Modeling the Thatcham Flood of July 2007

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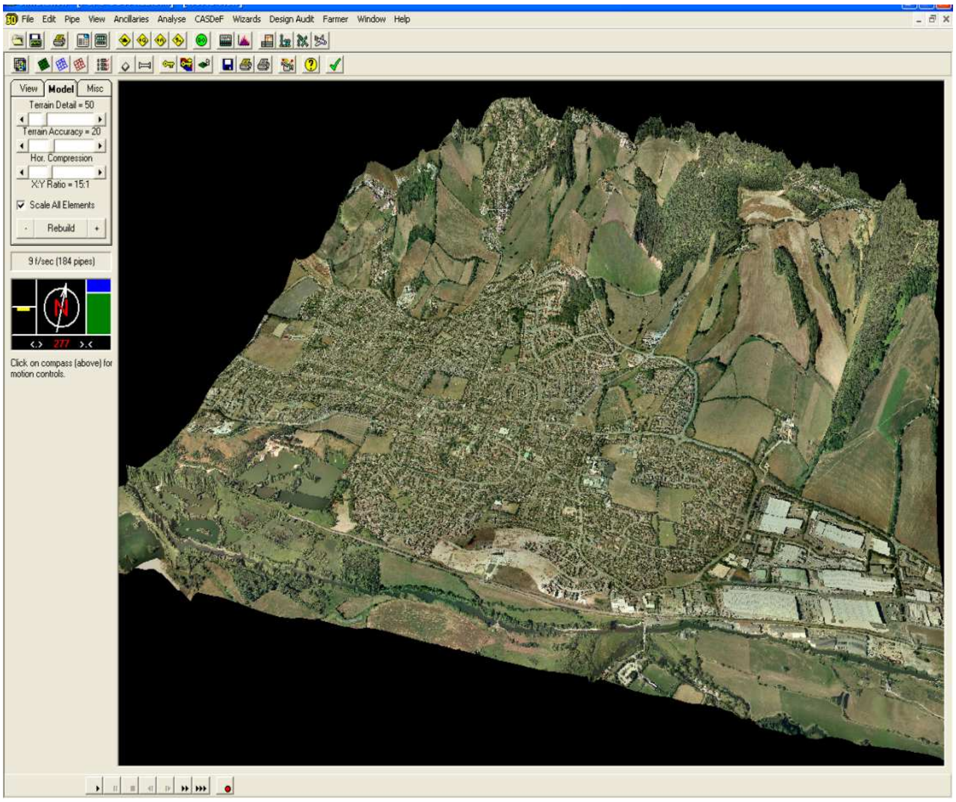

Fig 1: Thatcham Ground Model

Overview

On 20th July 2007, an unusual storm swept west across England along the approximate line of the M4 motorway. Thatcham, a town in Berkshire, was one of the worst affected. Many towns in England flooded that month from the Humber to Tewksbury. In fact there were 200 major floods worldwide in 2007 affecting 180 million people. Some of these floods were caused by rainfalls much more severe than those that crossed England but the amount of damage caused is related to whether the infrastructure can cope. In some parts of Australia, for example, the storm on 20th July would not be that unusual but in the UK such rainfall is a very extreme event.

The ability of the infrastructure to cope depends on climate history. A standard, statutory warning given to those who invest in the financial industry is that past performance is no guarantee of future trends. In drainage engineering we have assumed that past performance is a reliable guide and this assumption has been reasonable up to now.

Infrastructure, most of it built in the last 200 years, has been designed to cope with a climate that was assumed to be constant and predictable. If the climate changes then billions of pounds of investment made by several generations will be inadequate. If that change occurs within one generation it would not be possible to upgrade the infrastructure in time.

Where infrastructure in other countries has been designed to cope with very high rainfall rates gully design is very different to UK practice. The British Standard gully is very small when compared with the catch pits used in parts of Australia and the USA. It would not be possible to replace all UK gullies and their receiving pipes in one generation. A typical rate of long term investment in the UK would see our drainage network renewed in about 10 generations.

