Integrated Urban Drainage Modelling Guide

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CIWEM Chartered Institution of Water and Environmental Management

Contents

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Integrated Urban Drainage Modelling Guide

Introduction

1. INTRODUCTION

1.1 Purpose of the Integrated Urban Drainage Modelling Guide

The main interest in Integrated Urban Drainage modelling will be identifying and managing flood risk, which will include the response to heavy rainfall, interaction with tidal water and the consequences of blockages and failures.

This is the second edition of the Chartered Institution of Water and Environmental Management (CIWEM) Urban Drainage Group (UDG) Integrated Urban Drainage Modelling Guide, superseding the first version published in 2009.

The Integrated Urban Drainage Modelling Guide (**the Guide**) is intended to illustrate good practice in relation to the holistic or integrated hydraulic modelling of the various different components of urban drainage systems. The Guide can be referred to in contract documents but it is not intended to be used directly as a specification for modelling. It will however, provide suggestions for writing a suitable specification, if required.

The Guide is intended to accompany the Code of Practice for Hydraulic Modelling of Urban Drainage Systems (**CoP**[1]) published by the UDG of the CIWEM.

The primary benefit of this Guide will be to improve the consistency and quality of integrated modelling work for both client and supplier partners. It provides guidance on the approaches that are proportionate to the scale and complexity of the flooding issues considered. The Guide will also help with the technical development of individuals working in this specialist area. It is aimed at all Integrated Urban Drainage practitioners, across a range of expertise and experience. It is, however, not a substitute for this expertise and the appropriate level of training.

Although there is a section on software, the Guide is not software specific, but aims to encompass the more frequently used types of software. Some examples may use a particular software product.

1.2 Terminology and language

The Guide uses language and terms predominantly related to the United Kingdom and Ireland, although the practices outlined will be relevant for use internationally. It includes a glossary of terms to help the user who is not familiar with them.

In the Guide, the term 'pluvial' is used to describe flow that is the direct result of rainfall on a surface. In other documents and references, these flows are sometimes referred to as 'surface water', but for consistency we have used the term 'pluvial' throughout the Guide.

1.3 Target audience

The target audience is urban drainage practitioners who are actively involved in commissioning, developing, using and maintaining hydraulic models in the urban environment. This typically includes practitioners involved in sewer, pluvial and fluvial modelling.

In the **CoP**[1] reference is made to the terms '*Commissioning Body*' (that commissions the modelling) and the '*Modelling Team*' (that carries out the modelling work). In relation to integrated urban drainage modelling there are likely to be a number of Commissioning Bodies, each of which had previously commissioned or are intending to commission a hydraulic model for a specific purpose. In relation to integrated modelling, it is more appropriate to use the term '*Project Steering Group*' (PSG), which would typically comprise a range of Partners. These might be Government Departments, Environmental Regulators, Water & Sewerage Companies and/or Local Authorities.

For some IUD modelling projects, it may be that a single organisation is financing the study in liaison with other organisations. In these situations, a formal PSG may not be required, although one is recommended as experience has shown that this is the most effective way of achieving the general principles of consulting with stakeholders.

The term Modelling Team is retained but it may contain individuals from a range of different companies. In the Guide the term 'Modeller' is used for ease of reference but may refer to the team or an individual from the team.

1.4 Stakeholders and Partners

The Guide distinguishes between 'Partners' and 'Stakeholders'.

The term 'Partner' would be given to those organisations who contribute to or co-fund the project and may include Government Departments, Regulators, Water & Sewerage Companies (WaSC), Lead Local Flood Authorities (LLFA), Local Authorities and Internal Drainage Boards (IDB).

A number of stakeholders may have an interest in urban drainage modelling projects. This may include the needs and outcomes of the project, providing data to the project or for a potential future use of the modelling tools developed.

It is necessary to understand how different stakeholders are involved and interact as part of an urban drainage project and how the needs of customers are considered. This could include the impact on the public as the ultimate customers of urban drainage projects.

The '*Stakeholders*' may include (but are not restricted to):

- **Internal Stakeholders** – Any internal department with a responsibility for an aspect of a project (for example, Asset Planners, Operations Teams). Internal stakeholders could be from Water Companies, Regulators, Lead Local Flood Authorities, and/or Internal Drainage Boards
- **External Stakeholders** – External stakeholders could be from Government, Regulators, Water Companies, Lead Local Flood Authorities, Local Authorities, Internal Drainage Boards
- **Customers** – Could consider all aspects of potential customer interaction through Consumer Organisations (for example, Consumer Council for Water), Local Customer Action Groups, Domestic and Commercial Customers
- **Pressure Groups**

1.5 Project Steering Group (PSG)

Due to the multi-stakeholder nature of IUD projects, in most cases it will be necessary to have a Project Steering Group to ensure that all relevant parties are represented. It is envisaged that the PSG would include all of the Partners, with Stakeholders co-opted selectively and as considered appropriate. Good practice is for the PSG to develop a Stakeholder Management Plan, identifying systematically the relative importance of stakeholders to the project, and setting out a plan of action to communicate with, engage with and influence stakeholders. For larger and more complex projects it may be worthwhile considering using a RACI format and for each stage of the project where stakeholders are classified into four categories: *Responsible, Accountable, Consulted* or *Informed*.

1.6 Definition of Integrated Urban Drainage

Integrated Urban Drainage (IUD) is an approach to planning or managing an urban drainage system, which leads to an understanding of how different physical components interact and how different organisations must work together for it to operate effectively.

In its widest meaning, IUD considers all the aspects of an urban drainage system that contribute to water quality and flooding problems (for example, diffuse pollution, storm overflows, pumping stations (wastewater and storm water), sewage treatment works (STWs) and receiving water impacts). Whilst water quality issues are important, they are beyond the scope of this Guide, which concentrates on hydraulic modelling and improving understanding of urban flood risk. Surface flooding may originate from any part of the urban drainage system; and this Guide focuses on that flooding caused by interactions between different drainage components.

Although applicable across a range of situations, IUD modelling has a particular role in supporting the development of Surface Water Management Plans (SWMP) and Drainage and Wastewater Management Plans (DWMP).

Other applications for an IUD modelling approach include:

- Mapping flood risk
- Improved understanding of the impact of watercourse interactions on sewer system performance and the operation of storm overflows, pumping stations and other sewer assets
- Detailed analysis of the cause, effect and remedy of sewer flooding
- Strategic Flood Risk Assessments
- Detailed Flood Risk Assessments
- Development of emergency response plans
- Climate change adaptation and carbon reduction strategies (reduced energy use)
- Development of integrated flood risk plans for essential infrastructure and utility assets
- Improved understanding of the impact of tidal waters' (coastal and estuary) interactions on sewer system performance and the operation of storm overflows, pumping stations, sea outfalls and other sewer assets
- Identifying and assessing the consequences of blockages occurring in drainage networks

- Business case appraisals of potential capital expenditure schemes and identifying partnership funding opportunities

The modelling of flood risk due to groundwater emergence is beyond the scope of this Guide. However, there are many instances of interaction between groundwater (which may vary seasonally) and urban drainage systems, and this is considered in this Guide.

1.7 Types of urban drainage

There are two general types (or levels) of Urban Drainage System, and these generally differ in terms of hydraulic and flooding impact scale.

- **Minor Drainage Systems** – these are the underground piped drainage systems that may include individual building drains but are more typically sewers, culverted watercourses and highway drains

- **Major Drainage Systems** – these are the above ground drainage systems. These would include watercourses and rivers which form the principal drainage pathways for catchments and the overland flow paths on river flood plains and the urban environment. These are broadly classified into two types: within channel flows or overland flow paths. As a result, interactions are likely between different components of the major system.

Which of these broad types are likely to influence the aim of the study could be considered at an early stage. The type of drainage system, and the nature of the dominant or main drainage system in the flooding mechanism being considered, is one of the main factors influencing the choice of modelling approach and the relative levels of detail. **Section A2 – Modelling Concept** provides examples of the four main types of project most likely to be encountered. This section is intended to guide project teams (the PSG) in deciding on the best and most appropriate approach to take.

Attempts have been made throughout this Guide to break down the barriers between the traditional disciplines of sewer, river and surface flow modelling by discussing the modelling approaches and issues in the context of minor and major drainage systems. This approach follows many international contexts and also that followed by the Construction Industry Research and Information Association's (CIRIA's) **C635**[16].

1.8 What is IUD modelling?

The traditional approach to all hydraulic modelling has been to model a single system (for example sewer, river) with some form of boundary condition where there is any form of interaction between systems. When the interaction between systems is dynamic, there is frequently a need to model both systems in an interactive manner – this is where IUD modelling is required.

There are many ways in which different urban drainage systems interact with one another. The interactions may be relatively straightforward and represented by simple modelling or within a single modelling environment. More complex interactions, involving different scales of modelling complexity for the different systems, may require a number of modelling packages to represent the different components. In some cases, these models may need to be interlinked.

IUD Modelling is the term applied to modelling more than one system type and its interactions with other systems. It should seek to improve the understanding of current and future flood mechanisms and risk, and to help develop options to mitigate urban flood risk. For example, an IUD modelling study might consider:

- Sewer – river interaction (minor – major interaction)
- Pluvial – surface water sewer flooding (major – minor interaction)
- Overland flows – sewer – river interaction (major – minor – major interaction)
- Groundwater – sewer interactions (major – minor interaction)
- Sewer – tidal interaction (minor – major interaction)

This Guide focuses on the most common of these interactions which require modelling; namely the sewer, overland, river and tidal interactions. Less consideration will be given to groundwater interactions, although this will be commented on, as there may be a need to represent this in some cases.

IUD modelling should ideally be able to replicate historical flood events. It could then be used to gain a better understanding of past flooding related to the interactions between different components of the urban system. Once an IUD model is able to replicate a known flood event, there is greater confidence in the modelling tools and processes adopted to represent this flooding.

IUD modelling must give a better and more accurate representation of the problem than the individual component models, or there is no advantage in integrating the models.

1.9 Why undertake IUD modelling?

IUD modelling is likely to be more technically complex and time consuming compared with traditional drainage modelling methods. As such, the various Partners, Stakeholders and Modellers need to consider why IUD modelling may be required for each catchment or study. Typically, IUD modelling may be required in order to:

- understand complex interactions between different components of the urban drainage systems
- identify and understand multiple sources of flooding
- map areas at risk of multiple sources of flooding
- calculate damages from flooding
- identify the potential impacts on other drainage systems by interventions undertaken on one drainage system
- identify, evaluate and design integrated solutions (across minor and major systems)
- determine relative contributions from different Partners and Stakeholders to fulfil their obligations

The additional complexity and cost of IUD modelling when compared with more traditional modelling should be evaluated before committing to IUD modelling. In many cases where the problem and solution are readily apparent, more traditional approaches will be adequate. IUD modelling is not always required.

1.10 Types of IUD modelling

Historically, different aspects of the urban drainage system have been treated as independent areas of research and practice. They have often been developed in isolation from each other by different teams of hydraulic experts. Whilst the base hydraulic equations governing these models (for example, the St Venant equations, Manning's equation) show some commonality, the modelling methods and software developed can look and feel very different. Different key parameters have evolved in the modelling tools used to represent each hydraulic environment that dictate the choice of modelling approach used.

Many hydraulic simulation programs have evolved to a stage beyond modelling just one type of drainage system. These allow greater integration of river, coastal, above ground and sewer environments within a single modelling program. This enables increasing levels of complexity to be modelled.

The number of dimensions used in IUD modelling will generally fall within one of the following categories:

- 1D - one dimension (for example, a sewer and/or a watercourse model)
- 2D - two dimensions (for example, a pluvial runoff and overland flow model)
- 1D-2D - a coupled one-dimension and two-dimension model (for example, with sewers and watercourses modelled in 1D but coupled with a 2D mesh to model overland flow)

1.11 Experience and training of staff

Urban drainage modelling has always been a complex subject and, with more integration of systems and improvements in technology, it is continually becoming more complex. It is essential, therefore, that all staff involved in the work should have received training appropriate to the tasks they are carrying out. This Guide is not a substitute for such training. Training may be as part of formal education, by in-house or external training courses, open learning or on-the-job training. Records should be kept of the training individuals have received.

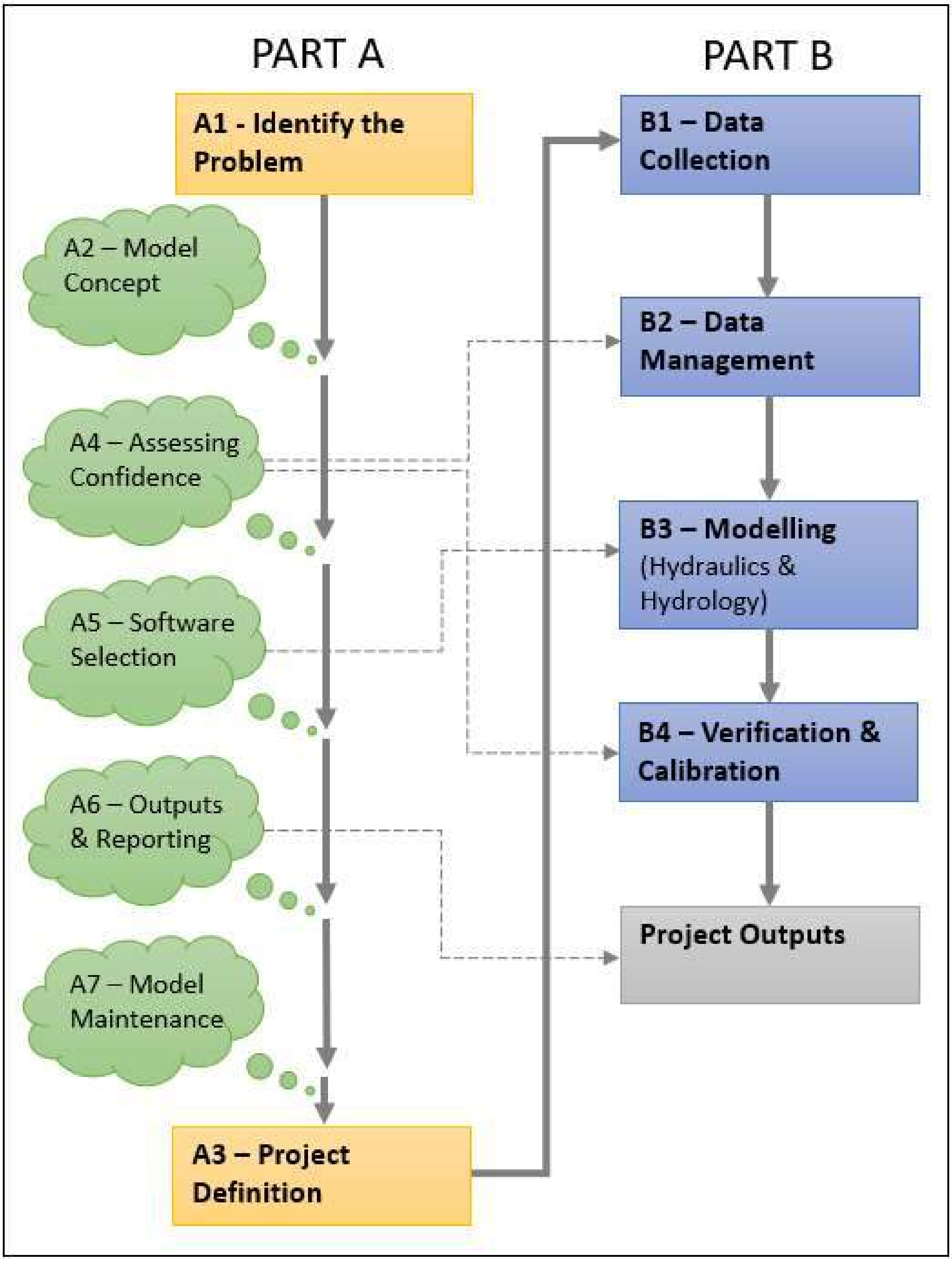
Work should be carried out by, or under the day-to-day direction of, a competent hydraulic modeller who should have a detailed understanding of the various processes involved, including amongst other things:

- Operational performance requirements for urban drainage systems
- Hydraulics of flow in sewers, sustainable drainage systems, watercourses and ancillary structures
- Urban hydrology
- The assumptions implicit in the way the software carries out the calculations
- Methods of flow measurement and their accuracy
- Engineering solutions

The CIWEM Urban Drainage Group (UDG) Competency Framework (**Competency Framework**[2]) provides a framework for defining the competency requirements of staff involved in a project and assessing individual staff competencies against those requirements.

1.12 Structure of the Integrated Urban Drainage Modelling Guide

The Guide is divided into two main sections, which follow the phases in most IUD modelling projects. The various stages are also shown in the flow chart below, which is also included at the start of each chapter of the Guide.



1.13 How to Use the Integrated Urban Drainage Modelling Guide

The Guide has been structured so that readers can easily find the section that is relevant to their requirements at that time without having to read the whole document.

Part A is related to setting up and planning the project before carrying out the actual modelling. Sections A2, A4, A5, A6 and A7 (shown on the flow chart as green 'bubbles') are intended to be advisory, helping the PSG progress from identifying the problem (**Section A1**) through to defining the project (**Section A3**). These sections also provide relevant information (shown with dashed arrows in the flow chart) to specific aspects of the data collection and modelling.

Part B relates to data collection, data management, modelling and verification/calibration.

PART A – PLANNING

Section A1 – Identifying the Problem

The key to successful IUD projects is to define at the outset what problems in the catchment need to be investigated and resolved. **Section A1** provides some guidance on how to identify the problem(s). The problems to be resolved by IUD modelling are frequently multi-faceted and interrelated, although sometimes a single cause cannot be readily identified. In a similar way, a single cause might be identified but the solution is multi-faceted. As well as identifying the problem it is also necessary to consider what is an acceptable risk.

Section A2 – Model Concept

Whilst the urban elements of most IUD modelling studies are usually readily identifiable, the other elements (fluvial, pluvial, tidal) cover a wide spectrum, each requiring a different approach. **Section A2** contains four examples of the most commonly found types of IUD projects, each with a different approach on how fluvial and tidal influences can be incorporated into an IUD project. These examples may not cover exactly how all IUD projects could be modelled, but they give enough information for the PSG to determine the appropriate modelling concept for every eventuality. It is recommended that the modelling concept or strategy is agreed and documented before any modelling starts, recognising that some elements may already have been modelled.

Section A3 – Project Definition

A successful IUD modelling project is one that has been adequately planned and defined at the start of the project. **Section A3** of the Guide identifies the different aspects of a study that may need to be agreed and formally recorded by the PSG. **Appendix B** provides a checklist pro-forma to use for recording all the agreements reached at the project definition stage.

Section A4 - Assessing Confidence

Many IUD modelling projects will reuse or convert existing models, whilst others may require new models to be built. **Section A4** of the Guide describes techniques that can be used to assess the level of confidence that can be placed in pre-existing and new models. It is important that models only need to be good enough for their intended use and assessing the confidence is a key metric in understanding what is good enough.

Section A5 - Software Selection

The Guide is generally agnostic to the different software products, but it was appreciated when starting to update the Guide that many Partners, Stakeholders and Modellers needed some guidance on the advantages and disadvantages of the different types of modelling software. **Section A5** of the Guide provides a sample of typical software products available at the time of writing this Guide. It also provides some guidance so that the PSG can make a better-informed decision about what modelling software should be identified at project definition stage.

Section A6 - Outputs and Reporting

Section A6 of the Guide provides some guidance on the types of model outputs and reporting that can be obtained from IUD modelling studies. It also considers the types of outputs that are appropriate for non-technical people to understand and appreciate. It describes the appropriate documentation that should be produced alongside all stages of the IUD modelling project.

Section A7 - Model Maintenance

A considerable amount of time and expense will have been spent on an IUD modelling project and the resultant model should be considered to be a valuable asset worthy of ongoing maintenance. It is important at the end of the project that the model is stored in a suitable manner and, where relevant, could be periodically updated in the future. **Section A7** of the Guide summarises the techniques that can be used to maintain models.

PART B – MODELLING

Section B1 - Data Collection

IUD modelling projects usually require large amounts and disparate types of data to be collected. **Section B1** of the Guide identifies the different sources and types of data that may need to be collected. It also explains what levels of detail are required in order to achieve the required confidence levels.

Section B2 - Data Management

IUD modelling projects not only require data to be collected but also require suitable data management processes so that the data can be effectively used. **Section B2** of the Guide discusses the ways in which data can be managed. Particular points to note are adhering to data sharing protocols and privacy under GDPR regulations. **Section B2** also describes a protocol that could be used for naming and structuring the different types of data in order to provide consistency and enable a checklist system to be used.

Section B3 – Modelling (and Hydrology)

Section B3 of the Guide provides descriptions on the different types of modelling that can be undertaken. There are substantial differences between the hydrological techniques used for fluvial modelling projects and traditional sewerage modelling projects. **Section A2** of the Guide has set out four examples of typical fluvial and tidal aspects of a project. These strongly influence the way in which the hydrology and the hydraulic modelling can be combined for the different types of IUD project. Section B3 sets out the recommended ways in which the hydraulic modelling and hydrology can be combined for a successful IUD project.

Section B4 - Verification and Calibration

Together with assessing the confidence in models, all IUD modelling projects will require a degree of verification and/or calibration. **Section B4** of the Guide identifies the techniques that can be applied to verify or calibrate different aspects of models.

Appendices

In addition to the sections listed above, there are also a number of other appendices that are included. These are:

> **Appendix A – Pre-Feasibility Scoping Study** - provides guidance on how, with regular liaison meetings and advance planning, it is possible to identify projects early enough so that funding streams and timescales can be aligned. Not every project will require a pre-feasibility scoping stage but for those that do this appendix also provides a checklist that can be used to help with and record key aspects agreed
>
> **Appendix B – Project Definition checklist -** provides a checklist and template for recording all the relevant aspects of an IUD project and the input from the different Partners and Stakeholders
>
> **Appendix C – Lidar -** provides guidance on the common problems and pitfalls in acquiring and using Lidar data
>
> **Appendix D – Topographic Surveys -** provides guidance on the techniques that can be used in undertaking topographic surveys, with particular emphasis on surveying urban watercourses
>
> **Appendix E – Culvert Inspections -** provides guidance on the techniques that can be used and the common problems and pitfalls when inspecting watercourse culverts
>
> **Appendix F – Modelling of Culvert Inlets -** provides guidance on how culvert inlets should be modelled
>
> **Appendix G – Modelling of Road Gulleys -** provides guidance on how and when individual road gulleys should be modelled
>
> **Appendix H – Hydrology -** deals with the role and techniques in respect of hydrological inputs to IUD projects

It is the intention that over a period of time and as more IUD projects are undertaken a collection of case studies will be written and published on the CIWEM website alongside this Guide.

1.14 Aligning with other practice

This Guide is not a standalone document and forms part of a suite of CIWEM UDG documents. It should be read in conjunction with the following CIWEM UDG documents:

Essential:

- Code of Practice for the Hydraulic Modelling of Urban Drainage Systems, 2017 (**CoP**[1])
- Rainfall Modelling Guide, 2016 (**Rainfall Guide**[3])
- Competency Framework, 2015 (**Competency Framework**[2])

- Various User Notes* (**WaPUG_UN**[24])

Relevant for Urban Pollution Management (UPM) and water quality modelling:

- Event Duration Modelling Good Practice Guide, 2016 (**EDM**[4])
- Guide to The Quality Modelling of Sewer Systems, 2006 (**Quality Modelling**[5])
- The Design of CSO Chambers to Incorporate Screens, 2006 (**CSO Screens**[6])
- River Modelling Guide, 1998 (**River Modelling**[7])
- River Data Collection Guide, 1998 (**River Data**[8])

In addition, there are a number of other significant external publications, some of which are listed as follows:

- Urban Pollution Management (**UPM**[9]) Manual, FWR Version 3.1, 2018, web based
- Sewerage Risk Management (**SRM5**[10]), WRc 2017, web based
- Flood Estimation Handbook (**FEH**[11]), Centre for Ecology and Hydrology, 1999
- FEH web service, Centre for Ecology and Hydrology, (pay-as-you-go web based) (**FEHweb**[12])
- Surface Water Management Plan Technical Guidance, Defra, 2010 (**SWMP**[13])
- The SuDS Manual, CIRIA Report C753, 2015 (**SuDS**[14])
- Ofwat/EA Drainage Strategy Framework, May 2013 (**Drainage Strategy**[15])
- Designing for Exceedance in Urban Drainage - Good Practice, CIRIA Report C635, 2006 (**C635**[16])
- Managing urban flooding from heavy rainfall – encouraging the uptake of designing for exceedance, CIRIA Report C738, 2014 (**C738**[17])
- Culvert, Screen and Outfall Manual, CIRIA Report C786, 2019 (**C786**[18])
- Sewers for Adoption 7th Edition, WRc, 2012 (**SfA-7**[19])
- Sewers for Adoption 8th Edition, WRc, 2019 (**SfA-8**[20])
- The Fluvial Design Guide, Environment Agency (web based). (**Fluvial Guide**[21])
- A framework for the production of Drainage and Wastewater Management Plans, 2019 (**DWMP**[30])
- Flood Estimation Guidelines, Environment Agency, 2020 (**Flood Estimation**[31])

If there is any discrepancy between this Guide and other CIWEM UDG documents, this Guide will take priority unless the CIWEM UDG documents postdate this Guide.

* WaPUG User Notes are a collection of short advice notes on specific aspects of urban drainage modelling. These have generally been written by individuals who have presented that topic at a conference and been asked by the Urban Drainage Group (previously WaPUG) committee to convert the conference presentation to a more formal User Note. User Notes are in pdf format and can be downloaded free of charge from the CIWEM UDG publications website.

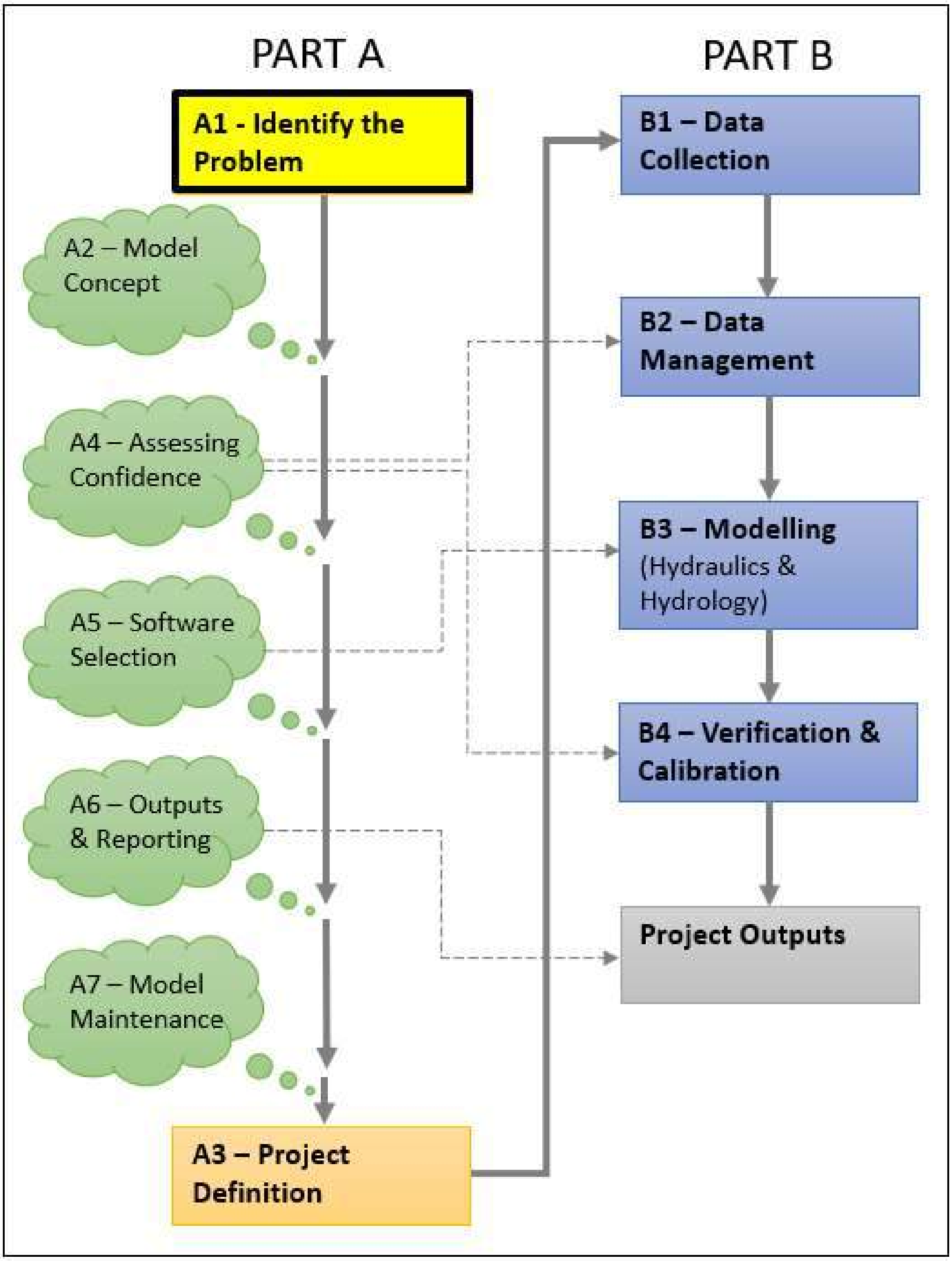
Integrated Urban Drainage Modelling Guide

Section A1

Identify the Problem

CIWEM Chartered Institution of Water and Environmental Management

A1. IDENTIFY THE PROBLEM



A1.1 Starting Point

The starting point for any potential project is to identify the problem that needs to be resolved, so that the requirements of the project are determined and can be developed into a well-defined scope.

It is likely that at the start of a potential project either a single Client such as a Water & Sewerage Company (WaSC), Flood Risk Management Authority (Environmental Regulator) or Lead Local Flood Authority (LLFA) will have identified that there is a problem (usually flooding).

It is also necessary at this stage to understand the acceptable risks as designing solutions for every eventuality may not be affordable or necessary.

A1.2 Identifying Responsibility

The next step is to identify whether the problem is the responsibility of a single organisation (for example, sewer flooding is the responsibility of a Water & Sewerage Company) or multiple organisations (for example, an LLFA in conjunction with a WaSC).

If the problem is the responsibility of a single organisation, it is unlikely that the project will be suitable for Integrated Urban Drainage Modelling unless there are other reasons to involve other Partners and Stakeholders.

A1.3 Developing an initial understanding of the problem

To enable the IUD modelling strategy to be determined, an initial understanding of the problem is required. Analysis from an initial review of flood incident records, national flood risk maps (if available), other data and initial model runs (if available) may enable an early indication to be made of:

- flooding mechanisms and interactions between different urban drainage systems
- whether there is a pluvial (surface water) runoff element in the flooding mechanism
- whether the flooding is influenced by tidal conditions or varying water levels in receiving waters
- scale of the flooding (for example, localised, town-wide or river catchment-wide)
- frequency of the flooding
- consequence of the flooding (for example, degree of nuisance, cost)

To enable the flooding mechanism and linkages between the systems to be understood and identified, it can be helpful to assess the source-pathway-receptor relationship of the flooding problem. The following questions could be considered:

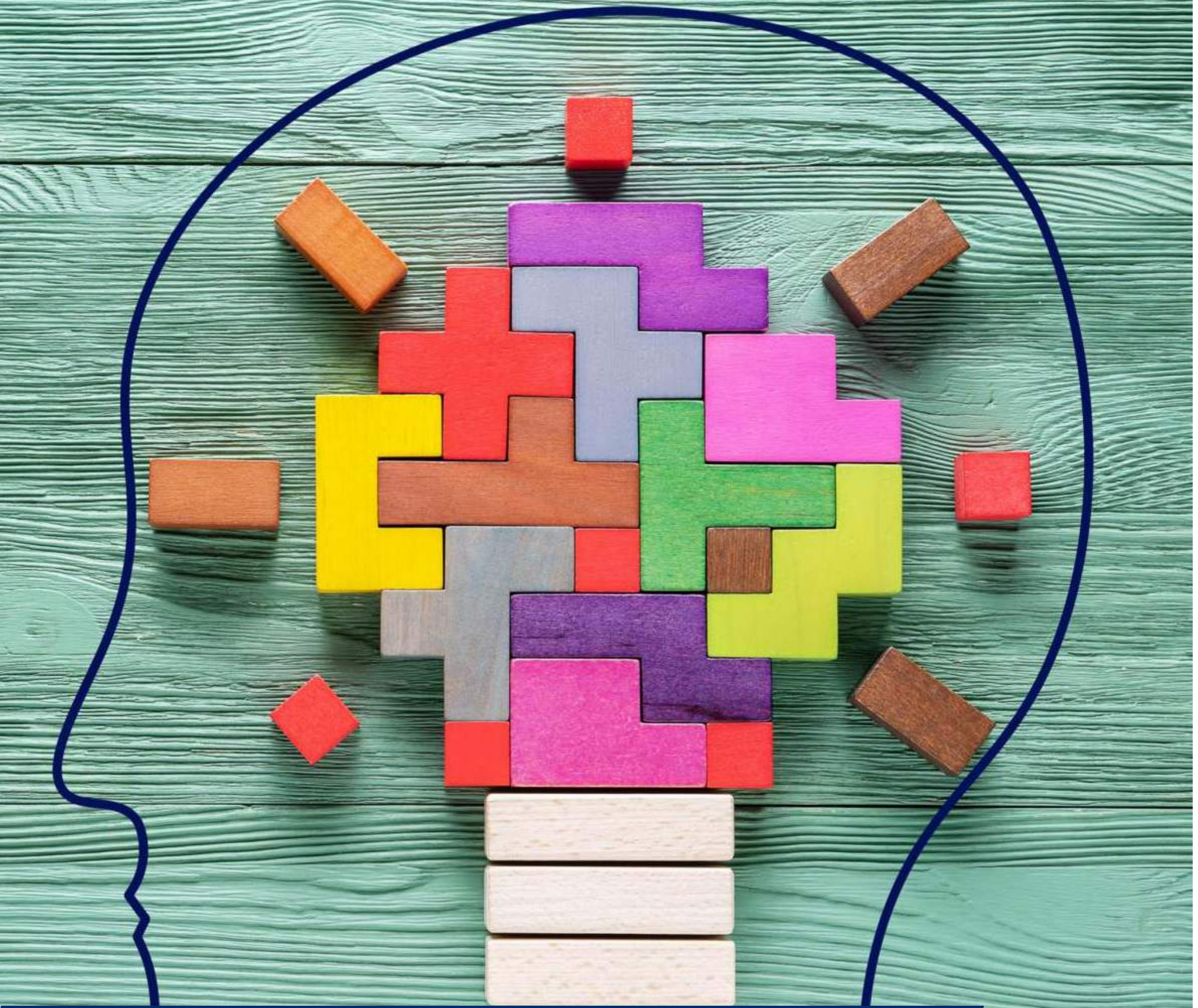
- From which drainage systems does the flooding originate (the sources)?
- Is there a pluvial runoff element in the flooding and, if so, where are the contributing areas (the sources)?
- How is flooding transferred from the source to a receptor (the pathways)?
- Where does the flood water gather and cause damage/risk (the receptors)?
- What are the key drainage system interactions that influence the flooding (the pathways)?
- Is the flooding mechanism a localised issue or related to hydraulic influences from elsewhere in the system (the pathways)?
- What range of input or boundary conditions for modelling (for example, tide levels) influence the flooding problem (the pathways)?

A1.4 Assessment of the likelihood of success

Once the flooding problem has been identified, an informed decision can be made about whether an IUD modelling project should be undertaken, considering the potential for success of the modelling project. An honest evaluation of the likelihood of success by the Partners and Stakeholders, based on previous project experience and catchment knowledge and understanding, should inform the decision on how to take the integrated modelling project forward. At this stage, an initial risk register for the project could also be prepared and documented so that all Partners and Stakeholders are entering the project with a common understanding of the situation and potential outcomes of the project.

A1.5 Pre-Feasibility Scoping Study

In many areas, there are regular meetings between LLFAs, WaSCs and Environmental Regulators. These meetings are an ideal opportunity to discuss problems and potential IUD projects. **Appendix A** provides some information on how formal pre-feasibility scoping studies could be carried out, if required.



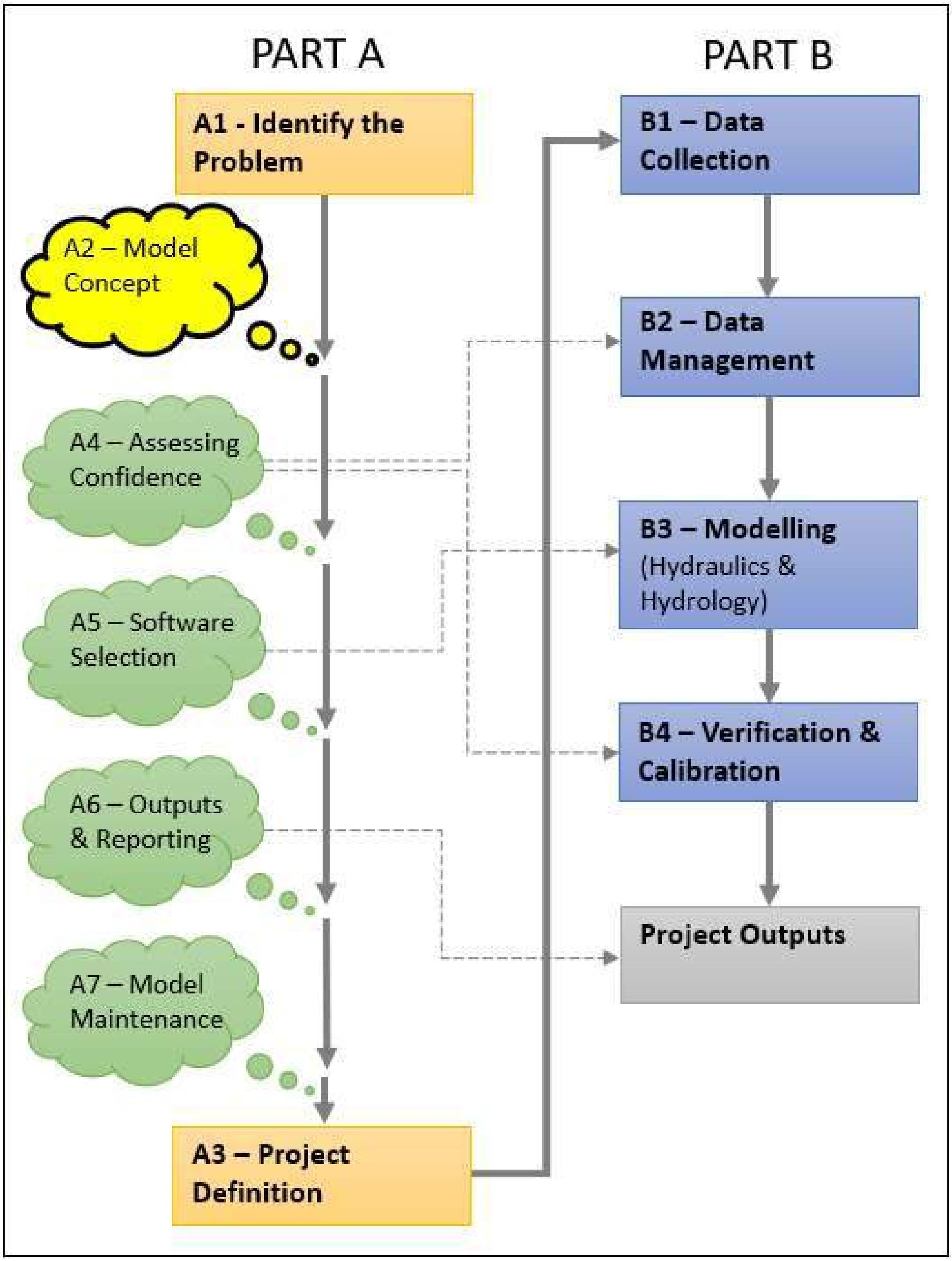
Integrated Urban Drainage Modelling Guide

Section A2

Modelling Concept

CIWEM Chartered Institution of Water and Environmental Management

A2. MODELLING CONCEPT



A2.1 Introduction

The purpose of this section of the Guide is to help the Project Steering Group determine at Project Definition Stage (**Section A3**) the most appropriate way to define the modelling concept. This section of the Guide has been written based on there being some modelling expertise within the PSG; if that is not the case, it may be necessary to employ an external party to advise.

The modelling and hydrology for any integrated modelling study are closely interlinked, which is why the 'Modelling Concept' is an important step in ensuring that the correct approaches to both are undertaken.

There are four main categories of modelling concept described in this section. These are not the only concepts available and are intended as a starting point for deciding the most appropriate way of organising the modelling and hydrology. The four categories described are also used in **Section B3** (Modelling) to help describe the modelling and hydrology options that fit together.

The sequence of plans shown for each model category are not intended to be followed as a step-by-step guide, but are intended to show the various factors the PSG should consider in deriving the overall model concept.

A2.2 Definitions

In the context of defining the different model concepts the following definitions have been used:

- The **Hydrological Boundary** (also known as the watershed) is the boundary of the area within which any rainfall would contribute to the model area. If there is a suitable monitoring installation a short distance downstream of the study area it may be sensible to extent the hydrological boundary down to that point
- The **Model Boundary** is the boundary of the area to be included in the integrated model
- The **Study Boundary** is the boundary of the area to be investigated

It is important to recognise that in the modelling concepts described in the following sections, these boundaries may be identical but may also be radically different.

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A2.3 Modelling Concept – Type #A (Contained)

The principle behind this concept is that the hydrological boundary, the model boundary and the study boundary are identical and that the model boundary is defined by catchment topography and the only inputs necessary to run the model are (a) rainfall and optionally (b) representation of different catchment wetness conditions at the start of a simulation.

Type #A models are likely to be at village or township scale rather than at city scale. Figures A2-1 to A2-4 show the typical arrangement for a Type #A model comprising an urban area with some surrounding rural areas.

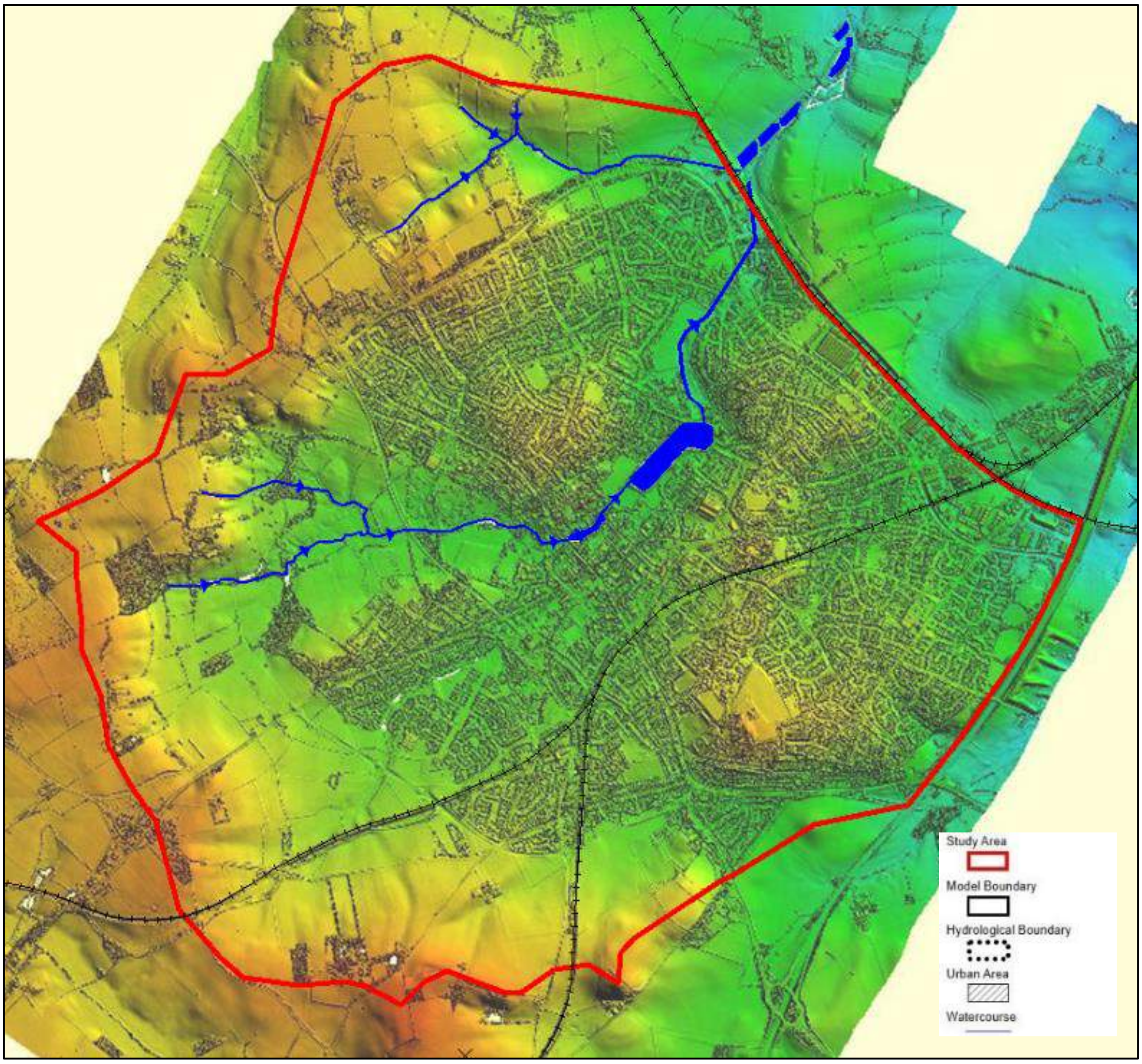

Figure A2-1: Typical Type "#A" Catchment (not to scale)

The hydrological boundary, the modelling boundary and the study boundary are identical and are formed by the higher ground around all sides except the north-eastern side which is formed by a railway embankment. In this example, the downstream hydraulic boundary for the model is formed by the culverts through the railway embankment. In other examples, it will be important to identify a suitable downstream hydraulic boundary.

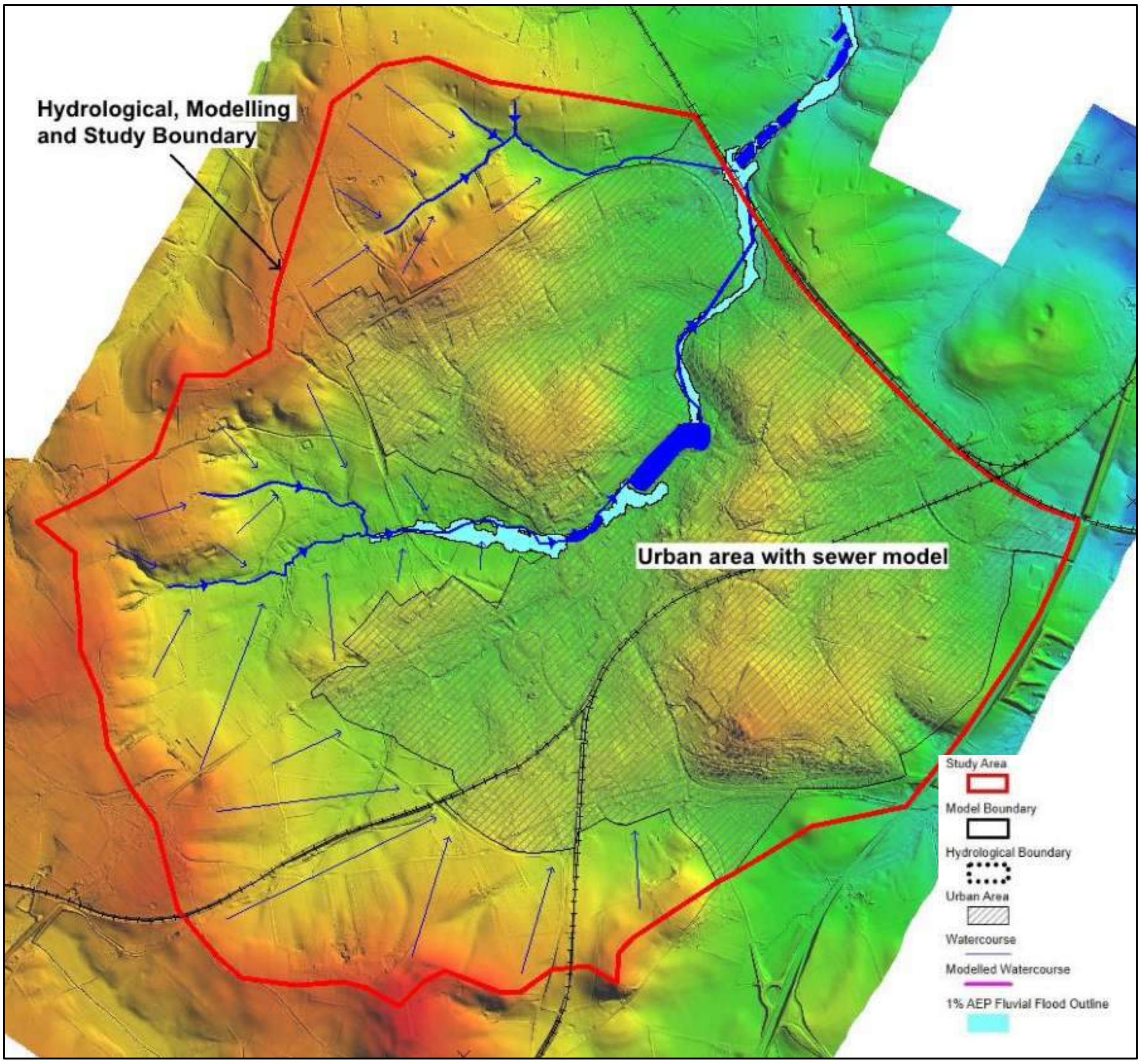

Figure A2-2: Urban Area, Watercourses, 100-year fluvial flood outline and Boundaries

Figure A2-2 shows the watercourses and the direction of the natural runoff from the rural areas. It also shows the 1 in 100 year (1% AEP) fluvial flood outline (in light blue) which, in this example, is relatively confined but provides a good reference as to how much of the watercourse should be modelled.

