mapping
"The flood map does not accurately reflect observed flooding in my area. I have local knowledge on the drainage systems and/or catchment permeability that is better than the default drainage rates. I want the improved maps to feed into future national RoFSW updates."

SUDS opportunities
"I want to create SuDS opportunity maps. So, I need to know where SuDS will make the biggest difference across my area."

Urban creep
"I want to investigate how urban creep could increase flood risk across my area. Or, I want to investigate the potential impact of strategies to reduce impermeable areas, for example, a policy to increase green roofs."

Asset maintenance
"We need to be better at prioritising maintenance on our surface water assets. I need to find out what impact it will have on flood risk if we reduce maintenance and where the highest priority areas for maintenance are."

Emergency planning
"I need to understand worst case scenarios for emergency planning. For example, what would happen if the drainage systems were to fail completely in my area?"

Development control
"Local residents are worried about whether a new housing development will increase flooding in their community. I need a simple way to explore the impact of the development taking into account the development type, area and layout."

[1] HALCROW AND JBA CONSULTING, 2012. Flood Map for Surface Water Improvements - Pilot Studies Final Evaluation Report. Report version 4.0 (May 2012).

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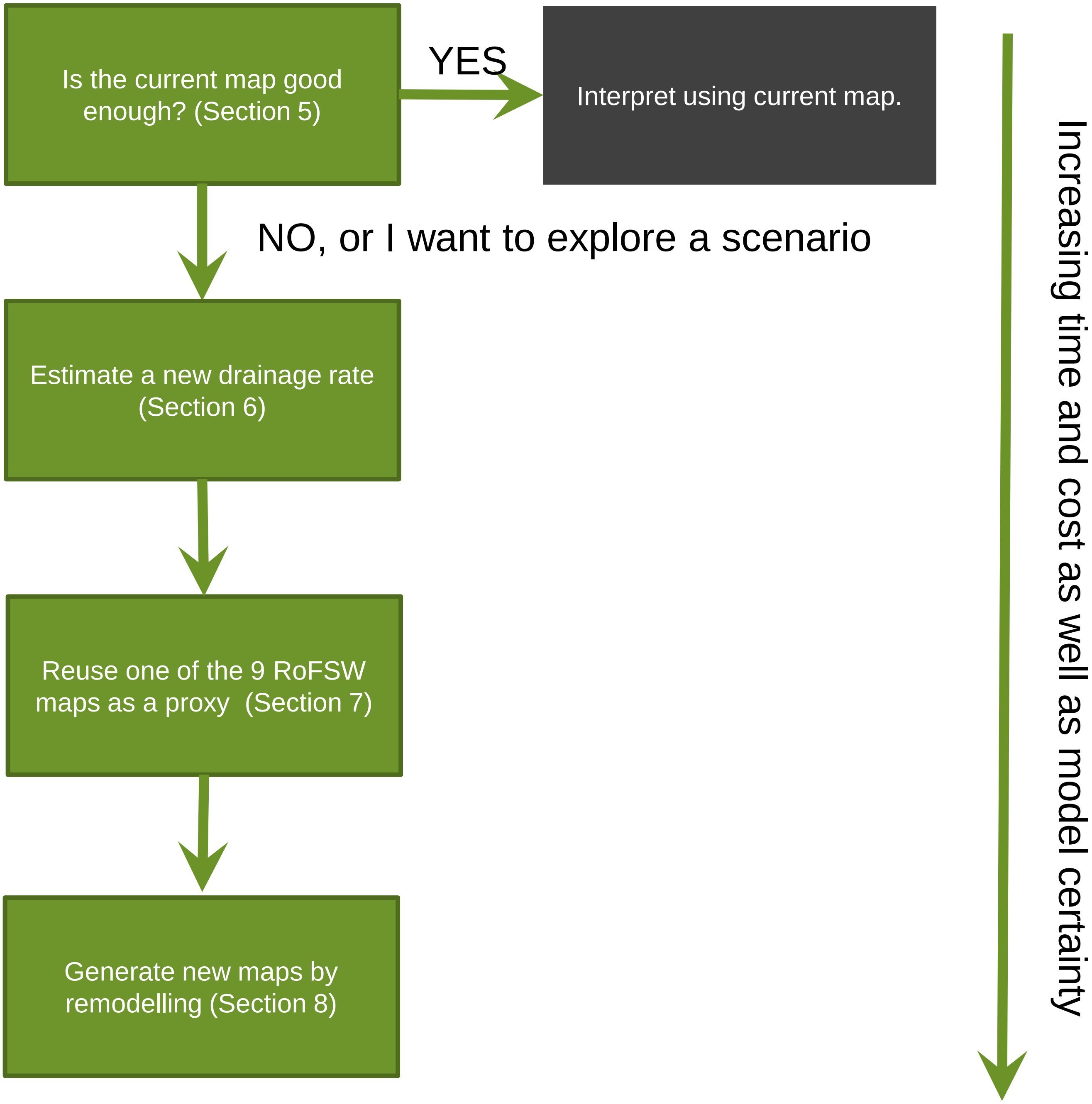
4. Process Overview

- Navigate by selecting 'Next Page' or right click on the relevant green box and open the hyperlink.



