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Where next for research in to simplified surface water flood modelling?

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Abstract: The Environment Agency has recently completed research looking at rainfall runoff assumption within national scale surface water flood mapping in England and Wales. In particular, the research focussed on the use of a single drainage rate parameter (x mm/hr) to represent the water removed by sub-surface drainage system. The research project developed a method for varying the drainage rate from the national default using local knowledge. We concluded that this approach was valid for the current generation of national scale flood maps. However, we also identified that there is very little scope to develop the approach further. Instead we suggest that new methods need to be developed to support future improvements to national scale surface water flood mapping.

1 Introduction

In England there are 3 million properties at risk from surface water flooding (Environment Agency 2014). By comparison, there are 2.4 million properties at risk of flooding from rivers and the sea. Future projections for climate change, urban creep and population growth all mean that surface water flood risk is only going to get worse.

So it is crucial that risk management authorities and local communities have a method for understanding the level of surface water flood risk that they face. In England and Wales, the Updated Flood Map for Surface Water (uFMfSW) has been published. It provides flood depth and velocity information, at 2 metre resolution for a range of flood probabilities and storm durations. It aims to give a broad understanding of flood risk in an area rather than accurate property level risk assessments.

1.1 Drainage rates as a model simplification

Creating a map with national coverage requires the underlying model to be simplified so that the model can built and run within a reasonable time. Simplification is also necessary when data is unavailable or cannot be collated cost effectively. For example, in England and Wales, there is no national dataset of drainage assets. In fact, model simplification is desirable for many reasons besides national flood mapping. It allows models to be run for real time purposes such as flood forecasting and enables models to be run multiple times to better understand model uncertainty or the impact of flood management options.

The main simplification used in the uFMfSW is to parameterise the drainage network. So, we assume that a fixed 12 mm per hour of rainfall is removed by the drainage network. The volume of rainfall that remains is used as the starting condition for a 2d hydraulic model run that resolves the full shallow water equation.

1.2 Problems with drainage rates

The use of a drainage rate succeeds in simplifying the model, but it creates several problems of its own.

- The national default of 12 mm per hour does not reflect local differences in the drainage network. This means that, some areas are overestimating drainage and others are underestimating. It also means that we can't show the effect that a change in drainage would make.
- The rainfall is removed only during model set up instead of during model run time. This is unlikely to be an issue when the same drainage rate is used everywhere, but could become important when water flows from an area with one drainage rate to an area with a different drainage rate.
- Related to the point above, the drainage rate is assumed to be constant throughout the storm event. In reality, the drainage system can remove more water at the beginning of the event than it can at end because at the beginning of the event the pipes are empty.
- The drainage rate removes water permanently from the system. This means that it doesn't reproduce the way that real sewers have storage capacity that fills up during an event. It also means that water doesn't emerge elsewhere in the model domain in the way that sewers behave when they surcharge.

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- Finally, the drainage rate is not a physical characteristic that could be measured or verified. Instead it is more of a calibration parameter similar to, say, Manning's n. This makes it difficult to parameterise with confidence.

1.3 Aim for this research project

This piece of research aimed to tackle the first problem described in the list above: the fact that our current default value of 12mm per hour does not represent local differences in the drainage network.

2 Method

We attempted two different approaches to tackle this problem: an empirical approach and a statistical approach.

2.1 Empirical approach

The empirical approach used case studies from six sites. The sites were Market Harborough (a market town in Leicestershire), Ellenbrook (a district of Ipswich, Suffolk), Stirchley (a district south of south of Birmingham city centre) and Liverpool (three areas in central Liverpool).

For each site we re-ran the flood models using a drainage rate of 6mm per hour and 18 mm per hour. By comparing these outlines (and the original 12mm per hour model run) against detailed local models we could see which of the three drainage rates most closely resembled the detailed model.

So that we could identify the right drainage rate, we performed both a visual comparison of the outputs, as well as looking at key metrics such as number of properties at risk.

Finally, we compared the six case studies to see if we could identify trends that could be used to predict the true drainage rate in other sites. The relationships that we looked at were: building density, impervious area, sewer diameter, sewer density, manhole density, sewer gradient and the distribution of pipe sizes within the catchment.

