

Entire Catchment Flood Modelling as a Planning Tool – River Trent Case Study

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ABSTRACT

Two-dimensional (2D) flood modelling techniques have been used on floodplain management investigations for some years now. Often these models would have only been applied to a section of an urban or rural catchment, and would not have covered the entire floodplain within the catchment of interest. With advances in computer hardware and modelling software; including the introduction of multiple 2D domain modelling, much larger flood models can be built and used. These advances in technology have meant that entire river catchments, including major and minor tributaries, can be modelled as part of a single overall model. This paper will discuss these software advances and their implications for flood modelling. Catchment flood models can be used to determine the impact of localised changes in land use or management on the entire river catchment and not just discrete sections of the waterway. Large scale developments; changes to planning schemes; changes to land management; flood mitigation works; river works, and the effects of climate change can all be assessed at this broad scale to determine the impacts not only from a flooding perspective, but also from a planning perspective. In the United Kingdom, the Environment Agency (EA) uses a strategic planning tool known as a Catchment Flood Management Plan (CFMP). The CFMP is used to identify broad policies for sustainable flood risk management that make sense in the context of the whole catchment, not just for localised townships or regions. The advantages of large catchment scale flood modelling as a planning tool will be investigated through a case study using the River Trent CFMP project. The River Trent CFMP project included the development of a flood model that covered an area of approximately 2,675 square kilometres and included the River Trent and seven of its major tributaries (including approximately 300 kilometres of waterway that were modelled as 1D elements).

INTRODUCTION

Continuing advances in computer hardware and the expanding capabilities of modelling software packages, including linked 2D/1D hydraulic models, and multiple 2D domains, have meant that hydraulic models are being applied over ever broadening spatial scales, with modellers continually pushing the boundaries of what these models can achieve. These advances have facilitated the development of catchment scale models that are of a geometric size and level of detail that would have been difficult to conceive only five years ago.

Computer hardware and Operating Systems (OS) developments, in particular, very large memory (VLM) architectures, with a processor and operating system that can use more than 4GB of RAM (the limit for systems using 32-bit addresses), greater processor speeds and cheaper storage solutions have begun to relieve some of the computational constraints previously placed on catchment scale modelling.

In regard to software developments, 2D/1D linking within hydraulic modelling packages has allowed complex pipe networks and river systems to be included into 2D floodplain models and has enabled the complex interaction of the river channel and floodplain flow to be modelled. Of particular importance is the introduction of multiple 2D domain capabilities. In certain software packages, including TUFLOW,

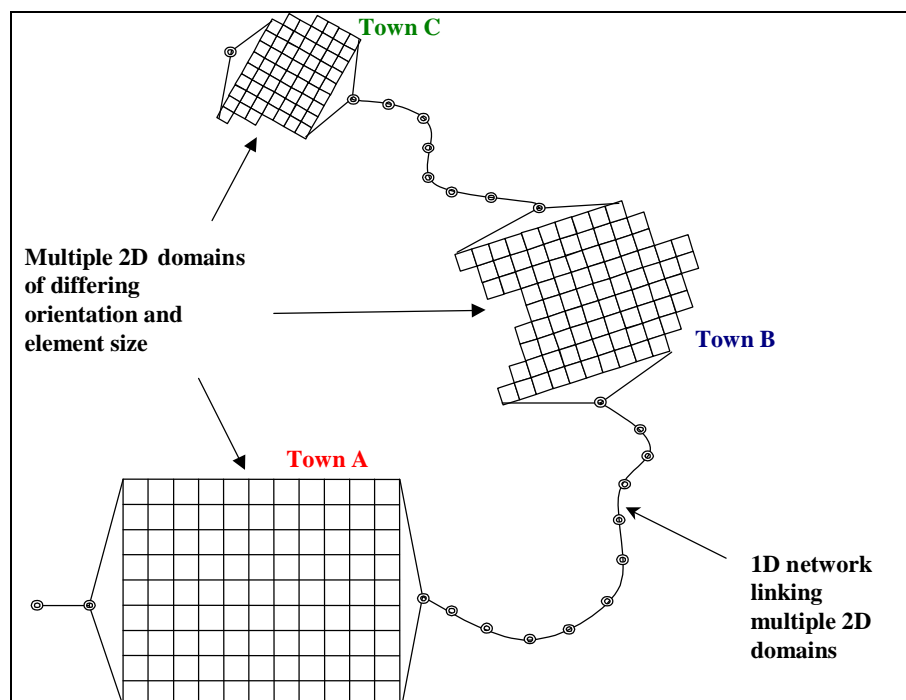
additional, finer resolution 2D domains can be nested within a broader, large resolution 2D domain. The ability to vary grid sizes throughout a model has meant that much larger models can be constructed, with coarser grid resolutions being adopted in less critical regions, and finer resolution grids being applied through the areas of interest. When combined with a 2D/1D modelling approach it provides a very powerful methodology for developing large-scale flood models.