5. Is the current map good enough?

This is guidance to help determine whether existing maps are fit for purpose. Remember that the Risk of Flooding from Surface Water is not intended for precise interpretation of flood risk at a property level. It was produced on a national scale to indicate broad areas likely to be at risk from surface water flooding. In some places is suitable for considering the risk of flooding to whole streets or collections of buildings.

The current map is good enough if:

- It predicts areas of known flooding. (Note: regular flooding might be identified in Risk of Flooding from Surface Water 3.3 percent annual chance extent. Exceptional flooding might be identified in Risk of Flooding from Surface Water 1 percent annual chance extent)
- It is consistent with areas that remain dry in heavy rainfall
- It is consistent with maps derived from more detailed hydraulic modelling

The current map could be improved through adjusting drainage rates when:

- Local drainage capacity provided by highways drainage, storm sewers or combined sewers is known to be either limited or more generous that ‘normal’. For example:
  - Limited drainage might occur due to inadequate or poorly maintained flow inlets like road gullies
  - Drainage capacity might be enhanced where pipe gradients are high (i.e. it is steep) or reduced where pipe gradients of low (i.e. it is flat)
  - Drainage capacity might be higher than anticipated by use of pumping stations or the relief provided by combined sewer overflows

Adjusting the drainage rates is not a suitable mechanism to improve the maps if flooding is the result of:

- Complex interactions between rivers (or the coast) and drainage systems
- Where underground flows are modified by the active control of pumps, gates or sluices
- Intermittent drainage asset failure (e.g. blockages, collapses or pumping station outages)

In these situations detailed hydraulic modelling is required.

6. Estimating a new drainage rate

- A local estimate of the drainage system capacity is made using a statistical analysis of the drainage system capacity equation which was used in the RoFSW to obtain the national estimate of the drainage system capacity (see A1).
- The parameters of the equation are percentage runoff (PR), critical duration (T_{crit}), level of service (LoS) and the depth-duration-frequency (DDF) parameters. One or more of the parameters is locally refined to calculate a local drainage capacity.
- A local drainage system capacity is calculated by following the steps in the flowchart and SC120020/1 Appendix C - Sewer Capacity Monte Carlo spreadsheet tool.
- If the revised drainage rate is between 9mm/hr and 15mm/hr (up to 3mm different from the 12mm/hr national default rate) the flood maps are unlikely to show a change.
- Please note, the FEH CD-ROM used in this project was superseded by the FEH Web Service (https://fehweb.ceh.ac.uk) in November 2015. Access data from here.

National estimate of parameters

- Percentage runoff 30%-80%
- Critical duration 0.5hr-2hr
- Level of service 5yr-30yr
- DDF parameters

Step 1

Use local knowledge to make an estimate of local range of parameters

Percentage runoff
1. Use fixed runoff equation
2. Collect data
3. Use qualitative indicators

→ Local estimate of percentage runoff

Critical duration
1. Use updated Flood Map for Surface Water critical duration grids

→ Local estimate of critical duration

Level of service
1. Use design level of service
2. Use detailed sewer models
3. Use knowledge of historic flood events

→ Local estimate of level of service

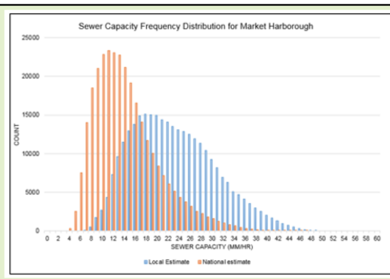
DDF parameters
1. Use FEH CD-ROM to estimate DDF for river catchment
2. Sample DDF sets from FEH CD-ROM

→ Local estimate of DDF parameters

Step 2

Carry out Monte-Carlo analysis of the drainage system capacity equation

Calculate mode and standard deviation of frequency distribution of the Monte-Carlo analysis



Step 3

Calculate local estimate of drainage system capacity

Upper estimate (mode + 1 standard deviation) ← Modal estimate (mode) → Lower estimate (mode – 1 standard deviation)

6.1 Use local knowledge to estimate a local range for the input parameters?

- To obtain a local estimate of the drainage system capacity, one or more of the input parameters that make up the drainage system capacity needs to be made. The national range can be replaced with a locally estimated range, or a single value.
- Which parameters are locally refined, and how, depends on the data and local knowledge that is available. Methods and sources of information for obtaining local estimates of the parameters are give in Table 6.1-1.
- Table 6.1-2 reports the sensitivity of the drainage rate equation to the ranges used in each input parameter. For example, drainage rate can vary 10 mm/hr between a minimum Percentage Runoff of 30 and a maximum Percentage Runoff of 80.