The national surface water flood maps also provide useful information to indicate whether there are significant pluvial flows entering the urban area; this may indicate whether 2D runoff modelling of both the rural area and also along the flow pathways in the urban area will be required.

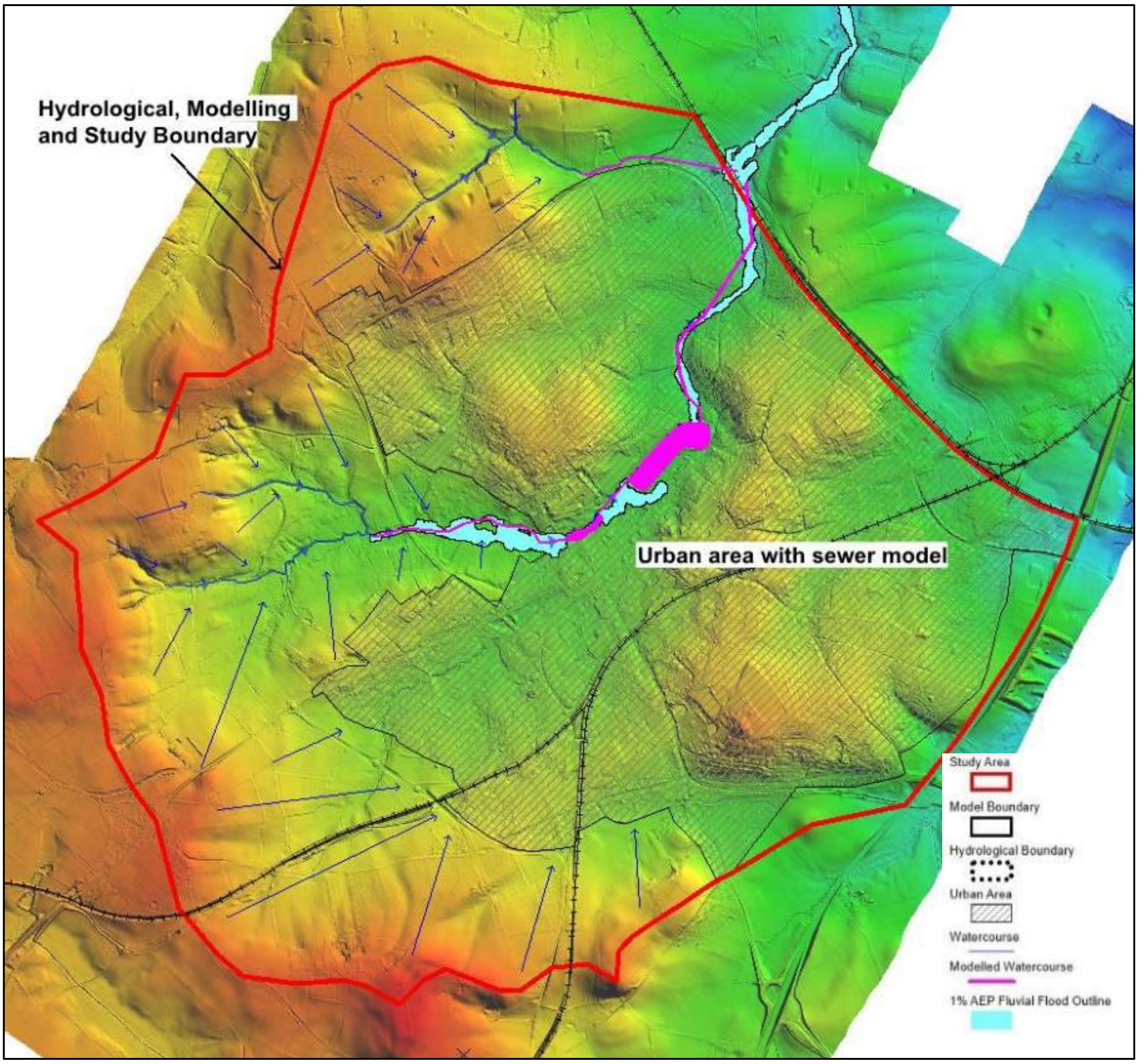

Figure A2-3: Extent of Watercourse Modelling (shown in pink)

Figure A2-3 shows in pink the lengths of watercourse that could be modelled. It includes the full length within the study area of the fluvial flood outline. **Section B3 – Modelling** provides more detailed guidance on how to determine the lengths of watercourses to be modelled.

If there are no GIS data available for the 1 in 100 year (1% AEP) fluvial flood outline, a useful starting point is for the length of watercourse modelled to extend at least 1km upstream of any urban areas; this allows for upstream flood storage options to be considered.

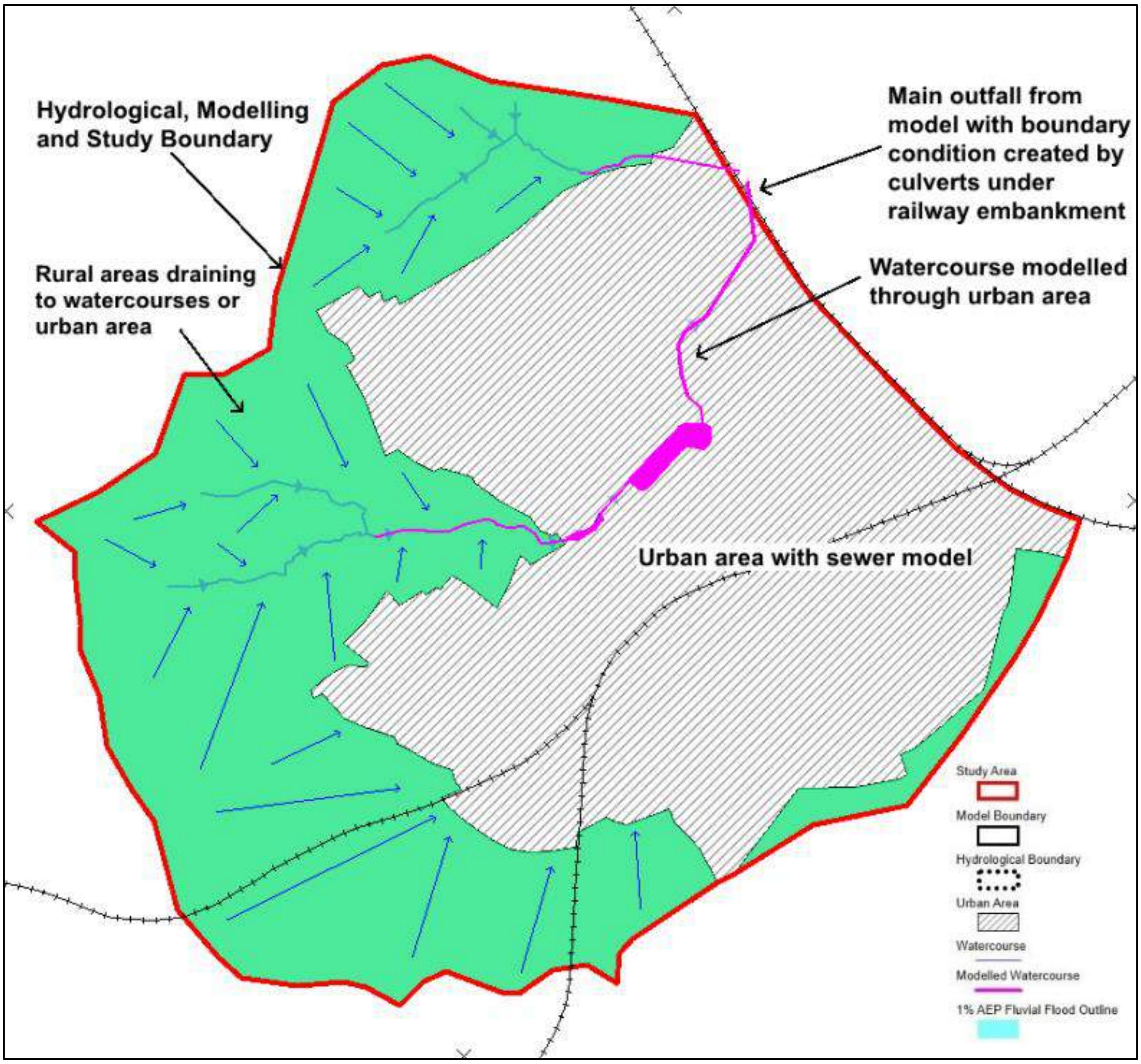

Figure A2-4: Model Schematic – Type "#A" Catchment

Figure A2-4 provides a schematic diagram of how the modelling could be organised for this type (Type #A) model. Creation of a similar schematic diagram is a good idea at Model Definition stage (**Section A3**) as it clearly shows what is intended.

A choice will need to be made between coupled 1D-1D and coupled 1D-2D modelling. This is determined less by the type/concept of the model and more by how the model outputs will be used. For example, if the outputs are going to be used in an economic appraisal, it may be necessary to have information about the depth of flooding at properties in the urban area (from more than one source), and therefore a coupled 1D-2D model maybe more suitable. However, if only the proportion of manholes that flood and the flooding volume are required, a coupled 1D-1D would probably be adequate.

The main features of this concept of model are shown in the following table:

Modelling Concept – Type #A (Contained)	
Hydrological Boundary	Defined from topography. FEH catchments unlikely to be sufficiently accurate at this scale.
Model Boundary	Identical to Hydrological Boundary.
Study Boundary	Identical to Hydrological Boundary.
Model Inputs	Rainfall (possibly initial catchment wetness conditions).
Rural Hydrology	ReFH/ReFH2 or 2D runoff (direct, Horton or Green-Ampt).
Urban Hydrology	Fixed, New UK, UKWIR.
1D, 1D-1D or 1D-2D	Generally, 1D with a narrow corridor along watercourses of 1D-2D.
Combined Probability	This is not an issue with this type of catchment as there is only one variable. It would however, be necessary to simulate a range of different storm durations.

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A2.4 Modelling Concept – Type #B (Simple Interaction)

The principle behind this concept is that whilst the model boundary and the study boundary may be similar, the hydrological boundary is larger, with one or more watercourses flowing into the study/model area.

For this type of model, it is probable that no previous hydrological assessment would have been undertaken to estimate peak flows or hydrographs for fluvial design events and, therefore, a hydrological study will be required as part of the model build. There will, therefore, need to be input from a Hydrologist.

Type #B models are likely to be at large village or township scale rather than at city scale. Figures A2-5 to A2-8 show the typical arrangement for a Type #B model.

Figure A2-5: Typical Type "#B" Catchment (not to scale)

This example of a "Type #B" catchment comprises an urban area with some surrounding rural areas. The modelling boundary and the study boundary are often identical and always very similar. These boundaries are defined by the area to be investigated, which is likely to be the existing urban area, any potential development areas and any areas where potential flood storage areas may need to be investigated.

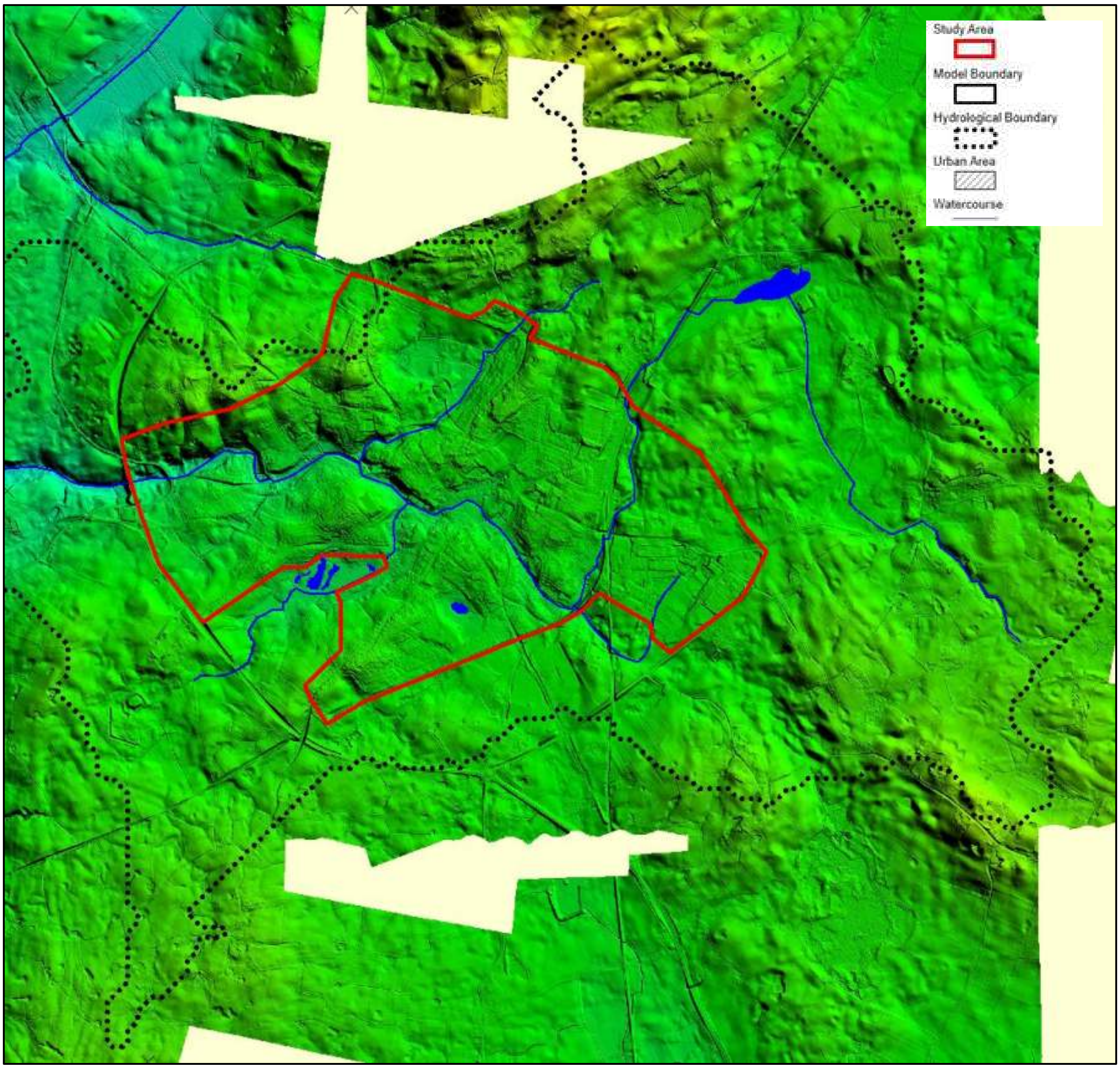


Figure A2-6: Hydrological Boundary for Type "#B" Catchment

Figure A2-6 shows the hydrological boundary (black dotted line) which is larger than the study/model boundary. It can be seen in this example that there are four watercourses that flow into the study/model area. The intention with this type of model is that a Hydrological Study will be needed in order to generate inflow hydrographs at each of the four locations (A, B, C and D) as shown in Figure A2-7. It will be necessary for inflow hydrographs to be created for all return periods and durations to be simulated. It can also be seen in Figure A2-6 that there are some blank areas – this is where there is no DTM.

Figure A2-7 shows with four large blue arrows the inflow locations (A, B, C and D) and the lengths of watercourse (in pink) that should be modelled. It includes the full length within the study area extended as far downstream as necessary to a suitable hydraulic break point.

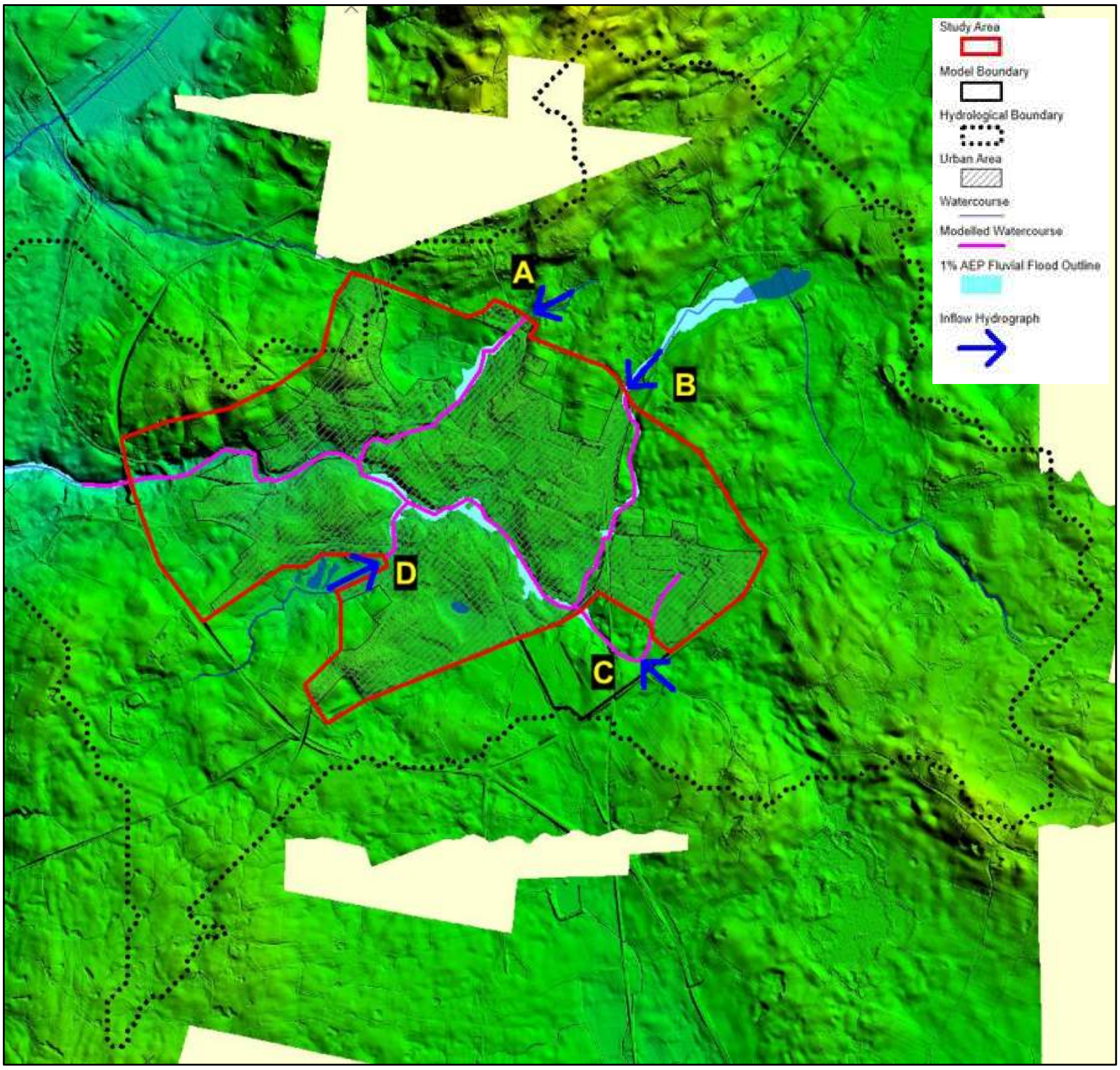


Figure A2-7: Modelled elements and inflow points

It can be seen in Figure A2-7 that the 1 in 100 year (1% AEP) fluvial flood outline (shown in light blue) extends outside of the study/model area. This is considered acceptable with this type of model provided that there is no significant flood storage outside of the study/model area. If there is significant flood storage the model boundary may need to be extended to encompass that area or a reservoir routing exercise may need to be undertaken when calculating the inflow hydrographs.

It can also be seen at Point 'C' that the model boundary goes outside the study boundary and that the inflow hydrograph connects part way along that watercourse. In these circumstances, care will be needed to avoid double counting.

Within the urban area (shown hatched) the model will be a standard 1D sewer model using standard urban hydrology. The rural areas outside the urban area but within the study boundary will use one of the rural hydrology techniques.

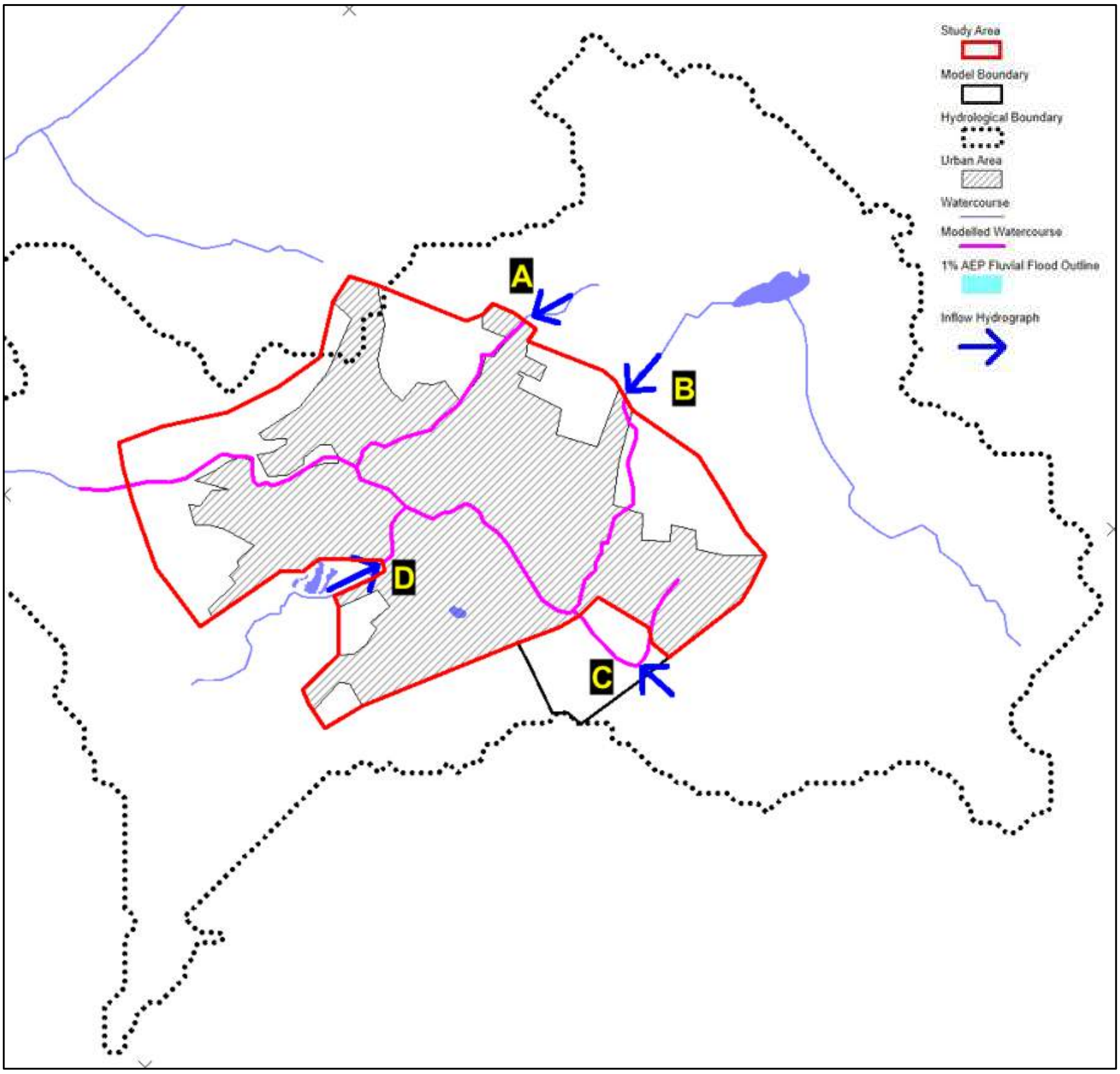


Figure A2-8: Model Schematic - Type "#B" Catchment

Figure A2-8 provides a schematic diagram of how the modelling could be organised for this type (Type #B) model. Creation of a similar schematic diagram is a good idea at Model Definition stage (**Section A3**) as it clearly shows what is intended.

The main features of this concept of model are shown in the following table:

Modelling Concept – Type #B (Simple Interaction)	
Hydrological Boundary	Defined from FEH catchments.
Model Boundary	Similar to the Study Boundary extended as necessary to enable modelling of relevant elements.
Study Boundary	Determined from the area to be studied.
Model Inputs	Rainfall and Inflow Hydrographs. It may also require different initial catchment wetness conditions or seasonal variations.
Rural Hydrology	Outside the study/model area a Hydrological Study will be required to generate inflow hydrographs. Within the study/model area the rural hydrology could use ReFH/ReFH2 or 2D runoff (direct, Horton or Green-Ampt)
Urban Hydrology	Fixed, New UK, UKWIR.
1D, 1D-1D or 1D-2D	Generally, 1D with a narrow corridor along each of the watercourses of 1D-2D.
Combined Probability	This type of model will present some challenges in respect of combined probability. These challenges will mainly be around duration and timing issues and it may be necessary to create inflow hydrographs for a range of storm durations rather than just the critical duration. Additionally, the critical durations for each of the watercourses might be different.

A2.5 Modelling Concept – Type #C (Complex Interaction)

The principle behind this concept is that there is an existing fluvial model for a major river that runs through the study area, and also that a Hydrological Study will have been undertaken as part of the development of that model. The hydrological boundary is considerably larger than either the study area or the model area.

The model boundary and the study boundary are likely to be different. The intention with this concept is that only a short length of the major watercourse is modelled, with the relevant section extracted from the existing fluvial model.

Type #C models are likely to be at a variety of scales ranging between villages and cities. Figures A2-9 to A2-13 illustrate the concept of a Type #C model.

When considering a study where there is a major watercourse, it is necessary to evaluate whether a Type "#C" concept or a Type "#D" concept (described later) are most appropriate.

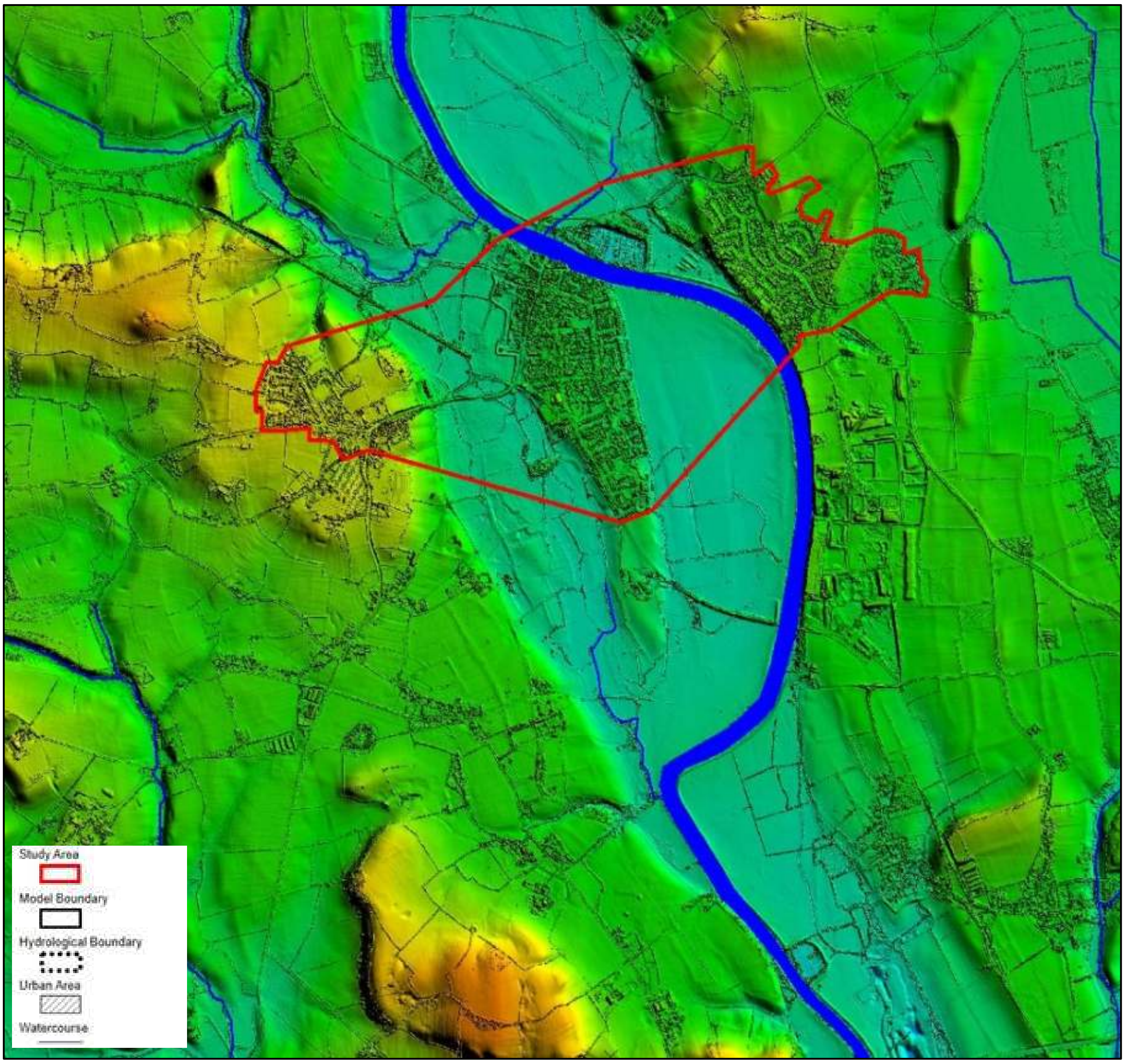


Figure A2-9 – Typical Type "#C" Catchment (not to scale)

Figure A2-9 shows this example which comprises three villages (or small towns) that straddle a wide valley within which there is a large river. The background to this Figure is a Digital Surface Model to help highlight the urban area. It can be appreciated from the colour shading how wide and flat the valley bottom is.

This example has been chosen because the central village/town forms an island when there is fluvial flooding from the major watercourse.

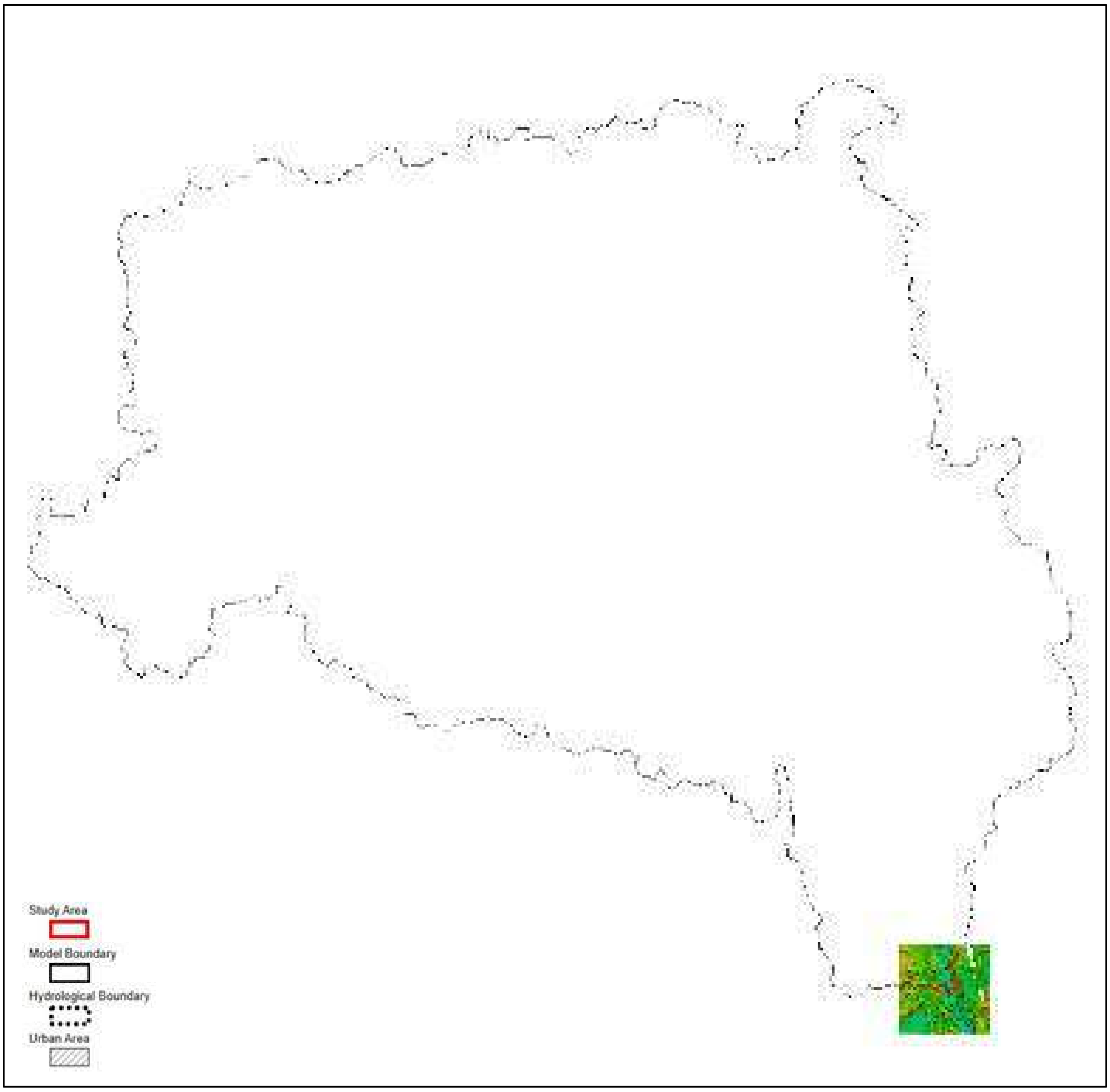


Figure A2-10: Hydrological Boundary for Type "#C" Catchment

Figure A2-10 shows the hydrological boundary for this example, with the green square in the bottom right-hand corner the same area as shown in Figure A2-9. This shows that the hydrological boundary is considerably larger than the study area.

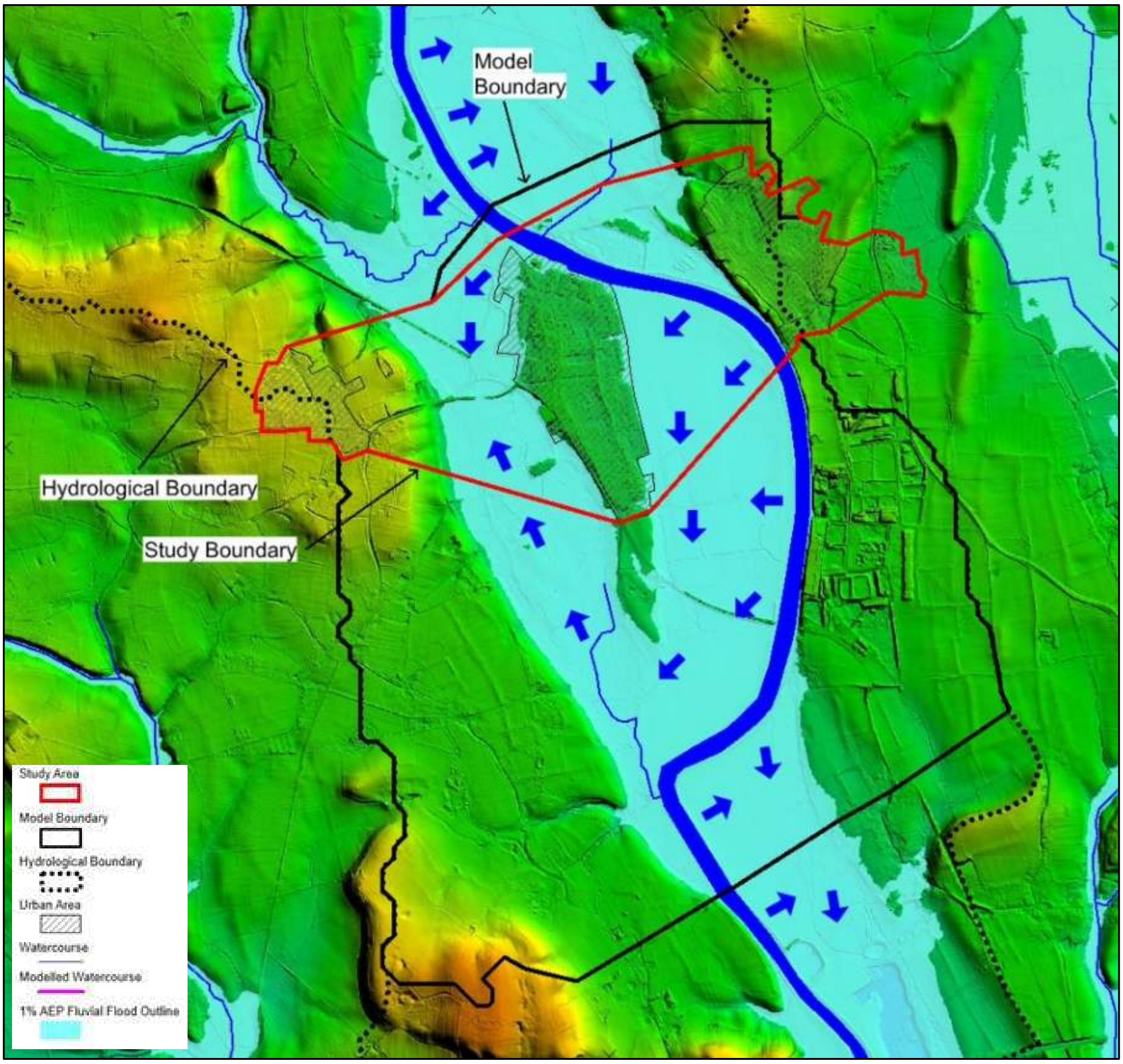


Figure A2-11: 1% AEP Fluvial Flooding from major watercourse showing flood flow directions

Figure A2-11 shows the 1 in 100 year (1% AEP) fluvial flood outline (from fluvial model simulations) and the blue arrows indicate the flow routes that can occur when there is fluvial flooding. It is essential in these circumstances to determine from the fluvial modelling results what the potential flow routes are so that they are fully replicated in the integrated model. It can be seen in this Figure that the model boundary (shown by the solid black line) is considerably larger than the study boundary. The model boundary follows the hydrological boundary (shown with black dots) either side of the major watercourse and is extended to coincide with a computational node point in the fluvial model.

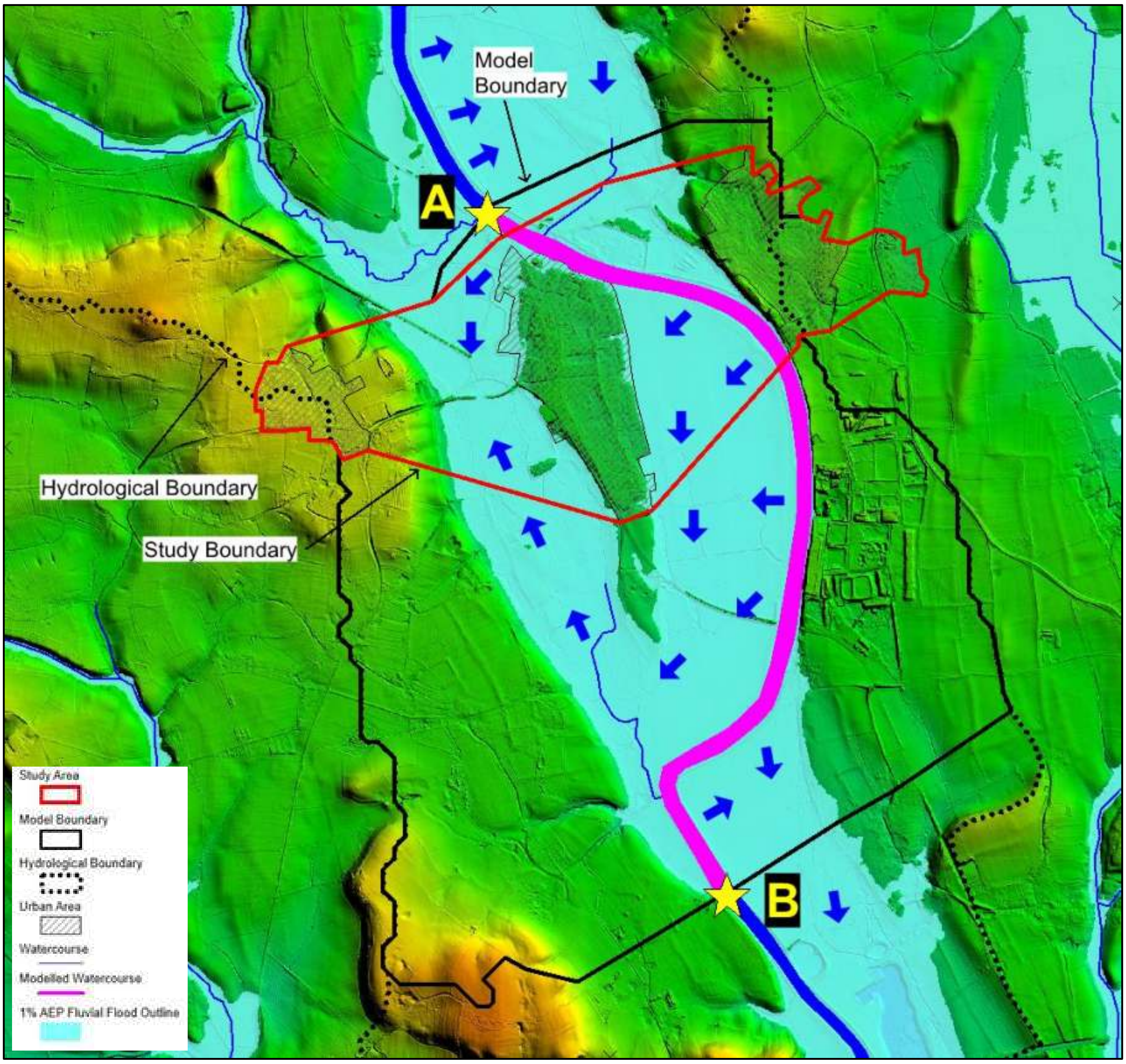


Figure A2-12: Modelled section of major watercourse with boundary locations

Figure A2-12 shows at Points 'A' and 'B' where model boundaries are created. These would normally be the locations of computational nodes in the fluvial model. At the upstream boundary (Point 'A') a flow hydrograph for the relevant storm return period and duration will be extracted from simulations using the existing fluvial model, capturing flows in channel and on the floodplain at this point. This will be used as one or more inflow hydrographs at the upstream boundary. **Section B3 – Modelling** provides further guidance on the variety of techniques that can be used to ensure that flow across the floodplain is adequately replicated.

Similarly, at Point 'B', a level hydrograph will be extracted from the fluvial model and used as a level hydrograph for the downstream boundary.

In order to represent the rural runoff within the model boundary and also to represent how the fluvial flooding propagates across the floodplain, it is probable that 2D modelling will be used for the whole of the model area.

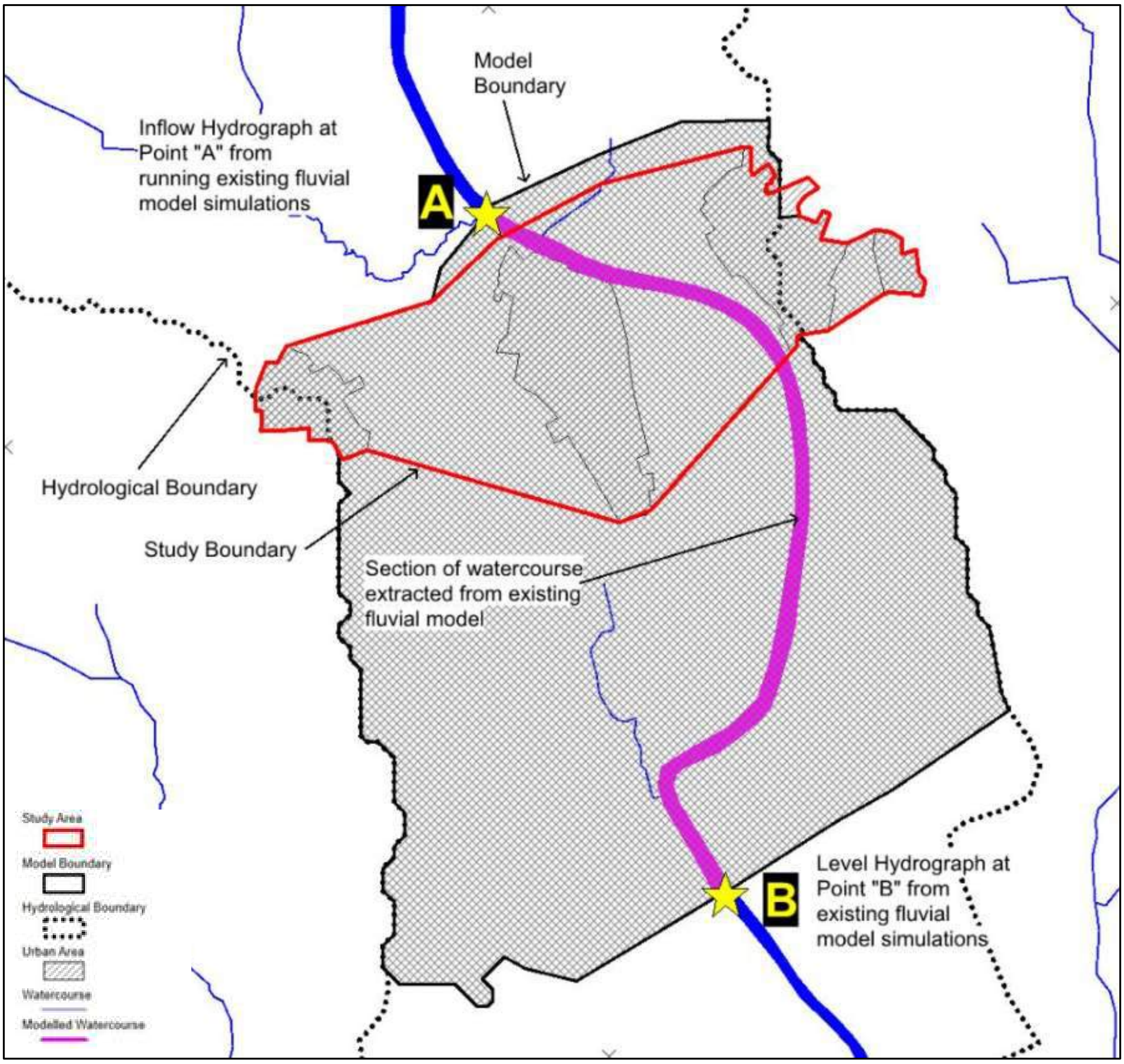


Figure A2-13: Model Schematic - Type "C" Catchment

Figure A2-13 provides a schematic diagram of how the modelling could be organised for this type (Type #C) of model. Creating a similar schematic diagram is a good idea at Model Definition stage (**Section A3**) as it clearly shows what is intended.

The section of the major watercourse that is modelled is shown in pink and it is assumed that this will be a simple extract from the existing fluvial model. It is recommended that once this section of river is incorporated into an integrated model, the updated integrated model is run without any urban hydrology flows to check the existing fluvial model results are replicated.

The main features of this concept of model are shown in the following table:

Modelling Concept – Type #C (Complex Interaction)	
Hydrological Boundary	This is the hydrological boundary for the major watercourse.
Model Boundary	Defined from computational nodes in the existing fluvial model of the major watercourse extended as necessary to encompass the study boundary.
Study Boundary	Determined from the area to be studied.
Model Inputs	Rainfall, inflow Hydrographs and level hydrographs from simulations using the existing fluvial model of the major watercourse.
Rural Hydrology	Outside the study/model area a Hydrological Study will already have been undertaken in order to build the major watercourse fluvial model. Within the study/model area the rural hydrology should use 2D runoff (direct, Horton or Green-Ampt).
Urban Hydrology	Fixed, New UK, UKWIR.
1D, 1D-1D or 1D-2D	Generally, coupled 1D-2D throughout model.
Combined Probability	This type of model will present some challenges in respect of combined probability. These challenges will mainly be around the likelihood of return periods occurring simultaneously in the study area and the major watercourse (and any tributaries).

