PAPER 2

Modelling for Extreme Events

by

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Modelling Extreme Events - A state of the Art Review

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Introduction

This paper is a collection of the thoughts and ideas of a number of WaPUG members which have been expressed in WaPUG workshops since 2001. Three of these have been specialised theme one-day events supported by FWR. The topics covered have been, urban flood routing, design criteria and performance for urban drainage, and recently, urban rainfall and run-off modelling. The aim of the paper is to suggest standardised approaches to the future design of urban drainage systems and to focus further research and development into the most productive areas.

Hydraulic designs of urban sewerage systems are usually based on a selected single event because short duration high intensity convective type storms are most likely to cause flooding problems. Run-off from paved surfaces is rapid and local drainage systems need to accommodate this. Trunk sewers need to be able to collect the flows from local systems and safely transport them either to treatment or a suitable watercourse. We have tended to use the same approach to design trunk sewers as for local sewers but systems which are very extensive may be over-designed. The single design event does require some special selection and, frequently, a range of durations is used in order to capture the most suitable one for different points in the collection system. However, whatever the approach, it is important to emphasise the temporal and spatial requirements. Daily rainfall information is by no means suitable for the design of local systems where the minute by minute change in rainfall intensity is critical. Also the coverage of storms is immensely variable and this is not adequately captured by current rain gauge networks. Moving from the empirical approach to something which is more deterministic therefore has its problems.

We are aware that topography has a substantial influence on properties which are vulnerable to flooding and recent developments in terrain mapping and flood routing are beginning to be used to identify these. In the past we have tended to rely on the freeboard between threshold and adjacent road surfaces to provide protection but we are increasingly finding this not to be the case. Alarmingly, little freeboard is also found on some new building development.

The incidence of climate change is a focus for all of these concerns. If climate change is likely to result in more intense thunderstorms the adequacy of our current urban drainage systems is of concern. We may also find that the progression of development and re-development in urban areas which is uncontrolled from a drainage perspective, is creating overland flood paths which have the potential for significant property damage and even loss of life.

Institutional Background

Tolerance of flooding events amongst property owners and their insurers, appears to be reducing but there is a continuous upward pressure on their numbers. This is driven by increasing impermeability in urban catchments coupled with climate change and greater willingness to report flooding. At the same time, there are other pressures on customers' bills from increasing quality requirements and the need to increase investment in maintaining assets. Coupled with this there are political limits to the increases in customer charges.

This paper seeks to establish long term sustainable solutions to this dilemma.

The recent UKWIR study CL10 on the effects of climate change on sewerage systems up to 2080, highlighted that we are likely to experience a greater number of events which cause flooding in the urban environment. Scotland could be one of the most affected areas. In reality, the current methods of drainage, by trying to contain all but extreme events within a piped system and constructed storage, are probably unsustainable.

Redevelopment over the next 80 years will replace a significant proportion of the urban environment. Through this redevelopment we have some opportunity to address some of these issues.

The key issue that needs resolving is to persuade developers and planners not to allow building in the paths taken by floodwater in the event of the piped system becoming overwhelmed. In other words, to reduce the risk of flooding, not just by reducing its likelihood, but also by reducing its consequence.

Redevelopment will also provide some opportunities to reduce flows in combined sewers through separation and through the implementation of SUDs.

What do we need to be able to deal with?

In designing improvements to urban sewer systems we need to be able to distinguish between, and evaluate, the following causes of flooding.

1. Run-off from the property itself
2. Escapes from public sewers
3. Backing up from watercourses
4. Overland flows which overwhelm inlets

Run-off from the property itself is usually a private issue and is adequately covered by building regulations. Escapes from public sewers are the responsibility of the authority which owns and maintains the sewers. Backing up from watercourses and rivers can be a complex issue but is now being addressed in the UK by the responsible bodies. However, overland flows which overwhelm inlets which is the case in extreme storms and may get more common with climate change, is not being ‘owned’ by anyone. The evidence of inadequate freeboard for buildings and no allowances for flood path routing is abundant.

Flood Path Mapping

Flood path mapping in urban areas has advanced significantly recently and the availability of digital terrain data makes it affordable in most circumstances. The extension of this into full two-dimensional modelling is also available at reasonable cost but here we lack knowledge of the storm profile and its coverage and the run-off process.

