Industrial challenge

Spatial rainfall distribution in flood modelling

Version 3

Environmental Modelling in Industry Study Group,
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Executive summary

Usually, spatially uniform rainfall and hydrology is assumed in most flood modelling. This could be over estimating risk leading to increased costs, or missing the critical patterns that lead to the most significant floods. Techniques to alleviate this are, for example, continuous simulation and Monte Carlo analysis. The question is whether the extra cost and time involved is worth the added confidence. The challenge for the mathematicians is to find an approach that gets some of the benefits of a more detailed approach, with only a minimal increase in modelling. We could focus on identifying which are the critical samples to analyse in the range of all possible flood events. Or we could try to screen those situations when uniform rainfall is not fit for purpose so we only use more detailed methods when needed.

How is rainfall usually modelled?

When we design flood defences and urban drainage systems, we usually design them to provide protection up to a certain standard. The standard is specified as the annual probability of experiencing an event of a given magnitude or higher, such as, 1 in 100 or 1%. Sometimes modellers also describe it using a return period, for example, this defence protects up to the 100 year flood event.

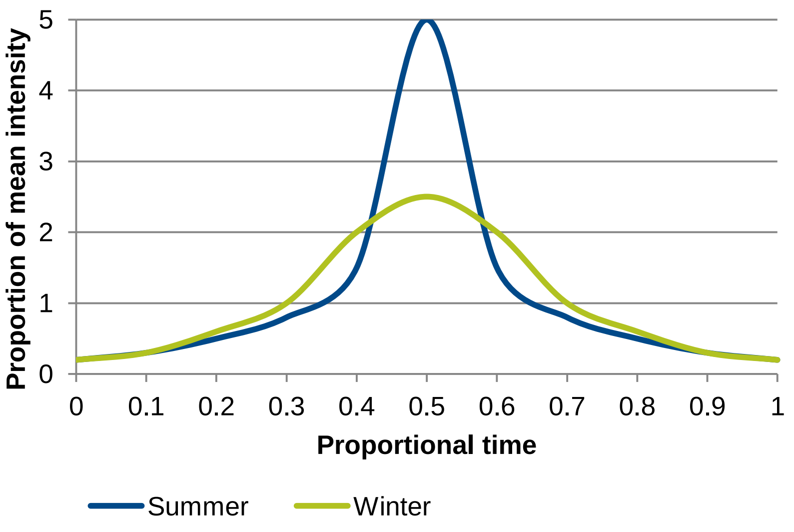

Figure 1: Standard hyetographs for winter and summer rain

The magnitude of a rainfall event is measured as the total volume of rain that falls. In the real world, rain falls unevenly across the catchment and through time. However, when modelling rainfall, we usually assume uniform rainfall through space and a standard shape of hyetograph (like the example shown to the left) to represent rainfall through time.

We usually vary the width of the rainfall distribution, while keeping the total volume constant, to find a critical storm duration. This is the duration of rainfall that maximises risk or cost, depending on the application. The critical storm duration could vary from minutes to days depending on the catchment

This combination of rainfall probability, rainfall volume and critical storm duration becomes the 'design event'. The design event is applied to the whole catchment uniformly throughout the modelling process. Often several design events are used to represent different probabilities of rainfall and to better understand the profile of risk.

Why does that cause problems?

There are several potential problems. Firstly, the assumption of uniform rainfall is not realistic. The figure to the right shows rainfall on 20 July 2014, when Canvey Island flooded. During that event the rainfall was highly focussed in just a small area. If it had been spread evenly across the catchment it may not have caused any flooding. In other areas, the assumption that the whole catchment gets wet could be overstating flood risk. It misses the fact that some areas of a catchment can provide compensatory storage in real events.

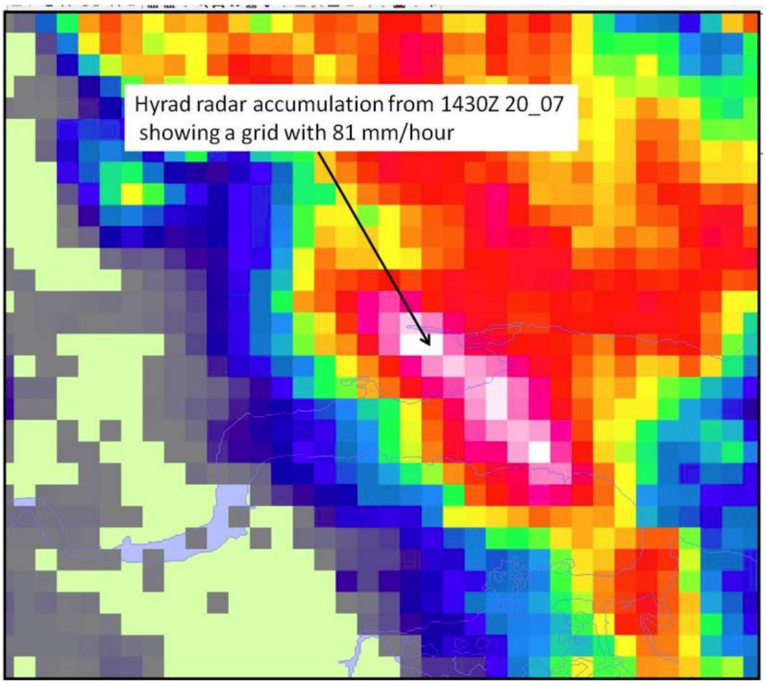

Figure 2: Rainfall radar from Canvey Island July 2014

Secondly, the catchment on which the rain is falling is not uniform. So the critical storm duration could be different in different parts of the catchment. Or, rain in one part of the catchment could synergistically combine with rainfall from another part of the catchment but only when the rainfall occurs in a specific, non-uniform, way.