A2.6 Modelling Concept – Type #D (Restricted Interaction)

The principle behind this concept is that the restrictive or backwater effects (from a large river or the open coast or estuary) on an urban drainage system can be represented by level hydrographs at each of the outfalls. This is particularly applicable when the study area is located in a coastal area or alongside an estuary where the water level can be influenced by a range of factors that are assessed outside of the modelling.

In this type of model concept the model boundary and the study boundary are likely to be different and the hydrological boundary will in effect be the same as the study boundary.

Type #D models are likely to be at a variety of scales, ranging between villages and cities. Figures A2-14 to A2-17 illustrate the concept of a Type #D model.

When considering a study where there is a large watercourse it is necessary to evaluate whether a Type "#C" or Type "#D" concept is most appropriate. The effects a major inland watercourse can have on an urban drainage system can be simulated by applying level hydrographs at each outfall from the urban drainage system.

In Type #D models the effects of tidal incursion or wave overtopping can be simulated; in these circumstances, it would be necessary for the modelling to be 2D, or coupled 1D-2D, with boundary conditions set in such a way that tidal or wave overtopping flows (determined from a separate modelling program) can be applied.

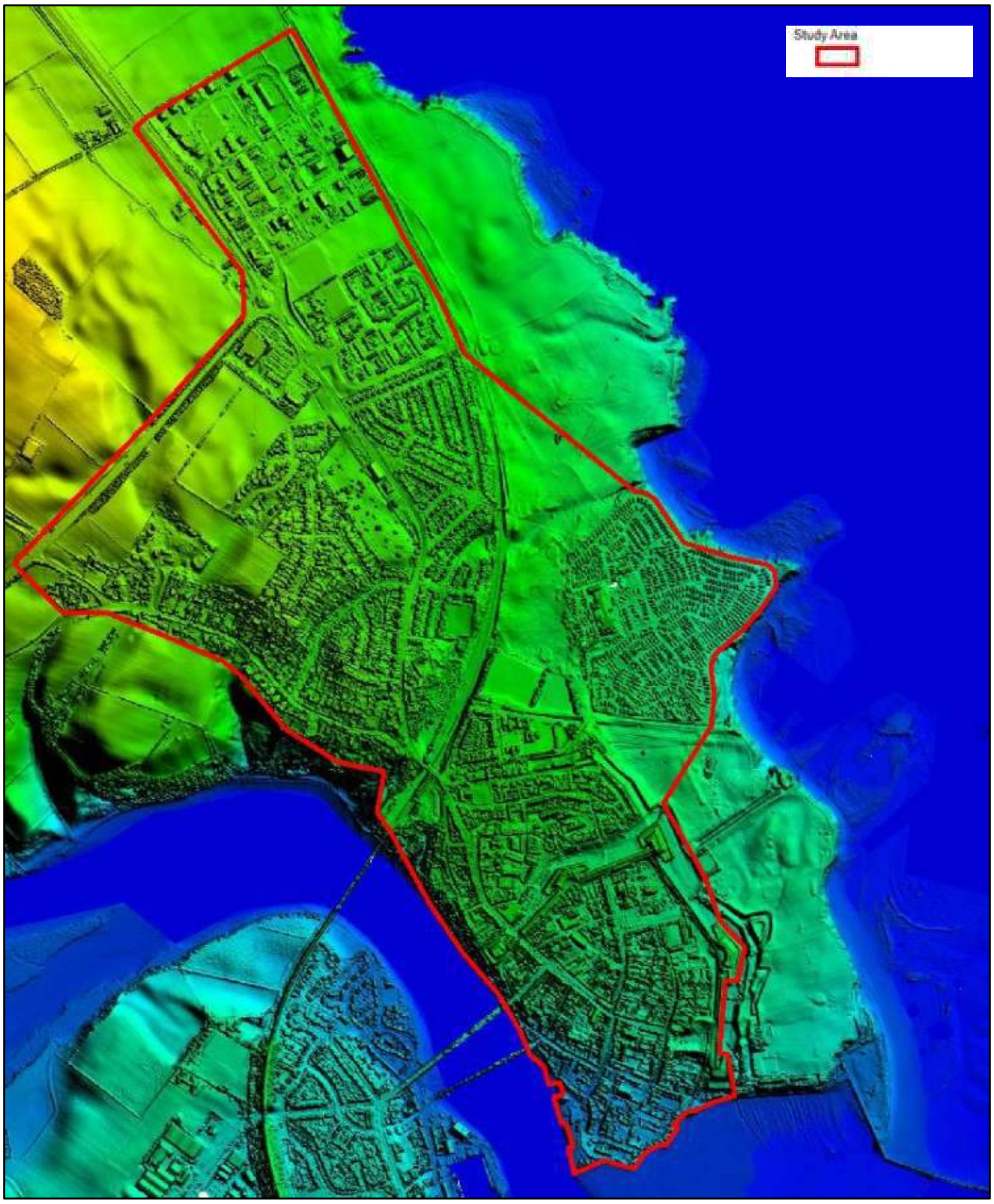


Figure A2-14: Typical Type "#D" Catchment (not to scale)

Figure A2-14 shows a typical coastal town with a tidal estuary along its southern boundary.

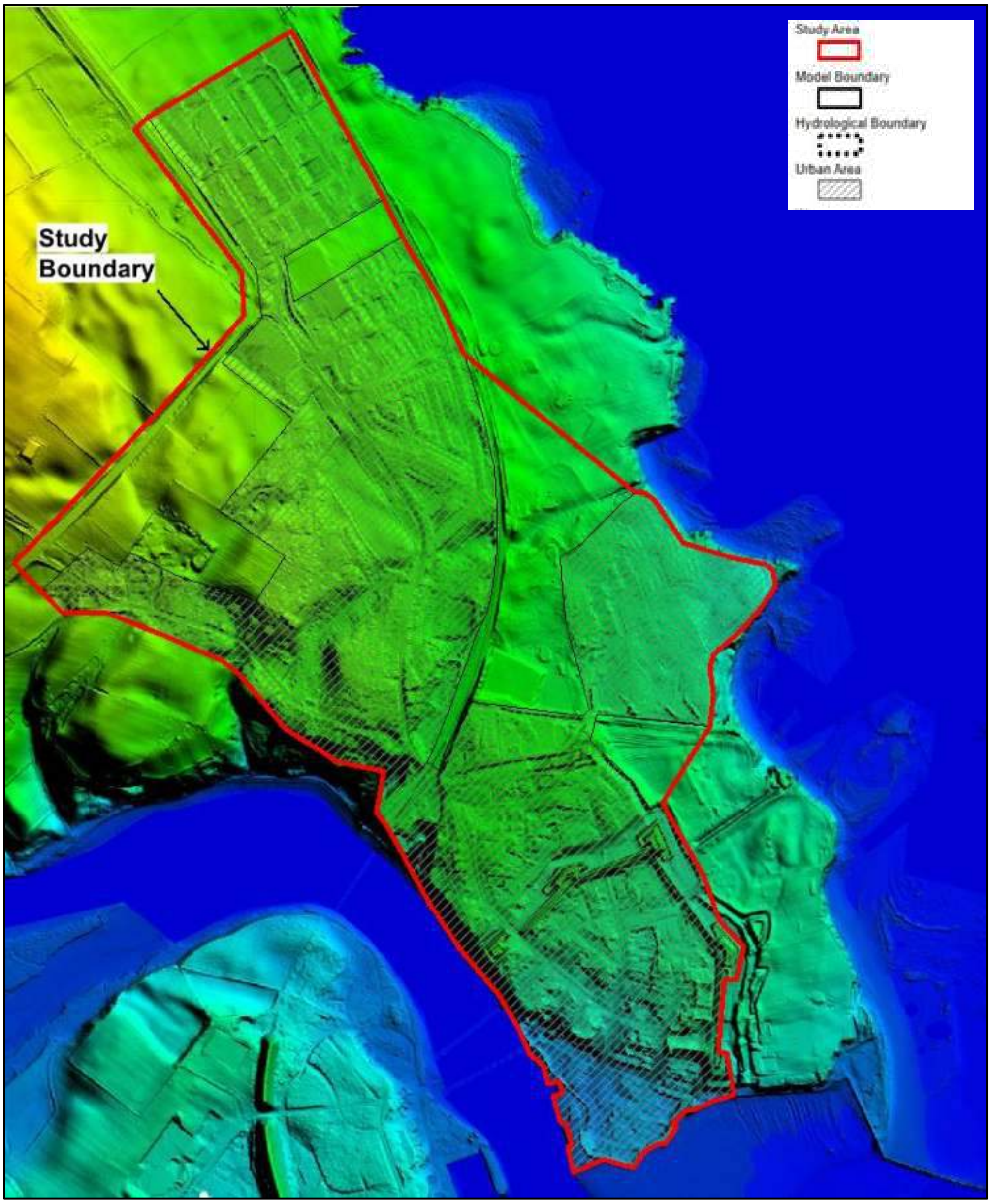


Figure A2-15: Study Boundary

The study boundary is determined from the area to be investigated.

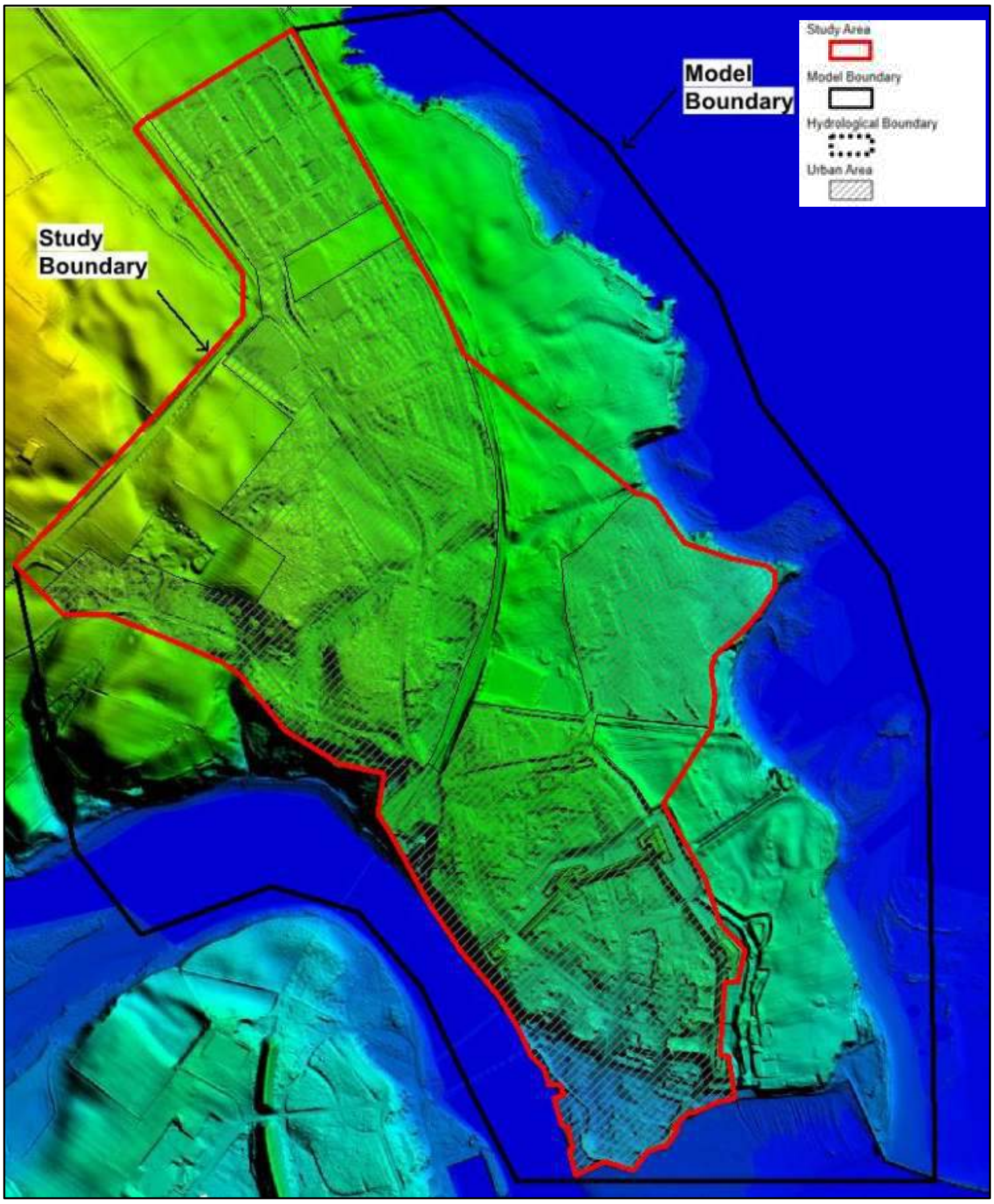


Figure A2-16: Model Boundary

The model boundary is shown indicatively in Figure A2-16. The model itself may not extend as far as shown but within this area suitable level hydrographs would need to be determined from some external source for all of the locations where there is an outfall from the urban drainage system.

It may be that the level hydrographs can be obtained from tide gauge records, tidal predictions or predictions of the level generated in the estuary from a combination of tide and fluvial flows.

If the model is to be used for simulating tidal incursion or wave overtopping, the model boundary would be along the crest of any tidal defences.

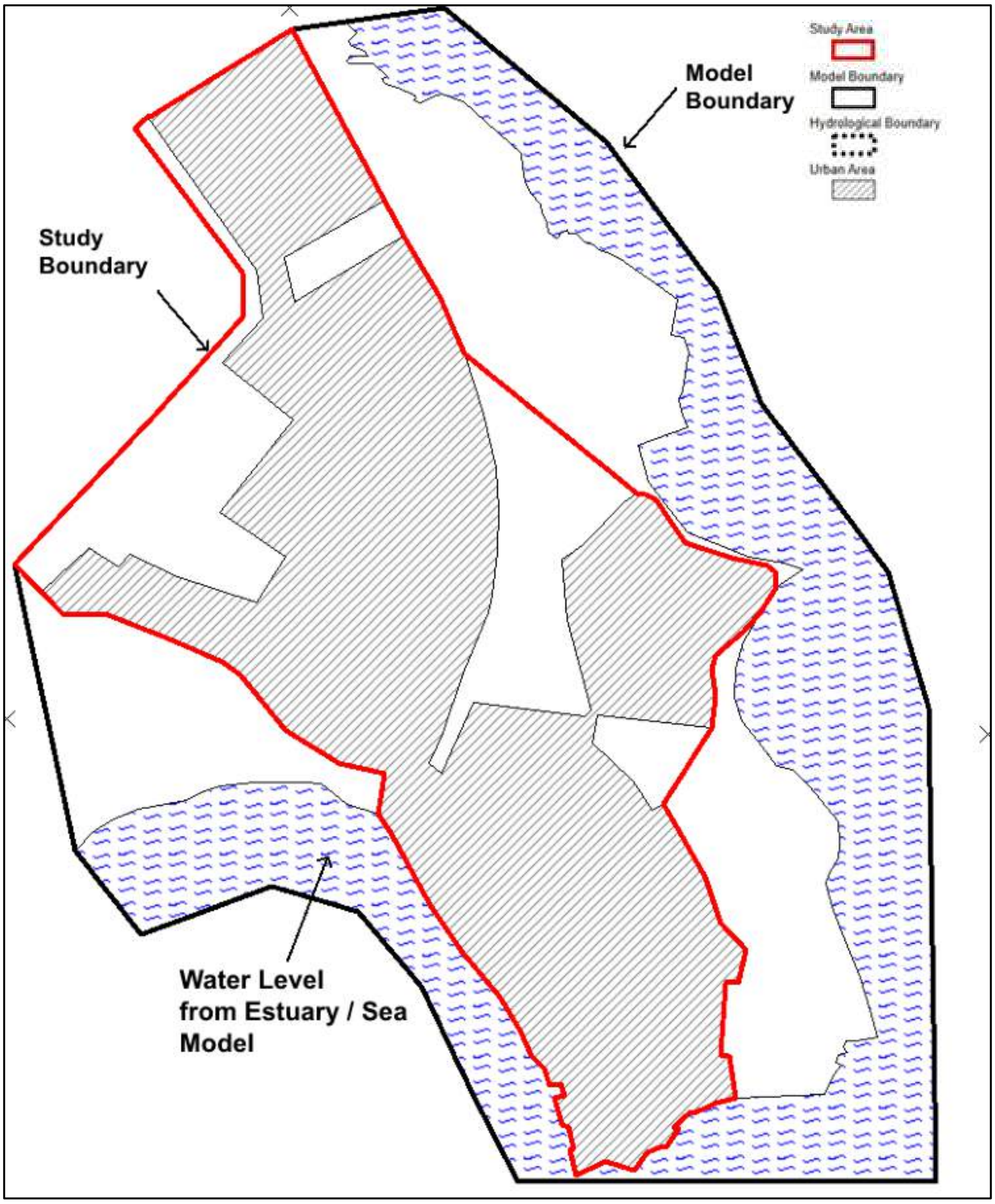


Figure A2-17: Model Schematic - Type "#D" Catchment

Figure A2-17 provides a schematic diagram of how the modelling could be organised for this type (Type #D) of model. Creating a similar schematic diagram is a good idea at Model Definition stage (**Section A3**) as it clearly shows what is intended.

The main features of this concept of model are shown in the following table:

Modelling Concept – Type #D (Restricted Interaction)	
Hydrological Boundary	Same as Study Boundary.
Model Boundary	Same as the study boundary extended as necessary to the crest of defences and/or the outfall locations of the urban drainage system.
Study Boundary	Determined from the area to be studied.
Model Inputs	Rainfall and level hydrographs from simulations using external models or other predictions of water levels.
Rural Hydrology	ReFH or 2D runoff (direct, Horton or Green-Ampt) if required).
Urban Hydrology	Fixed, New UK, UKWIR.
1D, 1D-1D or 1D-2D	Generally, 1D or coupled 1D-2D depending on how the flooding within the study area is to be represented.
Combined Probability	This type of model will present some challenges in respect of combined probability. These challenges will mainly be around the likelihood of return periods occurring coincidently with high tide levels.

A2.7 Other Types

This section of the Guide has illustrated four main types of model concept. There will undoubtedly be others, but the examples used have set out in detail the aspects that a Project Steering Group will need to consider at Project Definition Stage (**Section A3**).

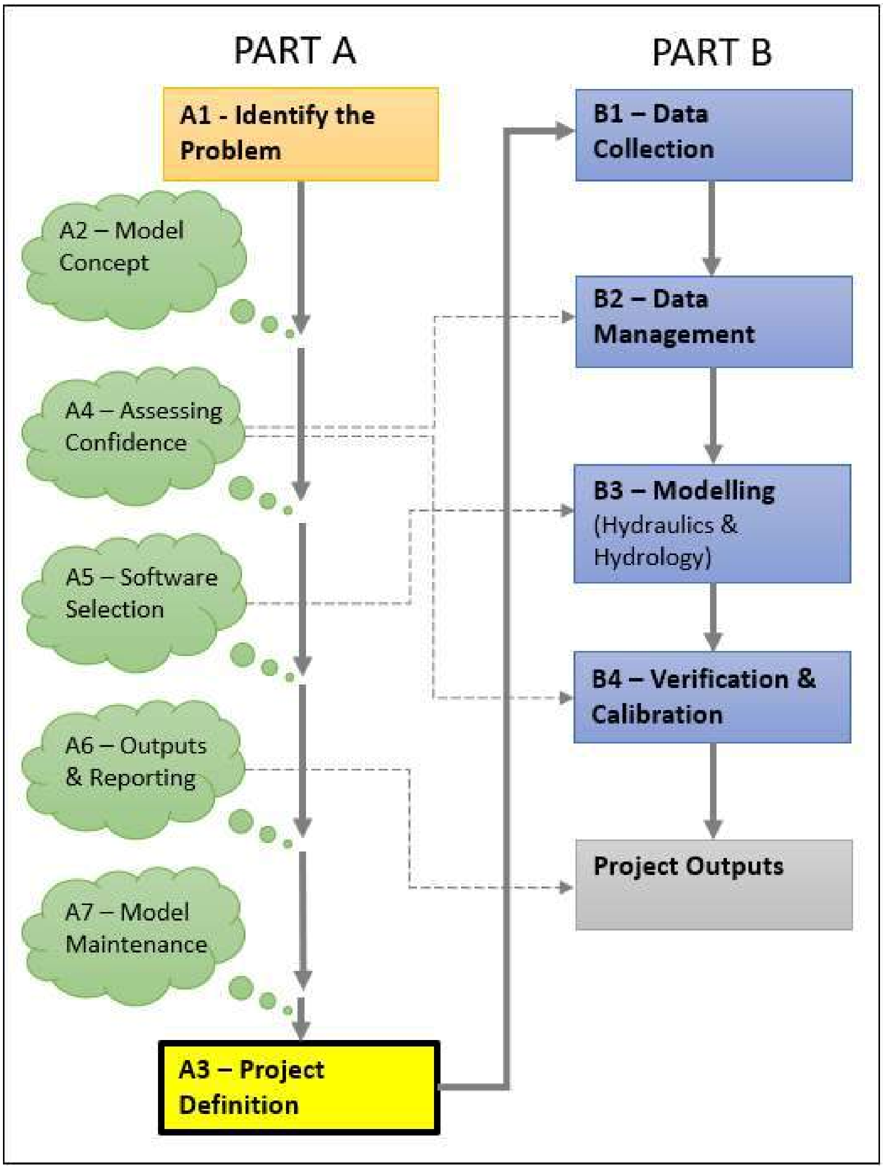
Integrated Urban Drainage Modelling Guide

Section A3

Project Definition

CIWEM Chartered Institution of Water and Environmental Management

A3. PROJECT DEFINITION



A3.1 Scope and context

This section covers the final work in the planning phase of a project and involves setting out in appropriate detail what the project objectives are and how they should be achieved. This section follows on from identifying the problem (**Section A1**) and the advisory sections on establishing an appropriate Model Concept (**Section A2**), the way in which confidence can be assessed (**Section A4**), identifying suitable software (**Section A5**), determining the project outputs and reporting requirements (**Section A6**) and determining how and who should be responsible for future model maintenance (**Section A7**).

This may also follow on from the scoping or pre-feasibility stage as outlined in **Appendix A** if one has been undertaken. There may be occasions when work commences with the project definition stage. However, it is recommended that all projects should start with identifying the problem even if that can't be accomplished quickly.

The key to a successful IUD modelling project is careful and detailed planning. An appreciation is necessary that the study will involve a number of stakeholders with different backgrounds, and a number of technical disciplines relating to urban drainage. The project is likely to involve of a number of Partners and Stakeholders and, due to its integrated nature, a project steering group will usually be required.

A3.2 Partners and stakeholders

The **Introduction** has provided guidance on who might be involved in IUD projects as Partners or Stakeholders.

A3.2.1 The project steering group

The Project Steering Group (PSG) should include all of the Partners and may also occasionally include key stakeholders. The PSG will form the basis of the decision-making process and will initially be responsible for adequately defining the project. Collectively, the PSG will usually be responsible for funding the project, although most, if not all, of the funding will come from the Partners. Technical reports and modelling outputs may be considered by the group so actions can be agreed and implemented.

The PSG would be responsible for agreeing the level of confidence required from any modelling study, balancing an acceptable level of risk, accuracy, budget and programme. In larger projects, technical aspects may be delegated to a Technical Group.

A3.2.2 The modelling team

IUD hydraulic modelling is a complex subject and it is essential that the team has the appropriate skills and knowledge.

It is important in IUD modelling that the lead modeller, who may be an expert in one field, has a high level of appreciation of modelling and ready access to modelling experts in the other fields. IUD modelling requires an understanding or appreciation of the assumptions within all the different urban drainage system models, including the different equations and default parameters used, for example, weir coefficients in sewer and river modelling packages can be significantly different.

An indication of the experience and training necessary within a team is given in the CIWEM UDG Code of Practice for the Hydraulic Modelling of Urban Drainage Systems (**CoP**[1]) and in the CIWEM UDG Competency Guide for Wastewater Network Planners (**Competency Framework**[2]). The **CoP**[1] is focused on sewer systems, whereas IUD modelling encompasses all sources and mechanisms of flooding. There are currently no competency guidelines for fluvial modellers.

The ideal situation will be that a multi-disciplinary modelling team with experienced fluvial modellers will be used. However, it is recognised that many integrated drainage models may only have a small watercourse component and accordingly many experienced wastewater modellers will attempt the watercourse modelling. In some instances when timescale and budget allow, it may be possible for wastewater modellers to teach themselves through tutorials and/or trial and error. It is however, recommended that any wastewater modellers undertaking fluvial or pluvial modelling should have received some formal training.

In respect of fluvial hydrology, the situation is likely to be different and it is unlikely that wastewater modellers will have the necessary skills to adequately determine the fluvial hydrological inputs into the model. **Appendix H** provides some guidance as to when it is essential to include an experienced Fluvial Hydrologist in the modelling team.

A3.3 Data Sharing Protocol

All Partners and Stakeholders are required to adhere to data security regulations (for example, GDPR) in relation to the confidentiality and security of personal data. However, it is not always appreciated that some data that is useful for IUD modelling is commercially confidential. Much of the data WaSCs hold is commercially confidential, whilst most data held by Local Authorities and Government departments can be disclosed without restrictions. In 2010, the UK Government created the Open Government Licence, and public bodies in the UK can now publish their Crown Copyright material under this licence. Material marked in this way is available under a free, perpetual licence without restrictions beyond attribution.

It is important that the PSG considers the confidentiality of all data to be used in the IUD modelling project and agrees a Data Sharing Protocol that will set out any licensing arrangements, disclosure of data to third parties and any other aspects that are relevant.

With an increased prevalence of remote working the data sharing protocol should also set out what communication programmes are permitted to be used and what security arrangements are required.

A3.4 Purpose and drivers

Before embarking on producing a new integrated hydraulic model, or coupling together existing models, the purpose and final use of the model should be clearly defined. If the final model is to be used to design a scheme, that should be recognised from the outset. IUD modelling is likely to be more technically complex and time consuming compared with traditional drainage or river modelling methods. As such, the various stakeholders and modellers need to consider why IUD modelling may be required for each catchment or study. Typically, IUD modelling may be required in order to:

- understand complex interactions between different components of the urban drainage systems
- understand multiple sources of flooding
- map areas at risk of surface water flooding
- calculate damages from flooding
- identify, evaluate and design integrated solutions (across minor and major systems)
- determine relative contributions from different stakeholders to fulfil their obligations

In each case, there is potential for differing requirements in terms of modelling techniques, standards of data collection, modelling detail and verification, leading to varying levels of model confidence.

It is, therefore, necessary to define the information required from the model, the points at which this information is required and the confidence required in the modelled outputs. The

Project Steering Group would normally be responsible for defining this. The PSG should determine which Partner organisation will be the custodian of the completed model, after taking account of the requirements of key stakeholders. In some instances, others may need to approve the modelling scope. For example, an Environmental Regulator may need to approve a model to be used for assessing the impact of intermittent discharges on the receiving environment.

There are significant differences between software packages and, in many cases, the methods that can be used to interlink models using different programs will vary considerably. For example, the interlinking of a minor and major system model from the same software provider will be substantially different from the methods used to interlink two or more models from different software providers. In some cases, it may be necessary to convert a model built using one program to a different one to make it more compatible for interlinking. **Section A5** provides some guidance on the differences and compatibility of different software packages.

A3.5 Assessing and measuring confidence

There is a degree of uncertainty in many aspects relating to modelling. The list of areas of uncertainty is large, given the number of data inputs and the complex numerical calculations that transfer physical processes into a mathematical form.

Over the years modelling practice has developed to attempt to manage these uncertainties by developing standards for significant elements of the modelling process for both inputs and outputs to provide some level of confidence in the modelled outputs.

It is important that the PSG considers the required confidence levels for the specific purpose of the project. Requesting confidence levels too high will result in an unduly expensive model, whereas levels set too low may result in a model that does not meet expectations. In most instances, budget constraints will have to be taken into account in defining the data collection and verification requirements that affects confidence.

The level of detail required for data collection is considered further in **Section B1**, and verification is considered further in **Section B4.** **Section A4** provides a framework for confidence to be assessed using a qualitative approach.

It is unlikely that a uniform standard of confidence will be needed across the whole model. The PSG will need to determine those areas (zones), watercourses or elements of the model that require a higher level of confidence, for example, in an area of reported flooding or a storm overflow discharge known to be impacting on the receiving environment.

A3.6 Collating appropriate existing information

Before undertaking any modelling it is vital to collate all existing data, models and reports from previous studies. This is to gain the best possible understanding of the existing problems in the study area (or future drainage problems due to changing demands such as new development, urban creep or climate change). Much of this data may already be available through previous feasibility or modelling studies. However, other potential sources of data should be identified and explored.

Further details on the data necessary for successful IUD modelling are outlined in **Section B1,** and **Section B2** provides guidance on how the data can best be managed.

A3.7 Reviewing and assessing existing models

Many Partners or Stakeholders have model libraries that contain a variety of different models built at different times, for differing requirements and using different specifications. It is possible that these models were built with obsolete hydraulic modelling software or more commonly earlier versions of the current hydraulic modelling programs.

The availability and suitability of existing models should be identified at the start of the IUD study with an assessment of their fitness for purpose. This involves assessing the suitability of the model and the confidence in the model for the intended use in the location where the IUD study is to be undertaken. The following issues should be considered in relation to the specified objectives:

- the purpose for which the model was originally built
- the date it was built
- the methodology of data collection
- the software and version used to run the model
- the implications of any simplifications, omissions or shortcomings in the model
- the implications of any updates or new releases of the software
- any changes that have been made to the network since the model was built
- the ability to predict flows and depth/surcharge levels with confidence in the area being considered. This would involve an assessment of the existing level of verification or calibration
- the level of detail in the linkage zone or boundary condition to another IUD model

Where an existing model is being considered for reuse, a formal assessment process should be carried out (unless one has already been done), allowing model confidence levels to be assessed in the areas detailed in **Section A3.4.**

The process should start with a review of the documentation of the previous model, if available, to ensure any limitations in the model are understood. If no documentation is available, additional checks will be required as there will be no information on how the model was built and verified.

It may be beneficial to carry out a two-stage process. This would entail a quick overview assessment to identify if the upgrade and reuse of the model is economically viable. If the model has good potential to be used, the second stage of the process would follow with a more detailed examination and assessment of the work required to bring it up to the required standards for the current purpose. Of particular importance with fluvial models is the way in which hydrological inputs were determined and whether the approach is still valid and can be adapted to be used in the IUD model.

The work involved in adapting existing models should not be underestimated and sometimes it may be more cost effective to start again and construct a new model.

The review must be undertaken before the model is used at any stage in the IUD study. A model that was identified as 'good' or 'fit for purpose' for a previous modelling study in the past, may not necessarily be so for the current IUD study. It is important that the modeller understands the original purpose of the model when reviewing the model to use in an IUD study. This can give early indications as to how useful the model may be and indicate any further model upgrade or verification requirements in the interaction areas.

A3.8 Types of model use and levels of detail

Section A2 sets out how the modelling concept for an IUD project can be developed and four examples are given. In addition to the model concept, it is also important that the level of detail required in each part of the model is identified and recorded. This section provides information on the typical levels of detail in models and their typical use.

Models (both existing and new) are likely to be defined based on their purpose and following a convention that considers four principal aspects of the model:

- The level of detail of the model
- What parameters are modelled, limited to hydraulic only in this Guide
- The number of dimensions in which the modelling is undertaken
- The hydrology that has been used in the model

All types of models may contain elements of the Minor Systems and/or Major Systems but the general principles apply in all situations.

The **CoP**[1] provides guidance on types of models and appropriate levels of detail. For most existing models of sewer systems this approach has been used and in the interests of consistency the same approach is set out in this Guide.

A3.8.1 Level of detail of elements of the model

The level of detail will generally fall within one of the following categories:

- Type I – limited detail, simplified, typically used in locations to gain an appreciation of hydraulic performance or to transfer flows to a more detailed part of the model
- Type II – planning, general purpose, typically used in locations to understand risk
- Type III – high level of detail, typically used in locations for detailed investigation and design

It is important to recognise that these model types help define the level of detail but not the level of confidence, which is a different matter, see **Section A4**. Many models built or updated will be a 'Hybrid' of the three levels, that is, they will have a varying level of detail in specific areas or in relation to certain types of assets or features, as detailed in the project scope. At locations where there are particular problems to be resolved or where intervention works are likely to be proposed, it will normally require a more detailed (Type III) approach in those areas.

Models typically have two components. These are:

- Flow generation: sub catchment definition, direct runoff, inflow hydrographs etc to give the parameters that are used to generate the flow (fluvial, foul sewage, surface water runoff, etc.)
- Physical details: definition of the assets (watercourse channels, manholes, pipes, channels, flow paths, ancillary structures, etc.)

Type I - Simplified

This type of model as its name implies, is a highly-simplified representation of the modelled network or river. Typically, this type will have specific objectives related to the whole catchment or applied to part of a large catchment. The specific objectives of this type of model detail could include providing:

- A simulation of the flows and conditions at one or more specific locations (for example, outfall, pumping station, treatment works)
- A simulation of the boundary conditions in a trunk sewer, an intercepting sewer or a watercourse so that more detailed model networks can be modelled with the correct downstream conditions, etc.;
- A simple framework model of a network into which a detailed model can be incorporated, obviating the need for boundary conditions to be deduced
- A reasonably accurate representation of a trunk sewer system, an intercepting sewer system or a watercourse without needing to model exactly the layout of tributaries or contributing sewer networks
- The backbone of a rapid simulation model such as one that might be required for flood forecasting purposes

These types of models on their own are not adequate for assessing flooding or other issues. However, Type I models may be successfully used as part of an integrated (hybrid) model.

Type II – Planning Type

This type of model detail is considered as ‘general multi-purpose’. This would typically be the default type of model in the absence of any specific requirements.

This provides an overview of a specific catchment area, which might be a discrete catchment in its own right or may be part of a larger catchment. The purpose of this type of model detail for hydraulic purposes is primarily as a planning or assessment tool to:

- Identify hydraulic problems within a drainage area, including identifying flooding risks, pluvial runoff area, surcharged pipes, throttles, reverse flows
- Simulate and identify the performance of Combined Sewer Overflows and other ancillaries
- Identify the need for possible hydraulic upgrading schemes and to carry out initial scheme appraisals
- Assess the impact of proposed developments, climate change and urban creep

Type II model detail should include all significant ancillaries and typically all known problem areas, particularly those of known flooding or surcharge. Simplification of the drainage network in the model is not normally undertaken, although consideration could be given to trimming smaller diameter sewers of 150mm or below from the model. All low-lying manholes and gullies at low points should be included in the model.

For watercourses, it would be expected that all ancillaries and structures would be included, that river cross-sections would be no more than 100m apart (except with sinuous or multiple channel water courses when closer intervals would be required) and the bank lines are clearly defined and match with the Lidar data.

Flow generation will be by an appropriate combination of direct runoff (pluvial) methods, rainfall-runoff methods, inflow hydrographs and wastewater generation.

Type III - Detailed

This type of model detail is appropriate for detailed investigations, scheme appraisals and for the detailed design of schemes. Generally, this level of detail will be confined to specific areas of interest.

Existing models may already be Type II models but will require a greater level of detail to become Type III models. Accordingly, it is frequently necessary to undertake additional surveys in specific areas of interest to obtain information not held in records and to confirm the accuracy, rather than rely on interpolated data.

Type III model detail will typically be within a model of Type II detail.

Flow generation will be similar to Type II models.

A3.8.2 Dimensions

The number of dimensions used in simulations will generally fall within one of the following categories:

- 1D – one dimension (for example, a sewer and/or a watercourse model). This would only comprise a forwards and backwards motion.
- 2D – two dimensions (for example, a pluvial runoff and overland flow model). This would involve a sideways movement as well as a forwards and backwards movement.
- 1D-2D - a coupled one dimension and two-dimension model (for example, with sewers and watercourses modelled in 1D but coupled with a 2D mesh to model overland flow).

The choice of how many dimensions are included in the model simulations will rely on the precision and accuracy in below and above-ground elements that are being integrated in the model.

A 1D model is able to simulate flows below ground level where water travels in one direction (such as in pipes or river channels) to high precision and accuracy. However, this does not enable a representation of flood extents or depths of flows above ground.

A 2D model is able to simulate flows across a ground surface (in more than one direction). This allows modelling of flows such as in a floodplain or across urban areas. However, the accuracy of channel representation and model runtimes can pose challenges.

An Integrated 1D/2D model can accurately represent flows in both storm drainage systems and river channels with a high degree of detail, as well as the flows across rural and urban surfaces under a wide range of flow conditions.

A3.9 Hydrology

There are a number of alternative methods for modelling the hydrology of a catchment, and the most suitable method to use will depend on a number of factors. There are significant differences in the use of normal hydrological methods for fluvial models and the multitude of methods used for urban drainage system models.

Reconciling the different hydrological methods is one of the most difficult aspects to resolve in Integrated Urban Drainage modelling, but, in most cases, it is fundamental to the success of an integrated model.

It is important that the hydrological approaches are reconciled at the project definition stage, especially if the project involves integrating existing models. This is introduced in **Section B3**, with more information in **Appendix H** of this guide.

A3.10 Modelling boundary conditions and interactions

As part of the project definition the PSG will need to understand the extent of interactions between the major and minor systems, in order to define the major system modelling requirements. In assessing this potential interaction, local knowledge is important, and information should be sought from other stakeholders, including Operations staff, who might have specific knowledge.

Checks should be made at outfall locations against fluvial flood map outlines (or with flood levels if available) for the appropriate return period to identify potential issues with locking of outfalls.

The response time of the watercourse to rainfall is critical when considering interactions. If the minor system and major system have similar times of concentration there is a strong case to integrate the two systems. If the major system has a significantly greater time of concentration a case can be made for the two systems to be treated independently.

Section B3 of this guide provides further guidance on hydraulic modelling, including the application of boundary conditions in integrated modelling, including consideration of joint probability and combined source events (for example, fluvial-tidal). At the Project Definition stage it will be important to begin thinking about appropriate boundary conditions and event combinations.

A3.11 Determining the IUD modelling strategy

An appreciation of the nature of the existing problems helps to define the IUD modelling strategy. This may include the agreement to upgrade existing models or build from new. If the influence of the different drainage systems, the watershed catchment boundary and interactions are well understood, it can be relatively straightforward to confirm the various disciplines of modelling required, the areas of interaction and the level of detail necessary. Where it has not been possible to develop a good understanding of the nature of the problem, then further data gathering and assessment should be undertaken to help plan the approach.

There are five key areas to developing an IUD modelling strategy:

- Confirm IUD modelling approach
- Determine new data requirements
- Determine modelling program(s)
- Agree model audit process
- Identify outputs and deliverables

A3.12 Confirming IUD modelling approach

A 'risk-based' approach prioritises modelling effort in locations of greatest risk. In general, the advice given here is to increase the level of modelling effort in those areas that are at greatest risk of flooding. Ultimately, the modelling approach used should be sufficient to answer the following questions with reasonable confidence:

- What is the probability of flooding occurring?
- What are the flood mechanisms in the study area?
- Which areas are at risk of flooding?
- What is the consequence of flooding?

The modelling approach used must be appropriate to the nature, complexity and scale of the problems to be addressed. It should be realistically achievable with the models that are available and/or that can be upgraded during the course of the study.

The approach should consider which components of the urban drainage systems need to be represented and to what level of detail. There should also be reflection around the modelled representation of potential flood risk reduction methods, which may form part of a mitigation for the flooding. This may have an impact on the model construction, and should be considered as part of confirming the approach.

Potential interactions between the various systems should be accounted for, as should the necessity to combine individual component models or extend models to include additional parts of the system. Models should be of sufficient extent or have boundary conditions applied to ensure all contributions are included.

The process required to select the modelling tools depends very much on the scale and complexity of the problem being investigated. As with all modelling studies, the modelling approach taken must be of the necessary technical standard to represent that problem to a level of accuracy that is acceptable to all individual parties and their own risk profiles.

A3.13 Documentation

Documentation is vital to carrying out a modelling project successfully. As a minimum, a scoping or project definition report should be produced. This would include the project objectives, the extent and type of models to be built, the data collection requirements and the results of any 'fit for purpose' reviews outlined. **Appendix B** provides an example form/checklist that could be used to support decision making and documentation in the Project Definition stage. It is likely that the PSG will want to approve the modelling approach set out at this stage and may also request that it is reviewed by the Environmental Regulator.

A3.14 And afterwards...

There is a significant cost involved in developing hydraulic models. It has been estimated that for WaSCs to rebuild all their sewer hydraulic models across the UK the cost would be around £500million.

The value of integrated urban drainage models will probably be less than this because a substantial element of the cost is for surveys. However, integrated urban drainage models represent a significant asset. Adequate maintenance over time will enable them to be used for a variety of purposes, including assessing the consequences of proposed changes in the catchment.

It is therefore recommended that even at the project definition stage consideration should be given to:

- How data will be shared?
- Will all Partners retain a copy of the model and, if so, how will any updates be controlled?
- Which Partner(s) will be the custodian of the final model?
- Will the model be maintained and, if so, by whom and how frequently?
- Who will be responsible for funding any ongoing model maintenance?
- Who will have access to the model?
- Will the model be available to external third parties (for example, Developers)?
- If external third parties are allowed to make changes to the model, how will they be checked and how will the changes be incorporated into the main model?
- Any other aspects associated with storing and/or maintaining the model

Section A7 of the Guide summarises the techniques that can be used to maintain models.

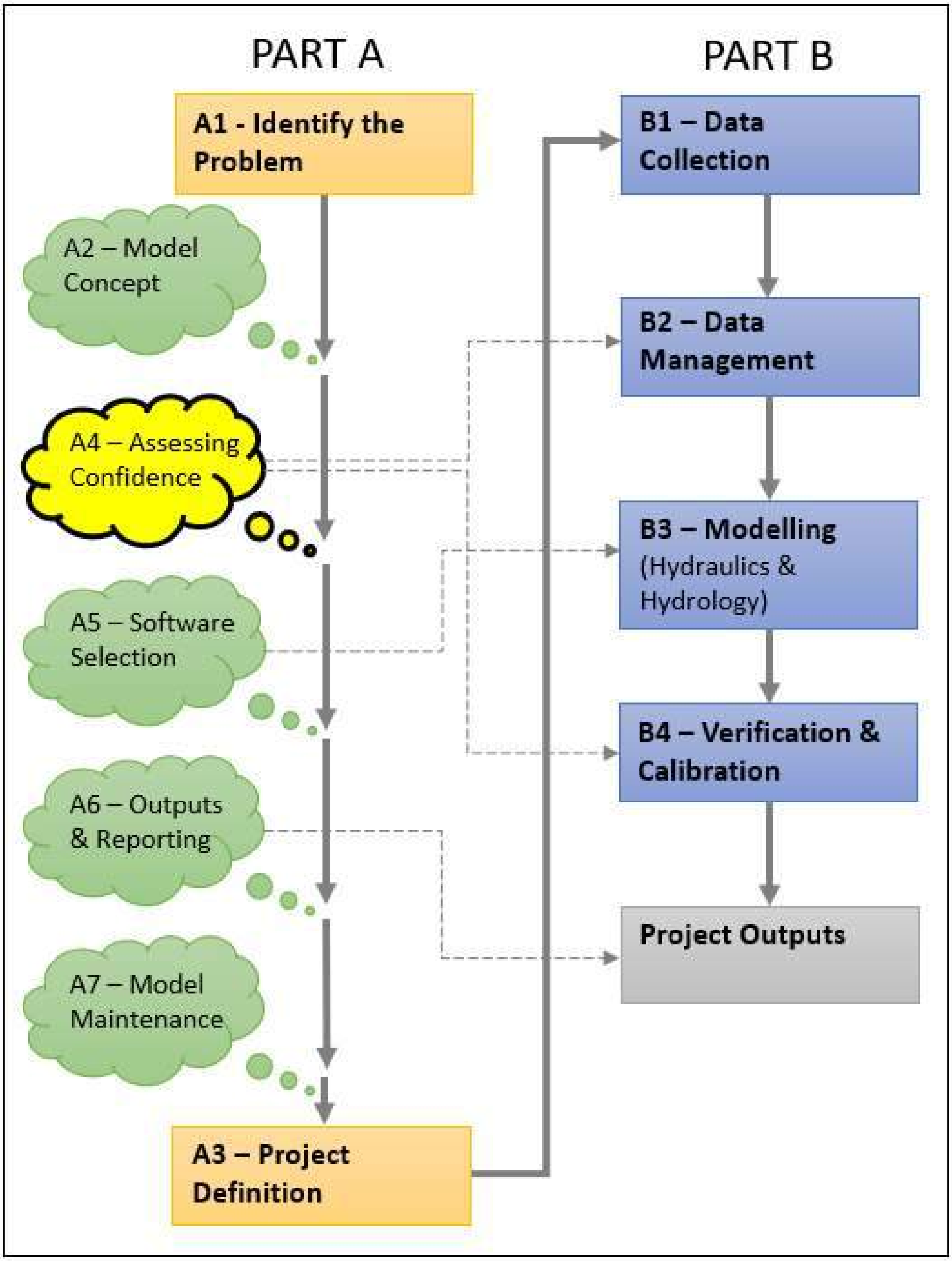
Integrated Urban Drainage Modelling Guide

Section A4

Assessing Confidence

CIWEM Chartered Institution of Water and Environmental Management

A4. ASSESSING MODEL CONFIDENCE



A4.1 Introduction to assessing model confidence

Model confidence is a critical factor in managing risk and uncertainty in all modelling processes. Models vary in their ability to replicate real-life performance and therefore in their fitness for intended use.

Using a system to qualify and/or quantify the risk and uncertainty against a range of metrics facilitates assess confidence in a consistent way to demonstrate how well models meet their required purpose. This enables confidence to be assessed and compared consistently.

This section sets out the guiding principles to consider when assessing model confidence and provides a framework to develop a confidence assessment approach.

Historically, model confidence has generally been based on expert judgement using model 'fitness for purpose' reviews with internal and, in some cases, external audit. This has taken into account all aspects of the model building and verification process in order to assess the confidence and limitations of the model. This is by its nature subjective and relies on judgement.

The CIWEM UDG Code of Practice for Hydraulic Modelling of Drainage Systems (**CoP**[1]) sets out two possible approaches to the assessment; a qualitative assessment building on historical practice but with more visual reporting, and a quantitative approach based on a scoring system. Whilst a quantitative approach can be applied to sewer models without too much difficulty, when evaluating the confidence in integrated models created from a wide variety of sources, a quantitative approach is considered to be too complicated. Therefore, this Guide only considers a qualitative (for example, a Red-Amber-Green) approach.

It is however, important to recognise that the final overall confidence assessment will always be a matter of expert judgement, which is why sufficiently skilled and experienced personnel are required to make the final judgement. It may be that personnel from different disciplines collectively make the final judgement as there are unlikely to be sufficient resources with adequate skills across all disciplines.

A4.2 Confidence assessment general principles

The confidence assessment approach should be transparent, consistent and repeatable. It should enable data to be interrogated, analysed and displayed geospatially at an appropriate scale. It should also be recognised that the confidence could vary over time due to changes in vegetation and geomorphology etc.

When existing models are reused in an integrated way it is likely that the Partner organisation that created that model will have already assessed the confidence in that model or the inputs to it. It is therefore important that the confidence assessment approach used for integrated models is able to take account of the previous work undertaken to assess confidence. The age of data, especially when used in a previous model, can be a factor in assessing the confidence that can be applied to that data.

The Project Steering Group (PSG) should determine at Project Definition Stage the confidence assessment approach to be used, tailored to that individual project. It is suggested that the categories for confidence assessment should (where relevant) consider:

- Asset (sewerage system) data confidence;
- Asset (watercourse culverts) data confidence;
- Watercourse (open channel) data confidence;
- Hydraulic structures data confidence;
- Sub-catchment data confidence;
- Hydrological confidence;
- Flow/level data confidence;

- Flow/level verification confidence;
- Flood extents, depths and frequency record data confidence;
- Surface features data confidence;
- Historical verification confidence.

A4.3 Evaluation approach

The evaluation approach should clearly set out how to rate the individual metrics in each category. The method applied will inevitably include an element of subjectivity and judgement but that should be minimised as much as possible to achieve consistency.

The PSG should consider the relative weighting or importance of the confidence categories depending on the purpose and requirements of the project. Some categories can be added or omitted as appropriate based on their importance in relation to how the integrated model(s) will be used in practice.

For example, each individual confidence category may be visualised in isolation and used qualitatively to evaluate the confidence at a specific location. Alternatively, a system may be developed that combines all the categories to give a single composite value of confidence at a specific location. A composite system, where developed, should be thoroughly tested, especially where weighting is applied to categories.