Design Criteria and Performance Standards for Urban Drainage Systems

We are sure that any of us who has been called on to explain the term ‘return frequency’ have had some difficulty in getting the message across. More recently we have been instructed to adopt higher design criteria to protect water companies’ customers from flooding. Water companies’ directors are therefore expecting higher performance standards. The problem is that extrapolation of our data and procedures is unsupported and we probably need to be more deterministic in our approach before we can take on extreme events.

We may also be asked to respond to the following:

What/How have you allowed for climate change?
What/How have you allowed for growth?
What/How have you allowed for maintenance?

All of these become more influential for extreme events.

For the empirical approaches of the past, we have relied on 'custom and practice' to bail us out which in turn has been based on the principle of 'affordability'. However, these criteria have an implied promise of performance which is commonly assumed to be 1:1, i.e. storm frequency is the same as flooding frequency (or design criteria is the same as the performance standard).

This is somewhat unusual. In other areas of engineering we might expect to see something like:

Design criteria = 'Factor of Safety' x Performance Standard.

It is easy to see that flooding frequency, though perhaps dominated by storm frequency, is influenced by a number of other rainfall dependent and independent factors. Examples are; catchment wetness, inlet condition, pipe roughness, manhole losses, siltation etc. We are also unclear as to what might be allowed for future loading to give a reasonable design life for investment, i.e. paved surface density and climate change for the year 2080 (say).

The design storm (profile, duration and return frequency) may also need some examination in this context, since it still has strong links (and certainly its origin) in the very dated 'rational method' which used a flat profile to generate peak sewer flows.

A good start might be to list all the possible influences on performance, however slight, and then tabulate the assumptions under the stage headings tabulated below.

Aspect/Topic	Model Build	Initial Verification	Final Verification	Design	FoS
Rainfall Input	Design Profile	Design Profile	Actual Events	Design profile at critical duration	1:1?
Base Flows	Peak as given	Peak as given	As surveyed	Peak as surveyed + growth	???
Antecedent Conditions	Average for design	Average for design	Actual	Average for design	???
Inlet Conditions	Standard density	Standard density	Modified as necessary	Standard density	???
Contributing Surfaces	As surveyed	As surveyed	As surveyed	As surveyed + new + creep	???
Siltation	No silt	No silt	As surveyed	Likely stable silt levels	???
Climate Change	No allowance	No allowance	No allowance	Size for 2080 ?	???

From this we may be able to deduce a factor of safety or at least be aware of the assumptions which are being made. We could produce some standard comments and assumptions which 'Design Generals' could amend as they best see the circumstances. We are not actually sure what we will find, perhaps more comfort than we are putting about, but something which will identify doubts and cover the risks. We will surely need to evaluate FoS's and bring the issues out into the open. A user note or COP could be produced in due course.

Using Design Rainfall

Models of urban drainage systems are becoming very sophisticated and now tend to cover large areas. However, the extent to which a single stationary design storm can be used to predict performance is more questionable as the plan area, or the catchment length or width increases. It is generally known that convective storms (which are regarded as the most intense) rarely cover more that 2 to 3 kms. Perception also questions the validity of a stationary design storm for long return periods and over long durations. These are known to be beyond the acknowledged research base and should only be used with care. We therefore have significant concerns about using existing information on design storms to represent extreme events.

One important aspect is that the areal reduction factor for point rainfall generated by a large model will reduce design rainfall intensities and this could result in the under-design of local sewers in sub-catchments and side branches.