The ability of TUFLOW to dynamically link multiple 2D domains of varying grid sizes and orientations, combined with 2D/1D linking, has meant that it is ideally suited for use when developing large catchment flood models. The following sections provide the basic theory of 2D-2D linking within TUFLOW, the principles of CFMPs and details of a recent model that has been developed as part of the River Trent Catchment Flood Management Plan in the UK.

2D-2D LINKING: THE THEORY

The TUFLOW flood and tide simulation software (www.TUFLOW.com) was used for the River Trent modelling.

TUFLOW has the ability to dynamically link any number of 2D domains, each of differing grid size and orientation (see Figure 1 and Figure 2). It has been extensively tested and proven on numerous studies throughout Australia and overseas (BMT WBM 2005).



(Gillam 2005)

Figure 1: Linking Individual 2D Domains with a 1D Network

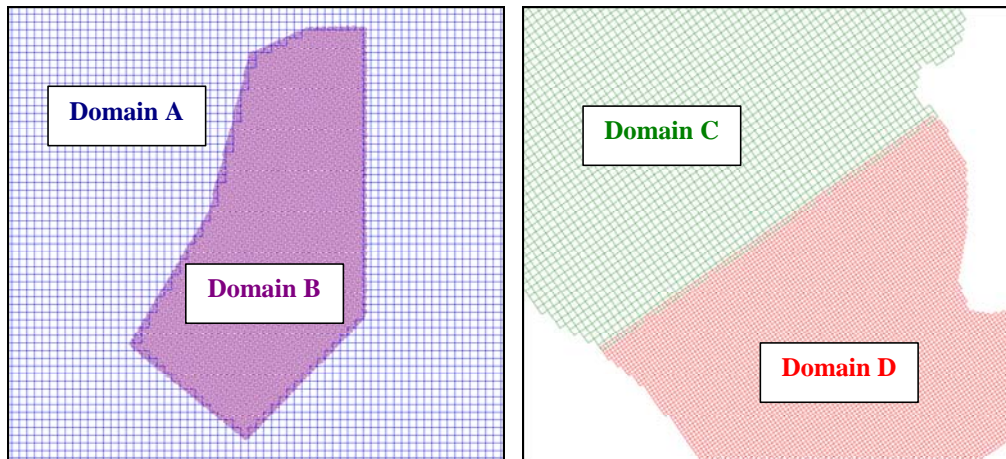


Figure 2: Examples of Embedding and Linking Multiple 2D Domains

Individual 2D domains are easily stitched together using the 2D-2D link feature. Floodwaters move between individual model domains via the 2D-2D link and a series of water level control points that can be automatically generated and/or controlled by the user. The link dynamically exchanges water between the two 2D domains via the water level control points every half timestep. Across the 2D-2D link, momentum is preserved provided the topography is consistent between the two 2D domains, and there are no rapid changes in flow direction along the link alignment (BMT WBM 2007). This is illustrated in Figures 3 and 4 by the preservation of the velocity fields and water surface slope between individual domains (BMT WBM 2005)

Within TUFLOW there is no limit to the number of 2D domains within a model and each domain still has the ability to be dynamically linked to multiple 1D domains of river systems, pipe networks, etc. The complexity and detail of a multiple 2D domain model is only limited by the capabilities of the computer and its operating system.