Table 6.1-1

Parameter	Method/information for making estimate of local parameter range		
Percentage runoff (PR)	Fixed UK runoff model equation	Level and rainfall data	Qualitative factors such as steepness
Critical storm duration (t_{crit})	Re-use existing data from RoFSW	Sewer design equations such as Wallingford procedure	Local knowledge
Level of service of drainage system (LoS)	Known design level of service	Detailed modelling studies	Local knowledge
Depth Duration Frequency (DDF) rainfall parameters	DDF parameters at centroid of catchment	FEH CD-ROM to obtain average DDF parameters	Sample sets of DDF parameters for model area

Table 6.1-2

Parameter	Estimated range (from national range estimate)	Change in drainage system capacity estimate (mm/hr)
Percentage runoff (%)	30-80	10
Critical duration (hours)	0.5-2	11
Level of Service	5-30	6
DDF parameters	9 representative sites for England and Wales (see Table A-0-1)	2

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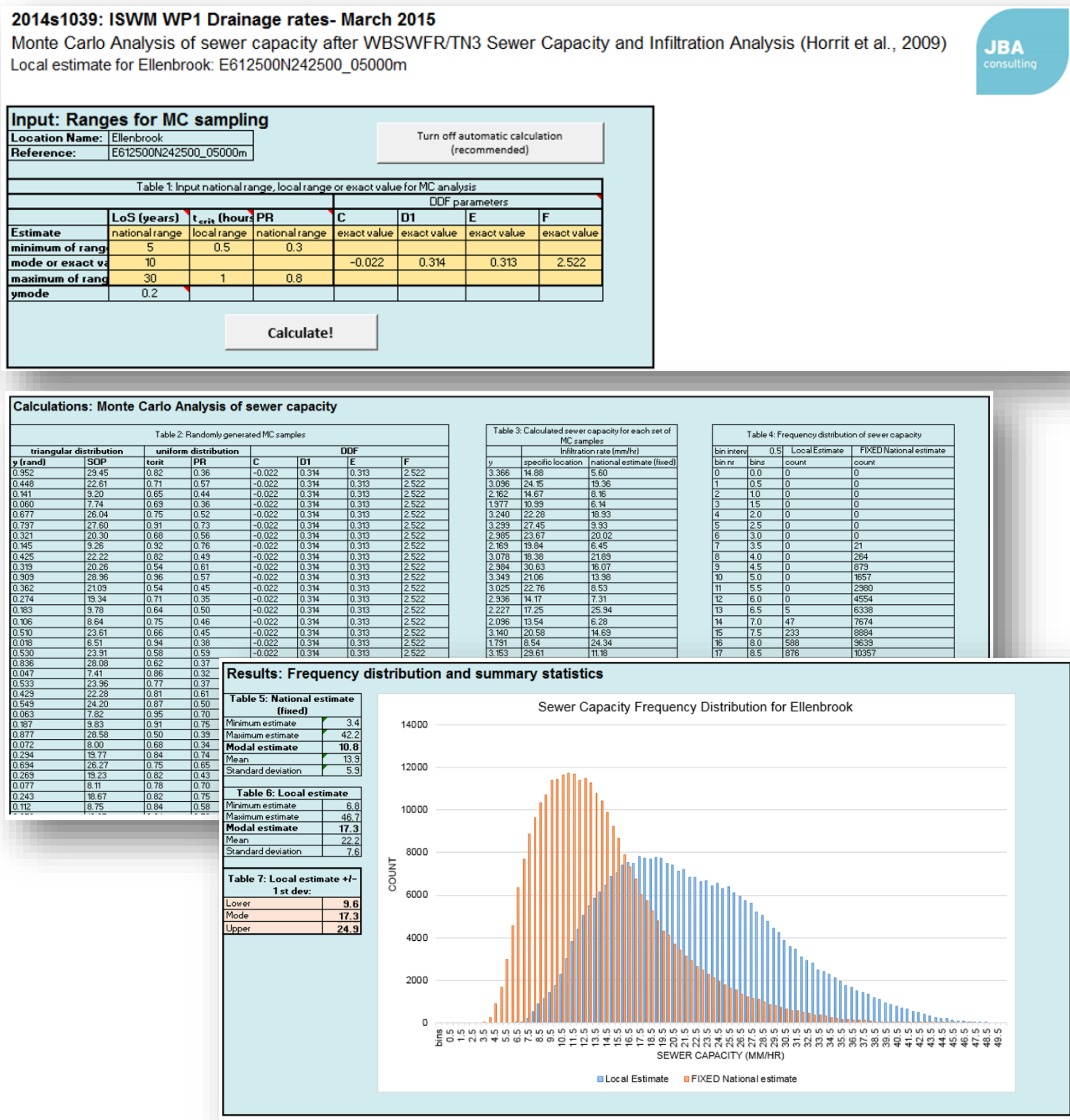
6.2 Carry out the Monte-Carlo Analysis of the drainage system capacity equation

- A Monte-Carlo analysis is a statistical analysis which relies on random sampling of parameters to understand complex processes.
- In the statistical method the locally defined ranges of the input parameters are repeatedly randomly sampled to solve the drainage system capacity equation (see A1).
- SC120020/1 Appendix C is an example Monte-Carlo calculator spreadsheet tool (image below). This can be used to plot a frequency distribution of the calculated drainage system capacities. The modal result is the locally calculated drainage system capacity.