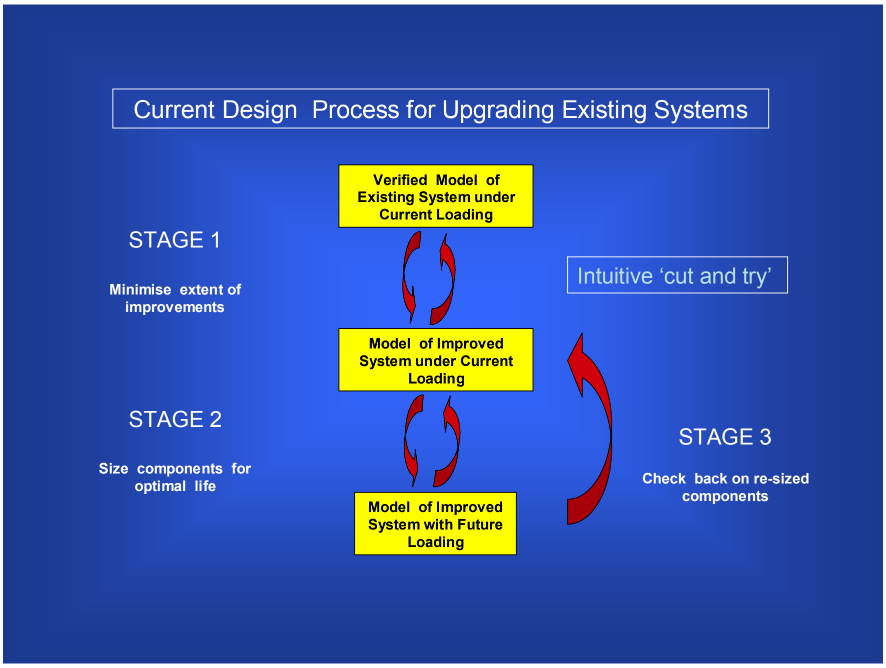
The current design approach employs the assumption that the return period of the storm is at least a first order indication of the return period of any flooding which is generated in simulations. There are however, a number of other variables which are peaked or averaged for ease of application.

In extreme events these averages may not be appropriate and the aggregation of peaks is unrealistic. For instance the assumptions that base flows set at 2xDWF will be maintained throughout a 240 min. storm or that the peak of the storm will coincide with peak base flows are therefore added factors of safety. Similarly, the practice of running a range of design storm durations and selecting the worst scenario for different parts of a system may be too conservative, since there must be a limit to the number of different duration 20 year (say) storms which can occur in a given period.

Simulation models tend to be 'worst case' and, in using the run-off process, losses from inlets to the system are not permitted. This means that high intensity extreme storms will be fully contained despite evidence that inlets have a finite capacity and both ponding and surface flows will occur in practice. These will need to be better accommodated in future modelling.

Modified Procedures for Sewer Improvements

The established design procedure for improvements to existing urban drainage systems which have signs of hydraulic inadequacy is illustrated below. It is a procedure which captures the detail of urban sewerage systems and relies on being able to simulate events realistically. This is crucial for model building and verification. Direct design methods used for entirely new systems are not suitable because the principal is to make best use of the existing system and to limit the extent and cost of improvements. This is done in Stage 1 by working on a simulation model of the existing system and introducing new elements into the model by 'intuitive cut and try', to eliminate areas of poor performance.



Current Design Process for Upgrading Existing Systems

STAGE 1

Minimise extent of improvements

Verified Model of Existing System under Current Loading

Intuitive ‘cut and try’

Model of Improved System under Current Loading

STAGE 2

Size components for optimal life

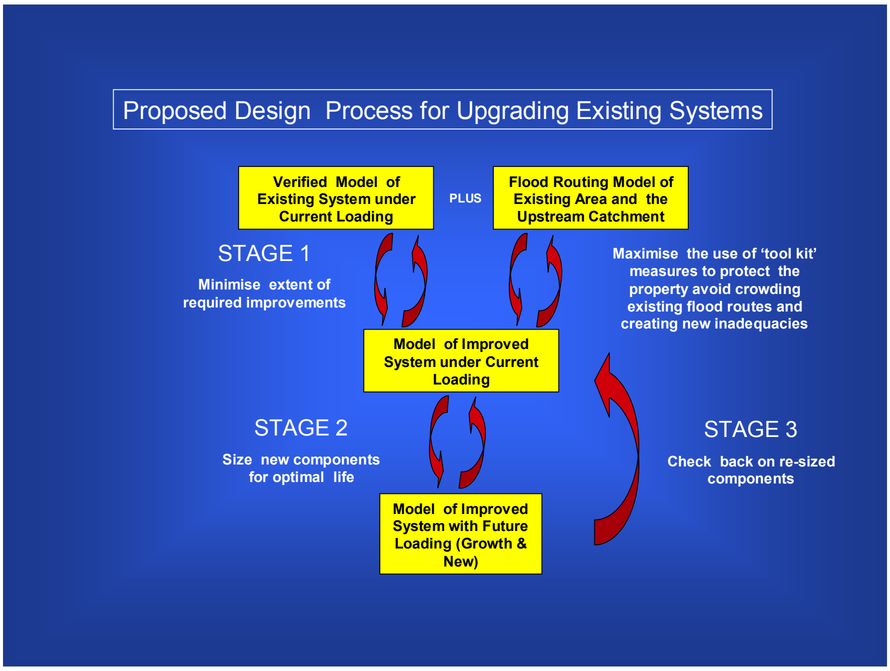
STAGE 3

Check back on re-sized components

Model of Improved System with Future Loading

In Stage 2 the model is upgraded to account for future growth and ‘new’ and the new components suggested in stage 1 can be modified (usually by size) to give a useful life. Consideration can also be given to making early investments to accommodate specific growth and future development. Stage 3 is a precautionary stage to check that components which are re-sized to accommodate growth do not themselves create new problems under existing loading.