2.2 Statistical approach

The national estimate of drainage rate used in the uFMfSW (12mm per hour) is obtained using a drainage system capacity equation, based on a modified form of the rational method. The single national estimate was created by using a Monte Carlo analysis across the range of possible input values.

The drainage system capacity equation takes into account the percentage runoff; critical storm duration; level of service of the drainage system; and the depth, duration and frequency parameters of typical rainfall events. The full approach is described in Horritt *et al* (2009).

For this approach we used the same Monte Carlo analysis but changed the input parameters, narrowing down the range of possible values using local knowledge about the catchment.

We compared predicted drainage rates against the drainage rates identified for three of the case studies used in the empirical method. We also used a further case study in Greater Manchester where the local authority had previously provided their estimate of the local drainage rate.

3 Results

The drainage rates that gave results closest to the detailed local model are provided below:

Area	Drainage Rate (mm/hr)
Market Harborough	18
Ellenbrook	18
Stirchley-Ripple Road	6
Liverpool A2	9
Liverpool A3a	6
Liverpool A7	12

Table 1. Drainage rate for each case study site that makes the national model most closely resemble the detailed local model.

3.1 Results from the empirical approach

The drainage rates identified from local models were compared against seven different characteristics of the case study sites. The seven characteristics were:

1. Building density
2. Impervious area
3. Average sewer diameter
4. Sewer density
5. Manhole density
6. Average sewer gradient
7. cumulative pipe frequency

The results are provided below, however, no strong relationships emerged from the results.

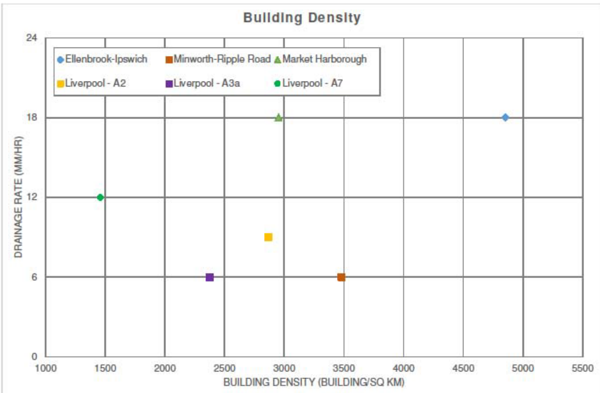

Figure 1. Building density comparison.

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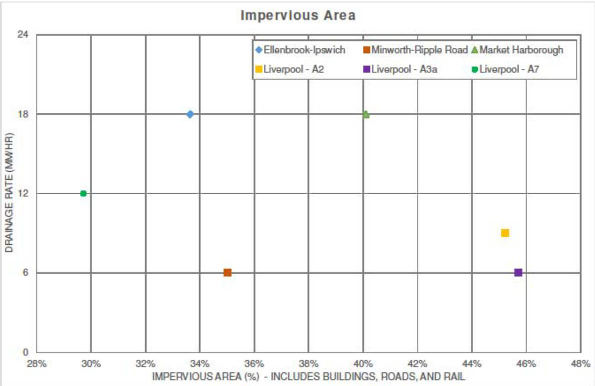

Figure 2. Impervious area comparison.

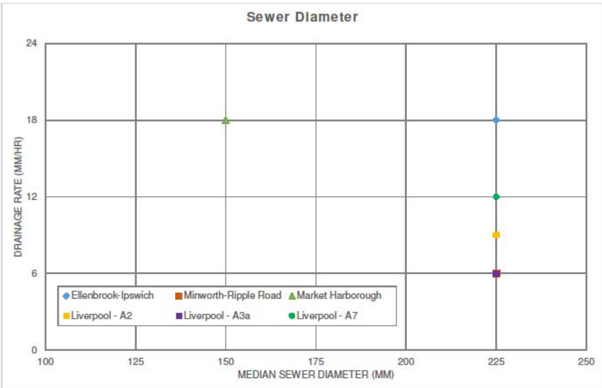

Figure 3. Sewer diameter comparison.