So it is not climate change that is the problem but the rate of climate change. The current predictions suggest that it will occur much faster than the normal rate of renewal of our infrastructure.

While the rainfall in England was not extreme by worldwide standards the damage it did to property in England ranked as the most expensive in the world in 2007.

55,000 properties were flooded, 7,000 people were rescued and 13 people died. It was the wettest summer since records began, with extreme (for England) rates of rainfall compressed into relatively short periods of time. The insurance claims were of the order of £3 billion pounds. This is not a reliable measure of the cost to the UK economy as much of the disruption, work lost and medical treatment is not claimed on insurance. It was the largest loss of essential services since World War II, with almost half a million people without mains water or electricity and transport networks failed. The disruption for many families put out of their homes lasted more than a year.

Fig 2: Record of properties flooded courtesy of West Berkshire District Council

A Different Type of Flood

There were also significant floods in 1998, 2000, 2002 and 2004 which have resulted in several billions of pounds of insurance claims. The government promises that at some point in the future it will spend a billion pounds a year on flood defenses but at the moment our investment in infrastructure is dwarfed by the flood damage.

2007 was the most expensive so far but there were other differences to previous floods. Many of the houses that flooded had not been identified as being at risk (most were classed as in PPS25 Zone 1). This was because the Environment Agency and others had been primarily interested in fluvial (river) and coastal flooding. Houses on high ground, miles from the coast flooded due to flash flooding caused by rapid sheet flows across rural and urban areas. It is known as pluvial flooding and of the 1,107 homes flooded in Thatcham, all were due to this flash flooding.

The Environment Agency has started producing maps of pluvial flooding. It is not the case, however, that pluvial flooding was being ignored by the industry prior to 2007 but it was thought (correctly) that predicting and estimating the damage caused by pluvial flooding was very difficult. This technology has developed rapidly and it is no longer difficult to analyze this phenomena but it has challenged the power and capacity of computers up until very recently.

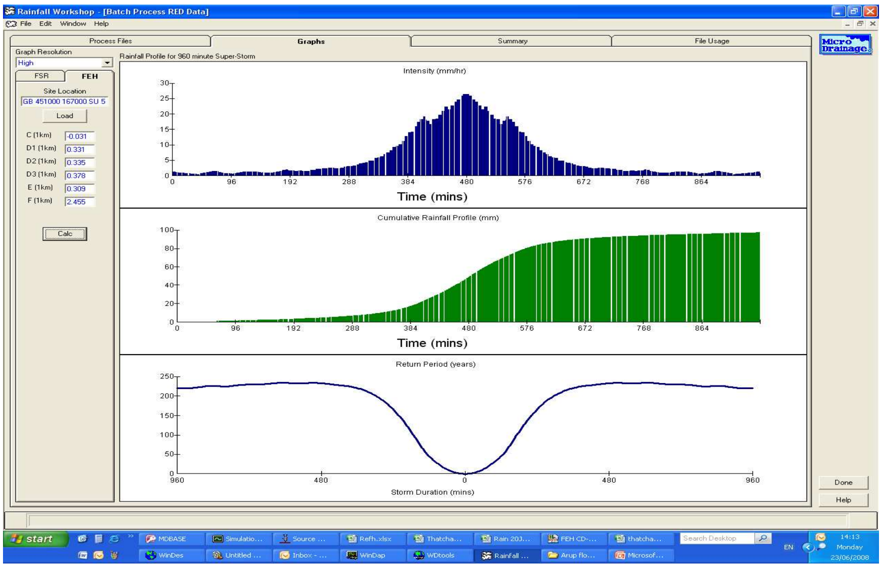

Fig 3: Return Period Analysis of Rainfall on 20th July 2007

Radical Rethink

These floods have spurred a radical rethink in the UK's approach to drainage design. The Pitt review addressed the organizational problems caused by water privatization and the decimation of Local Authority engineering departments over the last 20 years. The new Water Bill under consultation should go some way to solving these problems but will probably take another generation to take full effect.