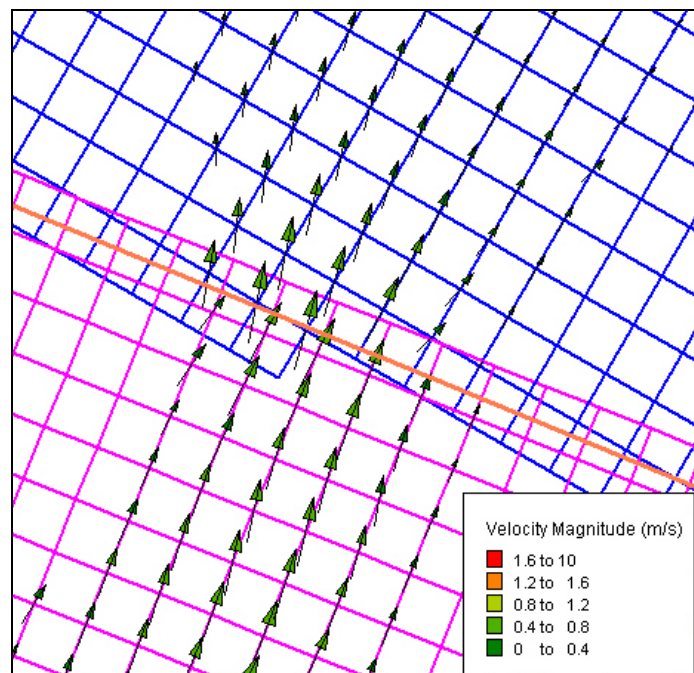


Figure 3: Preservation of velocity fields across multiple 2d domains

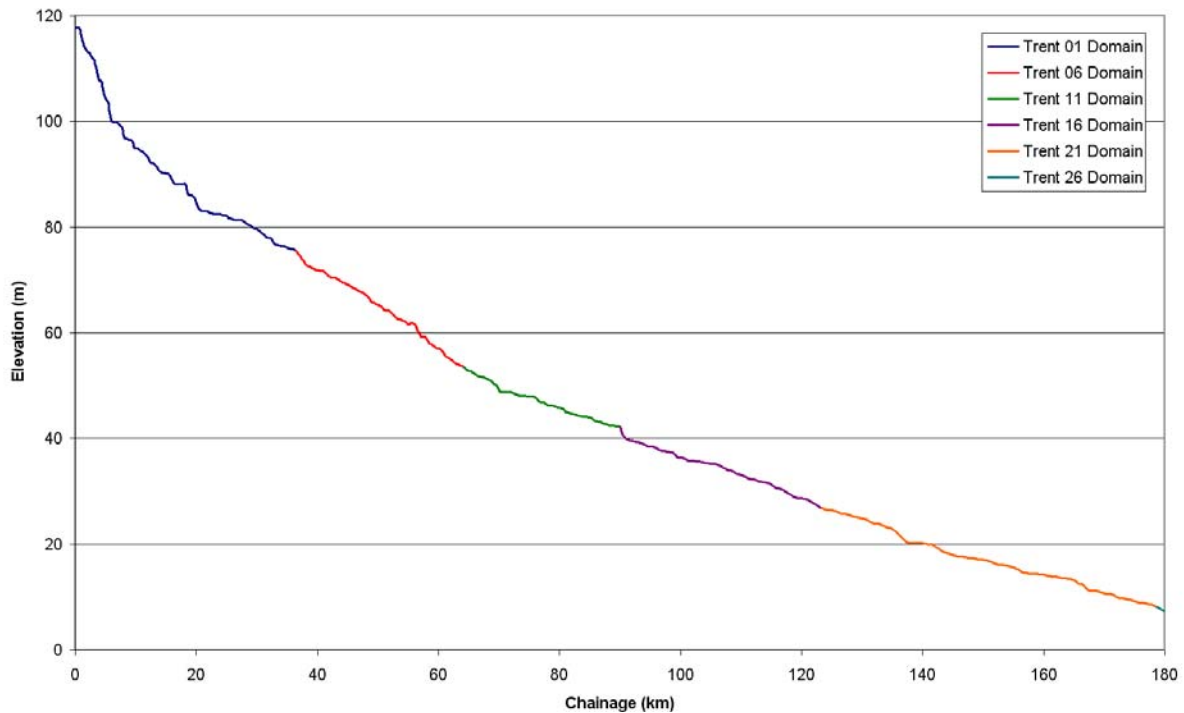


Figure 4: Preservation of water surface slope across multiple 2d domains

CATCHMENT FLOOD MANAGEMENT PLANS: THE PRINCIPLES

Catchment Flood Management Plans (CFMPs) support River Basin Management Plans under the EU Water Frameworks Directive (Figure 5). CFMPs are a strategic tool used by the Environment Agency, the regulatory body for flooding in England and Wales, to identify flood risks within a given catchment and look to determine policy that will manage those risks for the long term (50-100 year time horizon).

“A Catchment Flood Management Plan is a high-level strategic planning tool through which the Environment Agency will seek to work with other key decision-makers within a river catchment to identify and agree policies for sustainable flood risk management”

(Environment Agency, 2004)