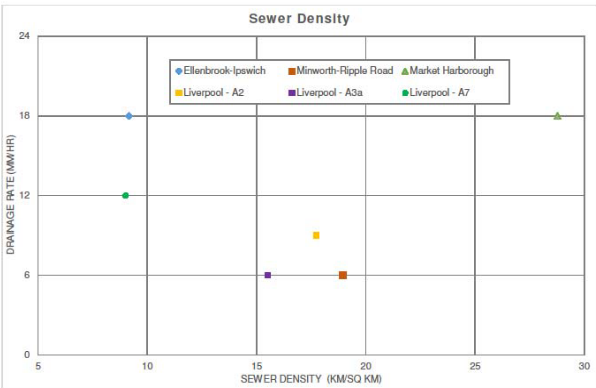

Figure 4. Sewer density comparison.

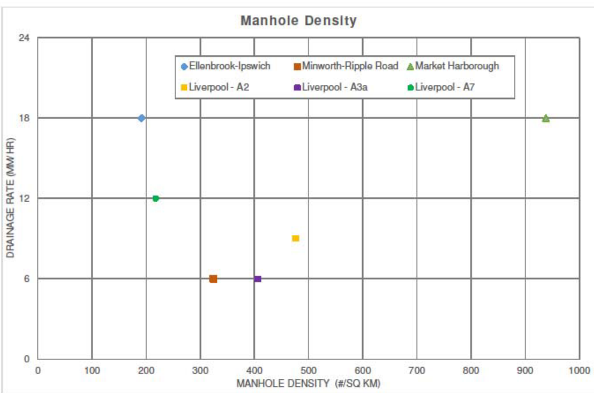

Figure 5. Manhole density comparison.

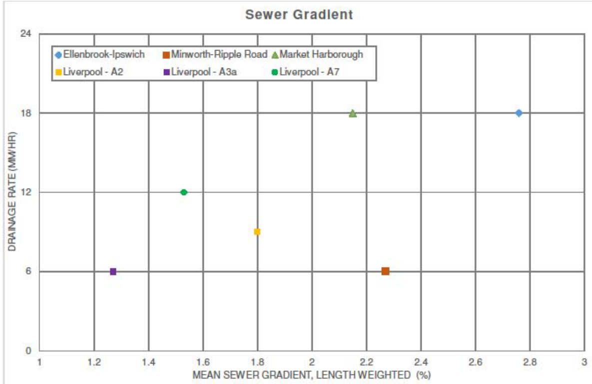

Figure 6. Sewer gradient comparison.

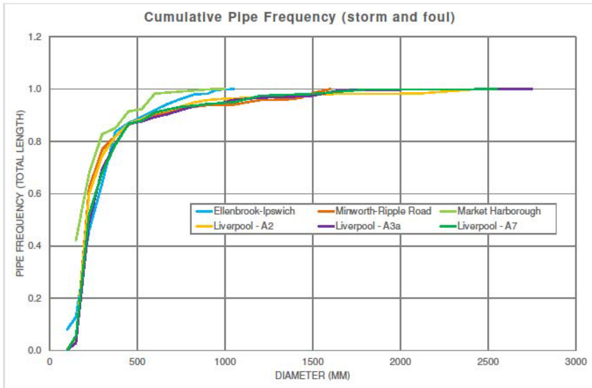

Figure 7. Cumulative pipe frequency comparison.

3.2 Results from the statistical approach

The statistical approach identified the following drainage rates for each case study.

Area	Drainage Rate (mm/hr)
Market Harborough	18
Ellenbrook	14
Stirchley-Ripple Road	10.5
Greater Manchester	16

Table 2. Drainage rate for each case study site as estimated by the statistical method.

These results can be compared to drainage rates extracted from local data, provided below.

Area	Rate (mm/hr)	Source
Market Harborough	18	Local model
Ellenbrook	12	Default estimate
Stirchley-Ripple Road	6	Local model
Greater Manchester	18	local staff estimate

Table 3. Reference drainage rate for each case study site for comparison against the outputs from the statistical method.

Most of these case studies focussed on improving the current estimate for the drainage rate. So we would hope that the estimate from the statistical approach is closer to the local data than the default national rate (12 mm/hr) is. The Ellenbrook case study was different in that it explored the impact of improving the level of service of the drainage system. We don't know what the drainage rate should be for the improved system but it should be higher than the default national rate.

3.2.1 Market Harborough

The input data used to estimate the drainage rate for Market Harborough is provided below. Local knowledge was used for storm duration and rainfall parameters.