The end result is that we may be over or under estimating flood risk in some areas. This means that some communities could be missing out on flood protection that they need. Other communities could be overprotected; this would mean that we are spending money where it is not needed.

What solutions have been developed?

Monte Carlo analysis selects different rainfall events randomly from a distribution of possible events. Each event can be modelled even as far as estimating which properties at risk. After hundreds, or sometimes thousands, of model runs an overall picture of flood risk is created which covers the full range of rainfall events that could occur.

Continuous simulation uses a historical or artificially generated rainfall record. Current guidance recommends at least 100 years of data, but ideally much longer records would be used. This rainfall record is modelled using a time step approach of, ideally, around 5 to 15 minute time steps. The resulting flooding is recorded and consolidated to give an overall estimate of flood risk based on the many individual events included in the rainfall record.

One of the advantages of continuous simulation is that it s better at understanding temporal rainfall distribution. So it can be used to understand impacts that might result from little or no rain. This can be important for modelling urban pollution. It can also be used to understanding the impact of multi-peaked rainfall events. In these situations rivers and sewers may not have been able to return to normal flows before more rain arrives.

A challenge that remains is that there is no established approach for developing stochastically generated, spatially varying rainfall. Instead practitioners can either use short historical records, or develop artificial rainfall records for a fixed number of points within their catchment.

Why aren't these improved methods being used?

Many practitioners feel that we already spend too much time and money on modelling. They argue that the resources used on modelling would be better spent getting on building actual flood defences. So they have no appetite for adopting more complicated techniques like Monte Carlo analysis or continuous simulation.

A potential secondary reason is a lack of experience and knowledge about using these approaches. As a result many practitioners won't know how to set them up, or what values to use in the parameters of each analysis.

What do we need from Maths Foresees study group?

We are looking for a way to gain some of the benefits of using a more complicated approach to analyse rainfall in flood models with only a minimal increase in the modelling resource and time.

Some ways to approach the problem could include:

Develop an approach to screening catchments

If practitioners better understood which catchments were sensitive to spatial rainfall distributions, they could limit additional effort to only those catchments where it matters. This could make it easier to justify additional resources by limiting it to fewer modelling studies. Screening would need to consider several factors including both the type of catchment and the purpose of the modelling study. The challenge here is in being able to predict the value of using a more detailed approach without having first used it.

Automate parts of the process

While staff time is expensive, computer run time is almost free. Are there parts of this process that could be done by a computer? Or, at least, done to a close approximation. For example it could be possible to create a formula to calculate input parameters that are normally manually estimated by an expert modeller. Alternatively, a brute force computing approach could be used which undertakes additional model runs but needs less user input time to set up. Finally, consider also which approaches could be used to help humans understand the final results more quickly.

Identify the critical samples or use re-sampling techniques

Monte Carlo analysis typically samples randomly across the full range of possible events. Similarly the data used in continuous simulation includes a lot of repeating or uninteresting data. Instead of analysing the full dataset, we could identify only those events or samples that define the probability space. Modelling only those critical samples would drastically reduce the modelling time needed.

Alternatively, use re-sampling techniques such as boot strap or jack knife to get more value from a smaller number of samples.

What rainfall data sources are available?

In the UK there are about 1,000 rain gauges. Rain gauges measure rainfall very accurately at a single point in space. Rainfall data can be available on a 2 minute time step, but in some cases the time step is much longer than this. Some rain gauges are connected by telemetry and can provide data in real time.

Weather radar systems cover most of the UK. These systems use radar signals to detect precipitation as it falls. The data is processed, corrected and quality controlled using automated algorithms. The final output is provided as a raster dataset. However not all errors can be removed and so weather radar is usually not as accurate as a dedicated rain gauge.

References and related material

The flood estimation handbook and flood studies report are the two main methods that have historically been used for generating design events in the UK

The CIWEM Urban Drainage Group's Rainfall Guide describes current practice for estimating rainfall and using rainfall data in urban drainage models. The document is only available in draft form.

Flood Forecasting Centre's rainfall report from Canvey Island, July 2014. This report gives a real world example of the rainfall data that we use.

DTI SAM - System Based Analysis and Management of Urban Flood Risks. One of the aims of this project was to "develop a rainfall tool which can produce data that is representative of at least 100 years of rainfall that is spatially as well as temporally representative across a catchment". This research represents one of the major pieces of research in this area in recent years.