The EA have published their first pluvial flood maps and Defra have published an approach to flood hazard analysis. Identifying the consequences of extreme rainfall on every new development has become good design practice through developing guides such as PPS25.

It will also change our approach to upgrading existing systems. If it is not possible to renew our underground drainage infrastructure before climate change takes its full effect then we must examine our over-ground drainage infrastructure. We must, through modifications to landscaping, building and road layout provide safe flood flow paths during extreme events.

Research and Development

The UK research establishment was aware of the pending challenge prior to 2007. The Flood Risk Management Research Consortium had applied itself to the problems of 2D overland flow analysis for several years and CIRIA published the first best practice manual for "Designing for Exceedance in Urban Drainage"in 2006. Also Water UK's "Sewers for Adoption, 5th edition", published in 2002, was the first water company specification that required engineers to examine the overland flow paths of extreme events.

The software development industry was also on the case prior to 2007. In fact the principles of 2D ADI models (used by most commercial 2d software) were first published in 1955 but it has not been possible until recently to use these methods on practical design cases as the analysis time could stretch into weeks.

A few years ago researchers at Imperial College, as part of FRMRC1, developed techniques to convert overland flows to 1d analysis. Flows that crisscrossed the urban landscape could be simplified into a network of channels and analyzed quickly. The rationale for this approach was to save computing time and capacity by avoiding full 2d sheet flow analysis. However the need to simplify the surface topography has been overtaken by the developing power of the software.

We have stressed that the engineer must understand the public's viewpoint. They do not care if a manhole is surcharged but they do know when their living room is flooded. The only way of determining that is through the integrated analysis of overland and underground flows.

We started on this path more than 10 years ago. It was first necessary to integrate ground modeling and 3d visualization into the software. The usability of these techniques was our prime concern. It was possible to produce 3d computer models 20 years ago but only after several weeks of work. It would also have been possible to survey a town like Thatcham and analyze the flows in 2d but this would have taken several years and not produced very usable results.

The day after Thatcham flooded our researchers and programming team downloaded a survey from the internet, built and analyzed the model in half a day.

Our challenge was to provide this very powerful technology for everyday engineering use and we had succeeded. However software development is a continuous journey of improvement and we decided to use Thatcham as a test case of the software's abilities and a development laboratory to identify future improvements.

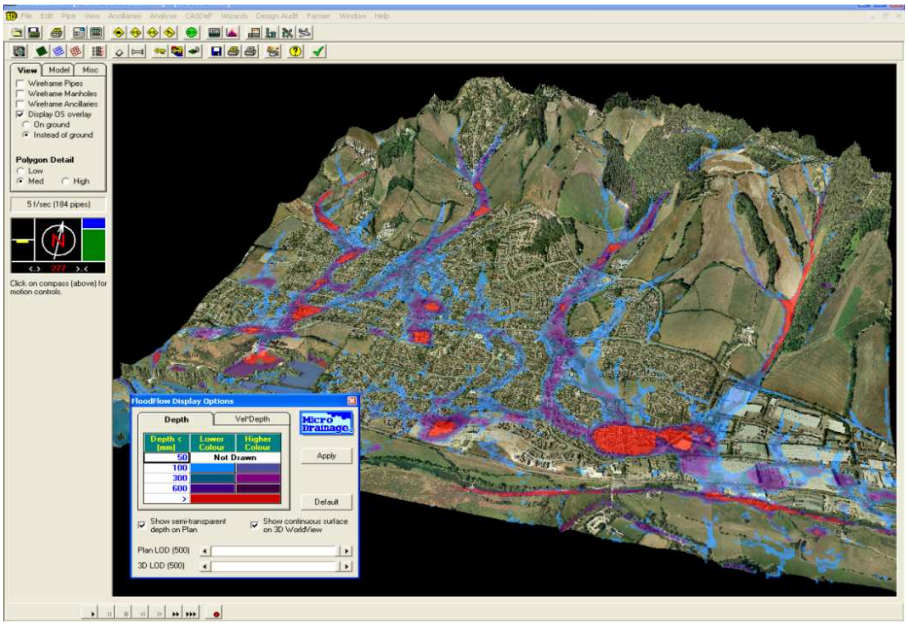

Fig 4: Modeled Flow Paths

The Perfect Storm: Case Study Objectives

The Met Office analysis of 20th July rainfall produced a return period of 169 years. It was also the wettest July for 150 years. This data alone does not fully explain the effect the storm had on Thatcham.