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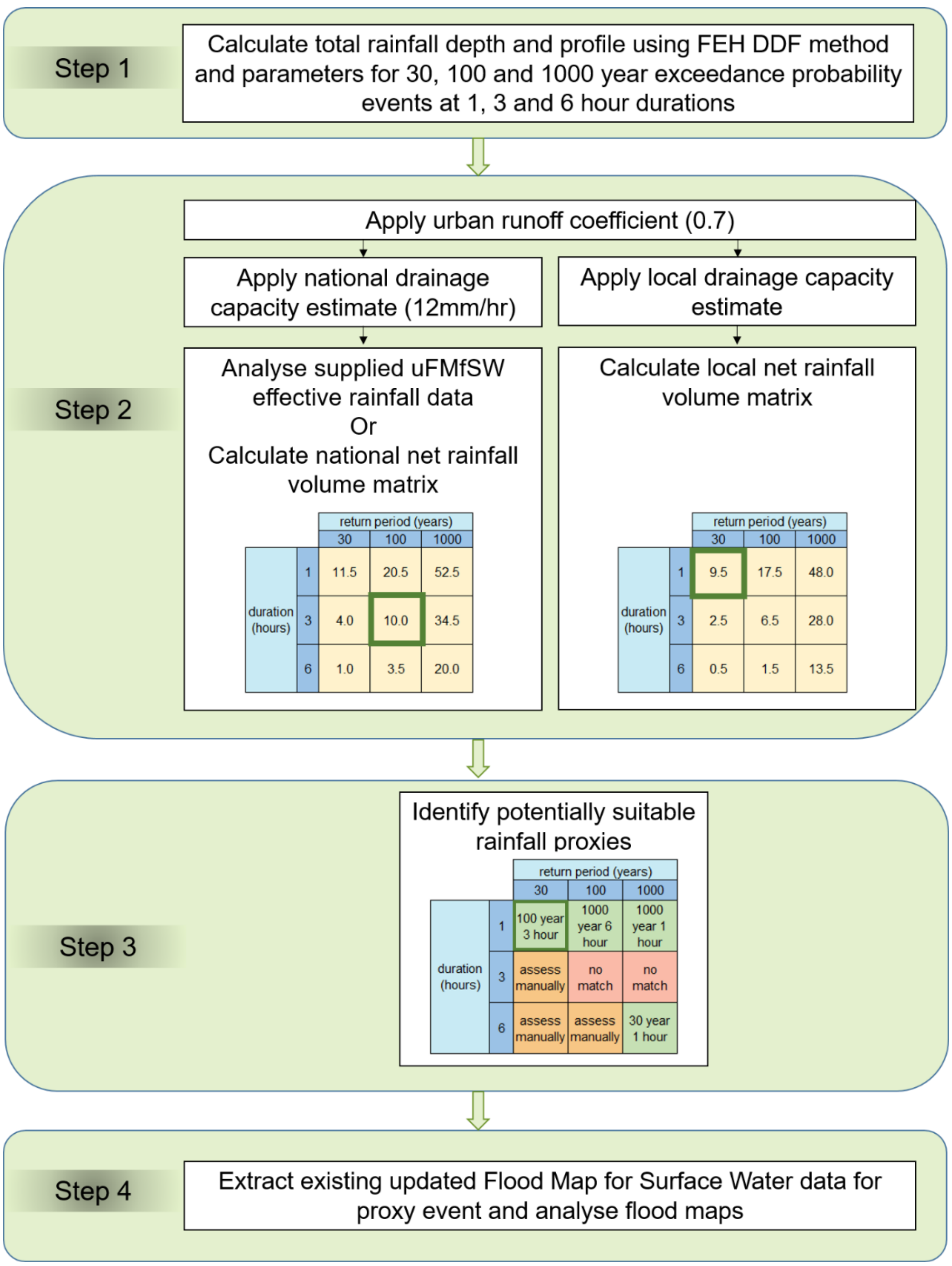
7. Re-using existing maps to represent different drainage rates

- A Rainfall Proxy method has been developed. It assumes that using the direct rainfall method storms with similar net volumes of rainfall produce similar flood extents. In the RoFSW 9 different rainfall scenarios were modelled: 3.3 percent (1:30), 1 percent (1:100) and 0.1 percent (1:1000) annual chance events with durations of 1, 3 and 6 hours. The RoFSW combines the maps to present the worst-case scenario.
- The maps for each of the nine rainfall scenarios is available on data.gov.uk and has been provided to LLFAs. The modelling can be provided to LLFAs on request.
- The Rainfall Proxy method re-uses this data. The summary process is shown in the flowchart and more information is provided on the following pages.



7.1 How do I calculate the total and net rainfall profile and volume using Flood Estimation Handbook methods?

- Calculate design rainfall profiles using the depth duration frequency model from the Flood Estimation Handbook (FEH) Volume 2[1] (the method used for the national modelling).
- The FEH equations can be implemented using a spreadsheet similar to the example Rainfall Calculator spreadsheet (shown below and provided in SC120020/2 Appendix D), or a software package of your choice.
- Required inputs:
  - The drainage system capacity used in the national Risk of Flooding from Surface Water modelling. This was 12mm/hr unless a different drainage rate was indicated by LLFA at the time. This was changed to 6mm/hr in places identified as having a low drainage rate and 18mm/hr in areas identified as having high drainage rates
  - The local drainage system capacity as calculated the in the Statistical Method
  - The FEH DDF parameters for the centroid of the model tile. The DDF parameters are accessed via the FEH Web Service
- Outputs:
  - The net summer rainfall profiles for the 3.3 percent, 1 percent and 0.1 percent annual exceedance probability events with 1, 3, and 6 hour durations for the national and local estimates of the drainage system capacity.