Input Parameter	Min	Mode	Max
Level of service (years)	5	10	30
*Storm duration (hours)	0.5	n/a	1
Percentage runoff	30	n/a	80
*Rainfall parameter C	n/a	-0.024	n/a
*Rainfall parameter D1	n/a	0.331	n/a
*Rainfall parameter E	n/a	0.304	n/a
*Rainfall parameter F	n/a	2.572	n/a

Table 4. Input data for Market Harborough. Changes from the national defaults are highlighted with *

The Monte Carlo analysis gave results with a mode much higher than the national default. This results matched exactly the data extracted from the local model.

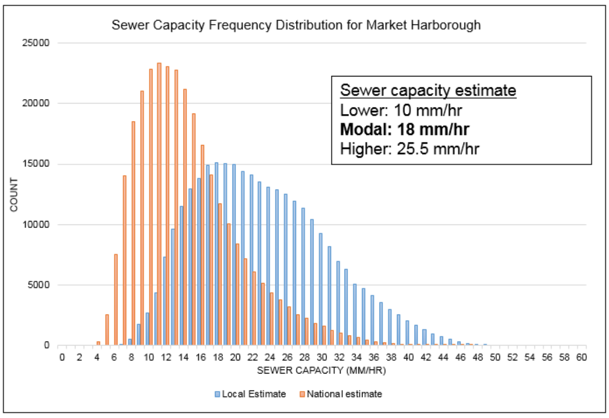

Figure 8. Calculated drainage rate for Market Harborough.

3.2.2 Ellenbrook

The input data used to explore the impact of improving the drainage system in Ellenbrook is provided below. Local knowledge was used for rainfall parameters.

Input Parameter	Min	Mode	Max
*Level of service (years)	10	20	30
Storm duration (hours)	0.5	n/a	2
Percentage runoff	30	n/a	80
*Rainfall parameter C	n/a	-0.022	n/a
*Rainfall parameter D1	n/a	0.314	n/a
*Rainfall parameter E	n/a	0.313	n/a
*Rainfall parameter F	n/a	2.522	n/a

Table 5. Input data for Ellenbrook. Changes from the national defaults are highlighted with *

The Monte Carlo analysis gave results with a mode slightly higher than the national default. This shows that the direction of change is as expected however further work would be needed to identify if the magnitude of change was correct.

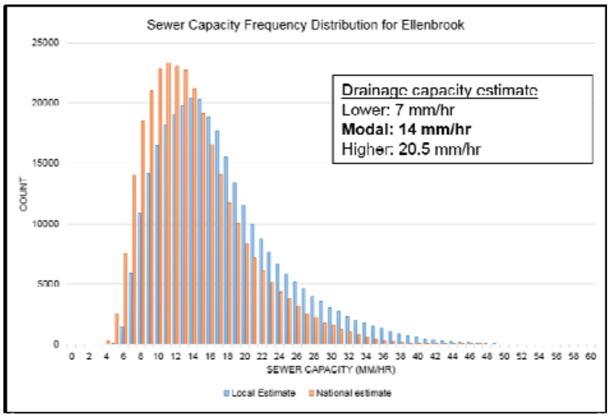

Figure 9. Calculated drainage rate for Ellenbrook.

3.2.3 Stirchley

The input data used to estimate the drainage rate for Stirchley is provided below. Local knowledge was used for the rainfall parameters only.

Input Parameter	Min	Mode	Max
Level of service (years)	5	10	30
Storm duration (hours)	0.5	n/a	2
Percentage runoff	30	n/a	80
*Rainfall parameter C	n/a	-0.027	n/a
*Rainfall parameter D1	n/a	0.348	n/a
*Rainfall parameter E	n/a	0.306	n/a
*Rainfall parameter F	n/a	2.412	n/a

Table 6. Input data for Stirchley. Changes from the national defaults are highlighted with *

The Monte Carlo analysis gave results with a mode slightly lower than the national default. This shows that te statistical method is an improvement on national default but it could be closer to the estimate from a local model of (6 mm/hr).