In the 30 days prior to the 20th July 113mm fell on Thatcham. On the morning of 20th July a further 100mm fell in 13 hours. 82mm fell in the last 6 hours of the storm providing a sustained high intensity rainfall on very wet ground. It was a perfect storm to maximize runoff and the worst 6 hour period produced a return period of 250 years (Figure 3).

- It was a unique opportunity to prove a computer model with data from an extreme event.
- We also wished to identify any difficulties modeling the event,
- improve the computer model and
- develop an efficient workflow.

Extreme Runoff Analysis

The UK does not have a national runoff equation that can deal with these extremes of rainfall. The "New Wallingford Equation" (now nearly 20 years old) overestimates runoff from events greater than 50mm. The Thatcham floods were due to a combination of rural runoff from above the town and urban runoff and a combined equation does not exist for this purpose. Research funding has been provided to update these equations but as yet no solution has been delivered.

We combined the REFH new rural runoff model with the "New Wallingford Runoff Model" to provide a unified approach to urban and rural runoff. This can be done by substituting the Napi and Pf terms with the pt and Pt variables calculated from the REFH model (see below).

Modified REFH formula for Urban Runoff.

$$PR = (IF * PIMP) + (100 - IF * PIMP) * \frac{pt}{Pt}$$

PR = percentage runoff
IF = effective impervious of urban area (poor=0.45, fair=0.6, good=0.75)

PIMP = percentage impervious (of whole catchment)

This equation is based on HR Wallingford's New Runoff Model

$$PR = (IF * PIMP) + (100 - IF * PIMP) * NAPI / PF$$

PF = Maximum soil moisture depth
NAPI = Net Antecedent Precipitation Index

PF and *NAPI* have been replaced by *Pt* (rainfall) and *pt* (net rainfall for rural catchment adjusted by Loss model).

Net rainfall, p_t, is measured in mm and its calculation is made up of a number of equations.

C_{max} (Maximum Soil Moisture Capacity, mm) is calculated from *BFIHOST* and *PROPWET*. C_{ini}, (Initial Soil Moisture Capacity, mm) also uses *BFIHOST* and *PROPWET*. The equation used for C_{ini} is dependent on the rainfall season, if design storms are to be used a correction factor is applied.

Starting with C_{ini}, the soil moisture storage, C_t, is calculated for each timestep throughout a storm by adding the rainfall (*Pt*). The net rainfall is then calculated from C_{max}, C_{ini}, and C_t. An alternative equation is used if $C_t = C_{max}$ at any point in the storm.

See - Revitalisation of the FSR/FEH Rainfall Runoff Model, Defra/EA, 2005.