A qualitative approach may vary in detail. In its simplest form, this could be a zonally applied descriptive summary of the data quality and model performance in each confidence category. This approach is subjective and whilst flexible, may be open to inconsistencies when compared with other approaches. Alternatively, increased detail can be applied using metrics with fixed criteria or bands within a rating system, such as Red-Amber-Green. An example of bandings that could be applied to data collection is defined in Table A4-1 by means of four categories (A to D):

- Category ‘A’ – this is the best possible method with extensive use of surveys or good quality records

- Category ‘B’ – this method is based on a reasonable amount of good quality record data with a limited amount of assumed or estimated data based on interpolation or inferencing

- Category ‘C’ – this method makes use of extensive existing data with significant amounts of assumed or estimated data

- Category ‘D’ – this method uses limited amounts of existing data with extensive use of assumed or estimated data

This can then be followed by a number (1 to 3) to signify the quality that can be attributed to the data. For example, data that has been obtained with quality control testing could be classed as Quality 1, whilst that with little or no checking could be assigned Quality 3. Combining the category of data collection method with the assigned level of data quality results in a Red-Amber-Green assessment of confidence as shown in Table A4.1.

Table A4-1 Example Data Quality and Confidence Approach

Method of Data Collection	A	B	C	D
Data Quality 1	A1 Green	B1 Green	C1 Amber	D1 Amber
Data Quality 2	A2 Green	B2 Amber	C2 Amber	D2 Red
Data Quality 3	A3 Amber	B3 Red	C3 Red	D3 Red

A4.4 Using confidence assessment for planning data collection

The confidence assessments procedures described in the preceding sections can be applied both to the assessment of the confidence in existing data (and existing models) and also in planning the data collection requirements in order to meet the overall project requirements. Table A4.2 provides an example of how a matrix could be compiled. In this example, the following symbols have been used:

- ☑ Assessed confidence
- ★ Planned confidence required for planned data collection
- ⦿ Target confidence (this is generally used for a summary assessment, for example, historical verification)

Table A4.2 is not intended to be a definitive matrix of confidence levels for all aspects of an IUD project; it is just an example. As the overall confidence in a model can be achieved in a number of different ways, it is recommended that the PSG creates a specific confidence matrix for each project, with rows inserted or removed as required. Towards the right-hand side of the matrix some cells are greyed out; this is to signify that these are below the recommended confidence level.

At a later stage in the project when some initial results are obtained, it may be necessary to undertake further data collection. This will usually be for the areas inside the flood outlines and is likely to include details of the properties at risk of flooding (for example, property type, land valuation, property category, threshold levels).

Table A4-2 Example of Confidence Assessment for Planning Data Collection

	A1	A2	A3	B1	B2	B3	C1	C2	C3	D1	D2	D3
Sewerage system data												
Pipe data			☑									
Pumping Station data	★											
Storm overflow data					☑							
Outfall data				★								
Watercourse data						⊙						
Culvert (barrel) data					★							
Culvert inlets		★										
Bridges data				★								
Cross-section data (survey)	★											
Cross-section data (interpolated)							★					
Bank line data								★				
Roughness data						★						
Weir data					★							
Sub-Catchment data												
Soil/vegetation data								★				
Definition				★								
Impermeable/permeable areas					★							
Runoff hydrology					★							
Hydrological data					⊙							
Gauge data		☑										
Catchment characteristics		★										
Tide data				★								
Flow/Level data												
Short-term flow survey data		★										
Permanent monitoring data		☑										
Telemetry data				★								
Rainfall data				★								
DTM data												
Lidar data		☑										
Topographic survey data	★											
Flooding												
Flooding record data					☑							
Post-flood survey data			★									
Social Media data						★						
2D Modelling data												
Surface features data					★							
Roughness data					★							
Walls etc							★					
Verification				⊙								
Flow/Depth verification				★								
Historical verification			★									

A4.5 Using data flags in displaying confidence

Where available, including alphanumeric data flags in modelling software provides a method of displaying the confidence in the input data used in the model. Most WaSCs use a standard set of flags. Where the integrated model incorporates a sewer model that is already flagged, the flagging should not be modified without agreement, and ideally any new data added to the model should use the same standard flags. Where data flags are used in the confidence assessment, the approach should consider how these might be used in parallel with or by modifying existing standard flags. As illustrated in Table A4-1, the data flags should be colour coded so that the confidence in the data can be visualised.

It is important that the impact of 'default flags' is understood when being used to assess confidence. If default flags in an existing model are to be replaced by confidence flags, then the values will need hard coding into the model data before the default flags are replaced.

A4.6 Assessing confidence in spatial units

The model confidence should be assessed at an appropriate spatial scale. For each category, the spatial unit may be:

- Asset data confidence - Point or zone, for example, project boundary, drainage area or storm overflow
- Sub-catchment confidence – Zone, for example, project boundary, drainage area or storm overflow catchment
- River reach – Point or zone, for example, river cross-section
- Flow data confidence - Point or zone, for example, flow monitor location
- Flow verification confidence - Point or zone, for example, flow monitor subcatchment
- Historical verification confidence – Point or zone, for example, flooding project area or storm overflow
- Within each spatial unit the confidence can be assessed by visualising the number of red, amber and green flags. This can be translated into a simplified overall confidence assessment as follows:
    - High Confidence – where 50% or more of data items have green flags and no more than 20% have red flags
    - Medium Confidence – where 40% or more of data items have green flags and no more than 30% have red flags
    - Low Confidence – where there are less than 40% of the data items with a green flag or more than 30% have red flags
- Obviously, different aspects of the model can have different confidence assessments within the same geographical area. For example, sewer asset data might have a higher level of confidence than the contributing area data

A4.7 Visualising confidence

Where the modelling software used allows, the confidence should be displayed geo-visually for the whole model as illustrated in Figure 4-1. Figure 4-1 shows the confidence in sewer data, with the colour of the lines showing the confidence and the line style showing the purpose of the sewer. A similar approach can be given to river reaches and culverted watercourses. Visualisation like this enables the confidence categories to be viewed either in isolation or together, and allows the user to switch between categories.

In order to visualise the data confidence geospatially for all categories and spatial units, a process will be required to generate composite scores; this can be based on the suggested confidence criteria described above. Where composite confidence values are produced, these can be displayed across a range of spatial units, relevant to the purpose of the model.

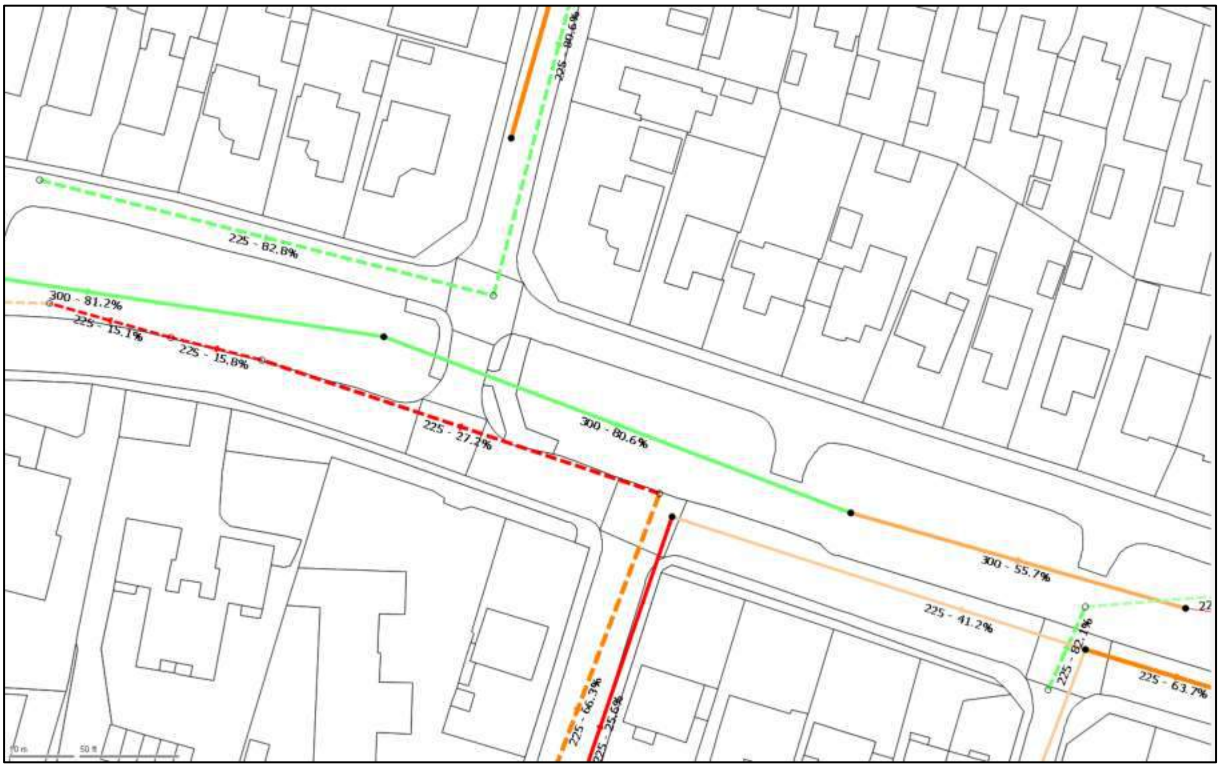
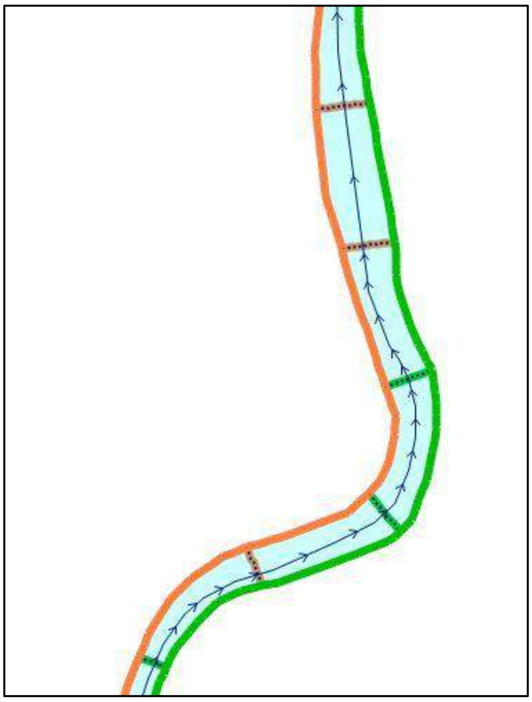


Figure A4-1 - Visualising Confidence – Sewers and Watercourse Culverts

In a similar way, the data confidence in relation to river reach modelling can also be visualised as shown in Figure A4-2.

Figure A4-2: Confidence Visualisation for Watercourse



In this Figure, the cross-sections and bank lines shown in green have a higher confidence (perhaps from surveys), whilst the other cross-sections and bank line shown in amber have a lower confidence level. Some simulation software can show this visualisation on their geoplan view, whilst other programs may require an export to a GIS program, which is then imported as a background to the network data.

Figure A4-3 shows how the simulation results can be visualised in comparison to the recorded flood outline, which is shown by the heavy black line. This visualisation enables the comparison to be easily appreciated.

Figure A4-3: Visualisation of Simulated Flooding compared to recorded flood outline

Another way in which data or simulation results can be visualised is by means of time-varying hydrographs as shown in Figure A4-4. This Figure is for the dry weather verification at a particular flow monitor; the procedure for creating these is explained in the **CoP**[1].

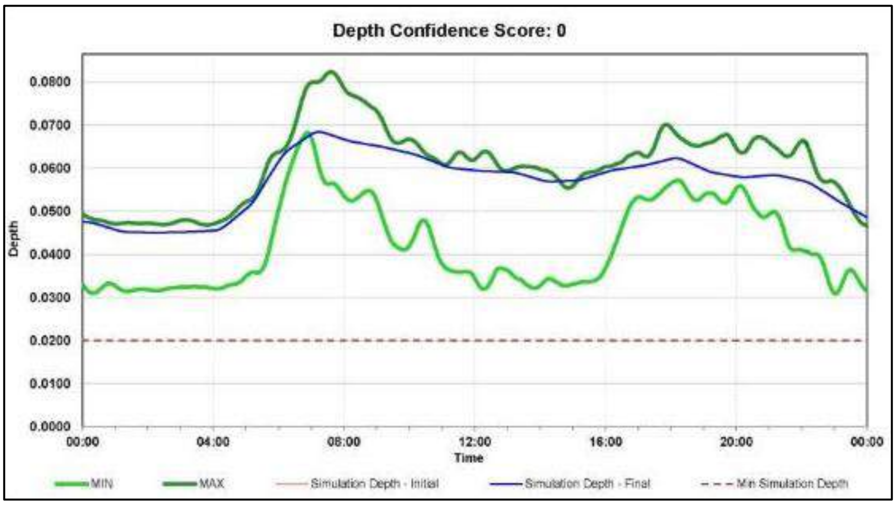


Figure 4-4: Visualisation with time-varying hydrograph

A4.8 Asset data confidence

Asset data accuracy has a direct impact on hydraulic model performance and is a key metric in assessing model confidence. Asset data confidence is a function of the quality of that data and its importance in the simulations. For example, pipe dimensions are far more important than the pipe material. **Section B1** describes how asset data may be acquired, assessed and categorised when it is entered into the model.

In relation to pumping stations and any other mechanical installations that respond to or can influence the flow regime it is important that the control/operation rules are given due consideration in respect of confidence. Simply taking an Operator's description is rarely adequate without some form of measurement and record keeping.

A4.9 Sub-catchment and polygon confidence

Section B3 describes how sub-catchment areas should be defined, assessed, surveyed, applied and amended during the model build and verification process. Elements to be considered for a confidence assessment may include:

- Area of runoff surfaces
- FEH catchment characteristics
- Connectivity of the area to the drainage system
- Runoff and routing model
- Soil classification

- Infiltration characteristics
- Surface and vegetation cover
- Rainfall profiles
- Dry weather flow components (population, PCC, trade/commercial flows and infiltration)

The assessment should consider the method of data acquisition, the data quality and whether the data has been modified during the verification process.

Alterations made without justification and evidence should be highlighted.

A4.10 Watercourse data confidence

Data for culverted watercourses can be treated in the same way as for the sewerage asset data. Particular attention needs to be given to assessing the confidence in the data used to model culvert inlets as these are usually the governing factor in the flow through a culvert. **Appendix F** provides some guidance on how culvert inlets should be modelled and illustrates the importance of each of the parameters.

Appendix D provides some guidance on undertaking topographic surveys in relation to watercourses and watercourse structures. Where river cross-sections are surveyed, a higher confidence can be applied when compared to cross-sections that are interpolated between surveyed cross-sections. The more interpolations that are made the lower the confidence becomes. Assigning a realistic confidence to bank lines is important when the model is a coupled 1D-2D model.

A4.11 Hydrology confidence

There are a number of different hydrological techniques that can be used. These are summarised in **Appendix H** and in **Section B3**. There are clear differences in the confidence that can be attributed to data from gauged catchments as opposed to ungauged catchments. It is usually the case that data availability will dictate the hydrological approach to be taken rather than the confidence requirements. Confidence in the results of a hydrological assessment will obviously depend on the confidence that can be attributed to the different items of input data, but thereafter it is largely subjective. Confidence can be increased by an independent Peer Review.

A technique that can also be used to increase confidence in the hydrological assessment is to carry out sensitivity assessments either on key items of input data or on the hydrology study results (for example, flow hydrographs).

A4.12 Data confidence for 2D features

The principal data for 2D modelling is Lidar data. **Appendix C** provides some guidance on how Lidar data is acquired, the accuracies that can be achieved, the problems associated with filtering and the use of ground truthing surveys. All of this information will enable an informed assessment to be made of the confidence that can be applied to the Lidar data.

Other data can be obtained from Ordnance Survey MasterMap data and also from images available in Google Streetview. There can be no substitute however, for visiting the site and measuring the height of walls, kerb faces etc and the location and condition of road gulleys.

A4.13 Flow and depth data confidence

Flow data is generated through the short-term and/or permanent monitoring of the velocities and/or depths/levels within the drainage systems. **Section B1** describes how this data can be collected and assessed for quality and accuracy. The confidence in the flow data should be assessed during the data collection phase. The following three metrics could be considered.

- The quality and accuracy of the monitoring equipment is particularly important for permanent installations where confidence may be categorised using a number of checks, including the amount of lost data, usability of data (ability to understand what the data is saying, knowledge of datum, where the measurement point is, what is being measured), and the record of checks and the accuracy at each site.
- Scattergraphs generated for depth and velocity data should be evaluated and categorised for quality when received. The **CoP**[1] provides advice on how scattergraph confidence can be assessed.
- Upstream and downstream flow balances should be checked and any issues dealt with where possible during the survey period. Confidence can also be assessed through correlation between data from gauges elsewhere in the catchment (or in some instances in other catchments). When assessing large volumes of hydrometric data from river gauges, double-mass plots and time series analyses can help to identify data quality issues at a specific gauge or to identify any gradual shift. This can form part of an assessment of gauged data confidence. Unresolved issues should be identified by assigning an appropriate low confidence rating for the flow data.
- When level or depth data from river gauges is translated to flows by means of a rating curve, there needs to be a confidence applied to that rating curve. Inevitably the confidence in flows determined in this way will be lower than the confidence in the original level data.

The flow data confidence is closely linked with the verification confidences as poor data will automatically impact on verification confidence.

A4.14 Confidence in Social Media data

There will be a considerable variation in the confidence that can be applied to social media data. Contemporaneous photographs or video recordings with time/date stamps, geo-referencing and clear images will obviously attract a far higher confidence than data that does not have these attributes incorporated. **Section B1** describes how social media data can be collected and assessed for quality and accuracy.

A4.15 Flow verification confidence

The **CoP**[1] provides advice on how the confidence in flow verification can be assessed.

A4.16 Historical verification confidence

Historical verification confidence can be assessed by comparing the results of model simulations with recorded flooding or overflow spill data. The degree of match can be assessed to give a confidence for each of the spatial units or attributes required.

The model should be divided into appropriate spatial units that represent the areas deemed important. This may be the whole model or a specific project area(s). The confidence assessment should consider the flooding of properties or area, the flooding source (sewer flooding, pluvial flooding, fluvial flooding), whether the flooding has been reported, and flooding mechanisms.

In 1D sewer models the criteria to consider may include the number of manholes flooding, the number of properties flooding (below or above ground) and the spatial distribution of the flooded manholes.

For historical flooding confidence, where there is frequently less reliable data, it may be necessary to adopt a more subjective approach, perhaps making use of social media data.

All metrics should consider the level of detail used and interrogated, recognising that there may be uncertainty in the input data and the level of field evidence collected. Very onerous criteria may give a perceived indication of low confidence, whereas in reality the model may adequately predict the flooding at a given location.

A4.17 Example of Confidence Assessment Matrix

Table A4-3 provides an example of a confidence assessment matrix for a completed project. In this example, the same symbols have been used as in Table A4-2 and, for comparison purposes, the planned data collection levels have been retained where they are different from the finally assessed levels.

As with Table A4-2, this is only an example and for each individual project some rows could be deleted, and additional rows inserted as required.

Table A4-3 - Completed Confidence Assessment Matrix

	A1	A2	A3	B1	B2	B3	C1	C2	C3	D1	D2	D3
Sewerage system data												
Pipe data			☑									
Pumping Station data	☑											
Storm overflow data					☑							
Outfall data		☑		★								
Watercourse data			☑			⊙						
Culvert (barrel) data					★	☑						
Culvert inlets		★	☑									
Bridges data			☑	★								
Cross-section data (survey)	☑											
Cross-section data (interpolated)							☑					
Bank line data					☑			★				
Roughness data					☑	★						
Weir data		☑			★							
Sub-Catchment data												
Soil/vegetation data						☑		★				
Definition				☑								
Impermeable/permeable areas				☑	★							
Runoff hydrology			☑		★							
Hydrological data		☑			⊙							
Gauge data		☑										
Catchment characteristics		☑										
Tide data			☑	★								
Flow/Level data												
Short-term flow survey data		☑										
Permanent monitoring data		☑										
Telemetry data				★	☑							
Rainfall data			☑	★								
DTM data												
Lidar data		☑										
Topographic survey data	★	☑										
Flooding												
Flooding record data					☑							
Post-flood survey data	☑		★									
Social Media data						★	☑					
2D Modelling data												
Surface features data					★	☑						
Roughness data				☑	★							
Walls etc					☑		★					
Verification		☑		⊙								
Flow/Depth verification		☑		★								
Historical verification		☑	★									

A4.18 Weightings and 'Fitness for Purpose' Review

The qualitative confidence assessment processes described in this section of the Guide will give an insight into the confidence in the different elements that are included in the completed model. However, there is a need to understand the relative importance or weighting of these elements in assessing the confidence in using the model for a particular purpose.

An example of this would be a storm overflow with detailed flow measurement. If the requirement was just to understand the spill frequency and volume from the storm overflow, then good historical and flow survey verification would have a very high weighting, and the asset and sub-catchment confidence in the upstream catchment would be of lower interest. However, if there was a project required to resolve the storm overflow impact by surface water reduction upstream, the sub-catchment confidence would be very important in the potential areas of the solution.

Hence the relative weightings of the different elements will change depending on the intended use of the model. Therefore, an expert review process that makes use of the information provided by assessing the confidence in the individual elements of the model will still be needed.

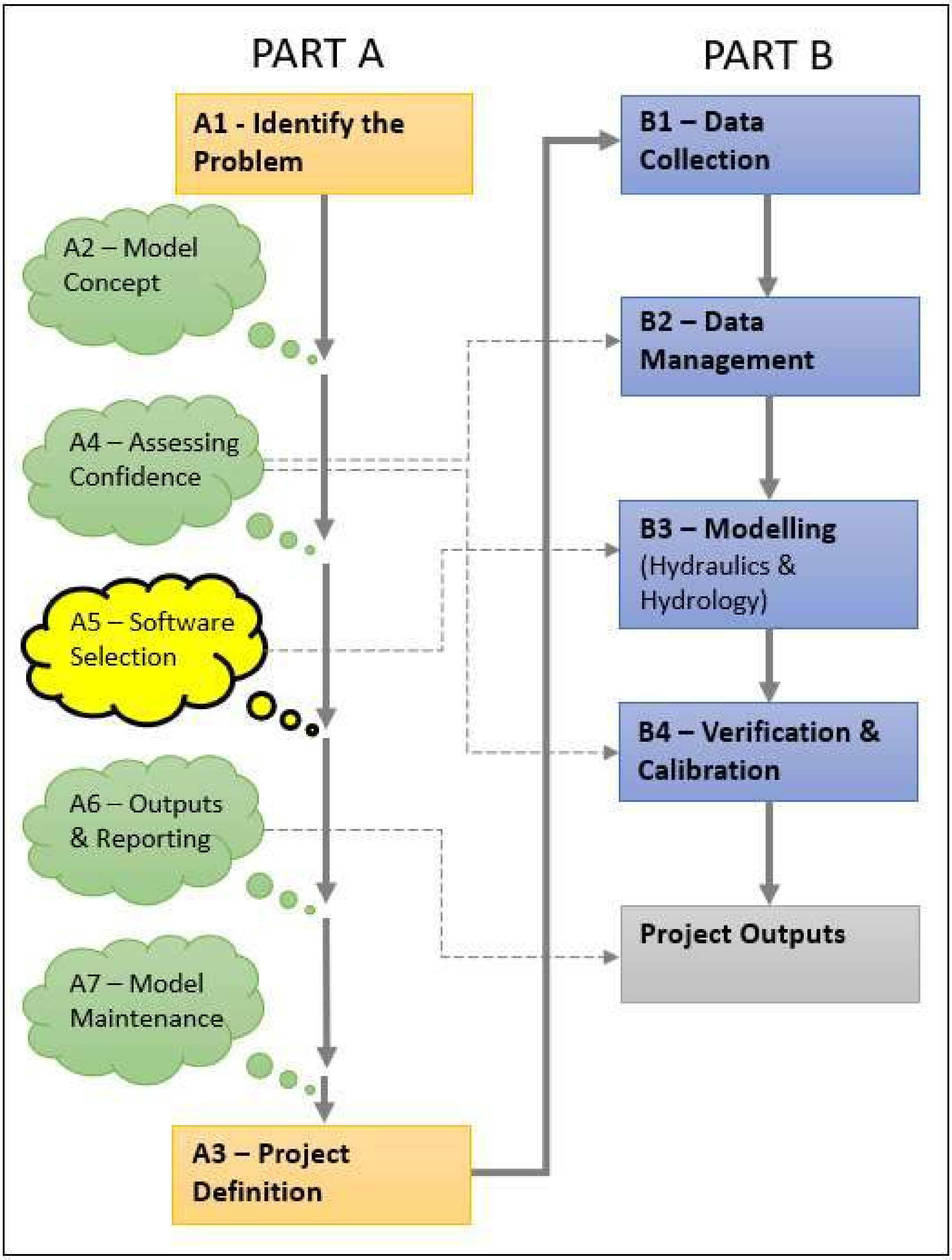
Integrated Urban Drainage Modelling Guide

Section A5

Software Selection

Chartered Institution of Water and Environmental Management

A5 SOFTWARE SELECTION



A5.1 Introduction

Before selecting the software to be used for the project, the problem should be fully identified (**Section A1**) so that it is clearly defined and there is at least a basic understanding of the main flooding mechanisms that need to be represented by the Integrated Model, as well as an understanding of any existing models and an idea of which Model Concept Type is likely to be needed (see **Section A2**). The choice of software for constructing and simulating an Integrated Model should be made during the **Project Definition** stage (**Section A3**) and agreed with the

Project Steering Group. This is likely to be informed by a number of considerations, not least knowledge of the software type used for any existing models.

The Guide is written in a way which tries to be agnostic to particular software products, whilst providing some guidance on the typically available modelling programs for UK based projects. This has been prepared following a workshop with software providers and developers (January 2020) and reference is made to the Environment Agency's benchmarking work (**Benchmarking**[29]).

This chapter firstly presents a discussion of considerations modelling teams should make when selecting a software type for an Integrated Model and is linked to the four Model Concept Types in **Section A2**. The section also includes a description of the main software types used for integrated urban modelling in the UK (at the time of writing), highlighting key features of the main programs used.

A5.2 How to Choose a Suitable Software Program

There are a number of points that need to be considered when choosing a suitable software program. These are discussed further below.

- What is the problem? During the stage to identify the flooding problem, the primary flooding mechanisms that will help guide software selection should be determined.

  For example, if a flooding problem was found to be a result of overland flow and an under-capacity culvert, a 1D/2D direct rainfall approach will likely be the most suitable, although if the problem is the capacity of a foul pumping station, then a 1D only model that allows real-time controls may be the most suitable.
- Are there any legacy models that need to be integrated? Typically, if it is identified during the **Project Definition** stage that a hydraulic model already exists of one or more of the components required to be included in the Integrated Model. If it is determined that the existing model is suitable to use (see **Section B1**), then the transferability/compatibility with the Integrated Model needs to be considered.
- What degree of integration is needed between different elements of the model? Is a fully integrated model of the sewer system, river and above ground surface required? Is it more appropriate to pass boundary conditions between separate models than to fully integrate those elements?
- What deliverables are required? It is crucial to determine that the selected software can produce the deliverables required by the project to the appropriate level of detail. For example, if velocities at different points within one river cross-section are required, a 2D representation of the watercourse may be the most appropriate. Or, if a large number of simulations with prolonged run times are required, then a software that can use the Cloud to run multiple models may be the most suitable.
- What scale/complexity is required? What scale of the model is required and what flood flow pathways are required to be represented? For example, if the scale of the model is required to represent flow paths around buildings, then a flexible mesh may be more suitable. Or, for example, if the model needs to represent a large estuary, then a model with a quadrangular mesh may be more suitable.

- Does the client have a preference? Some clients have hydraulic modelling requirements or in-house modelling guidance documents that could steer the software selection. If this software type is not chosen there may be other implications such as additional costs for the client if they aren't able to review the model or don't have additional training time.
- How widely is the software used? It may be harder to justify the selection of a niche/less commonly used software type for integrated urban modelling (see Section A5.3.3) because Partner and Stakeholder organisations may be less comfortable receiving or reviewing this kind of model and may not have the required software or licences to run or analyse the model. There would also be a smaller pool of modellers in the industry, meaning this is a less resilient solution that would potentially limit the future application of the model.
- Is there any future use for the model? It may be possible to identify at the project definition stage whether there is an opportunity for the model to be used as part of another project in the future and whether there is potential for 'added-value'. A typical example of this is where the primary purpose of the model is to provide flood extent mapping, but it could potentially be used in the future for flood forecasting. In these instances, it may be worthwhile considering a modelling software that can be more easily transformed into a flood forecasting model.

A5.2.1 Model Concept Type considerations

Section A2 identified four potential Model Concept Types for integrated urban modelling. There are no firm rules for which software type should be applied to each of those four types but Table A5-1 presents some decision-making guidance related to the model concept type. This is based on three generalised options that a modeller may have, depending on the availability of existing models and the assessment of those models in terms of suitability for use in integrated urban modelling.

The three main options most modellers will be faced with during the **Project Definition** stage are:

Option 1 - Maintain consistency with software used for any existing sewer model and add rivers and/or 2D surface as necessary

Option 2 - Maintain consistency with software used for any existing river model and add sewers and/or 2D surface as necessary

Option 3 - Build new model in software selected specifically for the project

As described in other sections of the report, an integrated urban catchment model will likely begin with one or more existing models, probably developed in one of the software types referred to in this section. It is therefore assumed that Option 1 or 2 will be more likely than Option 3 and the software section for the integrated model will be decided based on existing software used for either the existing sewer model or the existing river model.

Apart from the three generalised options, the selection of appropriate software types also has a spatial element in that the modelling team may also need to consider the size of the proposed model extent and the required model resolution (see **Section B3** for more information). The modelling team should, at **Project Definition** stage, attempt to estimate the likely number of model simulations needed and the potential duration of those simulations as this may influence the selection of modelling software.

Table A5-1 - Decision- Making Guidance relating to model concept type

Model Concept Type	**Description**	**Decision-making guidance**
#A	Hydrological boundary, model boundary and study boundary are the same. Model boundary is defined by catchment topography. Likely to be at village or township scale rather than at city scale. Generally, 1D with a narrow corridor along watercourses of 1D-2D.	• If sewer network is more complex than the rivers → **Option 1** • If river model is complex and/or includes some of the surface water sewer outfalls→ **Option 2** • If no existing models exist → **Option 3** At this scale, the river/fluvial flooding influence is likely to be lower compared to sewers or surface water so **Option 1** is probably the more likely decision in this case.
#B	Model boundary and the study boundary may be similar. The hydrological boundary is larger, with one or more watercourses flowing into the study/model area. Requires new hydrological study for fluvial hydrographs from upstream catchment. Likely to be at large village or township scale rather than at city scale. Generally, 1D with a narrow corridor along watercourses of 1D-2D.	• If sewer network is more complex than the rivers → **Option 1** • If river model is complex and/or includes some of the surface water sewer outfalls→ **Option 2** • If no existing models exist → **Option 3** As the river/fluvial flooding is more likely to be the dominating feature of the integrated urban model, **Option 2** is probably the more likely decision in this case.
#C	There is an existing fluvial model for a major river and a Hydrological Study will have been undertaken as part of the development of that model. The hydrological boundary is considerably larger than either the study area or the model area. The model boundary and the study boundary are likely to be different. The intention with this concept is that	As this Model Concept type assumes that there is an existing model of the main watercourse from which a reach will be extracted, **Option 2** is most likely. Will always be an existing model so never **Option 3.**

	only a short length of the major watercourse is modelled, with the relevant section extracted from the existing fluvial model. Type #C models are likely to be at a variety of scales, ranging between villages and cities. Generally coupled 1D-2D throughout model.	
#D	The restrictive or backwater effects (from a large river or the open coast or estuary) on an urban drainage system are represented by level hydrographs at each of the outfalls, for example, in a coastal area or alongside an estuary. Likely to be at a variety of scales, ranging between villages and cities. Figures A2-14 to A2-17 illustrate the concept of a Type #D model. Generally, 1D or coupled 1D-2D depending on how the flooding within the study area is to be represented.	**Option 1**, retention of the software type for the existing sewer network model, with the addition of a 2D domain if needed and application of level boundaries from other sources.

A5.3 Available Software

A5.3.1 Overview

Five main software types used in the UK (at the time of writing) for integrated urban modelling have been identified and are introduced below:

- Flood Modeller
- InfoWorks
- JFlow
- MIKE URBAN
- TUFLOW

The level of usage of each type varies, with Flood Modeller, InfoWorks and TUFLOW considered to be the most regularly used for integrated modelling at the moment. These three products are all commercially available, there is a pool of modellers available with experience in these software types across a range of organisations and models in this format are readily accepted by partners, clients and regulators. JFLOW is not used by a large number of organisations within the UK but should be considered here because of its use in the Environment Agency's Updated Flood Map for Surface Water (and in other national scale modelling projects). At the time of writing, MIKE URBAN is less commonly used in the UK for integrated urban modelling.

In addition to these five main/primary software types, there are a number of minor/secondary modelling software types, less commonly used for integrated modelling in the UK. These are listed in Section A5.3.3. As described at the end of this section, the range of software types available and the relative level of usage of those programs will vary over time and this section will need revisiting in any future updates of this guide.

Note that 'design' software (for example, MicroDrainage and Causeway Flow) have been excluded from this Guide as integrated urban modelling is not frequently used for detailed design, although it is recognised that there is the potential to integrate models, to some extent, in some of these design programs.

A workshop was held in January 2020 with representatives from different organisations representing the five main/primary software types covered here. The purpose of the workshop was to gather information on the main functionality and usability of the five main software types for integrated modelling (including case study examples) and to share a discussion around the selection of model software types on integrated urban modelling projects and on the future of integrated urban modelling. The outcomes from that workshop are incorporated into this section of the Guide.

A5.3.2 Main/Primary Software Types

A brief summary of each of the primary software programs available and adopted in the UK for integrated modelling is shown in Table A5-2 below, with information provided by the developers in January 2020. Software development is a rapidly moving field and therefore modellers are referred to developers' websites and user forums for more information and details of any updates since this guide was written.

Table A5-2: Main Software Types

Flood Modeller (Jacobs) https://www.floodmodeller.com/	• Allows river, floodplain and urban drainage systems within a GIS-like interface. • Solvers have been subjected to extensive testing and benchmarking exercises, which have demonstrated that they are some of the fastest and most robust solutions available. • Suitable for a wide range of applications, from detailed and complex urban catchments to large catchments and mapping potential flood risk for an entire country. • Flexible licensing structure. Available at no cost, the free edition provides 100 1D nodes and 100,000 2D cells, making it perfect for site-specific studies. For larger projects, use the Standard or Professional editions of the software, or use the cloud service.
InfoWorks ICM (Innovyze) https://www.innovyze.com/en-us/products/infoworks-icm	• Built upon the family of InfoWorks products from Innovyze. • Comprehensive and flexible system for fully integrated catchment/basin modelling and the management of those models. • It provides the ability to model the complete natural and engineered above- and below-ground drainage system, including sewers, surface water, rivers and floodplains. • The system provides a master database for storing model and hydraulic data, with all the tools necessary to create, edit and manage that data. When the model has been created, InfoWorks ICM allows you to simulate the behaviour of the catchment under a range of conditions. • Typically, it is applied for flood modelling, water quality modelling, catchment planning, water quality modelling, post event analysis, large-scale SUDS/LID impact modelling.
JFlow (JBA Group) http://www.jflow.co.uk/	• Commercially-available 2D hydraulic model that solves the Shallow Water Equations (SWE) using a finite volume formulation. Implemented on a regular grid using the supplied DTM and does not require any secondary grid generation process. • JFlow has been designed with the emphasis on easy set up and model specification for national-scale application using freely-available software (for example, Postgres, QGIS). Models are configured using databases, and this provides a highly-ordered means to store significant quantities of data. JFlow has also been specifically designed to run in parallel on Graphics Processing Units (GPUs) in order to run 2D models at very high spatial resolution across large areas. • JFlow has been tested successfully against the solutions available in the Environment Agency's 2D Hydraulic Model

	benchmarking exercise and has been used to provide the Extreme Flood Outline (EFO) for England and Wales (2002 to 2004), Fluvial Flood Zones for England and Wales (2004 to 2006), Updated Flood Map for Surface Water (2012 to 2013) and also the recent multi-source Flood Risk Assessment Wales for NRW (2018 to 2019).
MIKE URBAN (DHI Group) https://www.mikepoweredbydhi.com/products/mike-urban	• MIKE URBAN is the integrated modelling software package for urban water modelling activities, including water distribution, collection system and 2D flood modelling of the surface, dynamically integrated with collection systems. • The DHI software provides the option for dynamic coupling to a range of additional models, including, for example, advanced modelling of integrated catchments with shallow groundwater (MIKE SHE), coastal models (MIKE 21 and MIKE 3) and deep groundwater (FEFLOW). • If advanced river modelling is required, then the MIKE FLOOD can be used to couple 2D with MIKE URBAN+ and MIKE HYDRO river.
TUFLOW (BMT Group) https://www.tuflow.com/	• TUFLOW Classic/HPC/Quadtree computational engines are 2D grid based software for simulating surface water, flood and tidal flows. • Integrated within TUFLOW Classic/HPC/Quadtree is the 1D ESTRY hydraulic engine that allows the modelling of river systems and pipe network systems and the complex interaction between them. • TUFLOW/ESTRY allows the integration of 1D river channels and pipe networks as well as with the 2D domain to represent floodplains and urban surfaces.

The matrix presented in Table A5-3 includes an overview of the primary software programs, which identifies their main features and can be referred to when selecting software. This is not intended to be an exhaustive list but a list of those features pertinent to integrated modelling. The matrix has been developed in liaison with the software providers through a workshop and direct correspondence. For a more detailed understanding of how each model software type deals with any of those considerations and for more information about the usability of the five main software types, please consult the online materials available (links in Table A5-2).

A5.3.3 Minor/Secondary Modelling Types

In addition to the five main/primary software types above, there are other software types that contain some integrated urban modelling functionality and which are used to varying degrees across the UK at the time of writing. No detailed information is provided for these other software types but further information can be found online or via the software providers/resellers.

- **HEC-RAS**, US Army Corps of Engineers, https://www.hec.usace.army.mil/software/hec-ras/

- **Flowroute-I**, Ambiental Ltd, https://www.ambiental.co.uk/about/our-technologies/
- **SOBEK**, Deltares, https://www.deltares.nl/en/software/sobek/
- **3Di**, Nelen & Schuurmans, https://3diwatermanagement.com/

The above list is not exhaustive.

This section does not specifically reference software available for hydrological modelling (for example, flood frequency analysis or design hydrograph estimation). There is further information about hydrological modelling methods in **Appendix H** – Hydrology, including some references to software and other services.

Table A5-3: Main features of integrated modelling software

	Flood Modeller	InfoWorks ICM	JFlow	MIKE URBAN	TUFLOW
Model setup considerations					
1D, 2D or 1D-2D	1D, 2D & 1D-2D	1D, 2D & 1D-2D	2D & 1D-2D	1D, 2D & 1D-2D	1D, 2D & 1D-2D
Fixed grid or flexible mesh (2D) or combination	Fixed grid	Flexible mesh	Fixed grid	Fixed grid & flexible mesh	Fixed grid & flexible mesh
Methods for representing open channel cross-sections	Y	Y	N	Y	Y
Methods for representing conduits	Y	Y	Y	Y	Y
Methods for representing wave and surge effects (coastal and estuarine catchments)	Through boundary conditions	Through boundary conditions	Through boundary conditions	Y	Y
Foul water models available within the software	N	Y	N	Y	N
Availability of real time controls, for example, for pumping stations, sluices	Y	Y	N (simple control rules only)	Y	N (simple & complex control rules)
Methods for applying rainfall hyetographs (1D or 2D)	1D or 2D (to network or grid)	1D or 2D (to network or mesh)	2D (to grid)	1D or 2D (to network or grid/mesh)	1D or 2D (to network or grid)
Rainfall-runoff models available within software	Y (range)	Y (range)	N	Y (range)	Y (range)
Methods for the application of 2D roughness available	Y	Y	Y	Y	Y
Methods of varying runoff and infiltration across the surface	Y	Y	Y	Y	Y
Software/Engine Use					
Cloud based options available	Y	Y	Y	Y	Y
Links/compatibility to other software programs	Y (for example, TUFLOW)	N (can import other models)	N	N	Y (for example, FM)
In-built damage calculator available	Y	Y	N	Y	N
Software comes with GUI	Y	Y	N	Y	N
Online training (for example, video tutorials) available	Y	Y	N	Y	Y
Support desk/forums available	Y	Y	N	Y	Y

A5.3.4 Environment Agency benchmarking studies

The Environment Agency has carried out benchmarking tests of 1D and 2D hydraulic modelling packages (**Benchmarking**[29]) that are most commonly used in the UK. It is not recommended that a modelling software is used unless it has been thoroughly peer reviewed and tested over a period of time.

A5.4 The Future

This section has presented information on the software programs available at the time of writing. The market is asking for more complex solutions to be represented more easily, and all the software providers are investing in research and development to meet this desire. As noted above, modellers should always refer to software user guides and online resources for more information about the latest versions and developments. Through online forums and user groups, modellers are also able to influence software development.

Since the original publication of the first CIWEM UDG Guide to Integrated Urban Modelling (2009) there has been an increase in interest in and demand for integrated urban modelling, and the multiple benefits of undertaking this kind of modelling are well understood in the industry. Going forward it seems that this interest and demand will continue to increase so that Partners and Stakeholders can gain a more holistic understanding of multiple sources of flooding and the complex interactions between sources. Over this period, the software capabilities for integrated urban modelling have improved at pace and approaches to developing integrated urban models have become, and will continue to become, less constrained by software functionality.

Alongside the software development, there have been significant advancements in hardware capabilities as well. 10 years ago, hardware capability/capacity would have been a significant factor influencing decisions about model scopes, extents and resolutions. With advances in GPU processing, cloud data storage and simulations etc, hardware capability/capacity no longer needs to be the determining factor in choosing modelling software or approaches. At the time of writing, it seems likely that further advances and flexibility in processing approaches could result in faster model run times and/or an ability to run more simulations in parallel, therefore creating the potential for studies to take a more probabilistic or ensemble approach to modelling than is currently undertaken.

Advances over the last 10 years, and further advances to come, mean that the use of integrated urban models for real time flood forecasting and warning may become more feasible at town or catchment scale. In such setups, models are run with observed and forecast hydrometeorological data to enable real time predictions of flows and levels. This can be integrated with, for example, a community based flood warning system or with operational rules for structures and storage. This would satisfy a desire for movement towards more place-based forecasting and inundation forecasting (rather than level forecasts at gauges). Modellers engaged in this field will need to work with the Partners and Stakeholders with operational responsibilities to ensure that models developed are compatible with new and emerging operational systems.

As described in **Section B3**, it is possible to model urban areas in very fine detail without needing to apply the same resolution across the whole model. In this way, current models and projects are able to represent flow paths in urban areas in as much detail as needed to meet project requirements, for example, for flood mapping or economic appraisal. For these types of projects, there appears to be little need to further increase the level of detail in the model resolution in the future and, indeed, further increases in detail or resolution would bring additional modelling challenges, for example, the representation of turbulence effects around buildings.

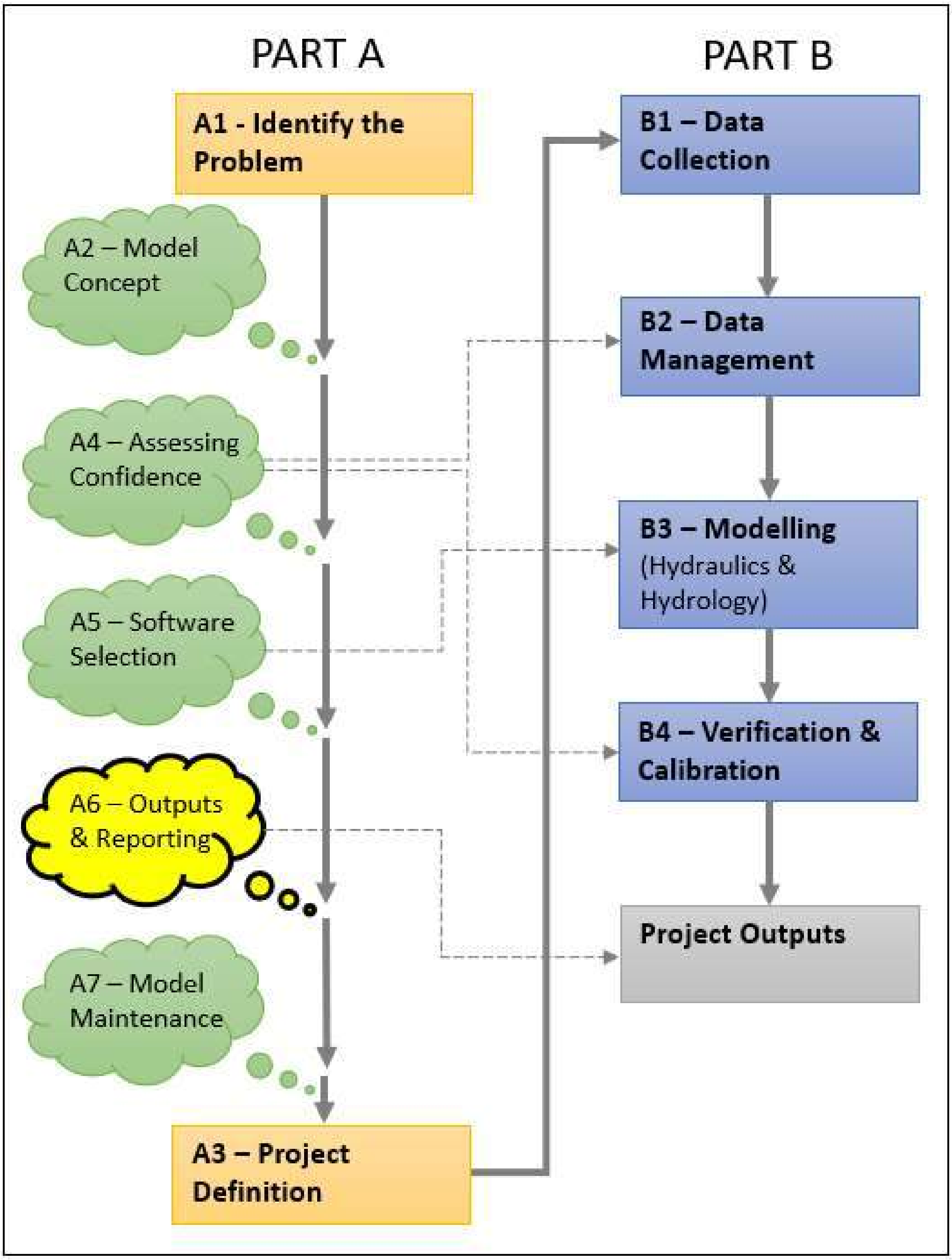
Integrated Urban Drainage Modelling Guide

Section A6

Outputs and Reporting

CIWEM Chartered Institution of Water and Environmental Management

A6. OUTPUTS AND REPORTING



A6.1 Introduction

After defining the problem (**Section A1**) one of the important next steps leading to defining the project (**Section A3**) is to decide what model outputs are required and what reporting and documentation is required.

This section of the Guide has been written to help identify the model outputs required, the formal reporting and also the model documentation.

A6.2 Model Outputs

There are numerous ways in which outputs from model simulations can be presented. Some outputs are intended to represent the flooding, whilst others are used as information for further analysis. The level of results post-processing needed varies depending on what outputs are required, therefore it is important to consider what the output requirements are at an early stage so there is enough time to produce them.

In some modelling software, a decision has to be made about the outputs required before the simulation is run, whilst other programs allow the decision to be made afterwards.

Before deciding on how the modelling should be undertaken it is essential that the requirements related to the simulation outputs are understood as this could influence how the modelling is conceptualised. For example, if the project requires properties at risk of flooding to be identified, then 2D is likely to be required. Conversely, if simple flood volumes are required, 1D modelling may be adequate. It is important that the modelling is not made unduly complex or detailed when the project requirements do not justify it.

Similarly, it might be that certain hydraulic modelling programs are better at providing certain outputs and therefore the simulation output requirements may influence the modelling software selected. **Section A5** provides some assistance in this regard. For example, if one of the required model outputs is a video replay showing simulated flooding (perhaps for use at a public meeting) the modelling software selected should be capable of producing that.

An important consideration is whether the simulation outputs need to be geocoded as this may discount those modelling programs that do not require all data to be geocoded. It may also be necessary to consider potential file sizes when deciding on outputs, for example, selecting an appropriate extent and resolution for 2D modelling to ensure file sizes remain manageable.

A6.3 Project Reporting

The requirements for project reporting will vary considerably, although some Partners and Stakeholders might have a standard specification for such reporting. It is recommended that the PSG discuss and agree what project reporting will be required and recorded as part of the Project Definition (**Section A3**).

If one of the project outcomes is to make an application for funding, it is important to understand what submission criteria is required for such applications and, in turn, to ensure that the project is structured in such a way to provide that information within the project reports.