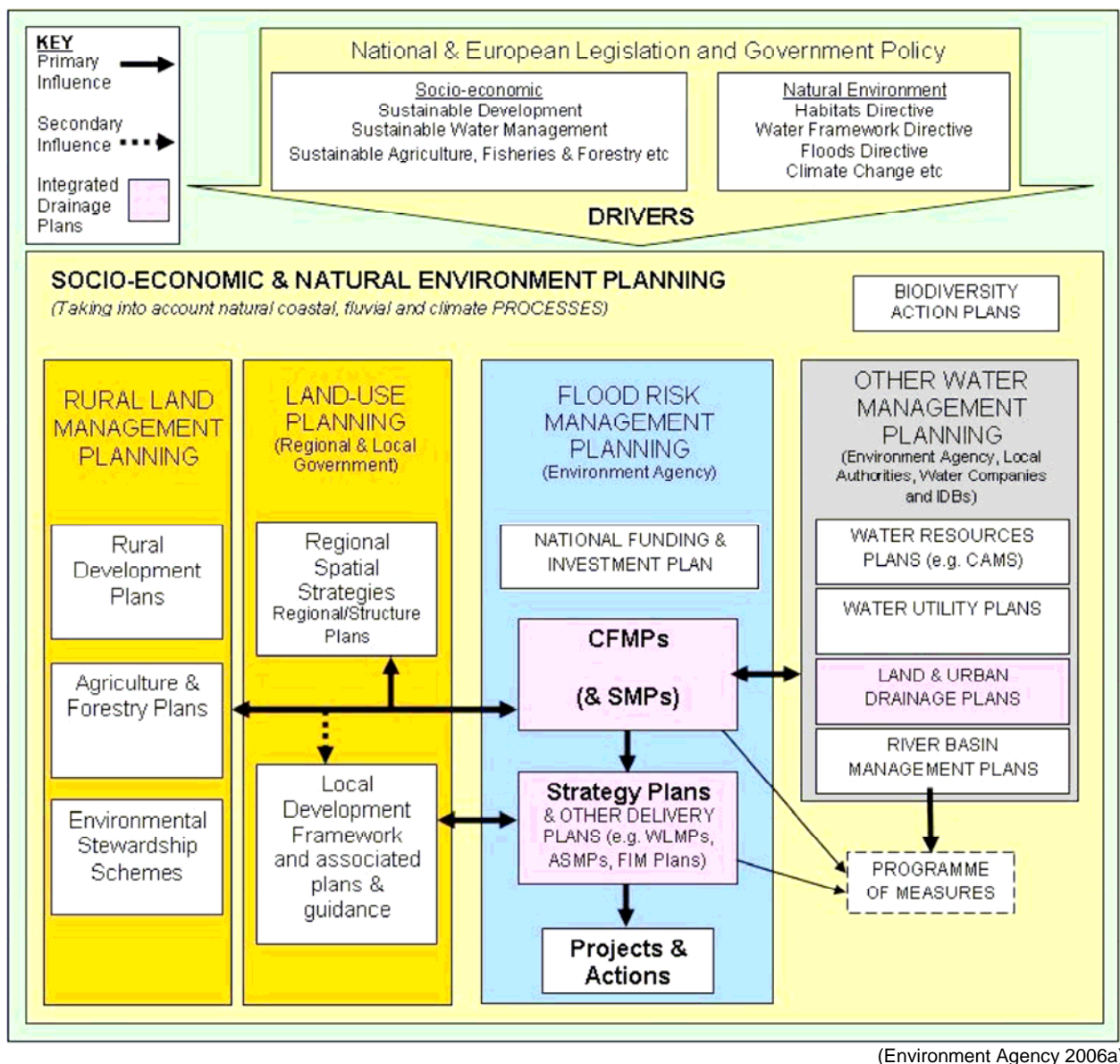


Figure 5: Context of CFMP within wider planning framework

The undertaking of a CFMP involves a process of flood risk assessment to identify the factors that are causing flood risks within a river catchment and how potential changes within the catchment itself will impact on the probability and consequence of flood events. The CFMP can be used to determine the impact of various changes to a catchment, including climate change, land use change and the use of flood defences (levees), and their subsequent impact on flooding behaviour.

The aims of the CFMP are designed to set the overarching direction of flood risk management within the specific catchment. Whilst these aims may not be achievable during the life of the CFMP, they provide targets that stakeholders can work towards. Specific aims of the CFMP include:

- *The reduction of risk of flooding and harm to people, the natural, historic and built environment caused by flooding;*
- *To maximise opportunities to work with the natural process and to deliver multiple benefits from flood risk management, and make an effective contribution to sustainable development;*

- *To support implementation EU directives, the delivery of Government and other stakeholder policies and targets, and the Agency's Environmental Vision;*
- *To promote sustainable flood risk management; and*
- *To inform and support planning policies, statutory land use plans and implementation of the Water Framework Directive.*

Environment Agency (2004)

For these aims to be achieved, a comprehensive understanding of the hydrologic and hydraulic regimes within the given catchment is required. To help with this understanding, hydraulic models are often utilised. These models are considered to be 'broad-scale' in that limited data, time and budgets are balanced in order to achieve the most representative model possible. It is this model that is utilised to develop the key objective from a CFMP: the development of complementary policies for long-term management of flood risk within the catchment that take into account the likely impacts of changes in climate, the effects of land use and land management, deliver multiple benefits and contribute towards sustainable development.