2014s1039: ISWM WP1 Drainage rates- March 2015

Effective Rainfall matrix calculator

Data Input

Please complete cells with yellow fill

place name	Ellenbrook
tile reference	E612500N242500_05000m

Table 1: Drainage rates				
	uFMFfSW rates		Local rates	
	urban	**rural**	**urban**	**rural**
percentage runoff	0.7	0.39	0.7	0.39
Infiltration capacity (mm/hr)	12		18	
Inf. cap. estimate type (modal/higher/lower)			lower	

Table 2: DDF parameters at centroid of model tile	
C(1km)	-0.022
D1(1km)	0.314
D2(1km)	0.218
D3(1km)	0.222
E(1km)	0.313
F(1km)	2.522

Calculation: Rainfall Frequency (At-A-Point) for 1, 3 and 6 hou

Table 3: rainfall frequency at a a point calculated from DDF parameters			
Return Period, T	30	100	1000
Gumbel Reduced Variate, y	3.384	4.600	6.907
Duration, D			
1	35.92	52.55	108.20
12	65.14	89.18	161.84
48	79.48	104.85	177.36
96	88.04	114.01	186.18

Table 4: Rainfall frequency for required durations calculated from table 2			
	30	100	1000
1.083333333	36.62	53.46	109.61
3.083333333	47.04	66.78	129.86
6.083333333	55.36	77.17	144.97

2014s1039: ISWM WP1 Drainage rates- March 2015

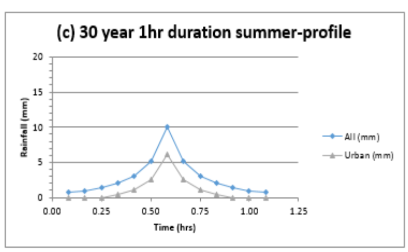
Effective Rainfall matrix calculator

Calculations: DDF Rainfall profiles with national estimate of drainage rates

table 1: DDF Rainfall	
Duration, D	1.08
Return Period, T	Rainfall (mm)
30	36.62
100	53.46
1000	109.61

Table 2: Design Storm Profile	
Profile	**SUMMER**
a	0.100
b	0.815

Table 3: 1 hour DDF Rainfall profiles				30 year return period Rainfall			100 year return period Rainfall			1000 year return period Rainfall		
	Time (hours)	z	y (Prop R	All (mm)	Rural (mm	Urban (mm	All (mm)	Rural (mm	Urban (mm	All (mm)	Rural (mm)	Urban (mm)
6	0.0833	1.000	0.019	0.69	0.27	0.00	1.01	0.39	0.00	2.07	0.81	0.45
5	0.1667	0.873	0.026	0.97	0.38	0.00	1.41	0.55	0.00	2.89	1.13	1.02
4	0.2500	0.741	0.037	1.37	0.54	0.00	2.00	0.78	0.40	4.11	1.60	1.88
3	0.3333	0.604	0.055	2.00	0.78	0.40	2.93	1.14	1.05	6.00	2.34	3.20
2	0.4167	0.459	0.084	3.06	1.19	1.14	4.47	1.74	2.13	9.17	3.58	5.42
1	0.5000	0.303	0.141	5.17	2.02	2.62	7.55	2.94	4.28	15.48	6.04	9.83
0	0.5833	0.124	0.275	10.08	3.93	6.06	14.72	5.74	9.30	30.17	11.77	20.12
1	0.6667	0.303	0.141	5.17	2.02	2.62	7.55	2.94	4.28	15.48	6.04	9.83
2	0.7500	0.459	0.084	3.06	1.19	1.14	4.47	1.74	2.13	9.17	3.58	5.42
3	0.8333	0.604	0.055	2.00	0.78	0.40	2.93	1.14	1.05	6.00	2.34	3.20
4	0.9167	0.741	0.037	1.37	0.54	0.00	2.00	0.78	0.40	4.11	1.60	1.88
5	1.0000	0.873	0.026	0.97	0.38	0.00	1.41	0.55	0.00	2.89	1.13	1.02
6	1.0833	1.000	0.019	0.69	0.27	0.00	1.01	0.39	0.00	2.07	0.81	0.45
			Sum Rf (mm)	36.62	14.28	14.39	53.46	20.85	25.03	109.61	42.75	63.73
			Max Rf (mm)	10.08	3.93	6.06	14.72	5.74	9.30	30.17	11.77	20.12



[1]FAULKNER, D.S., 1999. Flood Estimation Handbook. Volume 2: Rainfall Frequency Estimation. Institute of Hydrology, 110 pages.