A6.4 Hydrology Report

Depending on the Model Concept (**Section A2**) chosen and the Project Definition (**Section A3**), a separate Hydrology report may be required.

For Model Concept Types #A and #D adequate information can probably be contained within the Model Build and Verification (MBV) report, and a separate hydrology report is therefore not needed.

For Model Concept Type #B a separate Hydrology Report will probably be required. This should be a formal report and many Partners/Stakeholders have a standard format for these reports. It is frequently the case that the Hydrology Report and the hydrological assessment will be externally Peer Reviewed before the modelling can progress.

For Model Concept Type #C the assumption is that a separate Hydrology Report already exists and the hydrological assessment will have previously been Peer Reviewed (if that was necessary). In this case, there is no need for a new report, but the Hydrology section of the MBV Report should make adequate reference to it.

A6.5 Model Build and Verification Report

To allow for updating and upgrading, it is essential that the work involved in building and verifying the model is properly documented in a Model Build Report (frequently referred to as a Model Build and Verification (MBV) Report). As well as providing essential information to future users of the model, the documentation is also a basis for both internal and third party reviews of the work. This documentation is not to be confused with the requirement from a PSG for a final report, which may be significantly less detailed. The following should be considered as a minimum requirement.

Documentation can be in many forms. Some documentation may be in the model itself, either by user text or by using data flags, if the modelling software allows it. Other documentation may include calculation sheets, and reports at various stages of the model development, etc.

The MBV Report should ideally contain sections on:

A6.5.1 Purpose and drivers of the project

A summary of the objectives, purpose and confidence levels required by the PSG or individual Partners/Stakeholders involved in the project. Documentation created from the Project Definition stage (**Section A3**) should be included as an Appendix.

A6.5.2 Catchment description

A summary of the catchment, including a description of the existing major and minor drainage systems, ancillaries, area, population, types of development, ground, topography, potential interactions between the major and minor systems etc.

A6.5.3 Catchment issues/problems

For both the major and minor systems, this should include, in summary form, details of, among other things:

- Future development
- Hydraulic deficiencies and known flooding

- Environmental deficiencies
- Operational deficiencies
- Structural deficiencies

The documentation created at the Problem Definition stage (**Section A1**) should be included as an Appendix.

A6.5.4 Previous studies and existing models

Previous studies or projects in the catchment area should be reviewed and summarised.

Any documentation for any existing models that are incorporated into the integrated model should be included as an Appendix. Any Peer Review or Audit reports for the existing models should also be included. It should be recognised that many reports provided by WaSCs will be commercially sensitive and cannot be disclosed. The PSG should determine which previous reports etc can be included as appendices and which can just be referenced.

A6.5.5 Naming convention

This section should summarise the naming convention which was used (see **Appendix J**) for the data, model and results files.

A6.5.6 Modelling

This section should discuss and describe any changes made from the original Model Concept and Project Definition documentation. If the Project Definition document is a 'Controlled Document' (that is, revised and kept up to date), this section could be omitted.

A6.5.7 Data collection and management

Data will be available from a number of sources and can generally be split into two types; existing data or new data collected by external surveys.

Section B1 details the potential sources of data. All data should be collated and logged and a schedule of data used should be set up. Data that is only available in hard copy format should be included in an Appendix, but otherwise the data should be stored electronically in a Data Manual or, for large projects, in a Data Room. The report should provide a summary of all the data included in the Data Manual together with enough references so that the data can be retrieved easily.

The summary information included in the report should include:

- A summary of the data and its use in the project
- Reference to the source of the data
- Issue number and date
- Location of data in the Data Manual/archive system
- Confidence assessment, if any

Any subsequent amendments made to this data that did not result in reissuing the original source to the project should be included separately as an amendment.

Where conflicts have been identified between different sources of information, a schedule of the conflicts and how these were resolved should be included.

A6.5.8 Model development

It is imperative that the model development process is adequately recorded and documented. This may be by using data flags and user notes in the model or by external reporting (perhaps as a Model Log).

Typically, this would include but not be limited to:

- Boundary conditions (upstream and downstream)
- Details of any assumptions made, including interpolated data
- Changes made to the data with the justification for the changes
- Details of any simplification carried out
- Details of surveyed and interpolated cross-sections for watercourse modelling
- Culvert inlets
- Allowances for un-modelled storage
- Runoff surfaces and sub catchment boundaries
- Soil classes, surface cover and infiltration
- Area take-off, impermeability and runoff modelling
- Results of any validation checks and changes made
- Details of ancillaries included and omitted from the model, including calculation sheets
- Pipe, channel and floodplain roughness
- Bridges
- Headlosses and coefficients
- Silt and obstructions
- Flooding types
- Coupling (1D-1D, 1D-2D etc)
- Representation of buildings
- Representation of 2D features such as kerbs, walls etc
- Details of 2D parameters
- Inflows
- Tide conditions
- Anything else that is relevant to explain how the modelling was undertaken

Additionally, model stability should be recorded. Any locations where instabilities were identified should also be noted, together with details of the changes made to resolve them, where appropriate.

A6.5.9 Hydrology

This section of the MBV report should describe the Urban Hydrology used and, where relevant, the Rural Hydrology or references to the separate Hydrology Report.

For Model Concept Type #A models, this section should describe how the rural runoff/inflows have been developed and the parameters used.

For Model Concept Types #B and #C, this section should refer to the separate Hydrology Reports.

For Model Concept Type #D, this section should describe how the boundary conditions (for example, tidal, fluvial etc) have been derived.

Where the model is used for pluvial runoff, this section should describe the parameters used, any assumptions made, details of any infiltration parameters used and, in particular, whether any adjustments were made to the rainfall.

A6.5.10 Model verification, calibration and confidence

The verification, calibration and confidence assessment sections of the MBV report should include:

- A summary - outlining the main conclusions, including recommendations for future use of the model and unresolved issues
- Details of the permanent and temporary flow, depth, level or velocity measurement locations and how they were selected
- As an Appendix, a copy of any flow, depth or level measurement report, including any updates during the verification process
- Any supplementary comments from the modeller on the accuracy and usability of any flow, depth or level data
- Details of any calibration undertaken
- Details of any social media and/or other flooding data used
- Details of any flood outline (for example, wrack marks) data used
- Comments on the adequacy of storm events selected and the spatial distribution of the rainfall on an event by event basis. The basis for selecting the event should be included
- Details of any rainfall data derived from weather radar, its adequacy and spatial distribution
- Plots of the first fits of the model simulations compared with the observed data. This might be comparison graphs or may be plans to show the extent of flooding
- A detailed description of any changes made to the model during the course of the verification and the justification for making these changes
- The final verification plots together with an indication of the verification confidence, and explanation of the results

- A commentary on the final fits and a description of how well the model is considered to be verified. Any judgements taken or weaknesses should be highlighted and any sensitivity analysis reported
- Details of historical verification against reported flooding, surcharge, storm overflow performance and long-term monitoring, including a comparison with predictions using design storms and/or times series rainfall
- A commentary on the main flooding mechanisms identified

A6.5.11 Sensitivity testing

The purpose and outcome of any sensitivity testing undertaken should be explained in this section. It should also be discussed how this has been used to clarify or confirm any assumptions made and accordingly how confidence has been improved.

A6.5.12 Confidence reporting

The results of the confidence analysis should be reported using the guidance in **Section A4**.

The process lends itself to geo-visual analytics, which may be used to display the confidence scores at a variety of spatial scales. This may be done either within the model by using data flags or externally.

Figure A6-1: Example of 2D flooding verification

Some of the confidence assessment can be illustrated in geoplan format as shown in Figure A6-1. In cases like this, the report should have a commentary on how well the simulated flooding matches the observed data. It is also important to explain what depths the simulation results represent; in this example, depths less than 10mm are not shown.

A6.5.13 Conclusions and recommendations

It is imperative at Project Definition stage (**Section A3**) that the PSG determines how the 'fitness for purpose' is to be determined and reported on. It would defeat the purpose of an integrated modelling project if the aggregate confidence scoring and/or recommendations for further work are used to challenge the modelling.

The main conclusions should ideally include an indication of the fitness for purpose of the model, including a statement relating to any limitations of the model or parts of the model for future use in design etc, and recommendations for further work to resolve any outstanding issues.

The PSG should approve the conclusions and any recommendations before any report is disclosed (even in draft form) to other stakeholders or third parties.

A6.5.14 Scenarios

Model scenarios are frequently used to create variations from the baseline model. These might be future horizon models, historical models or models to consider various interventions, which might be operational changes (for example, sediment removal) or capital investment changes. The scenario naming should adequately explain the intervention considered, typically by using an acronym such as 'Opt01'.

A further description of the scenario should be provided, either within the modelling software or in a separate model log as well as the MBV Report. The description should detail the changes made to the model supported by any calculations made and references to any source data or assumptions. This should include the associated files used in the design, for example, rainfall used, any allowances for climate change, antecedent conditions.

Documentation should incorporate the following:

- Outputs from any fitness for purpose or suitability reviews of the model(s)
- Details of any different versions of the model created
- The time horizon of the future model(s)
- Details of any design horizon changes made to the verified model
- Details of any calculations made and references to any source data or assumptions

A6.5.15 Quality assurance and review including audit

Throughout the development of the modelling process there should be documented evidence of a sign off and review process involving suitably qualified staff. This could be an internal review or, if required by the PSG, an independent audit of the model and the modelling process.

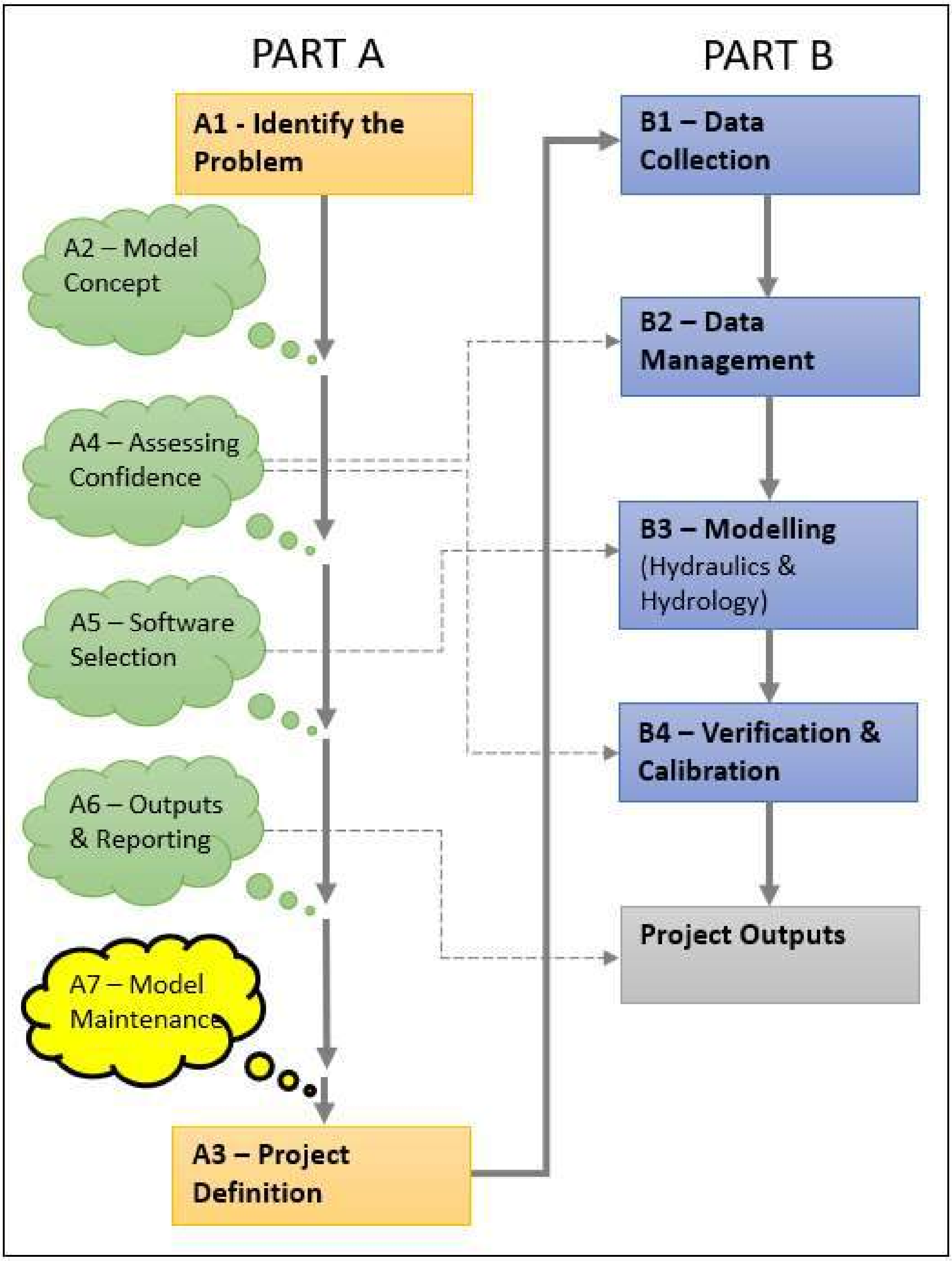
Integrated Urban Drainage Modelling Guide

Section A7

Model Maintenance

Chartered Institution of Water and Environmental Management

A7. MODEL MAINTENANCE



A7.1 Introduction

There is a significant cost involved in developing hydraulic models. Over successive AMP periods UK WaSCs have made multi-million pound investments in their hydraulic models. The cost of rebuilding this stock of models would be in excess of £500million. Environmental Regulators and Lead Local Flood Authorities have also made multi-million pound investments in their fluvial and pluvial models.

There is a balance to be struck between leaving these models 'on-the-shelf' and regularly updating them so that they remain current. Most organisations take an approach whereby their more important models or those with frequent changes are regularly updated, whilst those with very few changes are kept 'on-the-shelf'.

In relation to integrated urban drainage models there are some important issues to be discussed and resolved as part of the Project Definition (**Section A3**). This section of the Guide has been written to identify the main issues to be resolved.

A7.2 Model Ownership

It is likely that in most IUD projects there will be one or more existing models. Apart from ascertaining whether these models are fit-for-use in the IUD project, it is also important that the ownership of those models is clarified, whether the owners are prepared for them to be used and, if so, whether there are any conditions attached. A common condition is that if the models are provided for use they, nor any derivative model, can be disclosed to a third party without permission.

It is also necessary to determine who will have ownership of the final IUD model, who will be permitted to use it and in what circumstances. **Appendix B** provides a checklist that can be used to record the decisions made about ownership and the permitted uses of the model.

A7.3 Should Integrated Urban Drainage Models be Maintained?

Another important decision to be made alongside model ownership is whether or not the model should be maintained following completion of the IUD project and, if so, who should be responsible for the maintenance.

A7.4 Model Libraries

Most Partner organisations involved in IUD modelling hold a library of their models. These model libraries can hold models at national, regional or local scale. There are an important number of aspects about how these libraries are organised and managed.

These aspects may include:

- A robust naming convention for models
- A documented process for checking in and checking out of models
- A model tracking process
- All the documentation associated with the model, including any model confidence information

The model tracker should generally track the location and progression of a model, with updates to the tracker whenever a model is taken from and returned to the library. The tracker would detail the changes made to the model. The documentation associated with the model will also require updating.

If it is decided that at the end of an IUD project the integrated model is to be retained, it will be necessary to ensure that the model structure is compatible with the organisation of the library in which it will reside.

When building a new IUD model, it is advisable that the data structure and naming conventions that will ultimately be required for the model library are followed from the outset. Part of the Project Definition process (**Section A3**) is to decide and record these aspects. **Appendix I** includes information on commonly used data structures and checklists, etc and provides information on how these aspects can be recorded.

A7.5 When to Update or Maintain IUD Models

Models are a snapshot of reality at a certain point in time. Various changes in the catchment can make a model out of date. Some examples are:

- Population changes
- Per Capita Consumption Rate
- Measured Commercial Flow
- Measured and Permitted Trade Flows
- Urban Creep
- Infiltration
- Recent Development
- Changes in ancillary operation
- Wastewater Treatment Works WwTW changes
- Revised asset data
- Recent and committed Capital Schemes
- Operational changes and repairs
- Catchment changes (for example, changes in farming practices)
- Natural Flood Management (NFM) changes

There are various triggers and methods of determining whether to update or maintain a model. The four alternatives generally available would be to:

1. Maintain a model only when it needs to be used
2. Update the model after a fixed period of time
3. Update the model after a certain number of changes
4. Update the model after each change to the model, such as a new development or revised asset data

Table A7-1 outlines the advantages and disadvantages of the various approaches.

Table A7-1: Model Maintenance Approaches

Maintenance Type	Advantages	Disadvantages
Only when model needs to be used.	Potential saving as no updates needed to the model if it does not need to be used.	Delay in availability of the model when needed to be used again, due to need to update the model. Potential to use an out-of-date model if not enough time to update.
Fixed Time, for example, every 5 years	Updates can be done as part of a programme. Models never more than a fixed period out of date.	Potential to update models when not needed to be used. Model will still be out of date and may still require an update when needed to be used.
Update models after a certain number of changes	Similar to fixed time updates, but updates will only be done when there are sufficient changes, potentially focusing effort where needed. Models never more than a certain number of changes out of date.	Potential to update models when not needed to be used. Model may still be out of date when needed to be used.
Live Models	Model is updated as soon as new information is received. Models are up to date for immediate use.	Potential to update models when not needed. Costly and challenging to manage. May still need to periodically maintain models.

There is no definitive guidance to which of the above methods is best. This will depend on the potential use of the models, the frequency of use of the models and the confidence required in the models. If models are used for operational purposes, they will need to be maintained and updated more regularly.

For all of these maintenance methods processes need to be in place to identify changes in the modelled catchments, so that when future updates are required, the data will be available.

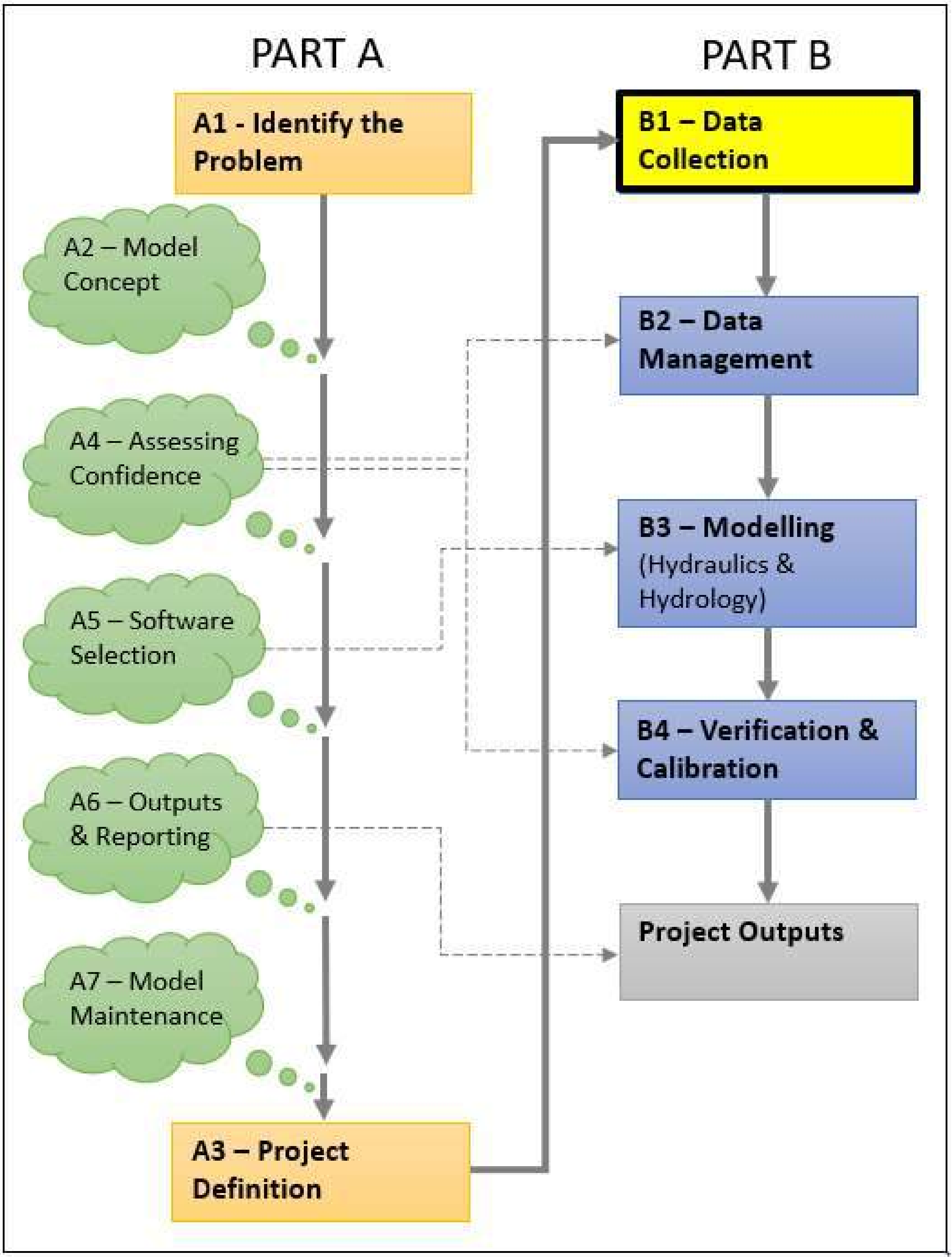
Integrated Urban Drainage Modelling Guide

Section B1

Data Collection

Chartered Institution of Water and Environmental Management

B1. DATA COLLECTION



B1.1 Introduction

Data collection, including surveys, may represent a significant part of an urban drainage modelling project's cost and programme and will directly influence confidence in the final model. Delays in data collection are a risk, with knock-on impacts on project delivery.

The different Partners and Stakeholders are already likely to hold data and the starting point should always be establishing a data sharing protocol (see **Section A3**) followed by an evaluation of the existing data and identifying whether it will be suitable for the project.

The CIWEM UDG Code of Practice for Hydraulic Modelling of Urban Drainage Systems (**CoP**[1]) includes a comprehensive section on the data requirements etc in respect of modelling piped systems (for example, sewers, highway drains). Reference should be made to the **CoP**[1] in relation to data collection for the 'pipes' elements of an integrated model. The exception to this is in relation to culverted watercourses, which are described in more detail later in this section.

This section of the Guide therefore concentrates on the data requirements and the processes for planning and implementing a successful data collection programme for other aspects of an integrated urban drainage project. It includes:

- General guidance for data collection
- Planning data collection
- Partnership working
- Data types and sources
- Data quality
- Surveys

The Rainfall Modelling Guide, 2016 (**Rainfall Guide**[3]) provides guidance on the different sources of rainfall data, its applicability and methods for measuring rainfall.

B1.2 Data Protection

It is important when planning a data collection campaign to recognise the importance of data protection legislation, including Data Protection Acts and GDPR. Some of the data, especially that obtained via social media, may contain personal information. Additionally, some data such as individual property addresses may be commercially confidential.

In relation to social media, due care and attention should be paid to privacy issues, with platforms continually revising privacy policies due to mounting pressure from the public and governing bodies.

At the Project Definition stage (see **Section A3**) a plan and programme for data collection should be agreed and documented.

B1.3 Principles for data collection

The principles for successful data collection are to strike a sensible balance between collecting data just for the relevant project or using economies of scale and collecting data with wider uses or covering wider areas. The principles are summarised in Table B1-1.

Table B1-1 Principles for successful data collection

Category	Principles
Programme	○ Obtain data and information in time to avoid delaying the programme. ○ Anticipate delays in getting data and have contingency plans to resolve these.
Quality and accuracy	○ Check that incoming data matches what is required.

Category	Principles
	○ Assess data confidence and identify any implications for the current project and future model use. ○ Resolve discrepancies between different information sources so the most suitable values are used in the project.
Efficiency	○ Assess all readily available data and information for reuse before recommending further data collection. ○ Justify additional data based on its value in reducing uncertainty. ○ Specify that data provided is in a format that requires minimal reprocessing before use; to reduce time, cost and potential errors. ○ Process data and information efficiently, including developing new methods.
Records	○ Keep records of the above for peer reviews or audits. ○ Provide data back to the relevant Partner at the end of the project to allow updates to the corporate records and storage for future use.

B1.4 Data Confidence

It is good practice for confidence grades to be assigned to data as this promotes transparency and helps identify risks. A suggested confidence scoring system outlined below is linked to the detailed confidence guidance included in **Section A4**. For the purposes of this section and in common with the **CoP**[1], four levels of data collection confidence are outlined. The reason for four levels rather than three is to provide more leeway about data that lies between the highest and lowest.

A High Detail/Confidence

B

C

D Low Detail/Confidence

The suggested data collection and checking methods for each class of data and for each level of confidence are summarised in Table B1-2. This promotes a tiered process to collect data and therefore a relationship to model confidence.

Typical data collection levels for use with each type of model are given in Table B1-2 below. This table should be read in conjunction with Table 3-1 in the **CoP**[1].

Table B1-2 Typical data collection levels

Model Detail Type	Type I	Type II	Type III
Digital Terrain Model (DTM) data	B/C	A	A
Watercourse and channel data	C	B	A
Ancillaries and Structures (Pumping Stations, Sluices, Watercourse Structures)	B/C	A/B	A
Watercourse culverts	C	B	A
Data for 2D Modelling	B	A	A
Flow and Depth monitoring data	B	A	A
Rainfall data	A	A	A
Operational data	B/C	B	A/B
Pipe Roughness data	C	B	B
Sediment level data	D	B	A
Social Media data	B	A/B	A/B
Sustainable Urban Drainage Systems (SuDS)	C	B	A

When lower levels of detail/confidence are applied, it should be expected that more data checking will need to be carried out at the model verification stage.

The summary below indicates when it would be appropriate to collect different levels of data considering the greatest need and uncertainty.

Level A data should be obtained where missing:

- In the location of all project drivers under investigation, for all elements of the hydraulic environments
- In the areas of main interactions between hydraulic environments and therefore model linkages
- For detailed overland flow modelling studies due to the importance of local topography
- For all main ancillaries that could affect the hydraulic performance

Data levels B-C closer to main areas may be considered appropriate, but Modellers must understand the uncertainty and risks associated with this. Level D data should be avoided for the main project drivers or interaction areas but may be considered in areas of less significance.

Using flags and geo-spatial mapping will help assess data confidence as detailed in **Section A4**.

B1.5 Geocoding and Datums

All data collected should be defined in accordance with the grid and datum agreed at Project Definition stage. By default, in the UK it should be to the Ordnance Survey grid and the O.S. level datum at Newlyn.

Many modelling programs require all data to be fully geocoded, and data should always be presented in such a way that this can be achieved.

B1.6 Planning Data Collection

B1.6.1 Approach

The data collection scope should be defined, including both existing and new data. Initially, existing data should be assessed, and its confidence evaluated (see **Section A4**), including any data collected as part of earlier studies. This, together with recommendations in previous reports, should help confirm the new data required and enable a plan to be developed.

In combination with identifying missing data, data confidence scoring should facilitate the compilation of a data priority list to help the data collection process, particularly where there are budgetary constraints. The priority list will define the data required and its relative importance, together with the potential sources, estimated costs and timescales.

B1.6.2 Sources of data

Table 3A-2 in Appendix 3A of **CoP**[1] includes a 'long list' of the data that may be used in an urban drainage study or project together with the likely primary data sources. The list was mainly compiled for use with sewer models and includes asset data, models, historical records/operational data, flow and other time varying data, hydrological data and mapping/digital terrain data.

Table B1-3 is a comparable list that aims to provide guidance for the additional data required for an integrated model. As with the **CoP**[1] table descriptions are provided for the four data collection levels A, B, C and D.

B1.6.3 Use of existing data

Existing data should be used as much as possible either in building new models or providing extra detail to existing models. Stakeholders who might hold information relevant to the modelling process should be contacted at project scoping or definition stage to assess what is available and to help with planning the survey programme.

Whilst it is ideal to have access to the original source data, it should be recognised that sometimes an adequate model may have already used that data even though the data is no longer available. Adequate checks should be undertaken before existing model data is used in this way.

B1.6.4 Data quality, data confidence and uncertainty

The collated data should be assessed for quality and completeness and stored for audit and documentation purposes. Typical metrics for measuring data quality include:

- **Accuracy:** Is the data reliable?

- **Completeness**: Is there any data missing?
- **Currency:** Is the data up to date?
- **Consistency:** Is there any contradictory data?
- **Compatibility:** Is the data produced on the same basis as other similar data (for example, have levels been established to a common datum)?
- **Credibility:** Is the data intuitively correct when tested against local knowledge or typical ranges of values?

B1.7 Lidar Data

Lidar data provides the primary data source for creating Digital Terrain Models (DTMs), which, in turn, are used within the modelling software to create a 2D mesh for use in simulations.

The Environment Agency, Natural Resources Wales (NRW) and the Scottish Environment Protection Agency (SEPA) are able to provide Lidar for most projects. This data is usually freely available but may not cover all of the project area. There are a number of commercial organisations who also hold Lidar data and may be able to fill in any missing gaps.

Appendix C provides guidance on how Lidar data is acquired and some of the problems or pitfalls associated with Lidar data. The accuracy of Lidar data has improved considerably in recent years and most data in the UK is at one metre or less resolution. Data from the EA, NRW or SEPA will have already been checked for accuracy, but when purchasing data from commercial organisations it is recommended that 'truthing survey' data associated with that data is requested.

The merging of different sets of Lidar data can be a complex matter and if done incorrectly can result in steps between data sets or even gaps between the data sets; in these instances, the effects on 2D modelling can be severe. If there are insufficient skilled resources within the project team to merge the data, most commercial organisations will undertake this for a fee.

Where there is asset data (for example, manhole cover levels) or watercourse bank levels available from surveys or from records, it is worthwhile undertaking checks to ensure that the levels in the Lidar data correspond with the levels from other sources. Where there are differences, it is important to ascertain why these differences exist and resolve them. Without the Lidar data, asset data and bank levels agreeing the results of any 1D-2D coupled modelling will be erroneous.

B1.8 Topographic and River Cross-Section Surveys

Appendix D provides some guidance on undertaking topographic and river cross-section surveys in relation to integrated catchment modelling.

B1.8.1 River Cross-Section Surveys

The EA, NRW and SEPA have detailed survey specifications for river cross-section surveys; these are used for Main Rivers or equivalent. **Appendix D** provides some guidance on how these specifications can be scaled down for surveys of small urban watercourses where some of the more onerous aspects of the specifications are not essential.

It should be determined at Project Definition Stage (see **Section A3**) what the survey specification should be and who should undertake the surveys.

The physical challenges of surveying river cross-sections should not be underestimated. It is essential that adequate risk assessments are undertaken and measures implemented to minimise any risks. If the surveys are undertaken during winter periods vegetation growth is at a minimum but water levels might be higher; conversely in summer the vegetation growth can impede visibility.

River cross-sections should be taken at all significant changes in channel form or alignment, at all outfall locations and in most urban contexts at intervals of no more than 100m. Data requirements will be sections (x, y and z) with banks defined looking downstream.

B1.8.2 Bank Line Surveys

It is not always necessary to have surveys of bank lines as most modelling software allows the bank lines to be created from the end points of the river cross-sections. However, there are instances where they are useful and when the bank line can be readily identified.

B1.8.3 Topographic Surveys

Topographic surveys are infrequently required for integrated catchment modelling. Where topographic surveys are undertaken, they should be to the O.S. grid and O.S. datum unless otherwise specified.

Surveys or data acquisition in relation to 2D modelling is discussed separately.

B1.8.4 Wrack Mark Surveys

Surveys of the wrack marks of previous flood events can be useful in verifying models and assessing whether models, particularly fluvial models, provide a realistic representation of the flooding risk. It should however be recognised that wrack marks are not always identifiable and may not have been surveyed until sometime after the flooding event. The use of drone surveys enables data to be acquired safely and quickly. The EA, NRW and SEPA have standard procedures for undertaking wrack mark surveys.

B1.9 Watercourse Structures and Ancillaries

At this early stage in a project it is worthwhile identifying which Partners and key Stakeholders already have data on watercourse structures and ancillaries. These details might include the original construction drawings and/or maintenance records.

Watercourse structures are locations where there can be eddy currents and, in some instances, deep scour holes. It is imperative that adequate risk assessments are undertaken with suitable mitigation measures before any survey work is commenced.

B1.9.1 Weirs

Cross-section surveys should be undertaken immediately upstream and downstream of weirs that are considered to be important enough and have a significant difference in level to warrant them being included in the model. Where it is safe to do so, the crest of the weir should also be surveyed. If it is unsafe to survey the full length of the weir crest, the level and crest shape at both ends of the weir should be surveyed.

B1.9.2 Sluices

Sluice structures involve moving parts that may operate automatically (for example, tidal sluices) or may operate with a mechanical control arrangement. It is important that the survey should establish how the sluice is operated and whether the moving parts can satisfactorily travel the full distance.

B1.9.3 Pumping Stations

Data requirements for wastewater pumping stations are described in detail in **CoP**[1]. Pumping stations on watercourses and drainage ditches operate in a different way, with the pumps frequently running for prolonged periods rather than the stop-start arrangement with wastewater pumps. It is also rare for pumping stations on watercourses to be anything other than just a simple lift without long pumping mains.

Typically, the following information will be required to represent watercourse pumping stations in a model:

- Number of pumps
- Pump types
- Pump characteristics
- On/off levels
- Nominal capacity
- Pump curve/head-discharge relationship
- Structure dimensions

Existing information should be used if available from previous surveys, operating manuals and manufactures data. Pump control logic and operating regimes should be understood and operations staff should be consulted, together with the collection of any available design documentation that will help in representing the pumping station in the model. Any monitoring data available should also be collected (such as pump run time logs, depth data, etc.).

Pump capacities cannot normally be determined by carrying out a 'drop test' as is the case with wastewater pumping stations. Initially, pump performance data from manufacturers can be used, but frequently it is necessary to substitute this with more up-to-date performance measurement to allow for wear and tear etc. The principal methods for ascertaining the actual performance characteristics of each of the pumps are either monitoring the pumps themselves or accurately measuring the water levels upstream and downstream.

B1.9.4 Abstraction Points

Abstraction from a watercourse operates either by gravity or by pumping. In the case of gravity abstraction, there will be some form of weir or submerged orifice discharging to a lower system, which might be another watercourse, piped system or drainage ditch. Abstraction by pumping is more common, and modelling requires the same data as described above. The data requirements for abstraction points are generally detailed measurements of the structures.

There are usually limits on the volumes and rates of abstractions and in order to enforce these limits there is usually some form of flow measurement. Data on the limits and flow measurement records should be obtained, but it should be recognised that these may have varied over time and may have a seasonal variation.

B1.9.5 Operational Control

Depending on the configuration of the ancillary, Real Time Control (RTC) may be required to control pumps or sluices. Understanding the operational control is important to avoid lengthy verification using incorrect/out-of-date conditions. It should be recognised that the control rules set out on paper may not be the actual ones in operation; it is recommended that discussions are held with operational staff.

B1.9.6 Bridges

For bridges crossing watercourses and where there is a risk of the structure interacting with the flow in the watercourse during high flow conditions, it will be necessary for an accurate topographic survey to obtain the relevant data. **Appendix D** provides guidance on the measurement of such structures. At bridges, it is recommended that watercourse cross-sections are surveyed at the upstream and downstream faces of the bridge and also a short distance upstream and downstream.

B1.10 Culverted Watercourse Surveys

Culverted watercourses fall into two main categories:

- Relatively new culverts constructed with a consistent material, whose route and connectivity are known and are generally in reasonable condition
- Historical culverts that largely have very few access points, built with a variety of material of different shapes and sizes, with largely unknown routes and generally in poor structural conditions

Appendix E contains some guidance on how watercourse culverts can be surveyed.

B1.10.1 Connectivity and Routing

A reasonable knowledge of the route and the connectivity of a watercourse is fundamental to being able to model the culvert in an integrated model.

Many historical culverts were constructed by simply piping existing ditches or watercourses without any change in route. Therefore, historical Ordnance Survey maps can be a useful starting point for understanding the likely route of a culvert.

The connectivity can be traced in a variety of ways. Using drain tracing dye is probably a last resort as changing the colour of watercourses can result in public complaints and environmental concerns. Tracing the route of a culvert will probably require the use of tracing techniques with a transmitting sonde pulled through the culvert whilst it is traced at ground level.

B1.10.2 Culvert Inlet and Outlet Structures

The capacity of most watercourse culverts is governed by the inlet arrangements rather than the capacity of the barrel of the culvert. It is therefore important that adequate details of the culvert inlets are obtained together with the shape, size and material of the culvert barrel.

Appendix F provides some guidance on the parameters that can be used for modelling a variety of different culvert inlet configurations and materials.

Culvert outlet structures are not as important as the inlets in respect of modelling, but nevertheless details will be required, with checks that the culvert barrel has remained the same size and shape as at the inlet. Invert levels at both the inlets and outlets will be needed.

B1.10.3 Trash Screens

Trash screens (see **C786**[18]) at culvert inlets can have a significant influence on the overall performance and it is therefore necessary to obtain detailed measurements of the screen. Depending on which modelling program is used, trash screens can either be modelled discretely or integral with the inlet structure.

Trash screens as their name implies are installed in order to collect trash and prevent it from entering the culvert. Trash screens can accumulate significant quantities of material and, in some cases, can become blinded. Information should be obtained from operational staff about how frequently the trash screens are cleared and what volumes of material are removed each time.

B1.10.4 Culvert Barrel

In order to adequately model watercourse culverts, it is necessary to understand the size, shape and invert levels of the culvert barrel. Many more recently constructed culverts tend to be reasonably short, straight and constructed with a single material of a consistent shape and size; the required data for these can frequently be obtained by observations and measurements at both ends. With older culverts, frequently the required data can only be obtained by internal surveys by CCTV, drones or man-entry.

The capacity of culverts can be significantly affected by accumulations of debris and sediment within the barrel. This should not be confused with the continuation of a natural watercourse bed through a culvert. The latest advice for culvert design (**C786**[18]) is to depress the culvert and create a 'natural' bed through the culvert matching the upstream and downstream watercourse bed materials.

B1.11 Surveys for 2D Modelling

Except in specific circumstances when more detail is required, most of the data required can be obtained simply from O.S. Mastermap and online imaging programs such as Google Streetview.

B1.11.1 Kerbs

Many of the overland flows in urban areas arising from pluvial runoff and sewer flooding are relatively shallow in nature and kerblines can have a significant effect on constraining and diverting flows. It is therefore important that they are modelled. The way in which they are modelled will vary from program to program. However, a common technique used is to depress the highways into the DTM by the height of the kerb face.

In some instances, it is necessary to model where there are dropped kerbs with a smaller kerb face. It is usually only necessary to specifically model these when there is a risk that water might flow off the highway and into other areas. In these cases, it might be necessary to take some level measurements at the vertices in order to model the dropped kerb and depressed footpath accurately.

B1.11.2 Walls, Fences and Hedges

Most data required for modelling walls, fences and hedges can be obtained from a simple walk around the catchment. It is usually best to undertake some initial modelling before the walk around so that measurements are not taken where they are not required.

There is frequently debate about whether the model should have walls that are not formally recorded as 'flood defence structures'. If the walls (sometimes referred to as 'defacto') do exist but are not recorded as 'flood defence structures', there is a chance that the model will not represent reality. One compromise might be to build and verify the model with all the necessary walls etc included and, once verified, create a version of the model with the walls etc removed, which are not recorded as 'flood defence structures'.

B1.11.3 Embankments

Depending on which modelling program is used, it may be that embankments are adequately modelled just using the Lidar data. However, in order to better define the crest level of embankments, it is recommended that breaklines are used, with data taken either from the Lidar data or from topographic surveys.

B1.11.4 Surface Cover and Roughness

As most overland flow is relatively shallow, the surface roughness can be very influential in the velocity and timing of the flow across the surface.

Ordnance Survey Mastermap provides a lot of information on the extents of different surface types. This data can usually be imported directly into the modelling program and assigned an appropriate roughness coefficient. There are many reference sources for determining suitable roughness values for different surfaces.

B1.11.5 Soil Conditions

Overland flows across permeable surfaces can also infiltrate into the soil and, in some cases, with infiltration basins, that is the method by which they are ultimately emptied.

If infiltration is significant and needs to be modelled, there are a number of sources of material that can be used. A common one used is the 'SoilScapes' website; this is mainly aimed at the agricultural sector, but it provides useful information about the shallow soils that are frequently the most relevant to infiltration. Data from the British Geological Survey can provide information at deeper depths.

B1.12 Flow and Depth Monitoring Surveys

Flow and/or depth monitoring can either be by permanent installations or equipment installed for a short period.

B1.12.1 Short Term Flow Surveys

Short-term flow surveys have traditionally been used to obtain data for the verification of sewer models. Guidance for undertaking short-term flow surveys is included in **CoP**[1] and in the WRc

Specification for Short Term Flow Surveys. Data is usually collected at 2-minute intervals, recognising the rapid rise and fall in water levels that usually occurs in sewers.

There have been recent attempts to use the same technology for measuring flows in watercourses. Where the watercourse is contained within a circular culvert the results have been relatively good. The results in rectangular and arched culverts have been less successful as during low flows the flow may not be centralised within the culvert. Results in open watercourses or at bridges have generally been very poor because of the absence of a consistent channel shape. Planning short-term flow surveys in watercourses may need to include some form of temporary works (for example, a V-notch weir) to facilitate good flow measurement.

B1.12.2 Event Duration Monitoring Data

Many storm overflows have in recent years been fitted with Event Duration Monitoring equipment. The equipment varies depending on how frequently the storm overflow spills, with more frequently spilling overflows requiring more sophisticated equipment that can record flows as well as water levels. For the less frequently spilling storm overflows the equipment only records when a spill actually occurs.

B1.12.3 Sewage Treatment Works Data

Most sewage treatment works have permanent flow measurement installations (MCERTS) to measure the final effluent discharged to the receiving waters. MCERTS is the Environment Agency's Monitoring Certification Scheme for England, which is a standardisation method to ensure accurate measurement of final effluent flows to check regulatory compliance with European Directives. Comparable systems exist in other countries.

B1.12.4 River Gauging Data

Most river gauges are permanent installations either measuring the water level and/or flow (either directly or indirectly from water level). Data from river gauges is widely used by hydrologists and is fundamental to many hydrological procedures. Data is usually collected at 15 minute intervals, recognising that river flows tend to rise and fall relatively slowly in comparison to the flow in sewers. River gauge data is generally collected by the Environment Agency, Natural Resources Wales (NRW) and the Scottish Environment Protection Agency (SEPA) and quality checked, with corrections made for missing or erroneous data. Many river gauges have been installed for a long time, which is essential for the long-term records needed for hydrological studies. Some peak flow data can be accessed from the National Rivers Flow Archive (NRFA) for a number of gauging sites. The EA, NRW and SEPA also hold data for a number of other gauging sites as well as detailed (for example, 15 minute) event records, which can usually be requested.

There's also a large and growing network of gauges (typically level only) installed by Lead Local Flood Authorities (LLFAs) from which data is available for verifying models. This data is often available to view online in real-time, as long as the gauge owner provides permission/access. Even with only a few years of data this data can prove useful in verifying direct rainfall models to level gauge data in small watercourses.

B1.12.5 Tide Gauge Data

There is a network of 55 tide gauges around the UK coastline. This network was set up in 1953 and has been recording continuously since. Data is generally available from the National Oceanographic Data Centre and includes the actual recorded tide level and the theoretical tide level; the difference being due to tidal surges etc. This data is recorded at 15 minute intervals and whilst it is recorded to chart datum it can easily be converted to O.S. datum.

B1.12.6 Telemetry and Operational Data

Most pumping stations and mechanical installations are equipped with telemetry systems, which communicate with a central control room. The installations vary considerably depending largely on the number of communication channels and the frequency of measurements. At the more sophisticated end the start and stop times of the pumps are recorded. In recent years, flow meters and/or pressure sensors have been installed in sewage pumping mains.

B1.13 Social Media Data

The technological advances in mobile phone technology and in particular the capacity and quality of photography and video recording has enabled a step change in the amount and quality of contemporaneous recording of flooding incidents.

It is fair to say that we have seen a massive change in the way we connect and communicate thanks to the fast-spinning world of Social Media and the opportunities it presents.

With 68% of the adult (16+) UK population using social media at the time of writing (ONS August 2019) and the trend looking set to continue, with new platforms being developed all the time, it's important to consider social media as a viable data collection opportunity.

Social Media channels have predominately been used by sales and marketing professionals to increase their brand recognition and reach by engaging directly with consumers and therefore increasing sales. More recently, those in more technical professions have realised the potential value of social media content as a primary source of data collection.

B1.13.1 Value of social media in the flooding sector

In the flooding sector, social media channels can be used to collect and disseminate data during and after flood events. Within an emergency response management situation, platforms such as Twitter and Facebook can also offer important real time data that can be used to better target response action.

Where modelling is concerned, social media in some instances can hold vital clues as to the root causes and mechanisms of flooding. Images, video and comments provided by eyewitnesses of flood events that are posted into the public domain can provide high quality data showing flood mechanisms in progress. It can help identify timelines of events, and potentially give additional information to that obtained via more traditional data collection methods.

The benefit of social media data is the sheer volume of posts. Of course, a resource as vast as social media doesn't come without its pitfalls. Even with the most sophisticated automated data mining tool, a certain level of manual moderation and sense checking will always be required, which can be limiting in terms of time and resource.

B1.13.2 Methods of data mining/harvesting

Manual searching

There are a variety of ways in which manual searches can be set up, with access to some social media sites easier than others due to privacy settings.

A hashtag (#) is a type of metadata tag used on social networks and social media platforms. It lets users apply dynamic, user-generated tagging that helps other users easily find messages with a specific theme or content.

Simple searches can be run using relevant keywords or by hashtag. The more precise the keywords the more likely that appropriate media will be found, although it depends largely on the referencing being correct.

Searching for georeferenced content

Some social media data might be geotagged when it was created, although it is important to recognise that sometimes the geotagging is where the data was posted rather than where the flooding occurred.

Following community flood groups

The usefulness of following community flood groups online should not be underestimated. Many of the Flood Action Groups have social media pages and/or groups or use specific hashtags to raise awareness of flooding in their communities. Undertaking a site walkover (or holding a drop-in event) with a Flood Action Group can be a useful way of gathering verification information or checking model results.

It may be that the local Flood Action Group is included in the Project Steering Group as a stakeholder, in which case its data should be freely available, and there may also be some data that it has not published.

Using social media search sites

There are a growing number of social media search sites, which in response to a query will search through all the available data corresponding to the query posted. Some sites will charge for this service but within the overall cost of a project the cost is very small and is usually worth the investment.

Automatic alerts

At the start of a project an automatic alert system can be set up so that if any information is posted during the study it will automatically be downloaded. These alerts tend to be platform specific and it may be necessary to set up multiple alerts on different platforms. The section below gives an example of such a system used on a project in Birmingham. This produced a wealth of information that was very useful to the project.

Example of Automated Twitter searcher tool

A major challenge is to filter the huge number of posts to a manageable amount of potentially useful information. This tool has been used to automatically search Twitter for a number of predetermined terms and filter these to only return Tweets that are relevant to flooding and rain. The basic input for the tool is a list of search terms, such as city names and hashtags like #BirminghamFlooding.

These Tweets are then filtered for keywords, for example, flood or rain. A basic swearing filter is applied to the tweets to reduce the amount of offensive language. Tweets can be checked to see if they have images attached and are downloaded if applicable.

The URLs of the tweets can then be exported to a multi-tabbed Excel spreadsheet along with hyperlinks to images, videos and tweets. Tests can be done to determine if the Tweets are geocoded and, if they are, points are then created and saved to a database. A separate test is carried out to ensure that the points are within the UK.

Whilst the tool has some limitations, in particular the lack of geo information due to privacy settings, the benefits of potentially unearthing records of flooding, which could be used for documentation and/or model validation, are undoubtedly worth investigating.

Newspaper and Television Archives

Television, local newspapers and national newspapers hold large quantities of archive material that is generally well referenced, giving date and location. The ease with which these archives can be searched varies considerably, but most can be accessed via the internet. In some instances, a more precise search can be carried out by the relevant newspapers or TV company on payment of a small fee.

B1.14 Flooding Record Data

Data on previous flooding incidents will be held by the Partners and Stakeholders involved in the study. It is important to establish whether the data is current or whether a capital scheme has been completed in the meantime, making it unlikely that flooding will reoccur in the same way.

B1.15 Data on Sustainable Urban Drainage Systems (SuDS)

Data requirements for SuDS essentially follow the same principles as for other ancillaries, but the data may be harder to determine or establish. Table 3B-1 in Appendix 3B of **CoP**[1] provides guidance on the main attributes for which data is required.