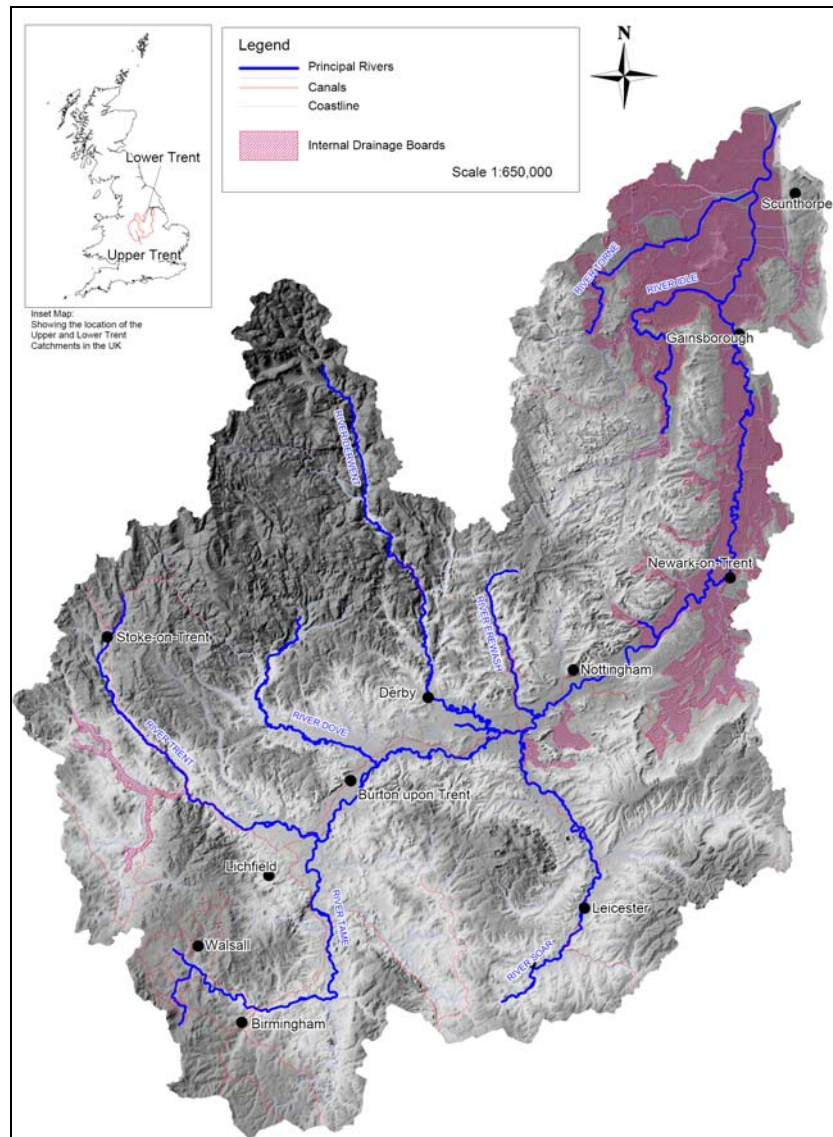
CASE STUDY: THE RIVER TRENT CFMP

Background

The River Trent catchment is the third largest river catchment in the United Kingdom. It covers an area of 10,452 square kilometres and is located within the Midlands (Figure 6). Traditionally, the River Trent was used as the line that separated Northern England from Southern England. The hydraulic model included the River Trent, along with 11 of its main tributaries and part of the Humber Estuary, where the River Trent discharges. The principle urban areas of the catchment include the West Midlands conurbation, Stoke-on-Trent, Derby, Leicester and Nottingham.

Key structures were incorporated into the model. The structures included: Cromwell Weir (the upstream tidal extent of the River Trent, located downstream of Newark-on-Trent); major flow obstructions including the numerous motorway and rail crossings; and the extensive network of defence embankment structures that exist not only along the River Trent System, but also its tributaries.

The range of modelled events included both tidal (to gauge the impact of the Humber Estuary) and fluvial. Joint probability analysis was not undertaken as part of the CFMP. The scenarios that were examined included climate change, sea level rise, land use change and urban growth.



Environment Agency (2006b)

Figure 6: River Trent CFMP Catchment Extent and Main Rivers

Challenges

The development of a catchment scale hydraulic model presented several challenges, which broadly fell into the categories of data requirements, computational constraints and modelling methodology.

Firstly, a thorough understanding of the data requirements for a CFMP is essential. Model datasets should be assessed at the outset to define the quality and limitations in order to determine whether they are fit for purpose. Close co-ordination and communication with various organisations within the catchment as well as the Environment Agency, reduced the need for data acquisition that is expensive and time consuming. As a CFMP is a long term document, the corresponding model data should be archived with sufficient metadata to determine, in the future, whether it remains suitable for the desired purpose. Furthermore, during the lifetime of the project some datasets are likely to become superseded. For instance, at the commencement of the River Trent CFMP the topographic data available was a mixture of SAR and LiDAR. Ubiquitous SAR coverage for the catchment was provided, whereas LiDAR was only available for comparatively small urbanised areas. The two datasets were often discordant, which resulted in artificial barriers within the underlying topography. Furthermore, due to the size of the SAR data, it was provided in

tiles that correspond to a numeric grid that covers the entire country. In some areas there were additional edge-matching issues. Despite the SAR being a less accurate dataset it was considered fit for the purpose in the context of a CFMP and favoured over the LiDAR because of its coverage. Subsequently, LiDAR coverage is now complete for the UK.