7.2 How do I calculate the rainfall proxy matrices?

- The total net rainfall volume matrices allow comparison of the total net volume of rainfall for the local drainage system capacity with the total net volume of rainfall of the 9 existing flood maps.
- The matrices hold the total net rainfall volume for the 3.3 percent, 1 percent and 0.1 percent annual exceedance probability events at 1, 3 and 6 hour durations.
- To calculate the **net** rainfall profile and volume, subtract the percentage runoff and sewer system capacity from the total rainfall profiles.
  - **National estimate**: Percentage runoff 70 percent and sewer capacity 12mm/hr (or 6mm/hr or 18mm/hr if the lower or higher estimate were used in the original mapping)
  - **Local estimate:** Percentage runoff 70 percent and sewer capacity as calculated using the Statistical method.
- The **total net rainfall volume** is the sum of the area underneath the net rainfall profile
- Each total net rainfall volume matrix shows the three annual exceedance probabilities ('return period') and durations for the national and local estimate. See tables below for example of total and net rainfall volume matrices for the national and local estimate of sewer system capacity

Table 1: Total rainfall Matrix

		Total rainfall (mm/hr)		
		Return period (years)		
		30	100	1000
Duration	1	37.5	54.0	108.5
	3	37.5	54.0	108.5
	6	37.5	54.0	108.5

Table 2: National Estimate effective total rainfall matrix

		Net total urban rainfall (mm/hr)		
		Return period (years)		
		30	100	1000
Duration	1	15.0	25.5	63.0
(hours)	3	6.0	13.0	43.5
	6	1.5	5.5	27.0

Table 3: Local Estimate effective total rainfall matrix

		Net total urban rainfall (mm/hr)		
		return period (years)		
		30	100	1000
Duration	1	11.5	21.0	56.5
(hours)	3	3.0	8.5	34.0
	6	0.5	2.0	17.0

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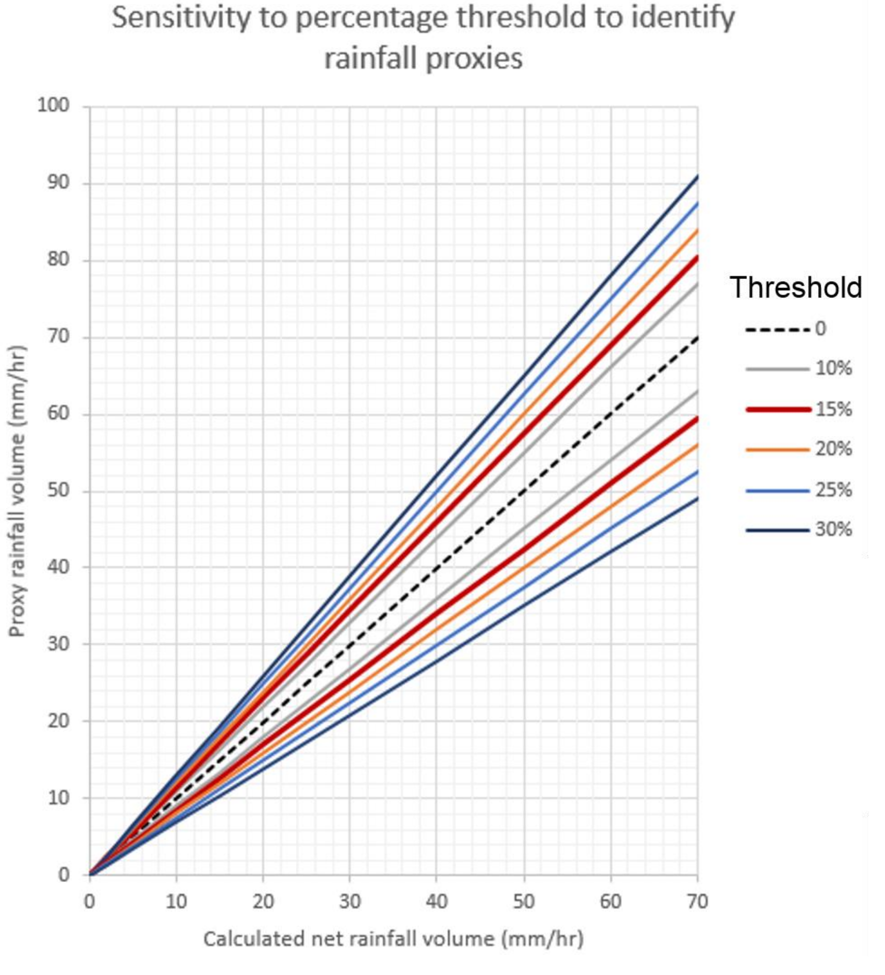
7.3 How do I identify potentially suitable rainfall proxies?

- Whether total net rainfall volumes are similar enough to be used as a proxies depends on the difference between them and on the sensitivity of the model area to the rainfall volume.
- The percentage difference between the rainfall volumes is used to quantify the difference between the volumes.
- The image below shows the limits of the rainfall volumes which are classed as ‘similar’ for the different thresholds.
- Judgement and sensitivity analysis is required to choose a threshold value.
- It is clear that at small rainfall volumes a very large threshold would be required to obtain any proxies. Therefore it is recommended that for rainfall volumes below 5mm/hr suitable proxies are identified using judgement by manually comparing the rainfall volumes.