Table B1-3 Data Collection Levels

Data	Data Level A	Data Level B	Data Level C	Data Level D
Digital Terrain Model (DTM) data				
Data sources	Lidar data with a minimum of 1 metre resolution with demonstrable checking having been undertaken. The Lidar data should have been acquired during a single sortie or should have been created with multiple data sets by experienced personnel and with full quality control checking. In small areas, the Lidar can be supplemented by detailed topographic surveys.	Lidar data with a minimum of 2 metre resolution supplemented and merged with photogrammetric data in open areas with a resolution better than 1 metre and with truthing surveys showing an accuracy of +/- 100mm. The data sets should be merged by experienced personnel.	Lidar data with a minimum of 2 metre resolution.	Data at 5 metre resolution from photogrammetry or from Interferometric synthetic aperture radar (InSAR) surveys.
Watercourse and channel data				
Data sources	A complete survey of the relevant section of watercourse, with cross-sections surveyed at locations defined during a walkover survey by the modeller and survey team.	Cross-section surveys at locations that are accessible and as defined during a walkover survey by the modeller and survey team with interpolation used to create intermediate cross-sections.	River cross-sections derived from a desktop exercise using DTM data with a limited number of cross-sections surveys to check.	River cross-sections derived from a desktop exercise using DTM data.
Ancillaries and Structures (Pumping Stations, Sluices, Watercourse Structures)				
Data Sources	Surveys should be carried out at all significant ancillaries and modelled watercourse structures. Data gathered should include RTC and long-term measured data (for example, Carts, EDM) and operational data, where relevant.	Data for ancillaries and modelled watercourse structures should be obtained from existing records, as constructed drawings, previous surveys, previous models or other reliable data sources. Surveys should be organised where there is insufficient data to model ancillaries/watercourse structures with the required accuracy. Data gathered should include RTC and long-term measured data and operational data, where relevant.	Data for ancillaries and modelled watercourse structures should be obtained from existing records, as constructed drawings, previous surveys, previous models or other reliable data sources. Assumptions should be made where there is missing data. Site inspections will normally be required. Data gathered should include RTC and long-term measured data and operational data, where relevant.	Data for significant ancillaries and modelled watercourse structures should be obtained from existing records, as constructed drawings, previous surveys, previous models or other reliable data sources. Desktop based assumptions should be made where there is missing data. If available, data should be gathered including RTC and long-term measured data and operational data, where relevant.

Data	Data Level A	Data Level B	Data Level C	Data Level D
Watercourse culverts				
Route and connectivity	Detailed surveys should be carried out to determine the route and connectivity.	The route and connectivity obtained from existing records, as constructed drawings, previous surveys, previous models or other reliable data sources. Surveys should be organised where there is insufficient data to model the culvert with the required accuracy.	The route and connectivity obtained from existing records, as constructed drawings, previous surveys, previous models or other reliable data sources.	Route determined from historical maps, with assumptions made that the route has not changed from original ditches and watercourses.
Inlet and outlet structures and trash screens	Detailed surveys.	Dimensions obtained from existing records, as constructed drawings, previous surveys, previous models or other reliable data sources. Surveys should be organised where there is insufficient data to model the culvert inlets etc with the required accuracy.	Dimensions estimated from photographs with features (for example, bricks) from which scaling can be undertaken.	Dimensions estimated from photographs.
Culvert size, shape material and roughness	Detailed surveys which may include CCTV, drone or man-entry surveys. For short, straight culverts observations from both ends may suffice.	Dimensions obtained from existing records, previous inspection reports and surveys, previous models or other reliable data sources. Surveys should be organised where there is insufficient data to model the culvert barrel with the required accuracy.	Dimensions obtained from existing records, previous inspection reports and surveys, previous models or other reliable data sources. Assumptions made for missing data.	Dimensions and invert levels derived from measurements at both ends, with assumptions made about any changes in size or shape along the route.
Sediment and Debris	Detailed surveys.	Sample surveys.	Mixture of sample surveys and assumptions.	Assumptions widely used.
Data for 2D Modelling				
	Data should be obtained from Ordnance Survey Mastermap data supplemented by adequate walkover inspections, taking photographs and measurements at relevant locations.	Data should be obtained from Ordnance Survey Mastermap data supplemented by some walkover inspections and the use of online images.	Data should be obtained from mapping data supplemented by some walkover inspections and the use of online images.	Data should be obtained from mapping data together with making desktop based assumptions.

Data	Data Level A	Data Level B	Data Level C	Data Level D
Flow and Depth Monitoring Data				
River flows and levels	Time varying river levels and flow data should be obtained using data from continuous monitor, with quality control applied to measurements.	Time varying river levels should be obtained using data from continuous level monitor.	River levels may be applied using periodic (for example, daily) level measurements.	River level may be applied as exceptional levels recorded otherwise normal levels may be assumed.
Tide levels	Time varying tide levels should be obtained using data from continuous level monitor.	Tide levels may be inferred from tide tables – adjusted from peak level measurements.	Tide level may be inferred from tide tables – adjusted from level measurement elsewhere.	Tide levels may be inferred from tide tables with no adjustment.
Sewer flow and depth data	Data should be obtained from a detailed short-term flow survey and from long-term records at WwTWs with full quality control checks. EDM data at storm overflows.	Data should be obtained from a detailed short term flow survey. With EDM data at storm overflows, if available.	Data should be obtained from long-term records at WwTWs.	Data from spot surveys using handheld equipment.
Telemetry data	Permanent monitors with data recorded and transmitted at close intervals.	Permanent monitors with data recorded and transmitted several times a day.	Permanent monitors with data recorded and transmitted daily.	Not used.
Operational data				
Temporary changes to the system	Data should be obtained from operations staff, operational records and/or data from permanent monitors.	Data should be obtained from operations staff, operational records and/or data from permanent monitors.	Data should be obtained from operations staff, operational records and/or data from permanent monitors.	Data should be obtained from operations staff, operational records and/or data from permanent monitors.
Flooding and surcharge data	Detailed data on flooding and surcharge should be obtained from flooding records, including third party sources. Long-term surcharge surveys should be carried out where appropriate.	Detailed data on flooding and surcharge should be obtained from flooding records, including third party sources.	Detailed data on flooding and surcharge should be obtained from flooding records, including third party sources.	A basic knowledge of major flooding points should be established from flooding records, including third party sources.
Other incident data	Data should be from operations staff, operational records and/or third party sources.	Data should be from operations staff, operational records and/or third party sources.	Data should be from operations staff, operational records and/or third party sources.	Data should be from operations staff, operational records and/or third party sources.
Pipe Roughness Data				

Data	Data Level A	Data Level B	Data Level C	Data Level D
Source and application	Information on roughness, and hydraulic problems should be obtained from available CCTV records.	Where sewer condition is known to be poor, available CCTV records should be inspected and the result used to assess roughness.	Global roughness values should be assumed.	Global roughness values should be assumed.
Sediment Level Data				
Source and application	Information on sediment depths should be obtained from available CCTV records.	Information on sediment depths should be obtained from available CCTV records where there are known sediment problems.	Assumed sediment depths should be included where there are known sediment problems.	Sediment depths should not be included.
Social Media Data				
Data Sources	Data from alerts and searches where the data is geotagged with the flooding location and date. Data from newspaper and TV archives with location and date reliably recorded.	Data from alerts, searches and archives where the data is not geotagged but there is some description of the flooding location and date.	Data from searches and archives where the location or date is not reliably recorded.	Data from searches and archives where there is no reliable information on location and date. This may need investigations to identify the location.
Sustainable Urban Drainage Systems (SuDS)				
Data Sources	Detailed surveys and/or As Built construction details together with performance data from in-situ testing.	Detailed surveys and/or As Built construction details together with realistic assessments of performance data.	Construction details together with desktop assessment of likely performance.	Estimated data based on observations or photographs of installation.

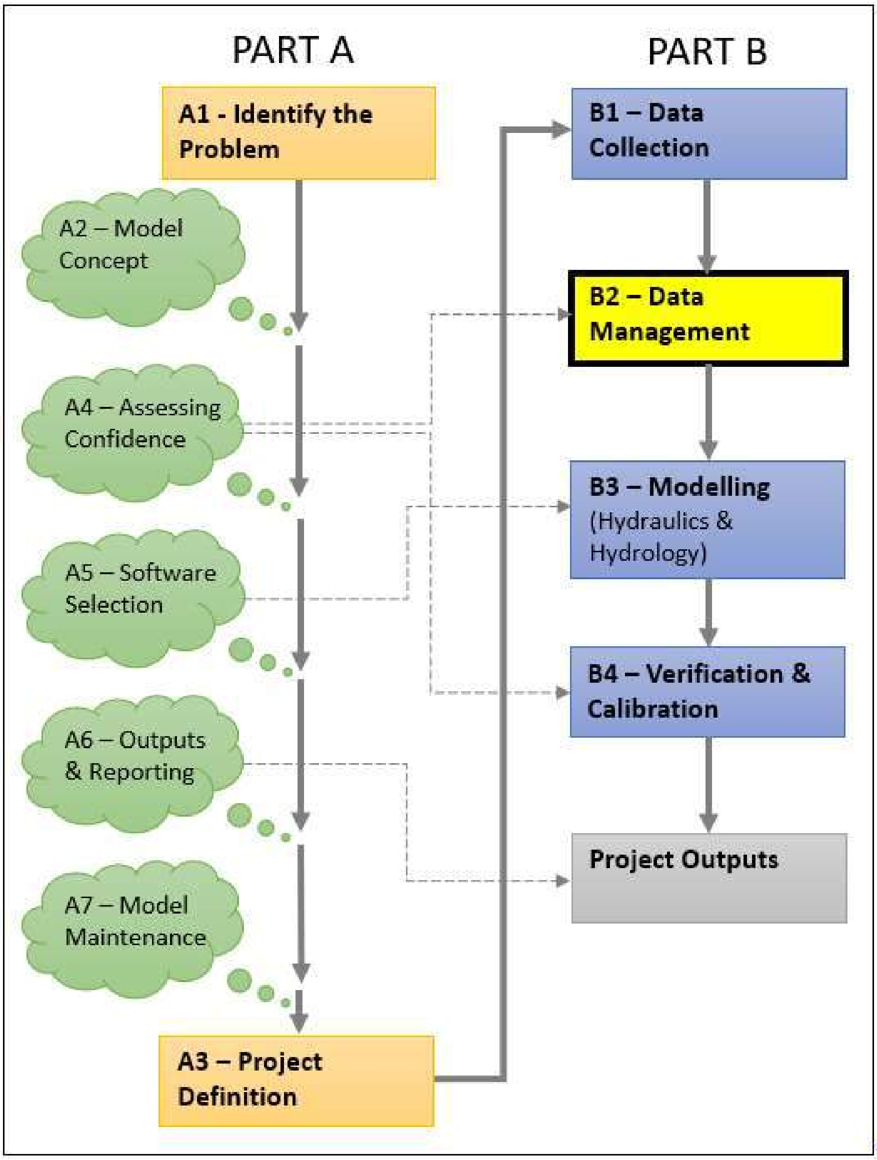
Integrated Urban Drainage Modelling Guide

Section B2

Data Management

Chartered Institution of Water and Environmental Management

B2 DATA MANAGEMENT



B2.1 Introduction

As with all modelling projects, data management on IUD modelling projects is critical to the success of a project, and it is important that data management procedures and systems are defined at the outset of a project. Data management should follow internal procedures for the client and the supplier (for example, ISO9001).

This section considers data management for three components of the project: incoming data, data storage, data processing and outgoing data. In addition, it also refers to the GDPR regulations that apply to data used in modelling projects.

On larger, more complex projects or when IUD modelling forms part of a wider inter-disciplinary project, data management systems, including BIM may apply to the project and would be defined by the wider project team. In these instances, modellers should refer to the project BIM Implementation Plan for guidance on data management on those specific projects.

B2.2 Incoming Data

Regardless of the system or format used, all incoming data for an IUD modelling project should be logged and this log would typically include:

- Type of data/summary title
- Owner/originator of data
- Date received (or accessed in the case of online data, for example, hydrometric data)
- Record of checking and reviewing that data (may include a link to a more detailed record and comments about the quality of the data)
- Format of data received and file location (assumed to be completely electronic)

The incoming data log can be created from an initial data request list and should be continuously maintained and raised with the PSG, where necessary. **Section B3** includes more information about the review of existing models to be undertaken prior to beginning an IUD model.

B2.3 Data Storage

All received data should be collated and stored in a suitable folder structure and should be backed up at suitable intervals. Many Partners and Stakeholders have specific requirements on how data should be structured and returned at the completion of the study. Some Partners also have specific data naming conventions. These are necessary to ensure that they either replicate or can easily be returned to fit within the Partner's data repository structure. **Appendix J** provides some guidance on data structure, naming conventions, and provides a checklist that can be used to ensure completeness and consistency.

B2.4 Outgoing Data

All outgoing data for an IUD modelling project should be logged and this log would typically include:

- Type of data/summary title (for example, draft/final)
- Date issued and who data has been issued to
- File name, format of data issued and file location (assumed to be completely electronic)
- Checks to ensure it meets the requirements of GDPR

An initial outgoing data issue log can be created from the project scope that should define the required IUD deliverables. It should be continuously maintained throughout the project. **Section A6** includes more information on project deliverables, outputs and reporting.

High IT security and large file sizes can create an obstacle to incoming/outgoing data. For example:

- Gaining access to external file sharing services is often tightly controlled by organisations
- Some organisations require the use of encrypted hard drives or memory sticks
- Downloading or unzipping certain files are blocked (in particular '.exe' files)

Data sharing methods should be agreed at project definition stage, to understand the constraints and potential issues.

B2.5 Common data environments

Whilst the use of common data environments is preferred to help with receiving and issuing data, it is acknowledged that there are often barriers to effective sharing between collaborative partners on an IUD project. This can be due to differing levels of cyber security and issues around the running of models from cloud-based platforms. A data sharing protocol should be defined at project definition stage and agreed between partners to ensure effective transfer of data.

B2.6 GDPR

Collaborative partners should be aware of their responsibilities with reference to the General Data Protection Regulations (GDPR) and ensure that all data is managed in accordance with the regulations. Data/information from the public and sensitive data must be managed appropriately by all partners. It is recommended that the latest government advice is obtained and followed.

B2.7 Data Licences

Some data (for example, Ordnance Survey mapping) is subject to licence agreements that might allow the data to be used for specific purposes or for specific periods. It is important that the licences requirements are followed; in some instances, this might prevent that data from being shared with all project Partners and Stakeholders, and may also prevent it from being archived.

B2.8 Data archiving

Once the project has been completed, it can be archived. Data must be processed to ensure that it can be made available for any requisite time specified by the project or any Partners or Stakeholders. The main consideration is to ensure that any archived data, together with any accompanying notes or guidance can be identified, found and accessed. It should be recognised that some data subject to licence restrictions may not be included in the archive; in those circumstances, a note should be included to explain that any future user may need to obtain a new licence for that data.

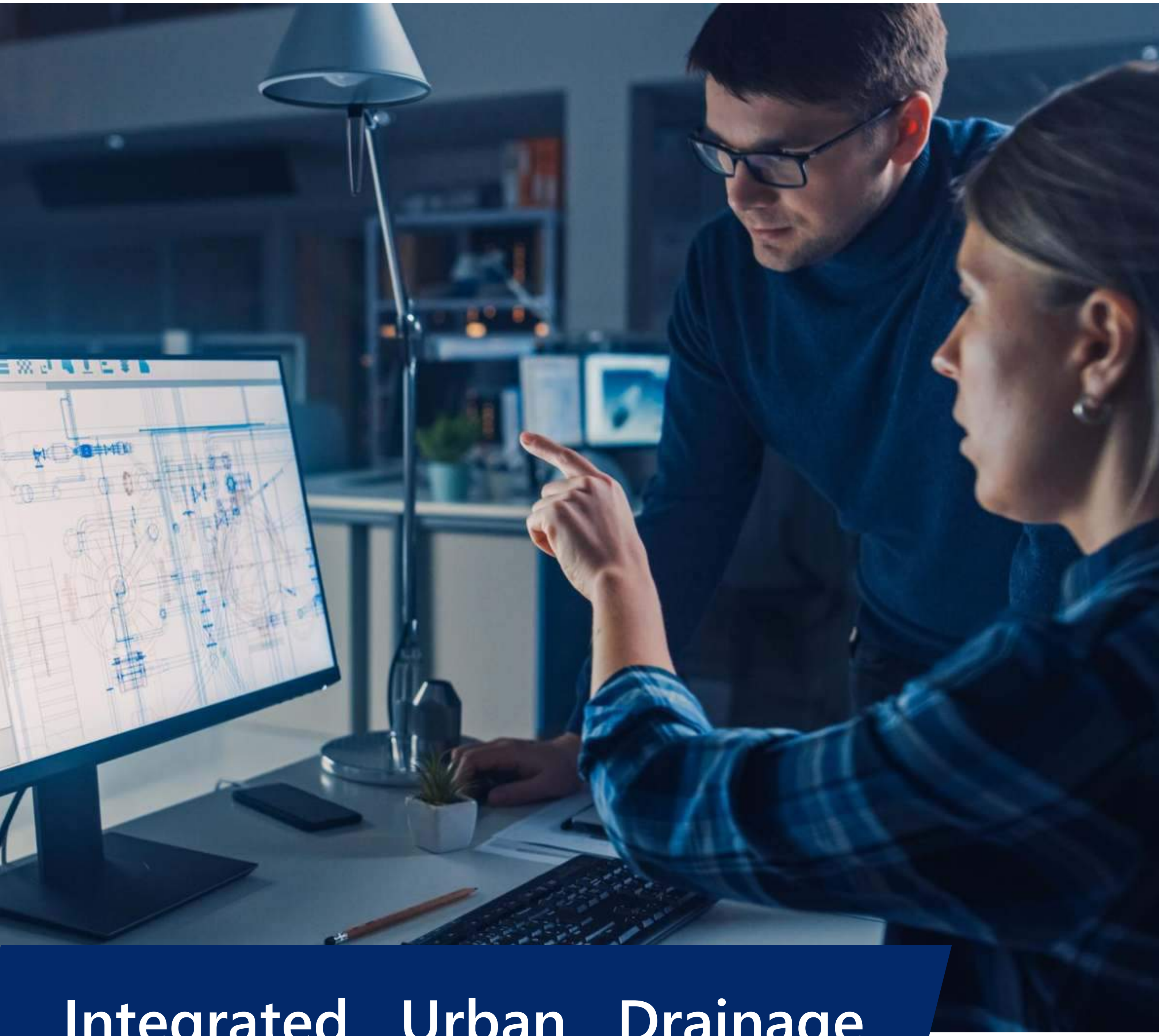
It should be agreed at project definition stage who is responsible for archiving the project data once the work has been completed. In most cases, it would seem appropriate for the party who holds intellectual property to be responsible for safely archiving the project. Archiving considerations should include safety of data, potential degradation of storage media, multiple copies/back-ups, accessibility of archiving system for future access.

Information generated as part of the project may be in digital (model, GIS) and paper records (survey notes, questionnaires).

- Digital files should be transferred to non-proprietary file formats (where possible) to ensure accessibility in the longer term

- Decisions on non-digital data will vary depending on the nature of the project and any legal, ethical or stakeholder requirements. It may be feasible to digitise some data if provision was made at the outset, with any costs built into the project funding

In the process of archiving, the question should be posed does all data need to be preserved? This will depend on the nature of the project and the accompanying data.



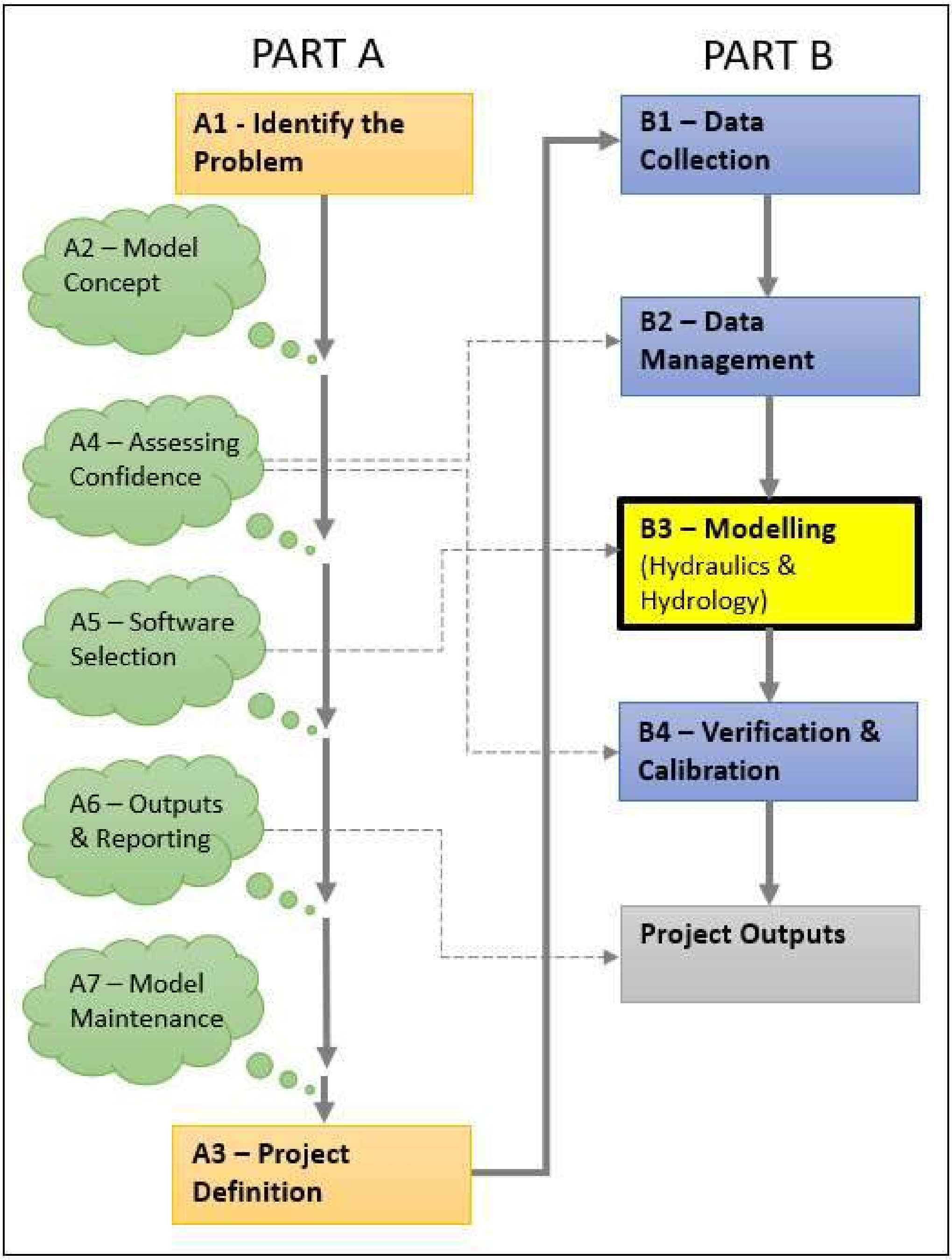
Integrated Urban Drainage Modelling Guide

Section B3

Modelling (Hydraulics and Hydrology)

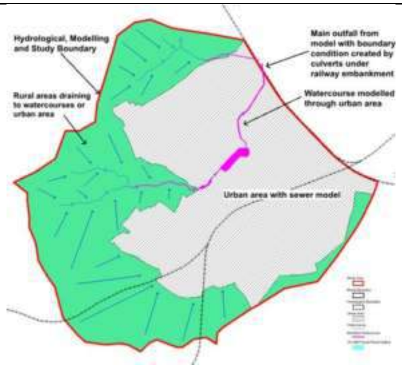
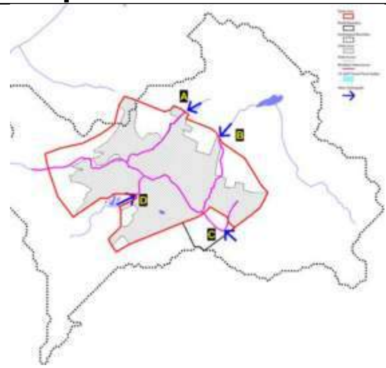
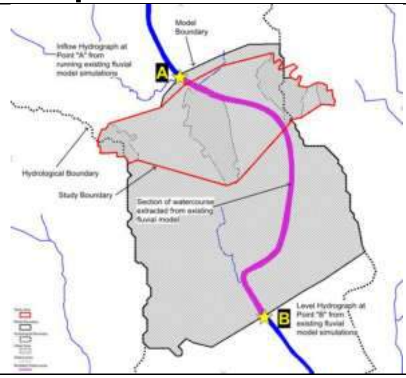
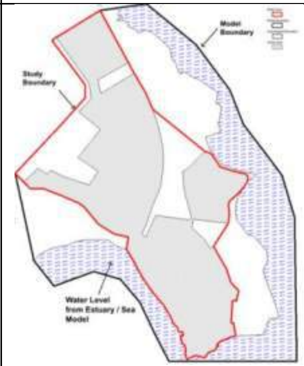
Chartered Institution of Water and Environmental Management

B3 MODELLING (HYDRAULICS AND HYDROLOGY)



This section of the IUD Modelling Guide provides detailed and practical guidance for developing integrated models and covers both the hydrological and hydraulic parts of those models. Where possible, guidance in this section is provided for the four different model concept types (**Section A2**), which are summarised below in Table B3-1. This section of the Guide is intended to provide general advice for modellers. Project specifications (for example, from the EA, SEPA, NRW, WaSCs etc) or details in the Project Definition, agreed for the specific project should always take precedence over this general advice.

Table B3-1: Summary of model concept types (more detail in Section A2)

	Type #A Contained	**Type #B Simple Interaction**	**Type #C Complex Interaction**	**Type #D Restricted Interaction**
				
Hydrological Boundary	Defined from topography. FEH catchments unlikely to be sufficiently accurate at this scale.	Defined from FEH catchments.	This is the hydrological boundary for the major watercourse.	Same as Study Boundary.
Model Boundary	Identical to Hydrological Boundary.	Identical to the Study Boundary extended as necessary to enable modelling of relevant elements.	Defined from computational nodes in the existing fluvial model of the major watercourse extended as necessary to encompass the study boundary.	Same as the study boundary extended as necessary to crest of defences and/or the outfall locations of the urban drainage system.
Study Boundary	Identical to Hydrological Boundary.	Determined from the area to be studied.	Determined from the area to be studied.	Determined from the area to be studied.
Model Inputs	Rainfall (possibly initial catchment wetness conditions).	Rainfall and inflow hydrographs. It may also require different initial catchment wetness conditions or seasonal variations.	Rainfall, inflow hydrographs and level hydrographs from simulations using the existing fluvial model of the major watercourse. (*)	Rainfall and level hydrographs from simulations using external models or other predictions of water levels.

	Type #A **Contained**	**Type #B** **Simple Interaction**	**Type #C** **Complex Interaction**	**Type #D** **Restricted Interaction**
Rural Hydrology	ReFH or 2D runoff (direct, Horton or Green-Ampt).	Outside the study/model area a Hydrological Study will be required. Within the study/model area the rural hydrology could use ReFH or 2D runoff (direct, Horton or Green-Ampt).	Outside the study/model area a Hydrological Study will already have been undertaken in order to build the major watercourse fluvial model. Within the study/model area the rural hydrology should use 2D runoff (direct, Horton or Green-Ampt).	Generally not necessary but within the study area the rural hydrology (if required) ReFH or 2D runoff (direct, Horton or Green-Ampt) could be used.
Urban Hydrology	Fixed, New UK, UKWIR	Fixed, New UK, UKWIR	Fixed, New UK, UKWIR	Fixed, New UK, UKWIR
1D, 1D-1D or 1D-2D	Generally, 1D with a narrow corridor along watercourses of 1D-2D.	Generally, 1D with a narrow corridor along each of the watercourses of 1D-2D.	Generally coupled 1D-2D throughout model.	Generally, 1D or coupled 1D-2D depending on how the flooding within the study area is to be represented.
Combined Probability	This is not an issue with this type of catchment as there is only one variable. It would however be necessary to simulate a range of different storm durations.	This type of model will present some challenges in respect of combined probability. These challenges will mainly be around duration and timing issues and it may be necessary to create inflow hydrographs for a range of storm durations rather than just the critical duration. Additionally, the critical durations for each of the	This type of model will present some challenges in respect of combined probability. These challenges will mainly be around the likelihood of return periods occurring simultaneously in the study area and the major watercourse (and any tributaries).	This type of model will present some challenges in respect of combined probability. These challenges will mainly be around the likelihood of return periods occurring coincidently with high tide levels.

	Type #A Contained	**Type #B Simple Interaction**	**Type #C Complex Interaction**	**Type #D Restricted Interaction**
		watercourses might be different.		
(*) In Type #C where there is a complex interaction, it is assumed that an existing fluvial model is available for the major watercourse. If not, it is likely to need a Type #B approach. In Type #C models, inflow hydrographs from existing fluvial models need careful consideration with respect to applying other rural and urban hydrological modelling in the integrated model to ensure there is no double-counting of inputs to the model. In other words, it should be checked that a part of the catchment contributing to the watercourse inflow hydrograph from an existing model is not also covered by the application of a rural or urban rainfall-runoff model within the integrated model.				

B3.1 Hydrological Boundary

The hydrological boundary of an integrated model is defined, for the purpose of this Guide, as the **boundary of the area within which any rainfall would contribute to the study area** (also known as the watershed). This boundary is generally defined by the topography of the catchment and can be delineated using several means, including the FEH web-service (**FEHweb**[12]), which is suggested in **Appendix H – Hydrology** as the main method of catchment definition.

It is important that the catchment delineated by and downloaded from **FEHweb**[12] is checked against OS mapping, the highest resolution DTM available, and a GIS layer or model of the sewer network. There are several GIS processes that can be used to delineate a catchment to a specific point from a DTM. These vary depending on what GIS package is used but all use a very similar (rolling ball) process and are useful for verifying a catchment delineated by **FEHweb**[12] or for identifying hydrological boundaries on catchments too small for effective delineation in FEH, which is based on a 50m grid. In urban modelling, it is particularly important to check the catchment boundary against sewer mapping/data as this is likely to change the delineation of catchment extents. In some cases, the contributing area boundary changes depending on the magnitude of storm events being considered. For example, while the surface water sewer system may define the contributing area under 'normal' events, in more extreme events when the capacity of the sewer system is exceeded, the topographic catchment is key.

- For Type #A models, the hydrological boundary will be the same as the model boundary and the study boundary. These catchments may be too small to be accurately defined by **FEHweb**[12]; in which case definition from the highest resolution DTM available is recommended instead.
- For Type #B models, the hydrological boundary is larger than the model boundary and the study boundary; often there is one or more watercourse(s) flowing into the study/model area. In these cases, it is assumed that some kind of hydrological analysis will be required to derive flows for the incoming watercourse(s), and that the first step in that analysis would be catchment definition. Depending on the number of watercourses flowing into the study/model area, model inflows may need to be estimated at several points where the watercourses enter the model boundary. The contributing catchments to these points will need to be delineated, and **FEHweb**[12] is the recommended starting point in these cases. This should then be checked against OS mapping, DTM data and the sewer network. Additional catchments will also need to be delineated to points on the watercourses within the model boundary for estimating check flows.
- For Type #C models, the hydrological boundary is significantly larger than the model boundary and the study boundary, and only a short length of the main watercourse is likely to be modelled. It is assumed generally that the main watercourse would already have been modelled and that design event flows would already exist and therefore there would be no requirement for detailed hydrological analysis to support the integrated model. However, if the boundary needs to be checked **FEHweb**[12] should be used, supported by OS mapping, DTM data.
- For Type #D models, the hydrological boundary is likely to be the same as the study boundary and identified through catchment knowledge, OS mapping, DTM data and the

sewer network. Detailed hydrological analysis is unlikely to be required in this case because the principle behind the concept is that restrictive (or backwater) effects from a large river (or the open coast or estuary) on an urban drainage system can be represented by applying a level hydrograph at the outfall in the models.

B3.2 Model Boundary

The model boundary of an integrated model is defined, for the purpose of this Guide as the **boundary of the area to be covered by the integrated model**. The model boundary would capture surface and sub-surface features and would encompass the length of any watercourses, sewer networks and ground surface to be modelled. The definition of the model boundary will depend on the objective of the project; the type of model required and an initial understanding of how the system functions.

For 1D models the model boundary will define the upstream and downstream extents of the networks to be modelled (sewer and river). For 2D or 1D/2D models the boundary will define the upstream and downstream extents of the networks to be modelled (sewer and river) and the extent of the ground surface to be included in the 2D domain.

- For Type #A models, the model boundary covers the full extent of the hydrological boundary (see Section B3.1).
- For Type #B models, the model boundary will be smaller than the hydrological boundary and is likely to be similar to the study boundary. The model boundary will be defined by the area to be investigated and is likely to include existing urban areas and to encompass the whole sewer network draining into the watercourse(s) within the study area. The model boundary may be extended to include potential development areas and upper catchments (if flood storage is being considered) depending on the required outcomes of the project.
- For Type #C models, the model boundary is likely to be larger than the study boundary and significantly smaller than the hydrological boundary. The extent of the main watercourse to be modelled will likely be a short length extracted from an existing fluvial model. The upstream and downstream extents will be selected, taking account of the schematisation of the existing model and in a way that captures the known flow routes and flood extents predicted by the fluvial model. Mapped and other results from the main watercourse model will provide the catchment understanding required to determine appropriate extents. The model extent will be extended to capture the whole study extent, even if this were not captured in the original main watercourse model.
- For Type #D models, the model boundary will be the same as or larger than the study boundary. After identifying the study boundary, the model boundary would be created by extending the model extents to reach the crest of defences, outfall locations of the urban drainage section and sea wall etc. It will likely encompass the whole sewer network draining through the study area.

B3.3 Study Boundary

The study boundary for an IUD model will be defined based on the aims and objectives of the specific project and is not actually used within the model. However, other elements of the model will be influenced by it as summarised in Table B3-1. The study boundary is not hydrologically or hydraulically defined and is instead based on the aims and objectives of the project as agreed at project definition stage. For integrated modelling, the study boundary will be urban and should be kept as tight/small as possible in order to manage run times and data requirements, whilst getting the resolution required to achieve the study objective.

B3.4 Model Inputs

For Type #B and Type #C models, **inflow hydrographs** are required at the upstream extent of the watercourse model. These inflow hydrographs represent the design event (flood) hydrology of the upstream fluvial catchment and are either applied as a point inflow to the hydraulic model of the watercourse or as a lateral inflow across a defined reach of the hydraulic model. As described further in **Appendix H – Hydrology,** the peak flow estimates may be derived by either statistical or rainfall-runoff methods. Rainfall runoff methods will likely be used to derive the hydrograph parameters and shapes. In more complex models where there are multiple watercourses (for example, including tributaries), inflow hydrographs would be needed on all watercourses in the model. The project team will need to agree collaboratively on the locations for inflow hydrographs during the project definition stage.

For Type #B models the inflow hydrographs are likely to be derived specifically for the purpose of the integrated modelling project. This would be done through detailed hydrological analyses, which forms a significant piece of standalone work, and is described in more detail in **Sections B3.5** and **Appendix H – Hydrology**.

For Type #C models these inflow hydrographs would be extracted from existing, larger, hydrological and hydraulic models of the main watercourse (for example, from an Environment Agency strategic flood model). When extracting flow hydrographs from existing models for use as inflows to new integrated models it is important to note:

- The methods that were used to derive inflows for the existing model and the date those methods were used, noting where the hydrographs have been adjusted to achieve better model calibration to historic events or to match peak flow estimates in the lower reaches of the model
- If the existing model is 1D/2D, results will need to be extracted from the 1D network and the 2D domain to ensure that all watercourse and floodplain flow is captured in the inflow hydrographs to be applied to the new integrated model
- Where inflow hydrographs are applied laterally in the existing model (that is, distributed between model nodes or along a reach), this should be noted and the same effect should be achieved in applying these inflows to the new integrated model, whilst being cautious of potential double-counting

For all four model types, **rainfall inputs** are required to be applied either to the sewer network (the sub-catchment approach) or directly to the 2D model grid or mesh. Typically, a rainfall depth is derived for a pluvial event of a given annual exceedance probability (or return period) and duration and this is usually derived for the UK by using the FEH Depth-Duration-Frequency (DDF) model, which can be accessed within **FEHweb**[12] or common modelling software types (for example, InfoWorks ICM and Flood Modeller). For rainfall to sub-catchment modelling, there are a number of different runoff volume models and methodologies to determine how much of that rainfall runs off the catchment into the drainage system (after accounting for losses), which are described in more detail in **Sections B3.5,** and **Appendix H – Hydrology**. For rainfall to 2D grid modelling, there are also a number of different methods for applying runoff coefficients and/or infiltration losses. Whilst the hydrological modelling is similar, the application of these methods varies depending on software type.

Type #D models will also require some kind of **level hydrograph** to represent conditions in the downstream waterbody into which the urban drainage network discharges for the full duration of the simulation. This level hydrograph may represent river levels or a tidal or surge level in an estuary or coastal environment. These level hydrographs would be extracted from existing fluvial/tidal models or created using appropriate coastal/estuary flood boundary datasets, with particular consideration given to the combined probability elements referred to in **Section B3.8**. In simple Type #D models a single level hydrograph may be sufficient, but multiple level hydrographs may be required to represent the varying level conditions along the river, estuary or coast. When extracting level hydrographs from existing models for use as boundaries in new integrated models it is important to note:

- The date and source the tidal boundaries used in the existing models were derived as these may have been superseded by more current or closer coastal datasets that may have updated predicted levels and tidal curves
- The modelling methodology and limitations used to derive level hydrographs at the downstream of the study area

Finally, in some cases, **catchment wetness information** will also be a necessary model input to represent antecedent conditions, which could be achieved by using Net Antecedent Precipitation Index (NAPI) or Urban Catchment Wetness Index (UCWI) values. There is further information on applying these in **FEH**[11] and **WaPUG_UN**[24]. These indexes are usually applied to the rainfall input data to make allowances for the wetness of the permeable surfaces at the start of simulations.

B3.5 Rural Hydrology (for large undeveloped areas)

Appendix H – Hydrology provides detailed information and UK references associated with the hydrological analyses methods likely to be used in an integrated model. This section simply summarises the main methods used for hydrological modelling in the rural/pervious parts of the integrated model area. The reader is encouraged to turn to the relevant sections in **Appendix H – Hydrology** for more detailed information on how to apply the methodologies. This briefly covers the use of hydrological modelling to derive model inflows for upstream rural catchment areas (upstream of the **Model Boundary**), but is more focused on the hydrological methods used to represent runoff from the green/pervious parts of the catchment within the **Model Boundary** (for example parks, gardens and other green spaces).

There are a number of methods that can be used for the hydrological analysis in the rural /pervious parts of the catchment. In the sections below where rainfall-runoff modelling is recommended, we have tried to clarify where we are referring to methods such as ReFH/ReFH2 that are used to derive inflow hydrographs for modelled watercourses and where we are referring to rainfall-runoff methods applied within the integrated modelling boundary, either via the application of rainfall to sub-catchment or rainfall onto the 2D grid/mesh. The runoff volume models and methodologies determine how much of the rainfall runs off the catchment into a watercourse or sewer.

- For Type #A models, ReFH/ReFH2 (**ReFH**[22]) is recommended if a rainfall runoff model is needed to derive inflow hydrographs for modelled watercourses. Alternatively, or additionally, 2D rainfall-runoff modelling can be used, with the option of accounting for losses to the ground through incorporating infiltration using models such as Horton or Green-Ampt. Further information on the choice between these models can be found in **Appendix H – Hydrology**. Some software (see Section A5) allows ReFH sub-catchments to be modelled within the program, avoiding the need for inflow hydrographs.
- For Type #B models, multiple hydrological approaches may be needed to represent the rural catchment. In this case where the study area and model area is likely smaller than the catchment hydrological boundary, a hydrological analysis will be required for the catchment outside the integrated model boundary to derive point inflow hydrographs. This is explained further in **Appendix H – Hydrology** and is likely to include the FEH Statistical Method and or the **ReFH**[22] rainfall runoff model. It is recommended that this analysis is undertaken by a hydrologist with experience of fluvial catchment hydrology. The integrated model will also require rural hydrology methods for the pervious areas within the model boundary and would likely use the same methods here as Type #A models, that is, rainfall-runoff modelling with options of incorporating infiltration models.
- For Type #C models, the rural hydrology approach would be similar to Type #B although it is expected that the main watercourse would already have been modelled and that peak flow estimates and inflow hydrographs would already exist from those previous studies. Rural hydrology methods within the integrated modelling area would be the same as Type #A and Type #B models, that is, direct rainfall-runoff modelling with options of incorporating infiltration models.
- Type #D models are unlikely to include significant areas requiring rural hydrology analysis, but if there are rural/pervious areas, the same methods would be used as for other model types, that is **ReFH**[22] or rainfall-runoff modelling with options of incorporating infiltration models.

For all types of model (#A, #B, #C and #D) rainfall-runoff modelling is suggested as a possible hydrological method for the pervious areas within the integrated model boundary. This can be applied either through the application of rainfall to sub-catchments or direct rainfall to the 2D model grid/mesh. 2D direct rainfall runoff methods are generally applied where the catchment isn't easily defined, for example, where there is a significant motorway or railway through the catchment likely to impact flow routes and contributing areas, or where the problem has been identified to be either partly or wholly from pluvial flooding. There is more information about direct rainfall runoff-modelling in **Section B3.11.4** and the decisions that need to be made in that type of modelling. The Environment Agency's Flood Estimation Guidelines **Flood Estimation**[31] are also a useful point of reference.

Table B3-2 provides important information about the commonly used rainfall-runoff models for the rural/pervious parts of the catchment. Further information can be found in **Appendix H – Hydrology**.

Table B3-2 – Overview of rural/pervious area runoff methods

Method	Overview	Key points to note
Fixed	Applies a fixed percentage runoff to permeable areas.	• The percentage runoff remains constant throughout the storm event and is identical for all storm events. • Most appropriate where a good estimate of the percentage runoff can be made. • It is not used for long or continuous storms as the 'fixed' percentage does not vary through the simulation.
Horton	The Horton Runoff Model (**Horton**[23]) was discovered by Robert E. Horton in 1933. The runoff model was interpreted by Horton as a separating surface that divided precipitation into two parts that follows different routes through the hydrological cycle. Simplistically, one part is initially absorbed by the soil and then proceeds through groundwater to the watercourses or is evaporated back to the atmosphere. The other part becomes overland runoff. The infiltration capacity is dependent on soil properties, capacity and the input of water. Once infiltration is exceeded, overland flow occurs.	• Has more flexibility (than the fixed percentage runoff method) in the variables and infiltration parameters. • Parameter selection relies on knowledge of physical soil properties. • Intended for modelling runoff from pervious or semi-pervious areas.
Green Ampt	An infiltration model (**Green-Ampt**[25]) named after two American physicists. It is a physically-based model commonly used to model infiltration in rainfall-runoff modelling.	• Intended for modelling runoff from pervious areas. • Parameter selection relies on knowledge of physical soil properties. • Percentage runoff varies over time through the duration of the storm. • Soil drying represented to allow continuous simulation. • Does not include evapotranspiration.
ReFH runoff routing model	Is a conceptual rainfall-runoff model (**ReFH**[22]) that enables the user to generate hydrographs for a rural catchment.	• Extreme event runoff. • Parameters use readily available FEH catchment descriptors. • Catchment and plot scale outputs are available.

The method should ideally be selected at Project Definition stage (**Section A3**) and is usually determined by company specific and/or regulator specific guidance. It is recommended that where no specific guidance exists, then the choice of method selected is documented with notes on why that method has been selected. In some cases, the selection of rainfall-runoff method may be changed during the model calibration phase.

B3.6 Urban Hydrology (including permeable areas within urban areas)

Urban hydrology comprises the runoff from both impermeable and permeable areas within the urban environment. The methods used are all rainfall-runoff methods and the main differences are in the way in which the permeable areas are treated; these are summarised in Table B3-3. Most hydraulic modelling programs use sub-catchments (also known as contributing areas), which define the area draining to an individual node or link in the urban drainage network. These sub-catchments contain numeric values for the extents of impermeable and permeable surfaces.

Once initial losses due to absorption, filling depressions etc have been completed, the percentage of the rainfall that runs off impermeable surfaces (roads, roofs etc) does not change during the storms. In contrast, the percentage runoff from pervious surfaces increases during the storms as they become wetter. Most hydraulic modelling programs therefore treat the runoff from impermeable surfaces as a fixed percentage (for example, 80%), with the balance assumed to drain onto the permeable surfaces within the same sub-catchment.

Appendix H – Hydrology provides detailed information and UK references associated with the hydrological methods likely to be used on the urban areas (impervious surfaces) in an integrated model. This section simply summarises the main methods used for hydrological modelling (runoff estimation) in the urban/impermeable parts of the catchment. The reader is encouraged to turn to the relevant sections in **Appendix H – Hydrology** for more detailed information.

The best source of information for urban hydrology methods is via the CIWEM UDG website. The most recent Code of Practice for the Hydraulic Modelling of Urban Drainage Systems (**CoP**[1]) provides a good overall summary of the methods. The CIWEM UDG website also contains several useful 'User Notes' (**WaPUG_UN**[24]), which provide more detailed information about certain topics, including urban hydrology, for example, User Note 28 – A new runoff volume model. Some software providers also provide information via their 'help' and support functions.

For all types of model (#A, #B, #C or #D) the same urban/impervious hydrology methods are recommended, that is, a choice between Fixed, New UK and UKWIR methods. These are summarised below and explained further in **Appendix H – Hydrology**. These runoff methods are usually implemented within the modelling software being used for the integrated model.

Table B3-3 - Overview of urban/impervious area runoff methods

Method	Overview	Key points to note
Fixed	Fixed runoff methodology has fixed percentage runoff from all surfaces including the permeable surfaces.	• The percentage from each surface (road, roofs and permeable) can be set differently. • The percentage runoff remains constant throughout the storm event and is identical for all storm events. • Irish Water specifications state that this method should be used for all impermeable surfaces. • This is generally used as a simplistic method. • It is not used for long or continuous storms as the 'fixed' percentage does not vary through the simulation.
NewUK	Works on the basis of fixed percentage runoff from paved areas and roofs but with a varying percentage runoff from permeable surfaces.	• There are only a small number of variables that can be used to alter the runoff from the permeable surfaces both in terms of magnitude and duration. • The principal drawback with this methodology is that when it is used with synthetic design storms it can sometimes lead to exceptionally large and false flooding volumes. • Irish Water specifications state that this method should be used for all permeable surfaces.
UKWIR	This method (**UKWIR**[26]) was developed to overcome the problems associated with the New UK method when simulating with synthetic design storms. This method uses more variables than the NewUK model and uses the HOST[2] soil classification rather than the WRAP[3] soil classification.	• This method has not yet gained widespread use in the UK but is gradually becoming more frequently used. • Irish Water is currently stating that this method "*shall not be used as part of a model build and verification*" until it has been further tested and its suitability confirmed.
Wallingford	This method is now very rarely used because of the limitations in the runoff equations used.	• This method is based on the 'PR Equation', which was developed from a very small data set and uses a small number of parameters, with the most important one being the PIMP (percentage impermeable) within the sub-catchment. It uses the PR Equation to calculate a single runoff value, which is then applied to the sub-catchment as a whole. With certain soil types and with

[2] Hydrology of Soil Types
[3] Winter Rainfall Acceptance Potential

Method	Overview	Key points to note
		large permeable areas the PR Equation can give negative runoff values. • This method is **not recommended**.

The method should ideally be selected at Project Definition stage (**Section A3**) and is frequently already included in the model if the IUD model is based on an existing sewer model. Otherwise, the method to be used is frequently determined by company specific and/or regulator specific guidance. It is recommended that where no specific guidance exists then the choice of method selected is documented with notes on why that method has been selected.

One of the main challenges in integrated urban modelling is that the water industry has its own guidelines and the environmental regulators have their own guidelines (mainly for river/coastal modelling). The two are not easily integrated and therefore the PSG will need to decide on the most appropriate methods to use based on the project requirements and the financial resources available. It is expected that most IUD projects will be based on an existing model, and it may be that the existing model will dictate what runoff methodology will be used.

B3.7 1D, 1D-2D or 2D

For all integrated models, there is a decision to be made between 1D only, 2D only or coupled 1D-2D modelling, and it is suggested that the PSG agrees at Project Definition stage (**Section A3**) which approach should be taken. Often the decision on the type of model to use is determined less by the concept type of the model and more by the study objective and what the outputs of the model are to be used for. It is considered unlikely that a 2D only model of the whole study area would ever be classed as integrated urban modelling. However, large portions of a study area might be modelled in 2D only with direct runoff.

If the model outputs are going to be used in an economic appraisal it may be necessary to have information about the depth of flooding at properties in the urban area (potentially from more than one source) and therefore a coupled 1D-2D model may be more suitable. However, if only an assessment of the proportion of manholes that flood and the likely flooding volume is required, a 1D model would probably be adequate.