Grid sizes, domain extents and orientations were all optimised to ensure that the minimum amount of computing power was required to run the final TUFLOW hydraulic model. Despite this, TUFLOW needed to be recompiled to allow large RAM allocations to take place, and computers running the model had to have their start-up procedures changed to allow individual programs access to additional RAM, usually reserved for WINDOWS applications. Despite these efforts, approximately 1.8 Gigabytes of RAM was required to enable the model to load all the required data and then to run the simulation. When run on a DELL Server PE2900 Intel Xeon CPU, 2.66GHz, the entire catchment simulation required 10.1 days to complete a 200hrs model run.

Several advantages came from subdividing the whole model domain into 25 separate sub-domains. These included:

- Applying variable 2D grid resolutions along the length of the watercourses to minimise model size;
- Ease of model development by error trapping within particular sub-domains to isolate instabilities;
- Flexibility in truncating the model to a specific area of interest that can be run separately (e.g., a fluvial or tidal model); and
- Updating relevant sub-domains as new data is made available.

Wherever 1D channel survey data was available it was incorporated in the model. Elsewhere, the watercourse was modelled in 2D and represented, where possible, by at least 2 grid cells. All the cross-sections within the 1D component of the model were sourced from various ISIS (a 1D hydraulic modelling package used extensively in the UK) models that had been completed by numerous consultants and covering different sections of the waterway. Matching cross sections into the underlying topography taken from the SAR data was a further challenge. 1D cross-sections were trimmed according to the grid resolution and the number of cells nulled by the embedded 1D channel, to prevent any discrepancy in conveyance.

Problems arose at the lower reaches of the main tributaries where the larger grid size applied to the main River Trent could not adequately represent the tributary channels in 2D, or the 1D channel survey did not extend to the width of the nulled 2D domain (Figure 7). To prevent the tributary channels dictating the grid size in the Trent sub-domains, which would cause a significant increase in the memory allocation and hence increase run times, additional small sub-domains were applied along the riparian corridor in the lower reaches of the tributary channels, minimising the impact of increasing the grid resolution.

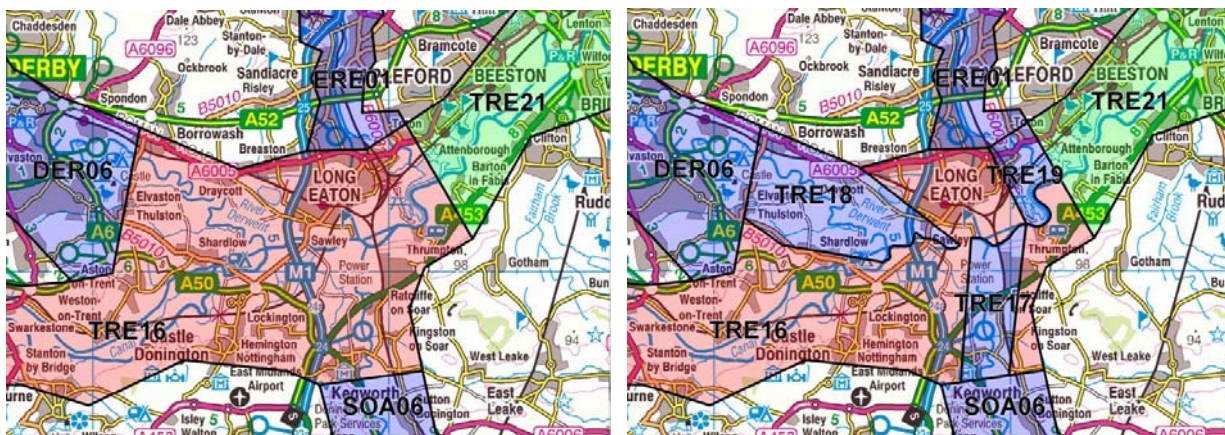


Figure 7: (Left) Initial sub-domains, DER06/SOA06/ERE06 (20m) TRE16 (60m), TRE21 (80m). (Right) Addition of sub-domains TRE17/18/19 (20m) along the lower reaches of the Trent tributaries.