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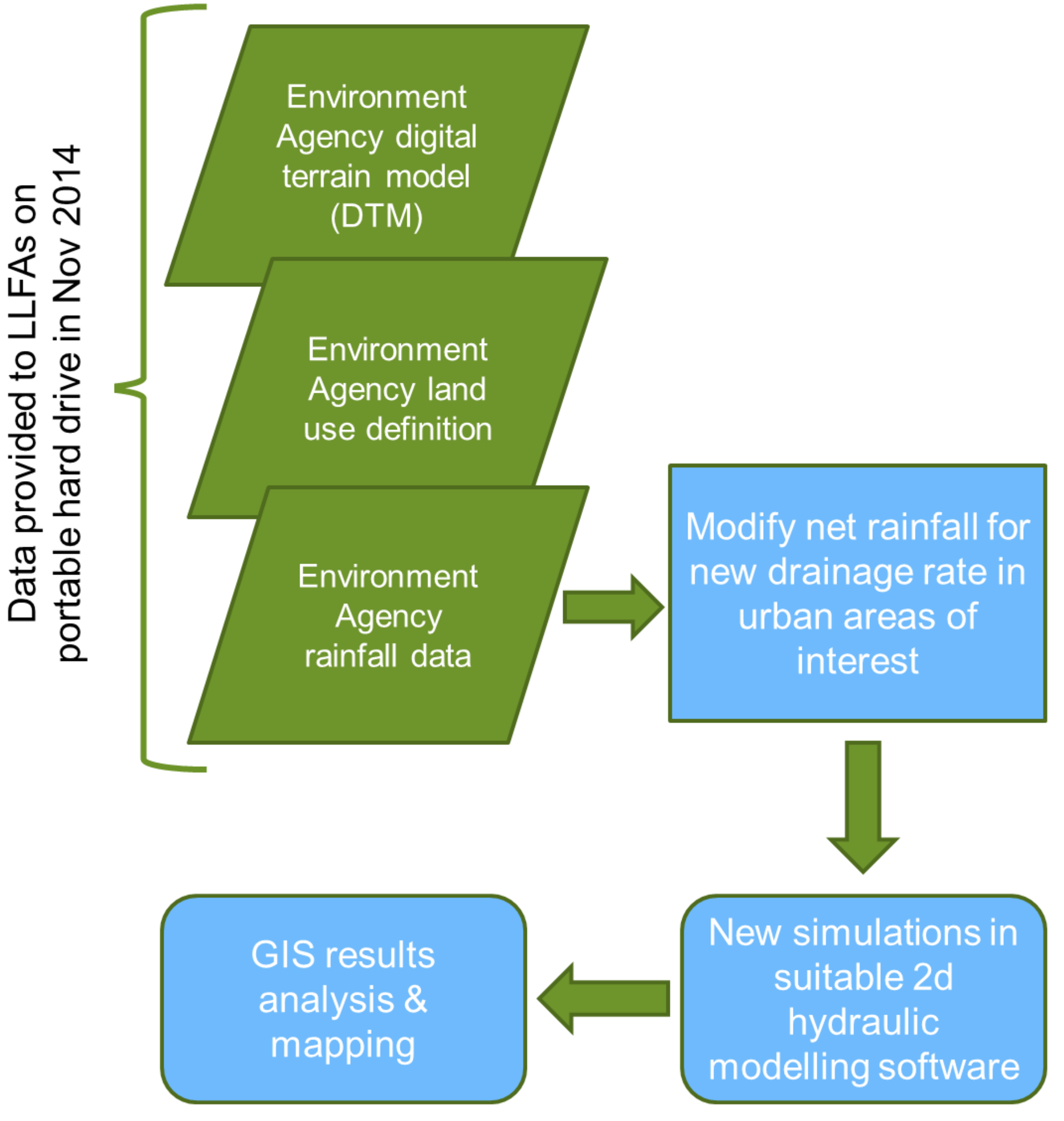
8. Remodelling to represent different drainage rates

- Commence fresh modelling using any suitable 2D software (see SC120002 2D Benchmarking science report)
- Re-use DTM and hydrology data used in RoFSW
- Apply locally specific drainage rate(s)
- Add further local detail (accurate DTM, water courses) as required



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9 Advanced analysis of flood maps & sensitivity to drainage rate

Various methods are available to analyse the flood maps. The method will depend on the purpose of the study.

Examples include:

- **Visual comparison**: (Figure 9-1) plot the depth, velocity or hazard maps using a suitable colour scale to allow a visual comparison to be made
- **Impact assessment:** (Figure 9-2) a large variety of impact assessment methods can be used to assess the difference between the flood mapping for the local and national estimate of the drainage system capacity. For example:
    - Property count[1]
    - Financial losses using established methods (e.g. Multi Coloured Manual)
    - Frequency count of flood depth/velocity/hazard cells
- **Fuzzy maps** (Figure 9-3) where an area has been remodelled using a range of values for the sewer system capacity a fuzzy map method can be used to assess sensitivity, or confidence in the flood mapping.

➲ Where modelled flood extent is sensitive to drainage rate this indicates that FRM options improving drainage capacity may be effective and worthy of investigation

➲ Where modelled flood extent is insensitive to drainage rate then there is a higher confidence of the mapping being robust

➲ For more information about using fuzzy maps see the SC120020/R Evidence Report, Section 4.3.4 Case Study site 4: Greater Manchester.