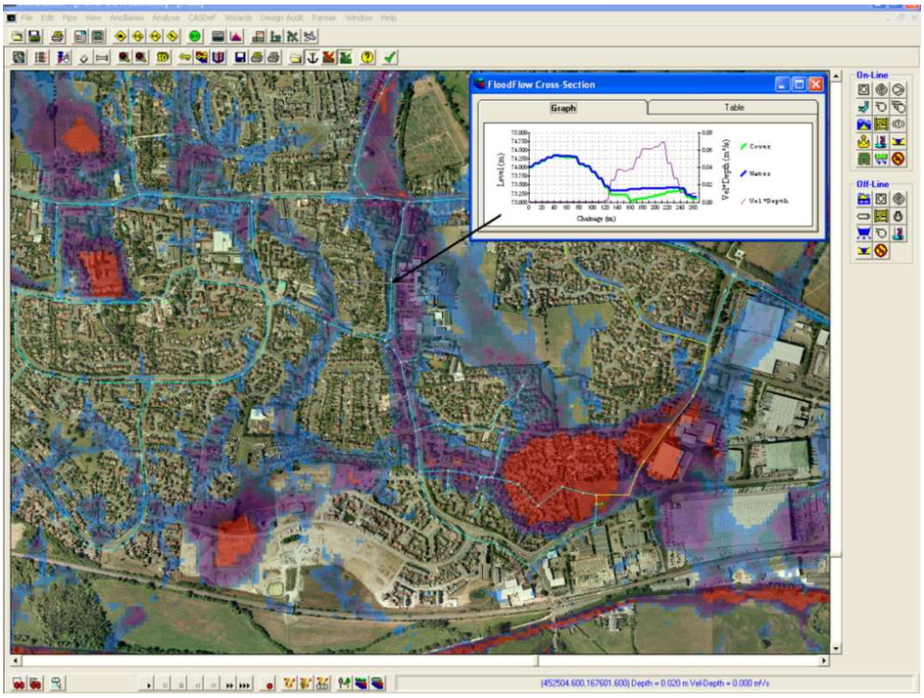

Fig 5: Dangerous flows past school on Stoney Lane

Large Data Sets

The next problem to overcome was the quantity of data needed to build a very detailed model. A survey on a 5m grid provides a reasonably detailed ground model over the catchment of 20 square kilometers. However the 800,000 levels could be thinned to 100,000 while maintaining an accuracy of +-100mm.

As the roads provide flow paths from north to south of the town it was preferable to input additional levels for kerb and camber definition. We used widely available road design software to provide additional road detail but we soon surpassed the limits of the computer and its operating system. A better approach was to detail the roads as 1d channels where initial 2d analysis confirmed the major flow paths. This also overcomes the tendency of 2d grids to blur the ground detail by averaging levels within the grid squares.

We anticipated that engineers would need to use very large data sets when analyzing combined 1d and 2d hydraulic analysis and we decided in 2005 to rewrite the suite for 64 bit computing and co-processors. This work was not published in 2007 but it will provide a significant improvement on the 32 bit technology that will be superseded over the next decade.

Fig 6: Cars being moved by floodwater down Stoney Lane

Analysis

The initial analysis identified:

- the flow paths,
- the sinks,
- and possible catchment divisions.

The flow paths were validated by reference to the insurance claims (see figures 2 & 4). The catchment divisions are useful to further reduce the quantity of data used in a single analysis run. We were then ready to add detail to the model where the main flow paths had been identified. 1d conduits were added to represent key:

- roads,
- ditches
- and natural swales.

We also ascertained that some of the flow paths were unacceptable. The velocity*depth rating on Stoney Lane, near the school was unacceptably high (figure 5) and indicated that cars would be washed downstream. Parents arriving to pick up children at the Kennet School experienced this on the day (figure 6). Again these photographs provided significant validation of the model (see also figures 7 and 4 for examples of flooding which corresponded to the 2d model predictions).

The next phase involved modeling critical sewers. It is very expensive to identify, survey and model all underground sewers so it is much more economic to use the 2d model to locate critical areas and include those sewers in the analysis. It is often believed that reliable data on existing networks is readily available but it is very unlikely to be the case.

It is possible to achieve the initial model in days and the more detailed model in a few weeks. A full drainage area study, including all underground sewers, would take longer and may not produce any additional relevant information.

Fig 7: Pond at Pipers Way is overwhelmed.

The initial findings were that:

- Stoney Lane provided an unsuitable overland flow path
- Pipers Way pond is likely to overload via overland paths
- The outlet to Pipers Way pond is the most critical sewer in Thatcham as it is the only eastern outfall from the town – the railway and canal dam the overland flows .

Part of the solution must include intercepting flows north of the town to reduce velocity*depth ratings and relieve Pipers Way pond.

We also checked whether these results could be achieved using standard design storms. Rainfall of significant duration and return period (6 hours and >100 year RP) provided similar results. Therefore the flooding at Thatcham is predictable with current technology.