Outcomes

An obvious advantage of a catchment scale model is its ability to assess the impact of the timing of tributary inflow across the catchment. This was particularly important in the River Trent Catchment where several major tributaries (River Derwent, Soar, Erewash and Leen) enter the River Trent in close proximity, in an area known as the Trent Valley Washlands (Figure 7). This reach is also highly urbanised with Derby, Castle Donnington, Long Eaton, Beeston, Clifton, West Bridgford and Nottingham all close to the banks of the River Trent. The Trent Valley Washlands are also shown in Figure 8 along with the preliminary base line mapping for the 100-year event over the entire River Trent catchment. A catchment scale model can be used, for instance, to assess the impact of coincident peak inflows in this area and how this may be ameliorated by changing land use policies in the upland regions of the associated tributaries.

Further advantages and disadvantages of whole of catchment modelling include:

Advantages

- The effects of a rainfall event can be modelled as it 'moves' across a catchment
- Can be used to gauge whole of catchment response to localised changes

Disadvantages

- Models are data intensive due to their scale
- Model run times can be considered excessive

The development of a catchment scale flood model has meant that the model itself can be used for more than just determining flood extent, flood impact and flood damages. It can be used to gauge the impact of planning policy, land use change and changing natural conditions on the entire catchment as a whole, not just at discrete section of it. When used in this way, catchment flood modelling can be a very powerful tool.

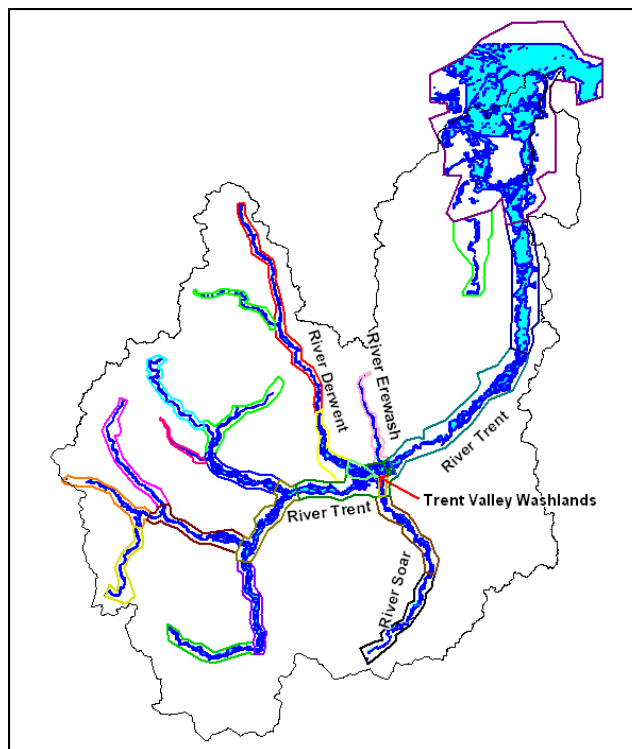


Figure 8: Preliminary Base Line Mapping

CONCLUSIONS

Catchment scale modelling can be used for much more than simply determining 100 year flood extents. As described throughout this paper, the application of these models can inform the planning and land management process and policies. However, these models, by their nature, are large and will be data, computer and time intensive. This type of model may not be viable for many catchments, but when they are used, their benefits extend beyond the simple declaration of flood extents, floodways and land subject to inundation.

ACKNOWLEDGMENTS

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