Typically, 1D or 1D-2D modelling is being recommended here for the watercourse part of integrated urban models. This requires surveyed cross-sections of the open channel watercourse and surveyed details of in-channel structures such as culverts, bridges and weirs. The spacing of surveyed cross-sections depends on the size of the watercourse, the length of the watercourse being modelled and the regularity of the watercourse along that reach. More frequent cross-sections would be required where there are significant changes in gradient of the channel bed, where there are significant changes in conveyance along the length of the watercourse, and around critical hydraulic structures. Interpolated sections can be used between surveyed sections if extra definition is required. Where 1D modelling is used, the floodplain may be represented using floodplain units, connected spills or parallel channels.

Deriving an appropriate 1D schematisation requires some early understanding of likely floodplain mechanisms (storage and conveyance). Where 1D-2D modelling is used with a 2D domain representing the floodplain, the definition of the 1D-2D boundary is often critical to model accuracy. 2D modelling of watercourses can also be undertaken and requires more bathymetry data in order to build a grid or mesh of the watercourse bed profile.

The following suggestions are made for different model types but are not prescriptive guidance and this will vary depending on specific project outcomes:

- For Type #A models, likely to be 1D only but may have a narrow corridor of coupled 1D-2D modelling along watercourses
- For Type #B models, generally 1D with a narrow corridor of coupled 1D-2D modelling along each of the watercourses
- For Type #C models, generally coupled 1D-2D throughout the model
- For Type #D models, either 1D or coupled 1D-2D depending on how the flooding within the study area is to be represented

Once a choice has been made between 1D or 1D-2D modelling, an appropriate software type can be selected, see **Section A5**.

B3.8 Combined Probability

Joint or combined probability is a statistical measure that calculates the likelihood of two or more variables occurring together and at the same point in time. Joint probability is often raised in flood risk analysis or flood risk management because flooding is often a result of more than one variable, for example, the combination of a tide level and river flow, or at a confluence where water levels may be affected by flows on both rivers. Having said that, joint probability is currently not widely used in the flood risk industry. The reluctance to embrace joint probability methods is largely due to the difficulty in understanding and applying the methods as well as the lack of published information on the dependence between the different variables.

There are a number of situations in an IUD model where joint probability is likely to be required and probably more so than in just a single fluvial model or individual sewer model. This must be discussed and agreed during the problem identification scoping (**Section A1**) and project definition (**Section A3**) stages. Often the decisions around joint probability will depend on the aims and objectives of the modelling as set out in the Project Definition stage (**Section A3**). For example, a different decision might be taken when combining events for flood mapping than for an economic appraisal project. To support these discussions, it is recommended that the reader refers to the latest guidance (**Joint Prob**[27]) and reports published by the Environment Agency and Defra as a starting point.

Important decisions that need to be made about joint or combined probability in relation to integrated modelling include:

- How to deal with the case where there are different time-to-peaks in different parts of the catchment? It is possible to delay the peak on one part of the catchment so that it corresponds with the peak in another part, resulting in a 'worst-case' scenario design event. However, this is unlikely to occur in reality.

- How to combine tide/surge levels (probability and timing) with fluvial events in the larger catchment and/or pluvial events over the urban part of the integrated model? Do you want to know what the impacts would be if high tide levels prevented the sewer network discharging through the whole duration of the pluvial event? Or do you want to model free drainage of the sewer network throughout the event to identify other pinch-points in the system?

At the Project Definition stage (**Section A3**) the PSG should decide whether a statistical assessment of joint probability is required or whether it is enough to decide and agree on event combinations with stakeholders (for example, a 1% AEP design storm with a MHWS tidal boundary) without assigning a specific combined probability. Whatever approach is taken it is recommended that sensitivity testing is undertaken to understand the sensitivity of the model results to decisions that were made in combining events.

B3.9 Critical Duration

The critical duration can be defined as the storm duration that gives the highest flow, water level or flood volume at specific locations or the largest number of flooding locations. It is only relevant when synthetic design storms and/or theoretical inflow hydrographs are used. For model simulations using time-series rainfall it is rarely necessary to consider critical durations.

For an IUD study, identifying the critical duration is unlikely to be straightforward for a few reasons:

1. There are likely to be multiple sites of interest
2. Sections of the catchment will have widely differing response characteristics
3. There may be multiple drivers or reasons for the study

The two main choices likely to be made with respect to storm duration are whether to apply:

1. A single storm duration across the whole IUD model, covering upstream rural catchments and the main urban study area
2. Applying different storm durations to the upstream rural catchments areas and the main urban study area

The choice between whether to apply a single catchment wide storm, or whether an integrated model might use a longer storm duration on a large contributing rural upstream catchment and a shorter storm duration over the urban area, will likely depend on the size, shape and other hydrological features of the catchment as well as the desired outcomes from the project. Decisions around the application of a single or multiple storm duration(s) should also be informed by observations from historic flood events when possible.

For model concept Type #A, it is likely that a single storm duration will be applied. For Types #B and #C there is a greater likelihood that different storm durations would be used, particularly as in the case shown for Type #C in **Section A2**, where the hydrological catchment boundary is significantly larger than the model or study boundary. For Type #D models, a single storm duration will likely be applied but there may be additional timing considerations about how this design rainfall event coincides with, for example, tidal conditions.

The selection of an appropriate storm duration becomes particularly important in modelling projects that include assessment of flood storage options of any kind and, in these cases, it is likely that a greater emphasis on duration testing will be needed.

Whichever approach is taken, it is recommended that testing is undertaken to determine the critical storm duration(s) for the study area. This is done by modelling a range of durations, considering the purpose of the study and the differing responses of the catchment. It is recommended that between three and seven storm durations are tested; the choice of durations to test may be informed by Water Company specifications, Environment Agency guidance or other suggestions, including estimating the theoretical critical storm duration from FEH methodologies. For 1D only models, a greater number of storm durations may be tested as run time and file size are less of a constraint.

Figure B3-1: Graph of Flooding on 2D Mesh

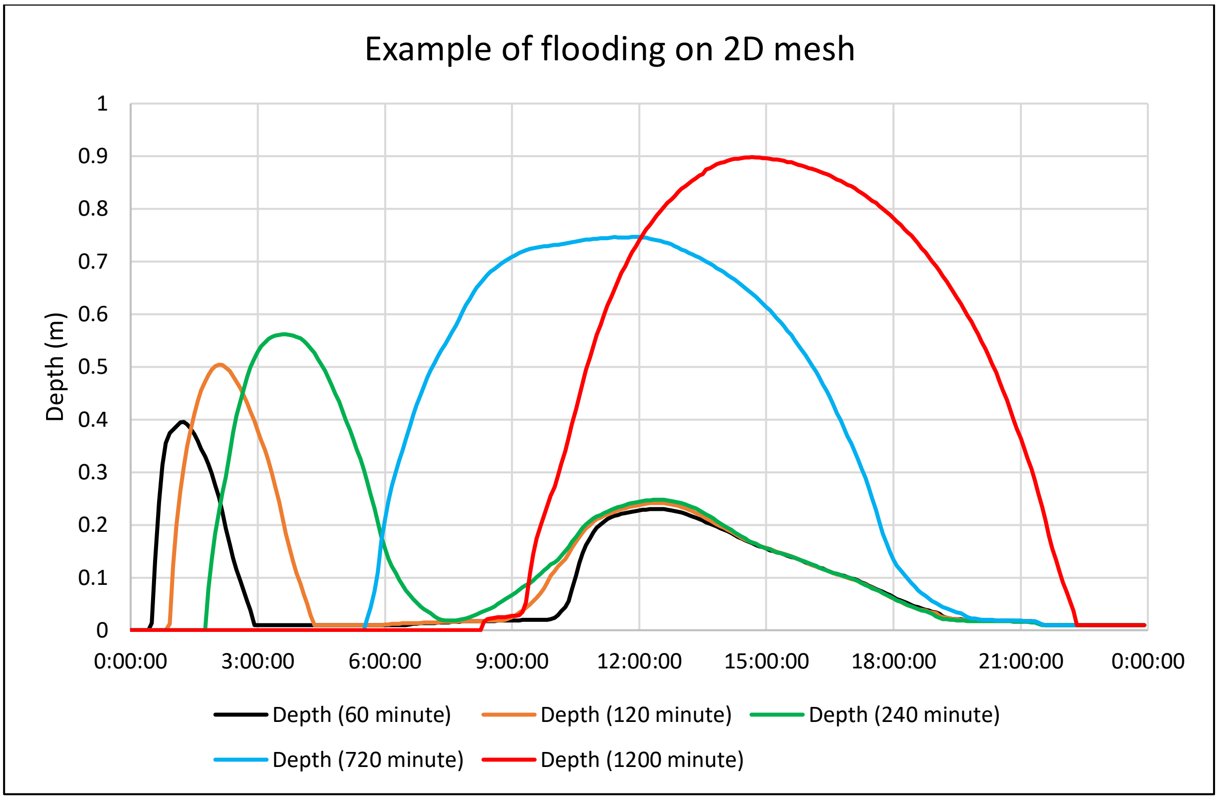


Figure B3-1 is a graph showing simulation results for a location on a 2D mesh where there is flooding both from the sewer system and from a watercourse. Simulations were undertaken with storm durations of 60, 120, 240, 720 and 1200 minutes, all with fluvial inflows into the model for 540 minutes (the theoretical critical duration for the watercourse). It can be seen that for the 60 minute (black), 120 minute (orange) and 240 minute (green) there are two flooding instances; firstly, from the sewer flooding and secondly from the watercourse. For the 720 minute (blue) and 1200 minute (red) simulations, the two peaks combine into a single peak, with the 1200-minute event giving the maximum depth of flooding.

By following this technique with coupled 1D-2D models the worst case can be determined for each triangle or rectangle in the 2D mesh by exporting the results to a GIS package and using that to determine the maximum depth from all the simulations. Figure B3-19 shows that for the area away from the watercourse it is likely that the 240-minute (green) simulation would give the maximum flooding.

The decisions made around the application of storm durations should be informed by the required outcomes of the project. For the purpose of flood risk mapping, a 'worst-case' scenario may be preferred, whereby the model is run for a number of storm durations and then a GIS exercise undertaken where the resultant model outputs (flood outlines, depths, hazard grids, surcharging manholes/pipes etc.) from each simulation are 'stamped' on top of each other, selecting the maximum result as illustrated in Figure B3-1. This essentially produces a single 'worst-case' scenario output for each return period. Alternatively, for scheme appraisal, a more realistic assessment may be required, with a single storm duration applied across the model area, and this storm duration selected based on critical conditions in the urban study area.

It should be noted that the critical duration may change if a solution is proposed or implemented that attenuates or diverts flows. Whenever a model is used for design purposes, it is recommended that the model is run for a range of storm durations to ensure that a solution is not under-designed.

B3.10 Considerations for 1D modelling – applicable to all model types

For detailed guidance on the 1D modelling of urban drainage systems, modellers are referred to the CIWEM UDG Code of Practice for the Hydraulic Modelling of Urban Drainage Systems (**CoP**[1]). For guidance on the 1D modelling of watercourses, modellers are referred to Environment Agency guidance (**Fluvial Guide**[21]). It is not the intention of this Guide to reproduce that guidance here.

As shown in **Section A2**, integrated urban modelling can be a coupled 1D-2D sewer and watercourse model. In this case, there is hydrodynamic interaction between these two systems representing, for example, the constraints that the hydraulics in the watercourse place on the discharge of sewers into that system, or the potential backing up impacts in the sewer system, reducing capacity for surface water when the receiving watercourse is in flood.

In this kind of interaction, the important points to consider in developing the integrated model are:

- The details, dimensions and levels of the outfall pipes and structures where they discharge into the main watercourse includes details of any manual or automatic control at the outfalls
- The cross-section, gradient and conveyance of the main watercourse (either open channel or culverted) on the reach where the sewer system discharges include any hydraulic control structures upstream or downstream of the discharge point that may influence the interaction
- The coincidence of peak flows from the sewer system relative to peak levels in the receiving watercourse and it may take several iterations of modelling to achieve the required degree of coincidence, depending on the time taken for runoff to pass through the sewer system

The outputs of a coupled 1D sewer – watercourse model will be a combination of typical 1D outputs from separate sewer and watercourse models.

B3.10.1 Modelling Culvert Inlets

The capacity of most watercourse culverts is governed by the inlet arrangements rather than the capacity of the barrel of the culvert. It is therefore important that adequate survey details of the culvert inlets are obtained and carefully modelled. **Appendix F** provides some guidance on the parameters that can be used for modelling a variety of different culvert inlet configurations and materials. The CIRIA Culvert, Screens and Outfall Manual (**C786**[18]) and the hydraulic modelling program help files also contain values for the parameters to be used, but they are not as extensive as those included in **Appendix F**.

Culvert outlet structures are not as important as the inlets in respect of modelling, but nevertheless should be carefully modelled.

B3.10.2 Modelling Road Gulleys and Manhole Covers

The wholesale modelling of road gulleys is not recommended as this level of detail is not necessary for most parts of the IUD model. However, in some areas where finer detail is required and where the capacity of road gulleys could be critical, it may be desirable to model the road gulleys. **Appendix G** provides some guidance on how road gulleys can be modelled by applying a head-discharge relationship. The appendix has data for the most common classes of road gulley found in the UK and a simple site walkover will enable most gulleys to be identified and classed. The head-discharge relationship varies depending on the longitudinal and transverse gradient of the road; sufficient information can be obtained from a site walkover to enable these gradients to be determined.

The appendix also includes details of how a head-discharge relationship can be created for manhole covers, which progressively increase the waterway opening as the manhole is lifted out of its frame as flooding occurs. This head-discharge also sets out in the opposite direction how little overland flood water can enter the manhole with the cover retained within the frame. If a head-discharge relationship for manhole covers is used, it should be considered how any flood water could get into the sewers or highway drains; in these instances, it might be worthwhile considering modelling the road gulleys in the vicinity of the manhole.

B3.11 Considerations for 2D modelling – applicable to all model types

2D modelling provides an additional level of detail in the depth and velocity information available in respect of overland flooding from overbank flooding from open watercourses, flooding from manholes from surcharged pipe networks and/or pluvial runoff.

2D modelling also allows for the representation of direct (pluvial) runoff and can be an alternative approach for applying rainfall or flow inputs to an integrated model, rather than applying rainfall to sewer systems via pipe networks or applying flow hydrographs direct to 1D watercourse models. This is referred to in this Guide as direct rainfall modelling.

The same principles of and considerations for 2D modelling apply whether or not rainfall is applied directly to the mesh/grid.

B3.11.1 Types of 2D models

Regular grid meshes

The computational grid of a 2D model can be created using a regular fixed (square) grid, which is simply created and typically has a faster simulation time than irregular flexible mesh models. The main disadvantage of a fixed grid is that it cannot align to complex geometries, which can lead to inaccurate representation of features in an area of interest. Nested grids can be created, whereby a higher resolution grid is created in one or a few confined areas where the finer scale hydraulics are important to represent, although the boundary between the grids can be a source of error and should be sense checked.

Irregular flexible meshes

The computational grid in a 2D model can also be created from a continuous, non-overlapping but irregular flexible triangular or quadrilateral elements. These elements can align to more complex features, which will vary the model topography more rapidly than a fixed grid, providing a more accurate representation. A flexible mesh can also be forced to resolve at a higher resolution in the areas of most interest and a lower resolution in areas of less interest, which is typically more easily set up than a multi-domain model and has seamless boundaries.

An advantage of irregular, flexible meshes is that the generation of the mesh can respond to the steepness of the terrain by means of a feature referred to as ‘terrain sensitive meshing’; this creates smaller mesh elements in steeper ground (perhaps where there are ditches) and larger elements in the flatter terrain. This automatically creates a finer mesh where there is likely to be more variation in flows.

The main disadvantage of a flexible mesh is that the simulation times are typically longer than when a fixed grid is used, which is exaggerated further when a direct rainfall component is applied to the 2D model.

B3.11.2 Extent of 2D models

The extent of the 2D model domain or mesh is a critical factor in determining the run time and resultant file sizes of an integrated urban model and therefore needs considering in these studies. An initial approximation of the extent of the 2D domain or mesh should be developed as part of the modelling concept (see **Section A2**), but this is likely to need refining during the model build. The extent of the 2D model domain is likely to follow the defined **Model Boundary.** To define the extent of the 2D model domain or mesh the following need to be considered:

- the **Study Boundary** (that is, the area of focus for the study)
- the extent of any existing models
- potential future uses of the model
- the **Catchment Boundary** considering hydrology, topography and contributing sewer catchments
- the likely maximum extent of flooding in the most severe event to be modelled, including considering Climate Change. Online flood risk mapping of fluvial and surface water flood risk (for example, the Environment Agency Flood Zone 2 (or equivalent in other regions)) and historical observations of flood extents can be used as an indication of the likely

maximum flood extent. It may be prudent to apply a degree of buffering to outlines from online flood risk mapping when defining the 2D model extent

- the long profile of the main watercourse/network that can be used to identify main hydraulic controls (for example, a catchment to a pumping station) to ensure these features are adequately covered by the 2D model extent

To define the 2D model extent GIS analysis of the ground surface (for example, rolling ball or similar) based on LiDAR or other DTM data may be used to identify main flow routes, areas of ponding and natural watersheds. It is recommended that, where possible, modellers try and avoid model extents based on political/planning boundaries.

B3.11.3 Resolution of 2D models

After the definition of the 2D model extent, the resolution of the 2D model grid or mesh is selected and again there should be an initial agreement around this in the **Project Definition** stage as part of the model approach. Consideration of the model resolution must also include the development of the 2D model geometry.

When selecting grid or mesh element sizes the model run time and resultant file size will need to be considered, but this should not be the main driver in decisions around model resolution. Rather, the initial model resolution should be selected based on an understanding of the topography and geometry of the catchment within the **Model Boundary** that is likely to influence overland runoff and flooding mechanisms. For example, a smaller grid or mesh element size will be required in the centre of a small/old town where flow may be along narrow or steep streets. Selection of the initial model resolution should also consider the eventual outcome of the modelling, projecting that there will be enough detail in the model outputs.

Within both regular grid and irregular flexible mesh 2D models there are methods available for including multiple grid sizes/varying mesh element size within the model, although variation in mesh element size is more easily achieved in an irregular flexible mesh model than within a regular grid model. This allows for an increased level of resolution in main areas where flow paths might be narrow or complicated (for example, around buildings) without having to have that fine scale resolution throughout the model areas. Some modelling packages include a feature for 'terrain sensitive' meshes (only for irregular flexible grids), which can automatically determine the mesh element areas based in the permitted vertical elevation differences between adjacent elements.

Approaches to multiple grid sizes/varying mesh element sizes will be considered at **Project Definition** stage, but may need further refining during the model development.

The topography of the 2D model (for example elevations of grid cells and mesh elements) is likely to be derived from a LiDAR DTM where this is available, enhanced with higher resolution survey data in places (see **Section B1**). Where LiDAR DTM is not available and a lower resolution/accuracy DTM is used, this needs reflecting in the size of the model grids or mesh elements. In all software used for integrated urban modelling it is possible to take a layered approach to building up the model geometry, thus allowing increased detail in resolution on key hydraulic features. Through careful file naming and management (including recording in model logs) it is possible to keep a clear audit trail of the development of the model topography.

Geometry adjustments made to the underlying DTM are used in 2D models to represent buildings, roads and kerbs, walls, fences and hedges and other topographical features and hydraulic controls. The level of detail in these geometry adjustments depends on the intended outcome of the project so should be considered at **Project Definition** stage (see **Section A3**) and may also influence the **Data Collection** strategy, see **Section B1**. Stakeholders and/or regulators may have requirements for geometric adjustments in models, for example, the Environment Agency flood modelling guidance refers to preferred methods for representing the effect of buildings in 2D modelling.

Although an initial approach to geometry adjustment will have been agreed at **Project Definition** stage (**Section A3**), this is another element of the model that may be adjusted through the model calibration and verification in order to better represent observed flow mechanisms.

To reinforce the preferential flow route generally offered by **roads**, it is common practice to 'sink' these linear features into the model geometry. This can be achieved simply by lowering model grids/mesh elements by a given depth (in mm) or by a more fined method, incorporating surveyed crest and kerb lines as breakline features to give a more accurate representation of road camber. Where there is a perception or observation that drop kerbs are an important mechanism affecting property flooding, a more detailed representation of these features would be required to identify properties at risk. Where a simple method of lowering grid cells or mesh elements by a given depth is chosen, OS Mastermap (or similar landcover data) can be used to identify the line and edge of roads.

The selection of an appropriate method for reinforcing roads will depend on:

- Availability of survey data
- Initial understanding of the importance of roads and road details on overland flow
- The level of detail required from the model outputs

There are multiple methods available for representing the effect of **buildings** in the 2D model surface and stakeholders and/or regulators may have specific guidance to apply in integrated urban modelling. The methods for representing buildings need to consider both the effect a building has on an overland flow path and, in a direct rainfall model, the management of rain falling directly onto a model grid cell or mesh element representing a building. The main methods used for representing buildings are noted in Table B3-4.

Table B3-4 - Overview of methods for representing buildings

Method	Effect on model geometry	Notes for direct rainfall modelling
Stubby building The grid cells or mesh elements representing the building (identified from OS Mastermap or similar) are raised above surrounding ground by a particular height. An assumed height (equivalent to average threshold height) can be applied to all buildings or building heights can be individually assigned using threshold survey. Where buildings are large relative to the model grid size or mesh element size, it may be necessary to 'flatten' the building first, applying a minimum, maximum or average level across the building polygon before undertaking any other transformation.	Overland flow cannot pass through the model grid cells or mesh elements until the depth of flow reaches the assigned threshold depth. Often combined with a high Manning's n value for buildings (0.1 or greater) to represent the roughness effect of buildings in the flow path.	To avoid the effects of rainfall 'ponding' within model grid cells or mesh elements that represent the building (because of the high Manning's n value applied) consider either removing the building polygons from the area of direct rainfall application or using a depth varying Manning's n value, that is, with a lower Manning's n value for shallow depths to allow direct rainfall to pass away rather than pond.
De-activation/removal from model Building polygons are identified from OS Mastermap or similar and then de-activated/removed from the model by various means depending, in part, on the modelling software used: • Cells or mesh elements can be deactivated/made non-active • Cells or mesh elements can be raised to an arbitrary height in excess of the likely depth of flooding	Overland flow cannot ever pass through the model grid cells or mesh elements. Overland flow is forced to pass around or between buildings when they exist on a flow route. The potential storage effect of a building is lost from the model representation.	Rainfall is not directly applied to these de-activated model grid cells or mesh elements. Note that if cells or mesh elements have been raised to a significant height, direct rainfall should not be applied to these cells or elements because of their weiring effect that would be caused at the edge of buildings.

Method	Effect on model geometry	Notes for direct rainfall modelling
Thin wall for outer edge Building polygons are identified from OS Mastermap or similar. A thin line (or a 2D linear feature in some programs) is used to raise grid cell points or mesh elements around the building in the main flow direction. This line is raised up to building height or an arbitrary height in excess of the likely depth of flooding.	Overland flow is generally routed around the building rather than through. The potential storage effect of the building is retained, for flow from some directions.	To avoid the effects of rainfall ‘ponding’ within model grid cells or mesh elements that represent the building (because of the ‘wall’ around the edge), consider removing the building polygons from the area of direct rainfall application.
Voids This is the simplest approach to take as it creates a void in the 2D mesh with an infinitely high wall (glass wall) around the building.	Overland flow is routed around the building but, if relevant, it allows the flow to pond up against the building. This is useful for very large buildings where direct runoff is not required as it reduces the overall size of the 2D mesh.	This method cannot be used with direct runoff modelling as there is no mesh covering the buildings.

Selecting an appropriate method for representing buildings will depend on:

- Partner, stakeholder or regulator guidance or preference
- Initial understanding of the importance of buildings and building details on overland flow
- The detail required from the model outputs. For economic appraisal of schemes and projects a modelled depth of water is required at affected commercial and residential properties. Where there are, for example, buildings that are large compared to the 2D model grid cell or mesh element size, a more refined method may be needed in order to generate an accurate prediction of flood depth for damages assessment.

2D models may also require the representation of other small-scale linear features likely to affect flow mechanisms, for example, **walls, fences** and **hedges**. Decisions about it and how to include these features will need to be agreed by the PSG considering partner, stakeholder or regulator guidance or preference, the intended outcome of the study, and local catchment specifics. For example, if the outputs of the project are likely to be used by the Environment Agency to update the Flood Map for Planning, which of these features are considered formal defences versus de facto defences, and how they should be represented in model simulations will need to be agreed in the **Project Definition**.

Where small-scale linear features like these are likely to exert a significant local effect on flow mechanisms, it is recommended that they are included in the model and this is definitely the case for Environment Agency owned flood defence assets. It is likely that representation of these features would be needed to achieve satisfactory calibration or verification of the model to observed floodplain mechanisms and data. Such features can be identified from OS Mastermap (or similar), satellite or aerial photography, site walkovers and from local experience and knowledge collated through the PSG. Data for Environment Agency flood defence assets should be extracted from the AIMS database. It is likely that other stakeholders or regulators may have similar databases of their own assets.

The representation of small-scale linear features needs to consider whether these features are wholly or partly penetrable by overland flow.

- If the features are wholly impenetrable, then raising the grid cell points or mesh elements would be the preferred method of representation in the model geometry. In some cases, it may be necessary to collect survey data to accurately represent the location or elevation of the features. Alternatively, it may be adequate to raise grid cell points or mesh elements by an arbitrary height to represent the effect they exert on local flow routes.
- If the features are partly penetrable, then it may be more appropriate to represent in the model geometry through the use of a high Manning's n values to represent the partial obstruction they create to flow paths. No specific guidance exists on the selection of Manning's n values for these features in 2D modelling and it is likely to require an iterative approach to find appropriate values, hopefully informed by model calibration or verification.

Within the modelling software typically used for integrated urban modelling it is possible to model small-scale linear features in a way that would allow these features to collapse or fail when a specific head of water is applied to them. This level of detail is unlikely to be a common requirement for an integrated urban model but could be undertaken as a specific or additional simulation if this kind of situation has been observed in the catchment.

It has been assumed that generally **open watercourses** would be modelled in 1D but there may be occasions when they are modelled in 2D within the grid or the mesh. This may be undertaken in the upper reaches of the **model boundary** area where there is no need to model complex channel or structure hydraulics, but the watercourse needs to be sufficiently well defined to represent the conveyance capacity and time of travel etc. Where there is a large open watercourse or estuary this could also be modelled in 2D if that is sufficient to determine, for example, water levels at sewer outfalls.

Reservoirs and lakes can be modelled in 2D with the 2D mesh set at the normal water level. It is necessary to set an appropriate Manning's n value to reflect the absence of any resistance to flow. In the case of direct runoff, it is also necessary to set the runoff at 100%.

Where the model geometry includes a raised feature such as a large road or railway embankment, further refinements of the 2D model geometry might be needed if there are **openings or structures** through these features for watercourses or overland flow routes, for example, culverts or underpasses. Such features can sometimes be identified within the LiDAR DTM, should show in aerial photography, and can also be identified through site visits and local knowledge from the PSG. These openings can be represented in the model in a range of different ways depending on which modelling program is used.

In addition to elevation, the other main component of a 2D model geometry is the representation of the **roughness of the land surface**, typically represented using Manning's n values. It is noted that this is outside the original intended use of Manning's n value in conveyance calculations and there is less guidance and fewer standards in 2D Manning's n values for representing various ground surfaces than there is for Manning's n values used in 1D channel modelling. Therefore, the selection of appropriate Manning's n values is based on engineering judgements and, where possible, should be calibrated or verified based on observed flood event data or validated against other modelling.

OS Mastermap (or similar) data is often the first and best source of data for defining areas of different land covering (a materials layer) and, because it is delivered in polygons with consistent ID type codes, can easily be linked to a table of Manning's n values. This can be enhanced by using photography and verified on site visits where possible.

B3.11.4 Direct (pluvial) rainfall modelling

As noted earlier in this section, rainfall can be applied directly to the 2D model grid or mesh to represent runoff in the **Model Boundary** area**.** This method of direct (pluvial) runoff modelling is most appropriate for catchments where:

a) there is a known issue of pluvial flooding from surface water runoff before it enters the sewer network or watercourse, which should be represented in the IUD model

b) where it has not been possible to accurately define a contributing area used to estimate the flows into a watercourse, for example, where the natural catchment has been dissected by infrastructure. Rainfall hyetographs are applied directly to the 2D model area and should be derived using the same DDF model as used for rainfall applied direct to sub-catchments

The same infiltration models referred to in Table B3-3 can be applied when direct rainfall modelling is used and these are specified within the modelling software. Typically, for 2D direct rainfall (pluvial) modelling, the choice is between the following methods to represent natural infiltration losses:

- Constant/fixed runoff percentage
- Horton infiltration method (**Horton**[23])
- Green-Ampt infiltration method (**Green-Ampt**[25])

There is no definite guide or specification as to which of these loss models should be applied in direct rainfall/pluvial modelling, although the Green-Ampt method is considered to be more realistic.

An alternative option that can be used is the ReFH or ReFH2 loss model, which can be used to translate total rainfall to effective rainfall before application to the 2D model area. If this method is selected, then particular care needs to be taken to avoid the double counting of losses in the model, that is, no further application of infiltration losses.

Where possible, the infiltration losses should be calibrated or verified if there is enough observed data available. Even anecdotal information such as an observed rate of rise in an area of ponded flood water may be enough to allow some verification of losses in a direct rainfall/pluvial model.

See Table B3-4 for notes on methods to handle the application of direct rainfall on cells/mesh elements with buildings.

One of the main considerations in direct rainfall or pluvial modelling is **double counting**. Care must be taken to avoid double counting inflows in the model. If direct rainfall is applied to a grid or mesh, then the runoff from this part of the model must not also be captured in any other boundary such as by sub-catchments or contributing areas. On the other hand, care must also be taken to ensure that runoff from the whole **model boundary** is accounted for in the model. Using a schematic of the model and catchment in the Project Definition stage to identify where and how different hydrological modelling methods apply to the integrated model can be a useful way of checking for any double counting. Undertaking simple water balance calculations on the model will also help check for double counting, and, where data allows, verification of modelled flow to peak flow estimates in the lower part of the catchment or model can be an additional check.

In some simple integrated urban models where direct rainfall is applied, the sewer network is not explicitly modelled and assumed loss values (sometimes applied as infiltration losses) can be used to represent the effect the sewer network would have in removing runoff from the impervious parts of the model area. This approach was taken in the pluvial modelling undertaken for the first generation of SWMPs when an agreed loss value was applied to represent this effect on roads, buildings and other hard standing areas. A fixed loss rate (mm/hr) is sometimes assumed or the assumed loss rate (maximum total loss) may be estimated based on an assumption that the sewer network can take, for example, a five-year storm. There are significant assumptions within this method and a danger in simply applying loss values that were used in a previous project. If this simple approach is taken, sensitivity testing must be used to understand the significance of the assumptions made.

B3.12 Considerations for coupled 1D/2D modelling – applicable to all model types

The way in which the 1D and 2D domains can be coupled varies between different modelling programs and the guidance provided for the program used should be consulted.

Generally, the coupling at manholes or other computational nodes is a point coupling, which is either based on a weir equation (with the circumference of the manhole area treated as a weir) or using a head-discharge relationship. If a head-discharge relationship is used it is important that it has suitable parameters for flows both into and out of the manholes.

Coupling for watercourses generally use the left and right bank lines as linear couplings. A discharge coefficient and Froude number are the usual parameters used to define the coupling.

The way in which the 2D mesh elements interact with the bank lines varies depending on which modelling program is used. Some programs allow the 2D mesh element to be artificially lowered or raised to match the bank lines; this can help with model stability.

B3.13 General comments – applicable to all model types

B3.13.1 Climate change

The EU Floods Directive on the assessment and management of flood risks requires climate change to be taken into account in the assessment of flood risk. In England, Wales, Scotland, Northern Ireland and the Republic of Ireland, each individual national government and/or regulator has produced its own national guidance and advice on adapting to climate change. These documents should be followed to ensure the appropriate climate change allowance is taken into consideration when carrying out an IUD study. These guidance documents are regularly updated and therefore the individual climate change uplift factors for rainfall intensities, peak river flows and sea levels are not provided in this document. Modellers are advised to check on the most up-to-date climate change allowances before running any climate change scenarios, and to ensure that the Model Log contains a record of and justification for the climate change allowances that have been applied.

B3.13.2 Input Data

Section B1 – Data Collection and **Section B2** – Data Management provide more information on the likely sources of data to be used in integrated urban modelling and guidance on how that data should be managed. This sub-section provides a brief recap of the likely input data for an integrated model, which is summarised in Table B3-5.

Table B3-5 – Likely input data for hydraulic modelling

• Gauge data - river gauge and short term flow monitors
• Event Duration Monitoring (EDM) for storm overflow/telemetry data
• CCTV survey
• Manhole survey
• Rainfall data, including long-term and short-term gauge data, weather radar, time-series rainfall and stochastically generated rainfall data (see CIWEM UDG Rainfall Modelling Guide 2015 (**Rainfall Guide**[3]))
• Tidal level data – daily tide curves and surge predictions
• Previous Models and Reports
• Photography, including aerial photography and observed flood event photos

The sources of data used in the model (including the date accessed) should be recorded within the model where possible and/or within the model log. It is important that this metadata is held within or with the model so that it is readily available for any model handovers, for example, for third party model reviews.

Other sections of this Guide cover the recommended elements of a review of an existing model as part of the development of a new model approach. The purpose of that review is to assess whether the model is fit for reuse and what, if any, amendments or refinements are needed. The outcomes of that review should also be retained within the model and/or the model log.

B3.13.3 Running Models

Integrated urban catchment models can be run for several simulation types and there may be specific considerations for the model runs of each type:

- Design events of a specified probability – used for a baseline assessment or flood mapping etc, may be undertaken with assets in place and operational or with assets assumed to be non-functioning
- Future events – taking into account climate change, urban creep and/or population growth projections to assess how flood risk might change
- Calibration or verification events – using input data based on observed catchment conditions and gauges, where available

- Sensitivity testing to understand the effects that modelling assumptions have on levels of confidence in the modelling
- Scenario testing to understand changes in flood risk as a consequence of, for example, structure blockage or removal, sedimentation of pipes, weed growth in channels
- Options and mitigation development – used to develop and assess potential impacts of a proposed development or flood risk management intervention and to develop mitigation if required

File naming and management is critical to the success of integrated urban modelling, especially if the modelling involves a range of simulation types.

There are many considerations when running integrated catchment models, some of which will be specific to particular software and others may depend on particular data or server setups. The points below note some of the main considerations when running the model; sometimes these are related to hydrological or hydraulic elements of the model, but often they are more practical considerations for a particular modeller or modelling team.

- Simulation times – integrated catchment models may have a long simulation time in order to capture peak flows and levels across a large and complex model boundary area. It is not always easy to predict at the outset how long a model might need to run for in order to capture that peak. Therefore, it is recommended that models are run for at least one long event in order to generate results that can be interrogated to find the peak time. Analysis of results from the timesteps towards the end of a run can identify locations where the depth of water is still increasing and this should be considered when deciding when to stop the simulation. The choice of simulation time will also be related to the selection of a critical storm duration, see Section B3.9.
- Simulation timestep – different modelling software have different requirements and capabilities in terms of simulation timestep, particularly when 1D and 2D models are combined and therefore modellers are referred to software user guides, help functions and support forums for specific information. Smaller model timesteps are sometimes required to debug or stabilise a model, but this does not always get to the root of the problem and is not recommended. Assessment of an appropriate timestep for 2D modelling can be linked to the Courant number, which is a function of the size of the model element and the anticipated depth of water.
- Output intervals – when selecting an output interval, modellers need to balance a need for sufficiently high resolution results to identify flow mechanisms (for example, the initiation of surcharge or overtopping) and to debug a model versus considerations around output file size. It may be that while high frequency output is needed during the model development process a lower frequency output is fine for final simulations and deliverables.

Modellers or modelling teams will also have decisions to make about modelling hardware (i.e. the specification of computers used), licences (i.e. local licences versus network licences) and potential cloud running options (for example, Flood Modeller). These local choices will be made by a modeller or modelling team depending on their specific circumstances and the pressure of the project, for example, programme versus cost. It is also noted that this is a fast-moving area and any guidance written around this would be quickly superseded and outdated. Therefore, there will not be any further discussion on these points in this guide.

B3.13.4 Output Data

Section A6 – Outputs and Reporting describes the model outputs and reports that would be generated from an integrated urban model. A few more specific technical details are provided below:

- In the model development phase, it is recommended that as much output as possible is generated, in time series and in map format. Different modelling software have differences in the format of outputs but, at minimum, it is recommended that level, flow, depth and velocity is output as well as any mass balance outputs generated by the modelling software. Additionally, outputs that show the time that peak level is reached or the length of inundation can also provide useful information, if available. This will enable modellers and modelling teams to fully analyse the results of the model, sense and reality check the results, undertake calibration and verification and debug any issues or instabilities in the model.
- For final runs, the types and frequency of output may be reduced in order to manage the file size of outputs. The final output types (and formats) will depend on the project specification. It will be important that those final outputs have suitable names, and are structured and managed in order to maintain usability in the future, see **Section A7** – Model Maintenance.
- All modelling software create their own check files, warnings and logs and these files should be stored with model results. These outputs should be used during model development for self-checking of the models. This is important information on the simulations that have been undertaken and is most useful when kept together with other model files. These files would form an important part of any third-party review of the model or handover for other uses.
- During model development results are viewed within the modelling software (for example, InfoWorks or Flood Modeller), within a GIS environment (for example, if using TUFLOW) or within Excel (or similar) and can be used either in their raw format or processed into alternate formats. For some specific outputs (for example, Environment Agency flood maps) there is very specific guidance on how these deliverables are processed and the latest guidance should always be sought from these partners or stakeholders during **Project Definition** (**Section A3**).
- Flood hazard to people is calculated as a product of depth and velocity (sometimes including a debris factor) using methods and equations from a 2006 Defra/EA R&D project (**Hazard**[28]). If hazard mapping is a required output from the integrated urban model it will be important to agree, at **Project Definition** stage (**Section A3**), which method should be used. Most software types can calculate flood hazard during the model simulation if this is required and then the outputs can be displayed in the agreed categorisation.

- If direct rainfall is applied in the 2D model and where there is an assessment of pluvial flood risk, it may be necessary to carry out additional processing of mapped outputs so that the grids or extents are clearly interpretable by technical and non-technical partners and stakeholders. Typically, this involves 'hiding' or not displaying results where the depth of water is very shallow in order to focus on the main areas of risk. The threshold depth for mapping would need agreeing at **Project Definition** stage (**Section A3**). It is recommended that this is managed through the colouring or symbology in GIS outputs such that the raw data is not lost from the original results.
- For projects involving an element of economic appraisal there will often be a need for a damages assessment, calculated based on the depth of inundation at commercial and/or residential properties. This assessment often requires buildings to be represented in a particular way and frequently requires a receptor database to be used, but the specifics of this will vary depending on the project and should be confirmed at **Project Definition** stage (**Section A3**). This information can be generated by damage assessment tools within modelling software or can be undertaken as a separate GIS analysis. Whichever method is chosen it is important to sense check the results, for example, around the edges of the flood extent, where the depth of flooding is very shallow or where there are large buildings that may only be partially inundated.

B3.13.5 Sensitivity Testing

Sensitivity testing is undertaken in modelling projects as a method of assessing confidence in the model results (see also **Section A4 – Assessing Confidence**). This is particularly important in cases where it has not been possible to undertake calibration or verification or where significant uncertainty remains after that calibration/verification exercise. Sensitivity testing provides a method of being able to quantitatively assess the impact of modelling decisions and assumptions on the output of the model. Typically, model parameters are varied, one at a time, to assess the impact on results that a different assumption would have made.

Sensitivity testing should be undertaken as an important part of the model development process and not as an 'add on' at the end of the project. Table B3-6 identifies a range of sensitivity tests that might be undertaken on an integrated urban model. It will not be necessary to carry out all these tests. The specific sensitivity testing requirements for a project will initially be determined at **Project Definition** stage (**Section A3**) but may be refined during the model development stage as knowledge of the model develops. It can be useful to carry out some sensitivity testing prior to model calibration/verification in order to gain an initial understanding of which parameters might be critical in the performance of the model compared to observed data. Other sensitivity tests should be undertaken at the end of the project to check, for example, how the overall conclusion of an appraisal might change depending on assumptions or decisions made within the model.

Table B3-6 - Suggested sensitivity tests for integrated models

Manning's n/Colebrook white roughness values	To understand how sensitive the model results are to the roughness values that have been assigned within it. Often varied by a percentage, for example, +/- 20%.

	Should be varied in 1D networks (open and culverted) and across 2D models. Also provides an indication of, for example, the impact on flood risk of increased vegetation growth in the channel.
Downstream boundary conditions	To understand how sensitive model results are to the downstream boundary conditions that have been applied – can assess how far upstream the influence of the boundary condition is seen in model results. Specifics of the test will depend on the kind of downstream boundary that has been applied. May be a change in a fixed level or in the gradient that has been used to automatically generate boundary conditions. Might identify a need to extend the downstream boundary further in the case that it is exerting a significant influence on model results at a key location.
Model inflow hydrographs or input hyetographs	To understand how sensitive the model results are to the magnitude of flow or rainfall applied to it, often varied by a percentage, for example, +/-20%. Could also be a proxy for a climate change scenario as it shows how sensitive the model results might be to an increase in runoff. Particularly important where there is significant uncertainty in the hydrological analysis used to derive inflow hydrographs.
Infiltration losses and runoff coefficients	Important when rainfall runoff methods used in either the application of rainfall to sub-catchments or in 2D direct rainfall modelling. If a fixed percentage loss value has been used, this could be varied up and down to assess the impacts on model results. If a variable loss value is applied (for example, through the Horton or Green-Ampt method) this could also be varied, or the model tested using an alternative fixed percentage loss.
Structure representation and coefficients	Specifics of these tests will depend on the software used and the way that structures have been represented in the model. Critical hydraulic structures should be identified, for example, by reviewing the long section results. The sensitivity testing focusing on these structures may involve, for example, adjustment of culvert inlet or outlet losses or adjustment of weir coefficients. This is also likely to form part of the model calibration and verification. If there are pumps in the catchment, additional sensitivity testing might include variations in the assumed pump rate, rules governing pump operation or efficiency. The models may also be tested with all or some of the pumps shut off.
Silt depths within pipe networks and culverted watercourses	Where the project steering group has identified siltation as a potential issue in the catchment, sensitivity testing of different silt depths could be undertaken. This may be

	done by raising the invert level of structures where silt is known to be an issue.
Storm duration and joint probability (coincidence of events)	As described elsewhere in this section, selecting an appropriate storm duration for integrated urban modelling is an important consideration. Regardless of what method is used to select a storm duration, it is recommended that sensitivity testing is undertaken on the final model to understand how impacts might change in a shorter or longer storm event. Where multiple sources of flooding are considered in the model and there has been a need to combine, for example, a pluvial storm event with assumed tidal conditions, there might need to be further sensitivity testing around: 1. The probability of different events that are combined 2. The timing of how those events are combined These sensitivity tests will always be project specific. It may not be possible to identify what storm duration/joint probability testing is required at **Project Definition** stage as this may only emerge during the model development and initial testing.

Assessing the results of sensitivity tests can be done in several ways, and this will depend on the setup of the model and the intended outcomes of the project. Methods to consider include:

- Comparison of stage and flow in 1D long-sections in pipe networks, culverted watercourses or open watercourse river reaches
- Tabular comparison of peak stage or depth at 1D model nodes in the pipe or watercourse network. This could be an absolute comparison (m) or a relative comparison of the percentage change in depth
- Comparison of the number of surcharged manholes. This could be an absolute or relative comparison (%)
- Difference grids created from max stage or depth data across the 2D model extent, also showing any difference in maximum flood extent
- Tabular comparison of the number of properties affected by inundation (above a certain depth)
- Other qualitative comparison, for example, of differences in flow mechanisms

The interpretation of the results of sensitivity testing should be presented in a way that carefully considers the original project specification and outcomes. Stakeholders and partners should be able to easily understand the implications of the sensitivity testing on the level of confidence in the model and what this means for the conclusions of the project and any decisions being made that rely on the model results for justification.

B3.13.6 Model Logs

A model log is an important record of the model development process, a record of the key decisions and assumptions made, and a summary of the outcomes of each stage. By keeping a model log as the project progresses the modeller will have all the information required for self-checking, QA reviews and for final project reporting. The model log also forms an important record for handover between modellers or organisations if this is needed during the project or between stages of work.

When setting up the model log, modellers should refer to guidance from the PSG at **Project Definition** stage (**Section A3**) as the requirements for different organisations can vary significantly. For example, at one extreme, the latest 'NEC 4 Minimum Technical Requirements' for Environment Agency projects specifies the requirement for a 'decisions log' listing all key decisions made during the modelling process, with references to corresponding meeting minutes or emails. This 'decisions log' then forms an appendix to the specified Model User Report. For other projects, this level of detail may not be required.

In addition, specific software packages offer a 'commit history' of the model database. This can be extremely useful for version control of the model, as the changes to objects in the model between the edited versions are automatically documented. At a later date these can be viewed as a commit history, clearly demonstrating the development of the model. In addition, regular use of the 'comments' dialogue box during a commit operation can provide an invaluable narrative as to the reasons for changes to the model, data sources and rationale.

There is no suggested or prescriptive template included in this guide, many organisations will have their own template log already, but it is recommended that any model log includes:

- Key project data, including staff names, dates and summary aims and objectives of the modelling
- Location of modelling files and explanation of file structure and naming convention (and maybe links to data sources)
- Sources of data used in the model, including any previous models, DTM, survey, inputs (rainfall, flow and other boundaries), asset data etc
- Record of decisions and assumptions made, with justification, and reference to relevant communications
- History of model runs and development, highlighting key scenarios (for example, results presented to the client or issued for third-party review) and noting model run parameters (especially where these vary from defaults)
- Record of final run names and associated files

File Naming Convention

Reference to a file naming convention has been made in the Model Log section above. It is not the intention of this Guide to present a specific or prescriptive naming convention, only to emphasise the importance of having a suitable naming convention in place. It is noted that many organisations will have their own naming convention system in place and projects Partners may have specific requirements for model files. The model naming convention adopted should be clearly documented in the Model Log. Principles to consider in the naming convention include, but are not limited to:

- Including a consistent identifier for the study that is used across all model input, run and output files
- Reference to the probability of the event modelled, as an exceedance percentage or return period
- Reference to the duration of the event modelled
- Clearly indicating the kind of scenario modelled, for example, baseline, climate change, sensitivity, option etc
- Not be overly complex such that it is difficult for modellers to use (and then potentially not used or used incorrectly) or such that it generates model file names and paths too long for the software used
- Include version control, generally through sequential numbering

The naming convention is expected to apply to files and folders used for organising modelling data. Careful file management is needed in integrated modelling because of the significant volume of data and files involved, therefore modellers should stay on top of this, for example, by implementing a suitable system before beginning modelling work and by removing superseded files to an alternative location when no longer actively used. The file management system will be specific to a particular organisation depending on server set-ups, cloud based storage systems etc and again it is important that this is documented in the Model Log.

B3.13.7 QA and Model Reviews

All organisations undertaking modelling will have their own internal quality procedures that they should follow in a modelling project. Many client or commissioning organisations will also specify quality procedures to be followed. It is not the intention that this Guide would supersede any of those already existing (and certified) QA procedures.