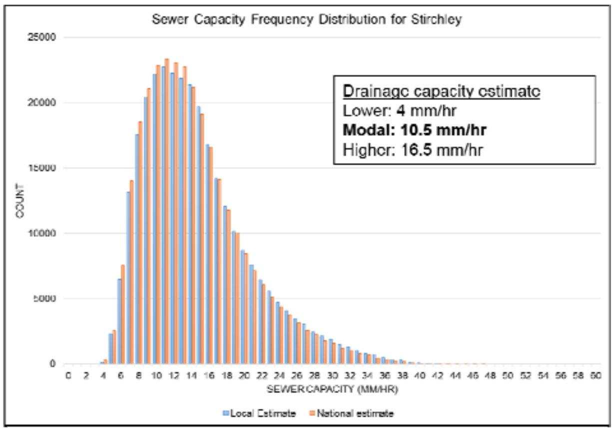

Figure 10. Calculated drainage rate for Stirchley.

3.2.4 Greater Manchester

The input data used to estimate the drainage rate for Greater Manchester is provided below. Local knowledge was used for storm duration, percentage runoff and rainfall parameters.

Input Parameter	**Min**	**Mode**	**Max**
Level of service (years)	5	10	30
*Storm duration (hours)	1	n/a	1
*Percentage runoff	60	n/a	85
*Rainfall parameter C	n/a	Varies	n/a
*Rainfall parameter D1	n/a	Varies	n/a
*Rainfall parameter E	n/a	Varies	n/a
*Rainfall parameter F	n/a	Varies	n/a

Table 7. Input data for Greater Manchester. Changes from the national defaults are highlighted with *

Because Greater Manchester covers a large area the rainfall parameters vary spatially. The Monte Carlo analysis gave results distinctive double peaked result reflecting the two different rates present. The mode was higher than the national default and compared favourably to the estimate by local drainage engineers of 18mm per hour in areas with surface water drains, and 0 mm per hour in the areas without them.

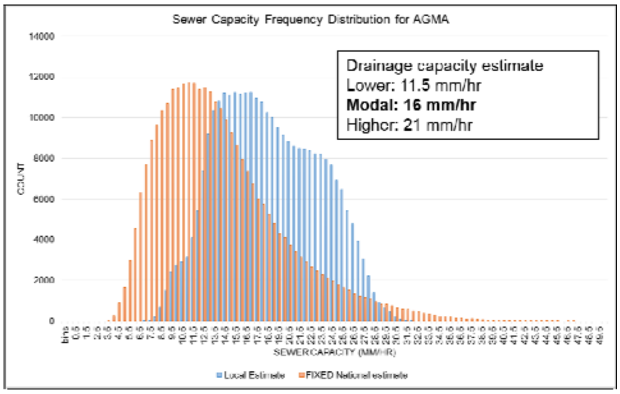

Figure 11. Calculated drainage rate for Greater Manchester.

4 Conclusions

Based on the case studies analysed in this work, it seems that the 12 mm per hour drainage rate, used to create the national scale uFMfSW was a good representation of typical drainage arrangements in many circumstances.

No clear relationships emerged from the empirical approach. That's not to say that such relationships don't exist but that we would need a far greater sample size to identify them.

In contrast though, the statistical approach gave answers that compared favourably with the drainage rates identified through comparison with detailed local models and drainage rates identified by local teams.

The statistical method could be used to help Lead Local Flood Authorities to produce more accurate maps. Alternatively, they could assess the impact of alternative future scenarios such as climate change or investing in surface water management measures by changing the input variables for the Monte Carlo calculation.

5 Recommendations for further research

As long as we continue to use a drainage rate parameter, most of the problems identified in section 1.2 will continue to stand. So effort spent refining the drainage rate may not lead to proportionate improvements in the quality of the model outputs.

Because of this, we would recommend that further research in this field should focus on a different direction.

One area that offers a lot of promise is an approach that has been called "virtual pipes". In this approach drainage networks are simplified down to inlets that can accept a certain rate of inflow and outlets that are connected to the inlets that may also have their own maximum outflow rate.

6 References

1. ENVIRONMENT AGENCY, 2014. Managing flood and coastal erosion risks in England: 1 April 2014 to 31 March 2015
2. HORRITT M.S, SHAAD, K. AND GILL, E., 2009. Sewer Capacity and Infiltration Analysis. Internal Technical Note (WBSWFR/TN3) to Environment Agency.