We suggest that this basic procedure is retained and accepted by the industry as ‘best practice’ so that we can move forward. However, it does not incorporate specific provision for urban areas which are at a topographical disadvantage or for extreme event modelling as described earlier. We shall therefore need to extend it to incorporate flood routing for events which overwhelm formal drainage systems. There is still some way to go with integrated modelling but, as a start, we suggest the modification below is adopted by those authorities and Companies who are responsible for sewers.



Proposed Design Process for Upgrading Existing Systems

Verified Model of Existing System under Current Loading

PLUS

Flood Routing Model of Existing Area and the Upstream Catchment

STAGE 1

Minimise extent of required improvements

Maximise the use of ‘tool kit’ measures to protect the property avoid crowding existing flood routes and creating new inadequacies

Model of Improved System under Current Loading

STAGE 2

Size new components for optimal life

STAGE 3

Check back on re-sized components

Model of Improved System with Future Loading (Growth & New)

This includes a parallel Stage 1 which examines freeboard and flood routing and incorporates local ‘toolkit’ measures which can be used to reduce the vulnerability of properties affected by flooding. It will also identify areas where there is little or no freeboard to accommodate an extreme event.

Full Scale Flood Routing

Full scale flood routing is desirable but, as described earlier, techniques are in their infancy. We believe that these should become part of the Town Planning process and planners should have the brief to create adequate flood paths. They should at least be in a position to direct redevelopment and new development such that existing flood paths are preserved and no new ones created where freeboard is limited.

Research and Development Needs

We recognise that there are a number of elements for extreme event modelling which are used outside the current knowledge base. This needs to be addressed although current practice is not viewed as being wholly wrong. There is a proliferation of uncertainties which are accommodated by taking the worst case and, what we fear is that we would be over-designing rather than under-designing. However the extent of over-design could be substantial and costly. Research to address these uncertainties and to evaluate the more sensitive would be welcome. An analysis using the Performance Based Management technique (The Italian Flag) developed by Professor Jim Hall of Bristol University is recommended. However some knowledge gaps which are immediately evident are suggested below.

1. Knowledge and standardisation of extreme storms including return frequency, profile, coverage, speed and direction.
2. Knowledge and standardisation of dual storms (for emptying storage).
3. Knowledge of inlet capacities and their inclusion into modelling.
4. An updated run-off model tuned to the urban scene which should account adequately for antecedent conditions and tailing off after storms.
5. Flood routing and 2D models (incorporating SUDS).
6. Knowledge and standardisation of creep in impermeable surfaces.
7. Knowledge of future maintenance practices for highway drains and watercourses as well as sewers.

Answers to these gaps would help us to replace some of the question marks in the earlier table.

The question of return frequency could be addressed by utilising a long rainfall record but we would still need the detailed profiles and coverage and probably the speed and direction of the storm as well.

The extent to which paved surfaces are increased by private improvements such as patios and extensions is known as ‘creep’. There is very little documented knowledge on this but we know that we should be making a suitable allowance in our proposals.

Similarly, for future maintenance, it is common to assume nominal siltation for the future and this may not be a dangerous assumption but may not be realistic for the future. We feel that most engineers would by happier with a researched view which could be used in modelling.

Conclusions

Our conclusions are summarised as follows;

- Storm frequency is only one variable which contributes to flooding frequency.
- We need to evaluate and account for uncertainty in all other variables.
- We need detailed information about extreme rainfall events.
- We should standardise our design process to take account of topography and incorporate flood routing.
- We should actively seek to direct R & D so that the established design procedures can be advanced to accommodate climate change and extreme events.

Full scale integrated modelling of all urban drainage systems is perhaps some way off and would not be justified in all cases but, having identified potential flood routes with simpler terrain models, awareness will increase. This should pave the way for the adoption of formal flood routing proposals and provide for greater sustainability.

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