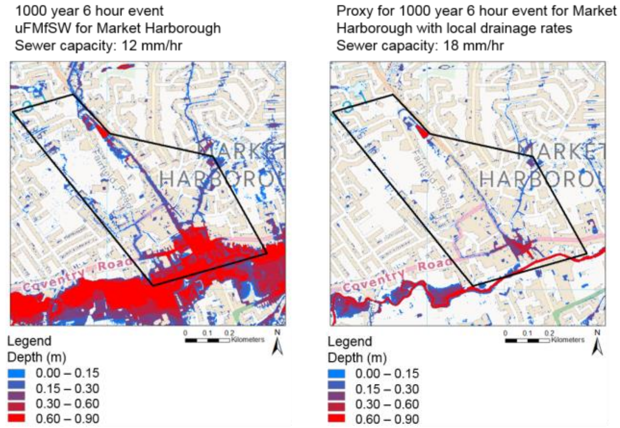

Figure 9-1: Visual assessment of flood depths

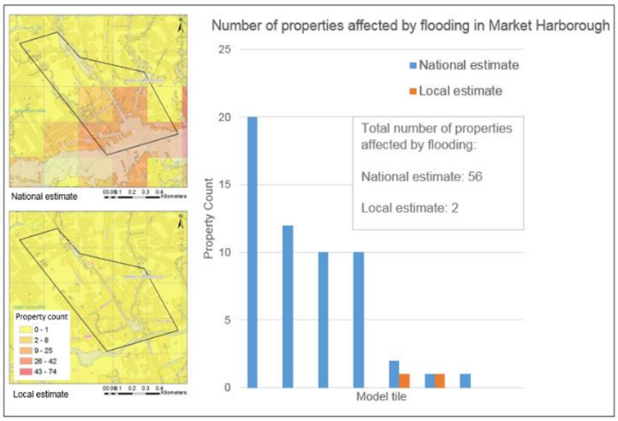

Figure 9-2: Property count impact assessment

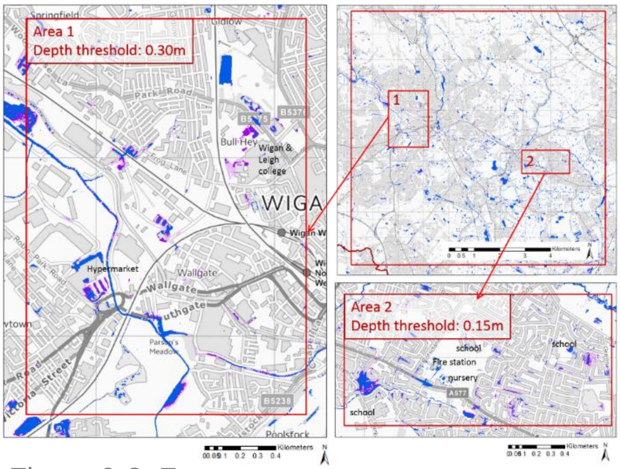

Figure 9-3: Fuzzy maps to assess sensitivity to the drainage system capacity

1 Property counts for RoFSW should not be a sum of address points, but should use the shared property counting method for surface water. Please contact UFMFSW@environment-agency.gov.uk for a copy of the counting guidance.

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Supplementary information

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A1 The drainage system capacity equation & national parameters

Derivation of 12mm/hr drainage rate

Obtaining a national estimate of man-made drainage capacity is challenging due to the complex and varied nature of drainage infrastructure found in urban areas. However, a national estimate of 12mm/hr for drainage system capacity was derived by Horritt et al. (2009) who used a modified version of the Rational Method:

$$Rate = PR.T_{CRIT}^{(Cy+D1-1)}.e^{Ey+F} \quad (A.1)$$

$$y = -ln\left(-ln(1-\frac{1}{LoS})\right) \quad (A.2)$$

Equations A.1 and A.2 take into account the percentage runoff (PR), critical storm duration (T_{crit}), Level of Service of the drainage system (LoS) and the Depth-Duration-Frequency (DDF) parameters which describe the rainfall (C, D1, E & F).

A range and distribution of each parameter was estimated across England and Wales (Table A1.1). The range of percentage runoff was based on five pilot sites: Bradford, Kensington and Chelsea, Torquay, North Brent, and Swindon. Percentage runoff was calculated for each site based on the percentage impermeable area (PIMP) using the Wallingford Procedure.

Table A1.1: Parameters used in the national estimate of the drainage system capacity

Parameter		National range	Distribution
Percentage runoff (PR)		30% to 80%	Uniform
Critical storm duration (t_{crit})		0.5 to 2 hours	Uniform
Level of service of drainage system (LoS)		5 to 30 years (mode of 10 years)	Triangular
Depth Duration Frequency (DDF) rainfall parameters	C	-0.026±0.0034	Normal
	D1	0.38±0.039	Normal
	E	0.30±0.011	Normal
	F	2.4±0.063	Normal

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Related reports and tools

The following documents are available to download from the Environment Agency Research and Development website.

Science summary

- SC120020/S Improving surface water flood mapping: estimating local drainage rates

Evidence Report

- SC120020/R Improving surface water flood mapping: estimating local drainage rates

Monte-Carlo Analysis spreadsheet (Appendix C)

- SC120020/1 Appendix C_Sewer Capacity-MC Analysis Tool (v0.2-March 2015).xls

Rainfall Calculator spreadsheet (Appendix D)

- SC120020/2 Appendix D_Effective Rainfall Matrix Calculator (v0.3 March 2015).xls

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It's our job to make sure that air, land and water are looked after by everyone in today's society, so that tomorrow's generations inherit a cleaner, healthier world.

Our work includes tackling flooding and pollution incidents, reducing industry's impacts on the environment, cleaning up rivers, coastal waters and contaminated land, and improving wildlife habitats.

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