QA reviews of new models are generally carried out before the release or use of any modelling results, for example, in economic appraisal or design. It is often recommended that QA reviews are carried out at multiple stages of a modelling project in order to ensure that the model remains focused on the desired outcomes identified at Project Definition stage, including achieving the required degree of accuracy and level of confidence. Typically, QA reviews may be carried out at some or all of the following stages in an integrated modelling project:

1. QA review of the proposed technical approach developed during the Project Definition before modelling begins

2. QA review of the initial model, after early model runs and calibration and verification. This would include a check of the calibration and verification performance against the agreed Project Definition
3. QA review of the final model and baseline runs prior to use in appraisal, design or optioneering
4. QA review of the model used in appraisal, design or optioneering
5. QA of final delivery package, including all model files, reporting and outputs

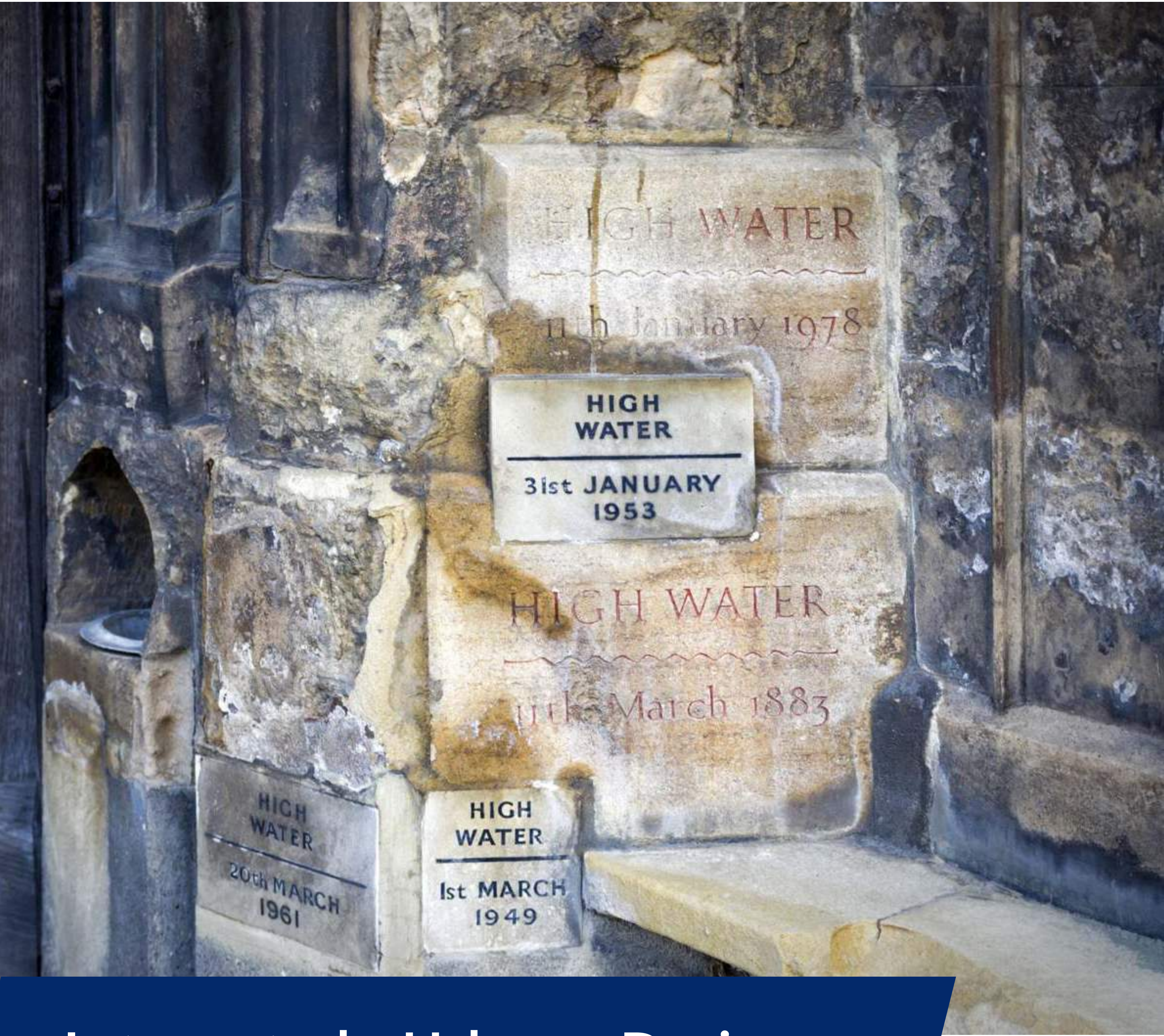
Organisations will often have their own template(s) for carrying out QA reviews and this Guide is not going to include new templates. The list below identifies key questions to consider in a QA review. Some of these questions may be yes/no, whereas others would benefit from a red-amber-green (RAG) type assessment. Additional commentary is likely to be needed where the review identifies action that needs to be taken. It is suggested that QA reviews should focus on assessing whether the model and model outputs meet the project aims and objectives accurately enough and with sufficient confidence, as designed in the **Project Definition** (**Section A3**). Starting with the aims and objectives, the reviewer can assess how well they have been met before detailed review of the model set up.

- What do the model results show in terms of flood consequences and impact and does that make sense hydrologically and hydraulically? Review time series, long profile, cross-section and mapped results
- How do the results vary between the different events modelled? Does this make sense when comparing one event with another? For example, different probabilities, durations, combinations
- Has the model made appropriate use of the data sources available and followed the data plan agreed at Project Definition stage?
- Does the model meet the agreed accuracy and performance for the calibration and verification events?
- What do the results of the sensitivity testing show, can this be explained and what does it mean in terms of assessing confidence in the model? (Relate this to what was agreed in the Project Definition)
- Are there any areas or periods of instability, poor model convergence or mass balance errors and what does that mean in terms of assessing confidence in the model? (Again, relate this to what was agreed in the Project Definition)
- Are the model files sensibly named, ordered and structured so that others can find what they need in the model?
- Is the model log a complete and ordered record of model development and decisions and assumptions made?

The PSG or one of the project Partners may also review the model, reporting and outputs at any or all of the stages identified above and may, in some cases, commission an independent third party to carry out that review. Sufficient time should be allowed in the programme for these reviews, including time to rectify or respond to any issues raised and for a second review, if necessary.

Additionally, as noted earlier in the Guide, where a model already exists and may potentially be reused as part of the new integrated model, it is the modelling team's responsibility to undertake a review that can establish whether the model is fit for purpose in the new integrated modelling project. This review should be undertaken taking the new Project Definition into account so that the reviewer's mind is very focused on the desired outcomes of the new integrated modelling project. This review would have a different objective to a QA review of a new integrated model as it is seeking to answer different questions. The main questions to be considered in a review of an existing model are listed below, and, as above, some of these questions may be yes/no, whereas others would benefit from a RAG type assessment. Additional commentary is likely to be needed where the review identifies action that needs to be taken before the model can be reused. This could include:

- What were the aims and objectives of the original modelling project and were they met?
- What has changed in the catchment since that original modelling project was carried out and are those changes significant in the context of the hydrology and hydraulics of the catchment?
- What has changed in terms of policy, guidance or regulations since that original modelling project?
- What sources of data were used in the original modelling project, would they still be considered up to date, have they been superseded by more recent data, or should they be updated with new data collection?
- What was the resolution of the original model and is this sufficient for the new integrated model? For example, spacing between cross-sections, inclusion of all sewer pipes, 2D grid or mesh size
- Do the results of the original model make sense? For example, check flooding mechanisms, effects of structures
- Was the original model calibrated or verified against observed data and how well did it perform? Does it meet the required level of accuracy for the new model, as specified in the Project Definition?
- Did the original model show any signs of instability, convergence problems or mass balance errors?
- What sensitivity testing was carried out on the model and what did it show? Does this provide an indication of the level of confidence in the model and is that assessment of confidence sufficient for the new model, as specified in the Project Definition?
- What design events (flood events or time series) was the original model run for and does that cover the full range of events needed for the current integrated modelling project?
- What was the run-time, run duration and time-step of the original model and would that be acceptable for the programme of the new integrated modelling project?



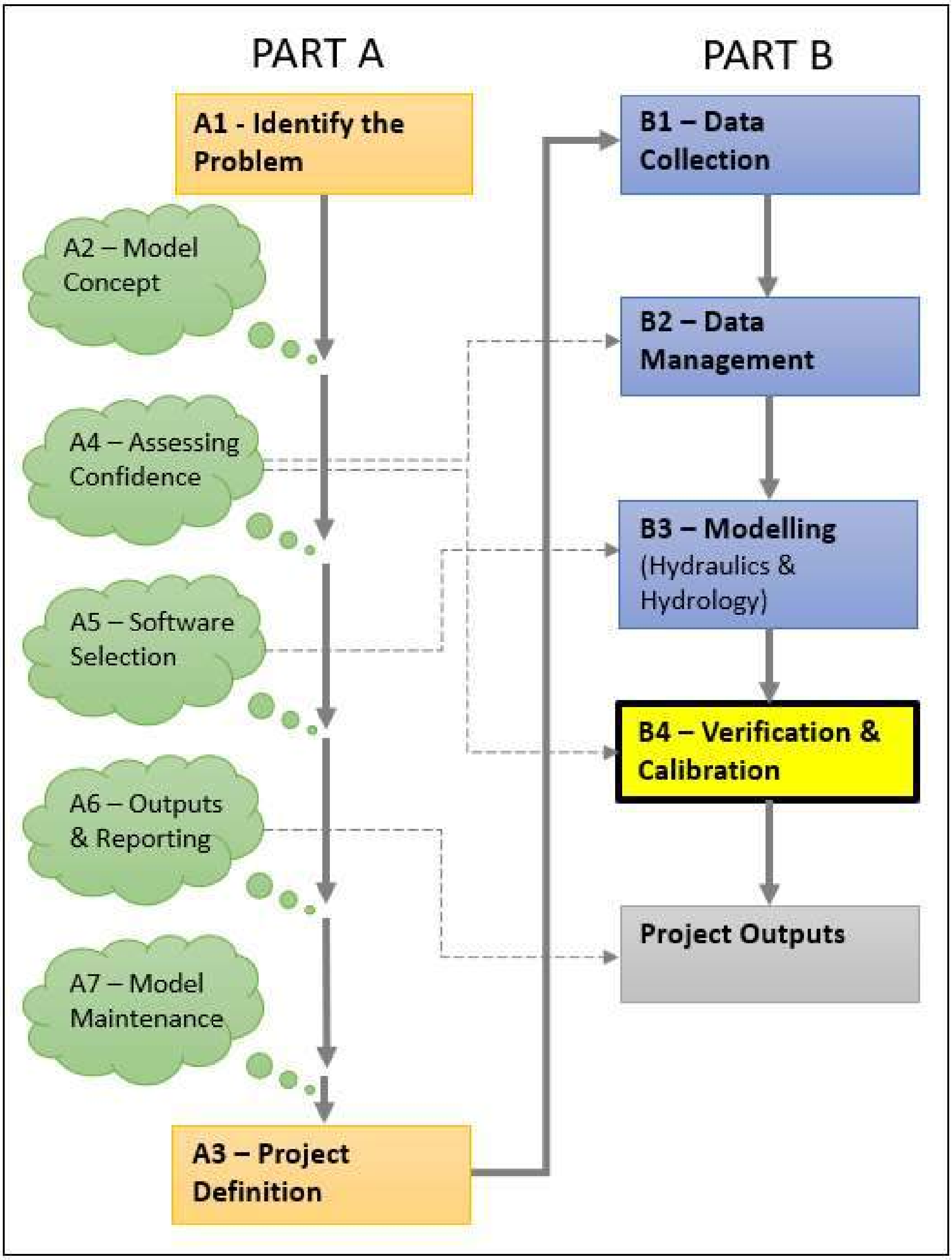
Integrated Urban Drainage Modelling Guide

Section B4

Verification and Calibration

CIWEM Chartered Institution of Water and Environmental Management

B4 VERIFICATION AND CALIBRATION



B4.1 Introduction

Verifying the model against measured data and historical observations indicates whether the model is replicating known performance. Verification should take into account the purpose of the model. This can influence the accuracy requirements and the relative importance of different elements of verification.

There is a big difference between calibration, verification and force-fitting of models.

Verification is the process of checking a model against independent data to determine its accuracy. Any changes to the model should be made only where this reflects the physical state of the drainage network and not solely to make the model fit the observed data.

Calibration is the process of adjusting model parameters to make a model fit with measured conditions (usually measured flows). This process should be followed by verification, using a different set of data to that used in the calibration. Most models are subject to a degree of calibration following initial verification, as it is normally only possible to verify the dry weather flow and fast response from directly connected paved areas. Pervious response is far less certain and usually involves a degree of calibration.

Force-fitting is the process of making arbitrary changes to a model to make it fit observed data and should not be undertaken. The dangers of force-fitting are described in CIWEM UDG **User Note 13**.

The results of the verification will influence the model confidence within each of the defined confidence zones (**see Section A4**)

B4.2 Calibration

The necessity for calibration will vary between the different modelling concepts and also between catchments. The role of calibration within each model concept type is discussed below.

B4.2.1 Model Concept #A

For this modelling concept, all of the runoff from both rural and urban areas is simulated within the modelling program. The urban areas runoff will generally not require any calibration with verification following the standard approach for sewer models.

For the rural runoff and the flow in watercourses it is unlikely that there will be any permanent flow or depth measurement installations and the definition of suitable parameters for the runoff characteristics and infiltration coefficients etc will probably need to be based on first principles. Calibration of these parameters may be necessary in order to obtain a match with recorded flood outlines/depths. It may also be necessary in this calibration to take account of any seasonal variations.

B4.2.2 Model Concept #B

For this modelling concept, the runoff from the urban areas (and small permeable areas) is simulated within the modelling program. The urban areas runoff will generally not require any calibration with verification following the standard approach for sewer models.

The fluvial flows and runoff from rural areas outside the model boundary are input into the model as inflow hydrographs, which will have been created in the Hydrological Study for the project. Depending on what methodology has been used for the Hydrological Study there may have been some calibration required as part of that study. It would normally be expected that no further calibration of the inflow hydrographs would be considered acceptable. It may also be worth noting that the Hydrological Study may have only produced inflow hydrographs for synthetic design events rather than specific events. The approach taken in the Hydrological Study might be restricted if inflow hydrographs are required for specific events.

B4.2.3 Model Concept #C

For this modelling concept, the runoff from the urban areas (and small permeable areas) is simulated within the modelling program. The urban areas runoff will generally not require any calibration with verification following the standard approach for sewer models.

The fluvial flows and the downstream boundary conditions will have been derived from the fluvial model for that large watercourse, which, in turn, will already have had a Hydrological Study completed. The Hydrological Study may have involved a degree of calibration.

It is recommended that the flood outline and flood depths derived in the integrated model are compared with those from the fluvial model for the same design event to ensure that there have been no major increases or decreases due to only modelling a portion of the large watercourse. If there are large differences, the reasons for these should be explored and understood before any further calibration is undertaken. It should be recognised that due to the very large differences in time-to-peak for the large watercourse compared to the urban runoff it is unlikely that a simulation of a specific event will be possible; it is more likely that synthetic design events will need to be used.

Where there are river gauges on the large watercourse in the vicinity of the study area it may be possible to satisfactorily simulate a specific event, in which case it is unlikely that any calibration will be considered acceptable.

B4.2.4 Model Concept #D

For this modelling concept, which may have a tidal or estuarial regime as the boundary condition, it is possible that some calibration will be required in order to adequately represent the boundary conditions. For example, if the tide levels for a specific event are obtained from the National Tide Gauge Network it is likely that some adjustments will be needed to ensure that the data represents the correct timing for that location along the coast. A simple pro rata approach between two tide gauges may be adequate. If there is a strong fluvial component in estuarial locations it may be necessary to also make allowances, which ideally would be based on river gauge data or a fluvial model of the watercourse.

The urban areas runoff will generally not require any calibration with verification following the standard approach for sewer models. However, it should be recognised that any short-term flow survey monitors installed at locations where there is a tidal influence may have been affected by backwater effects. This is discussed in more detail later in this section. If a short-term flow survey is carried out it is considered prudent to also install a tide gauge so that the data derived from other sources can be calibrated to match local conditions.

B4.2.5 Other Model Concepts

In Section A2 four basic modelling concepts have been described. In some cases, the modelling concept for a particular project may be different or may be a combination of the four basic types. In this situation, it may be that some calibration is required. As a general rule in these situations where some calibration is required it is the source data that should be adjusted rather than the way in which the modelling program uses that data.

B4.3 Verification procedure

There is no definitive sequence of working through the stages of verification. The final model should satisfactorily replicate historical observations and should also be verified with available flow and depth data sets. Any changes made because of checking one data set should not invalidate the verification for the other data set.

The verification procedure and criteria for sewer and urban drainage models are described in detail in the CIWEM UDG Code of Practice for Hydraulic Modelling of Urban Drainage Systems (**CoP**[1]).

Some modellers prefer to carry out the historical verification before the verification with the data from the short-term flow surveys, followed by returning to the historical verification. This can be useful to give an indication of the way in which the model is performing in respect of fluvial, pluvial and sewer flows; this can be important to check that the interactions between these are adequately simulated.

When models are verified (using the methods described below), it is important to note that in all cases this should be undertaken with the hydraulic model geometry representing the actual conditions observed during the time of the observed flood event (or at the time of the flow survey). Model geometry and parameters would match the physical scenario they are representing. For example, a flood alleviation scheme constructed since the time of the observed event would not be included in the model geometry and structures/defences that were known to have failed or malfunctioned in the observed event would be modelled in that way (and not modelled as fully operational).

B4.4 Verification with flow data

B4.4.1 Reviewing flow/depth data

Before using any flow or depth data for verification purposes, the data should be carefully reviewed. The review could include volume balance checks, timing of peak flows or depths. For data collected for enclosed conduits (sewers, culverts etc) it is recommended that log-log scattergraphs are plotted in accordance with the guidance given in the Code of Practice for Hydraulic Modelling of Urban Drainage Systems (**CoP**[1]).

The modeller should then assess whether there is sufficient data to verify the model to the required level of confidence. Poor quality data should normally not be used for verification, but if nothing else is available this data may have limited uses but should be treated with caution.

In general, no changes should be made to the model during verification, other than where they have been independently shown to reflect the physical condition of the system. However, it is accepted that slow response will probably require a degree of calibration, especially for indirectly connected flows. All changes should be recorded in the model and/or documentation.

B4.4.2 Verification for enclosed conduits

For enclosed conduits (sewers, culverts etc) and those 'open' locations where there is a consistent shape the observed flow/depth data should be used to create time-varying hydrographs of flow, depth and velocity (if the velocity data is available). This is the data that should be used to compare with the simulated results.

The CIWEM UDG Code of Practice for Hydraulic Modelling of Drainage Systems (**CoP**[1]) sets out two possible approaches to the assessment; a qualitative assessment building on historical practice and a quantitative approach based on a scoring system. Whilst a quantitative approach measuring the closeness of fit between two lines (the observed and the simulated) using the Nash Sutcliffe Efficiency Coefficient (NSEC) can be applied to sewer models without too much difficulty, it is considered to be too complex to use for integrated models.

The Code of Practice sets out in detail the verification target standards to be achieved. These are summarised in a table, which for ease of reference, is included below at Table B4-1. The references to the NSEC criteria have been retained for completeness.

Table B4-1 Storm Verification Targets

Parameter	General	Critical Locations	Comments
Shape	Good match (NSEC if used >0.5)	Good match (NSEC if used >0.5)	An evaluation technique may be used to compare the shape such as the Nash-Sutcliffe Efficiency Co-efficient (NSEC) method together with a visual check. More information on this approach is included in Appendix 5.B of the Code of Practice
Time of peaks and troughs	±0.5 hour	±0.5 hour	The timing of the peaks and troughs should be similar considering the duration of the event
Peak depth (un-surcharged)	±0.1m or ±10% whichever is greater	±0.1m	
Peak depth (surcharged)	+0.5m to – 0.1m	±0.1m	Relaxation may be appropriate in deep sewers. Where coupled 1D-2D models are used the 'critical locations' criteria should apply
Peak flow	+ 25% to -15%	±10%	
Flow volume	+20% to -10%	±10%	Excluding poor/missing data

The 'Critical Locations' referred to in Table B4-1 are generally ancillary structures such as storm overflows or at the interface between the 1D domain and the 2D domain (i.e. near the onset of flooding).

Where permanent data sets are available these should be compared with the simulated performance where the data is of good enough quality to be used and compared with.

Significant predicted flooding during the flow survey period should be substantiated by evidence of real flooding or a clear explanation for there being none. The model should reproduce all hydraulic flooding known to have occurred during the flow survey period.

B4.4.3 Verification for open channels and watercourses

In most cases, watercourses have irregular shaped cross-section profiles with relatively wide beds that make accurate flow measurement almost impossible. Therefore, verification in respect of flow is not considered feasible and greater reliance will be placed on verification against depth measurements and/or extents of out of bank flows.

It is likely that most rainfall events that occur during a typical short-term flow survey will be unlikely to be of sufficient magnitude to have created any out-of-bank flows. This makes it difficult to verify watercourse elements of an integrated model just from data obtained during a short-term flow survey. By careful planning of monitor types and locations taking advantage of watercourse reaches with a reasonably consistent cross-section, it may be possible to obtain some useful depth data that can be used for verification.

However, the main approach to watercourse verification is to obtain reliable rainfall data for part events when the extent of out-of-bank flooding occurred and was sufficiently well recorded.

The target criteria for verification of watercourse elements of the model should be ±0.1m in respect of depth (or level) and ±0.5 hours in respect of timing of peaks if any time varying data is available.

B4.4.4 Verification at hydraulic structures and ancillaries

The target criteria for verification at hydraulic structures (weirs, storm overflows, pumping stations etc) should be those set out in Table B4-1 in the column for 'Critical Locations'. It should be recognised that any permanent flow/depth measurement at hydraulic structures may have a sampling interval of 15 minutes and, in very responsive drainage systems, the measurement may not necessarily capture the peak. If the sampling interval is considered to be too long and if a short-term flow survey is carried out, it may be worthwhile supplementing the permanent measurement equipment with an additional one with a shorter sampling interval.

B4.4.5 Verification with river gauges

River gauges tend to only be located on larger watercourses. These generally only measure the depths, but at some locations a head-discharge (or rating curve) has been derived, which means that the depth readings can be translated into flows.

For model concept Types #A, #B and #D it is unlikely that there will be any reliable river gauges within reasonable proximity. There may be suitable river gauges for model concept Type #C but that cannot be assured. It should be recognised that with Type #C models the maximum water level in the large river is unlikely to be due to the same rainfall event as the localised and quicker response in the urban area; it is more likely to have been caused by preceding conditions.

Where there is river gauge data that can be used, the target verification criteria would be ±0.1 metres.

B4.5 Verification for Pluvial Runoff Models

Verification of pluvial runoff/2D models or the overland flow elements of urban drainage models rarely occurs with any form of flow or depth measurement because of the relatively rare occurrences of overland flow or flooding. The pluvial runoff and overland flow elements of models should be verified with historical observations, with the flooding mechanism and/or flow routing replicated. Historical data can be used to estimate the depth of flooding, flow directions and velocities and be compared with the model prediction. Data captured from community CCTV cameras and social media sources generally forms the most reliable data for comparison purposes. There are frequently some indications in photographs from which to estimate the depth of water and/or the flow velocity. These might be as simple as the extent of car wheels still visible, whether car number plates are visible and the amount of street furniture still visible. Figure 4B-20 shows an example of pluvial runoff along a street from which the depth and velocity can be judged.

Figure B4-1: Example of Pluvial Flooding

It is important to recognise that any photographs are unlikely to have been taken at peak flow conditions.

Town Centre CCTV can be especially useful due to the elevated position of cameras and all data time stamped so that the time of peak flow conditions can be ascertained.

The other important aspect in the verification of pluvial runoff models and overland flow is whether the flow routing matches anecdotal evidence. It may be that there are surface features that have a significant influence on flow routing and it is important that these are adequately represented in the model. The most reliable source of anecdotal evidence of the actual flooding mechanism/flow routing are the individuals affected who may not have posted any information on social media but nevertheless may have photographic or video evidence that they have submitted to their insurance company. Together with project stakeholders it may be worthwhile developing a strategy for communicating with the affected householders.

B4.6 Verification with Trash Line Data

Verification using trash line data is a technique commonly used for fluvial models when the maximum water level is compared with the measured trash line. It is important to recognise that the accuracy of the trash line can be quite variable and patchy, with a number of factors potentially affecting whether it truly reflects the maximum water level. Techniques for capturing the trash line data more quickly after a flooding event are improving all the time, with advances in surveying by drones making significant improvements over more traditional techniques.

All modelling programs can provide simulation results for the maximum water level. Some programs can produce that information directly, whilst others require a degree of post-processing.

Figure B4-2: Verification with trash line data

Figure 4B-2 shows an example of how the simulated results (in blue) can be compared with the measured trash line data (shown as the solid black line). In this example, the simulated results are shown for depths greater than 10mm.

This technique is best suited to conditions where the flooding creates a reasonably level pool with low velocities. In cases where there is pluvial runoff causing flow along streets, this verification technique may be less successful.

It is also worth noting that trash line surveys are generally only undertaken after significant fluvial flooding events. In the absence of such data, it may be that there is more reliance placed on replicating the properties actually flooded and the depths of flooding reported within those properties.

B4.7 Historical Verification

Historical verification is probably the most important element of the model verification process. Ideally, one or more historical flooding events are replicated by the model; this is usually only possible when the rainfall data is available with sufficient spatial accuracy and when the extent of flooding was documented. If the model satisfactorily replicates the flooding it provides a high level of confidence in the model not just for the Modelling Team and the PSG but also for the general public.

Where long-term records of historical rainfall information are available, they may be used for historical verification, but if the rainfall data is from a single permanent rain gauge the spatial accuracy is likely to be poor for spatially varied summer events. When combined with radar data, or for winter events, the accuracy may become acceptable.

Where no suitable historical rainfall data is available, design storms with return periods of 1 in 1 year, 1 in 5 years, 1 in 10 years, 1 in 30 years and 1 in 100 years should be tested with the model for flooding. Predicted flooding should be compared with reported flooding, which should be reproduced by the model in terms of location, magnitude and frequency.

Significant predicted flooding should be substantiated by evidence of real flooding or by a clear explanation for there being none. However, small predicted volumes may be considered insignificant since they may not be perceived as flooding on site. For example, in 1D only models, during heavy rainfall on roads, volumes as large as $10m^3$ can sometimes be viewed as acceptable standing water or not recognised as flooding. However, inside a building, the smallest volumes are likely to be unacceptable. The modeller should also take into account how the model is built and whether there are limitations that contribute to uncertainty in the prediction of flooding. For 2D models, or coupled 1D-2D models, flood volumes are less relevant and emphasis should be on matching flow routes, velocities, flood depths and extents. For 'conveyance' flooding the flow direction, velocity and flow depth should be considered. For 'ponding' flooding the extents and maximum flood depth should be considered.

Significant discrepancies between the observed and predicted flooding should be investigated. Errors identified in the input data should be corrected, or the flooding database updated if further reports of flooding are found. Operational problems such as sediment, obstructions, pump failures and others can be an influential factor in flooding. The modeller should obtain detailed records of all operational activities carried out in the local area both before and after the flooding incident.

B4.8 Non-compliance

Non-compliance is acceptable if it is justified by limitations in the measured data or is justifiably insignificant in the context of the model purpose.

Where the target verification criteria are not met and further investigation fails to identify a cause, the likely reasons should be reviewed. If the model input data has been shown to be correct, but the model does not generate target compliance, then using further storm data from other sources such as long-term data or previous flow surveys should be considered, where available. The project definition should also be carefully reviewed as it may still be possible to consider the model sufficiently verified in some circumstances, provided that:

a) The reasons for the non-compliance have been determined but cannot be modelled and have been assessed as being unimportant to the subsequent use of the model. For example, a transient feature such as the manual operation of a penstock is known to be a cause of the discrepancy. There should be credible evidence that the cause has been correctly identified and that the model would otherwise be considered adequately verified

b) The cause of the discrepancy cannot be isolated but an assessment of the effect of likely causes on the accuracy of the model has shown that this will not be detrimental to the model purpose. Sensitivity analysis, using a number of different versions of the model with different possible combinations of scenarios, can be helpful in assessing the boundaries that can be placed on the confidence in the model

B4.9 Translating Model Verification into Model Confidence

Section A4 sets out the principles of how confidence can be assessed. The confidence assessment process needs to be transparent, consistent and repeatable. It should enable results and data to be interrogated, analysed and displayed geospatially at an appropriate scale.

The model should be divided into appropriate spatial units that represent the areas deemed important. The Project Definition (**Section A3**) should have identified those areas where a higher confidence level is required. The confidence assessment derived from the input data will support the confidence level for each spatial area, however it is the confidence level derived from the verification process (and particularly the historical verification) which is most influential.

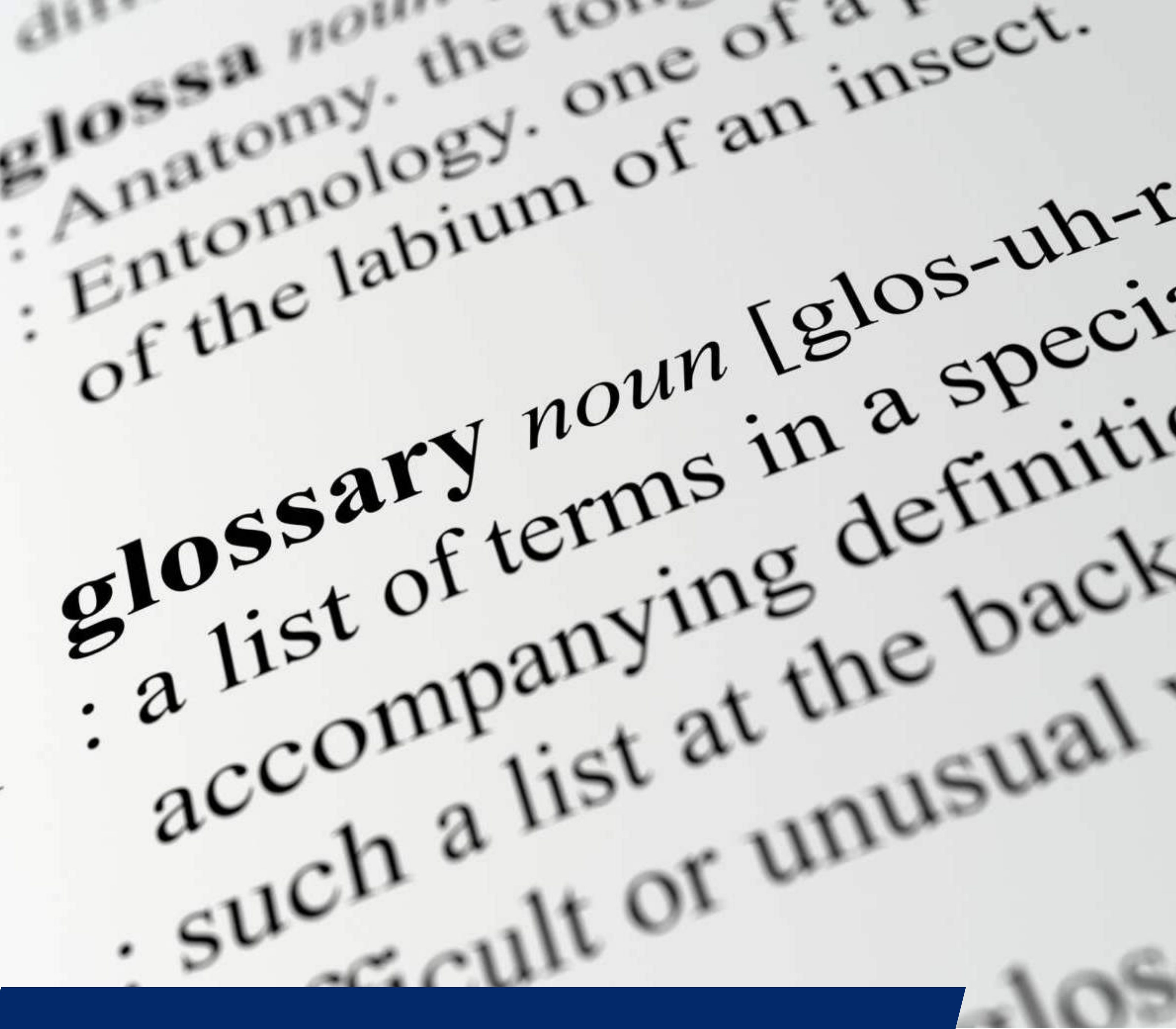
The confidence level should consider the flooding of properties or area, the flooding source (sewer flooding, pluvial flooding, fluvial flooding), whether the flooding has been reported and flooding mechanisms. In 1D sewer models the criteria to consider may include the number of manholes flooding, the number of properties flooding (below or above ground) and the spatial distribution of the flooded manholes.

For each spatial area, the Modeller should assess the confidence that can be attributed to how well the model will replicate flooding in that area in accordance with Table B4-2. This will inevitably involve a degree of subjective judgement, but a consistent approach should be applied across the whole Study Area.

Table B4-2: Confidence Levels

High	• Flooding of properties is replicated for greater than 80% of the recorded properties that have flooding with correct flood frequency. • The simulated level (and extents) of 'ponding' type flooding matches the recorded data to within ±0.1m. • The simulated conveyance flooding (overland flow or pluvial flooding) agrees with anecdotal or other data in respect of route, depth and velocity. • In the absence of sufficient recorded flooding data, the input data used has a High level of confidence.
Medium	• Flooding of properties is replicated for between 50% and 80% of the recorded properties that have flooding with correct flood frequency. • The simulated level (and extents) of 'ponding' type flooding matches the recorded data to within ±0.2m. • Most of the simulated conveyance flooding (overland flow or pluvial flooding) agrees with anecdotal or other data in respect of route, depth and velocity. • In the absence of sufficient recorded flooding data, the input data used has a confidence level in the range of Medium to High.
Low	• Flooding of properties is replicated for less than 50% of the recorded properties which have flooding with correct flood frequency. • The simulated level (and extents) of 'ponding' type flooding matches the recorded data to within ±0.5m. • Only some of the simulated conveyance flooding (overland flow or pluvial flooding) agrees with anecdotal or other data in respect of route, depth and velocity.

It is however, important to recognise that the final overall confidence assessment will always be a matter of expert judgement, which is why sufficiently skilled and experienced personnel are required to make the final judgement. It may be that personnel from different disciplines collectively make the final judgement as there are unlikely to be sufficient resources with adequate skills across all disciplines.



Integrated Urban Drainage Modelling Guide

Glossary

Chartered Institution of Water and Environmental Management

GLOSSARY

Term	Definition
ALTBAR	Hydrological term for mean catchment altitude above sea level.
Ancillary	Non pipe and conduit devices forming part of a sewerage and watercourse system, for example, storm overflows, pumping stations, flow controls.
Antecedent Conditions	The condition of a catchment before a rainfall event.
ASPBAR	Hydrological term for an index representing the dominant aspect of catchment slopes.
ASPVAR	Hydrological term for an index representing the invariability in aspect of catchment slopes.
Backwater	Build-up of flow in a pipe due to a restriction downstream.
BFIHOST	Hydrological term for a base flow index that is a measure of catchment responsiveness derived using the 29-class Hydrology of Soil Types (HOST) classification.
Calibration	Process of adjusting model parameters to make a model fit with measured conditions (usually measured flows). This process should be followed by verification.
Canal and River Trust	The organisation (previously known as British Waterways) responsible for 2,000 miles of canals and rivers in England and Wales.
Catchment	An area of land where rainwater drains into a single watercourse.
Catchment Descriptors	A range of descriptors derived from FEH web service that summarise the key parameters for a catchment, enabling a hydrological assessment to be undertaken.
Catchment Flood Management Plan (CFMP)	A strategic planning tool through which the Environment Agency understands the factors influencing flood risk, and how best to manage this risk. These are now largely superseded or redundant.
CEH	Centre for Ecology and Hydrology.
CIRIA	Construction Industry Research and Information Association.
CIWEM UDG	CIWEM Urban Drainage Group.
Climate change	Changes occurring to the climate (with particular regard to precipitation).
Colebrook-White	An empirical equation relating flow to roughness and gradient of a conduit and the viscosity of the fluid.

Term	Definition
Combined Drainage System	A single pipe drainage system where both foul and storm runoff are conveyed in the same pipe.
Combined Sewer Overflow (CSO)	A relief structure allowing the discharge of diluted untreated wastewater from a combined sewer during a rainfall event, when the flow exceeds the wastewater network capacity. These are now termed 'Storm Overflow'.
Conduit Head loss	Energy losses in pipes and channels generally due to friction.
Confidence	A measure of how confident a modeller is that either an element of a model or the whole model matches reality.
Confidence - Qualitative	A measure of confidence based on expert judgement.
Confidence - Quantitative	A measure of confidence based on a numerical scoring system with pre-set scores to be achieved.
Connectivity - assets	The connectivity of the physical assets in a drainage system.
Connectivity - surfaces	The connectivity of the runoff surfaces to modelled nodes.
Continuous Simulation	A simulation run that extends over more than just a single rainfall event and includes the intervening dry weather periods.
Contributing Area	The total area of a subcatchment that can contribute runoff to a point in the drainage system.
Critical Duration Storm	The duration of design storm necessary to produce the maximum flood level, flow or volume at a specific location in a drainage system.
Culvert	Conduit used to direct the flow of water, usually below a structure such as a building, road or railway.
Department for Environment, Food and Rural Affairs (Defra)	UK Government Department that deals with environmental risks and works towards securing a sustainable society and a healthy environment.
Depression Storage	Rainfall retained in surface hollows that does not contribute to runoff.
Depth - Discharge relationship	A relationship between depth of flow and the associated discharge rate (also known as stage-discharge, particularly in a fluvial context).

Term	Definition
Depth-Duration-Frequency (DDF)	The relationship between rainfall depth, rainfall duration (total time over which rainfall occurs) and frequency (return interval) at which the intensity-duration relationship is expected to recur.
Design Storm	A rainfall hyetograph of a specific duration whose total depth corresponds to a particular storm return period or recurrence interval, usually chosen from an IDF curve.
Designing for Exceedance	An engineering philosophy for the design and management of urban sewerage and drainage systems to reduce the impacts that arise when flows occur that exceed their capacity. Guidance published by CIRIA.
DG5 Register	A WaSC held register of properties that have experienced sewer flooding due to hydraulic overloading or are at risk of sewer flooding.
Digital Elevation Model (DEM)	A digital map of the elevation of the ground surface and includes building and vegetation etc.
Digital Terrain Model (DTM)	A model of the terrain of the earth's surface (bare earth), which excludes buildings and vegetation.
Diurnal profile	The temporal variation in dry weather flow during the day, generally expressed as a multiplier of average dry weather flow.
DPLBAR	Hydrological term for the mean distance between each node on the IHDTM (Integrated Hydrological Digital Terrain Model) grid and the catchment outlet (in kilometres) used to characterise catchment size and configuration.
DPSBAR	Hydrological term for a landform descriptor (mean Drainage Path Slope) providing an index of overall catchment steepness.
Drainage Area Plan (DAP)	A full assessment of a sewer systems performance and condition made by the WaSC, investigating hydraulic, operational, structure and environmental performance. It also proposes a strategy to achieve the desired levels of service.
Drainage Strategy Framework	A good practice guide for the development of WaSC drainage strategies.
Dry Weather Flow (DWF)	The continuous discharge of domestic, commercial and trade wastewater directly into the sewer system together with base infiltration.
DWMP	Drainage and Wastewater Management Plan.
Economic Regulator	The economic regulator of the water industry in the UK. In England: Ofwat, in Scotland: the WIC, and in Northern Ireland: The Utility Regulator.

Term	Definition
Environment Agency (EA)	An executive non departmental public body tasked to protect and improve the environment, and to promote sustainable development. The EA plays a central role in delivering and implementing the environmental policies of central government in England.
Environmental Regulator	In England: the Environment Agency (EA), in Northern Ireland: the Northern Ireland Environment Agency (NIEA), in Scotland: the Scottish Environment Protection Agency (SEPA), in Wales: Natural Resources Wales (NRW).
Ex Section 24 Sewer	Former private sewers serving more than one property that were transferred to public ownership in 2011.
Exceedance Flows	Excess flow on the surface once the capacity of the below ground drainage system is exceeded.
FARL	Hydrological term for the Flood Attenuation by Reservoirs and Lakes index.
Fast Response	Flow entering the sewerage system as a result of direct links between the stormwater collection system and the sewer system, generally from impervious areas. This has a very short response time to rainfall on the catchment.
FEH Web Service	www.fehweb.ceh.ac.uk. The FEH Web Service, launched on 9 November 2015, updated and replaced the FEH CD-ROM application. The FEH Web Service provides the data at the heart of the flood estimation procedures, including the release of the new FEH13 rainfall model.
Fit for Purpose	A model that has been considered suitable for the purpose it is required to be used for, taking into account the uncertainties in developing the model and the associated risks in using the model.
Flags	A notation system allowing the source of information to be traced and the confidence to be assigned to the data.
Flood	Temporary expanse of water that submerges land not normally covered by water.
Flood Estimation Handbook (FEH)	Gives guidance on rainfall and river flood frequency estimation in the UK.
Flood risk	Likelihood of flooding occurring and the consequences of it happening.
Flood Risk Assessment (FRA)	An assessment of the likelihood and consequences of flooding in a development area, with recommendations of any mitigation measures.
Flood Studies Report (FSR)	Provides techniques for design flood and rainfall estimation in the UK. This has been superseded by the Flood Estimation handbook.
Flood Modeller	Hydraulic modelling software produced by Jacobs.

Term	Definition
Floodplain	Flat, low-lying area adjacent to a watercourse and prone to flooding.
Flow Survey	A survey carried out over a period to monitor the response of a drainage system to measured rainfall and dry weather conditions.
Flow to Full Treatment (FFT)	Rate of flow that receives treatment at a Wastewater Treatment Works. This is usually controlled flow with diluted flows above this rate discharged to the environment following settlement through storm tanks.
Flow to Works (FTW)	Rate of flow arriving at the inlet of a Wastewater Treatment Works.
Fluvial flooding	Same as river flooding.
Force-fitting	Process of making arbitrary changes to a model to make it fit observed data. Should not be undertaken.
Foul Flow	Wastewater from domestic, commercial and industrial premises.
FPDBAR	Hydrological term for the mean depth of water on floodplains in a 100-year event.
FPEXT	Hydrological term for the floodplain extent as the fraction of the catchment that is estimated to be inundated by a 100-year flood.
FPLOC	Hydrological term for the location of floodplains within the catchment.
Gauging Station	A river depth recording station. Some stations can measure flows directly, whilst others can translate the depth readings to flows.
Geographical Information System (GIS)	A mapping system to analyse and display geographically referenced information.
GPS	Global Positioning System, used to determine geographical location and elevation.
Greenfield runoff	The natural rate of runoff that would occur from a site that is undeveloped or undisturbed.
Groundwater flooding	Flooding caused by increases in the water table to above ground level, due to rainfall.
Head loss	Energy lost due to resistance to flow, due to friction in pipes, bends and manholes etc.
Highways Agency	Executive agency of the Department for Transport (DfT), responsible for operating, maintaining and improving the strategic road network in England.
Highways Authority	Local authority responsibility for managing, maintaining and improving England’s roads that are not under the responsibility of the Highways Agency.

Term	Definition
Hydraulic Model	A mathematical model developed to represent the physical characteristics of a drainage system, including assets, topography and hydrology.
Hydrological Summary	A monthly summary of hydrological records and information published jointly by CEH and the British Geological Survey.
Hydrology	The scientific study and practical implications of the movement, distribution and quality of freshwater in the environment.
Hydrology of Soil Types (HOST)	An improved system of soil classification based on more detailed analysis of the hydrological parameters of soils. There are 29 HOST classes.
Impermeable area	See Impervious surface.
Impervious surface	A surface that does not allow infiltration of rainwater, such as a roof, road or hard standing.
Infiltration - Hydrology	The process by which rainfall penetrates the ground surface and fills the pores of the underlying soil.
Infiltration - Sewers	The entry of groundwater into a sewer system through the pipe work. It may also include the entry of unplanned flows into a sewer system via manholes or misconnections.
InfoWorks ICM	Hydraulic modelling software produced by Innovyze.
Integrated Urban Drainage (IUD)	Approach to planning or managing an urban drainage system that leads to an understanding of how different physical components interact.
Intensity-Duration-Frequency (IDF)	The relationship between rainfall intensity (amount per unit of time), rainfall duration (total time over which rainfall occurs) and frequency (return interval) at which the intensity-duration relationship is expected to recur.
Intermittent Discharge	Non-continuous discharge from the Wastewater Network to a watercourse. This will include discharges from a storm overflow, emergency overflow or a storm tank.
Internal Drainage Boards (IDBs)	Independent bodies responsible for land drainage in areas of special drainage need that extends to 1.2 million hectares of lowland England.
Inundation	The flooding of an area with water.
ISIS	Hydraulic modelling software produced by Jacobs (generally superseded by Flood Modeller).
JFlow	Hydraulic modelling software produced by JBA.

Term	Definition
Joint Probability	Sometimes referred to as 'Combined Probability'. This is the probability of two or more events occurring simultaneously (for example, peak river flow and peak discharge from a surface water sewer).
Land Use	Catchments zoned based on ergonomic, geographic or demographic use of land, such as residential, industrial, agricultural and/or commercial, together with the drainage system type.
Lead Local Flood Authority (LLFA)	Upper tier Local Authority responsible for reducing the risk of flooding from surface water, groundwater and ordinary watercourses under the Flood and Water Management Act 2010.
LDP	Hydrological term for longest drainage path length (in kilometres).
LiDAR	Light Detection and Ranging. Ground elevation data.
Link	An element of a model linking two nodes. This could be a conduit or a feature, for example, a weir or a control.
Main River	Main rivers are usually larger streams and rivers, but also include smaller watercourses of strategic drainage importance. The Environmental Regulator has responsibility for main rivers and these are designated by Defra.
Major drainage system	The above ground drainage systems. These would include watercourses and rivers that form the principal drainage pathways for catchments and the overland flow paths on river floodplains and the urban environment. These are broadly classified into two types: within channel flows or overland flow paths.
Making Space for Water	Making Space for Water is the cross government programme taking forward the developing strategy for flood and coastal erosion risk management in England.
Manhole Headloss	Energy losses at a manhole.
MCERTS	Environment Agency Monitoring Certification Scheme for equipment, personnel and organisations. In this case, certified flow monitoring at wastewater treatment works (WwTW).
Met Eireann	Irish Meteorological Office.
Met Office	UK Meteorological Office.
MIKE	A suite of hydraulic modelling programs produced by the Danish Hydraulics Institute.
Minor drainage system	The underground piped drainage systems that are typically sewers but could also be culverted watercourses or highway drains.
Misconnections	Misconnections are surface water connections to a foul system or vice versa by householders or commercial premises.
Model	A numerical representation of physical assets and processes.

Term	Definition
Model Maintenance	The process of maintaining hydraulic models for future use.
Modelling Team	Team responsible for carrying out the modelling project.
Nash-Sutcliffe Efficiency Coefficient (NSEC)	The Nash–Sutcliffe model efficiency coefficient is used to assess the predictive power of hydrological models.
National River Flow Archive	A data archive with records of flows in UK rivers.
National Tide Gauge Network	A network of 44 tide gauges around the UK coast that record tide levels at 15-minute intervals.
NHMP	National Hydrological Monitoring Programme.
NODC	National Oceanographic Data Centre (custodians of the National Tide Gauge data).
Node	A point in a modelled drainage system that receives runoff and other inflows, that connects links together, or that discharges water out of the system. Nodes can be manholes, junctions, storage units or outfalls. Every modelled link is attached to both an upstream and downstream node.
NRW	Natural Resources Wales (Welsh equivalent to the Environment Agency).
Ofwat	Economic Water Industry Regulator for England and Wales.
Operations	The process of operating and maintaining a drainage system.
Ordinary Watercourse	An ordinary watercourse is any other river, stream, ditch, cut, sluice, dyke or non-public sewer that is not a Main River. The local authority or Internal Drainage Board has powers for such watercourses.
Overland Flow Path	The path that runoff follows as it flows over a surface until it reaches a collection channel or drain.
Partially Separate Drainage System	A drainage system where there is a mixture of a combined system and a separate system, usually with the inclusion of separate surface water sewers.
Pass Forward Flow (PFF)	Flow that continues on through the network after passing through a network ancillary.
Pass forward flow at first spill	Continuation flow from a storm overflow at the moment the overflow spills.

Term	Definition
Per capita consumption (PCC) (G)	The amount of domestic and unmeasured commercial water returned as flow to sewer, generally expressed as units of litres/head/day.
Pervious (Permeable) Surface	A surface that allows water to infiltrate into the soil below it, such as a natural undeveloped area, grass verges or a gravel roadway.
Pitt Review	An independent review of the 2007 summer floods by Sir Michael Pitt.
Pluvial Flooding	Flooding that results from rainfall-generated overland flow before the runoff enters any watercourse or sewer.
Postal address point data (PAF)	The Postcode Address File (PAF) is a database that contains all known 'Delivery Points' and postcodes in the United Kingdom.
Preissmann Slot	The Preissmann slot is a fictitious slot above the soffit of a pipe to allow the use of open channel flow methods to simulate pipe flow in surcharged conditions. As this introduces additional conduit area in the model, there needs to be a reduction in system storage to compensate for the slot.
PROPWET	Hydrological term for the catchment wetness index (the proportion of time soils are wet).
Rainfall Induced Infiltration	Non-continuous storm flows that enter a sewer due to inflow from land drainage as well as increased infiltration from subsurface flows through cracked pipes and leaking joints etc.
Return Period	The expected average time between the exceedance of a particular extreme threshold. Frequently used to express the frequency of occurrence of an event, for example, rainfall or flooding.
Revitalised Flood Hydrograph Models (ReFH/ReFH2)	Hydrological software to calculate rainfall-runoff and other parameters using the revitalised flood hydrograph method to generate flood peak flows and hydrographs from given rainfall events for both catchments and development sites. Published by Wallingford Hydro Solutions.
River flooding	Occurs when river flow exceeds the channel capacity due to rainfall, covering the adjacent floodplain with water.
RMED-1D	Hydrological term for median annual maximum 1-day rainfall (mm).
RMED-1H	Hydrological term for median annual maximum 1-hour rainfall (mm).
RMED-2D	Hydrological term for median annual maximum 2-day rainfall (mm).
RTC	Real Time Control.

Term	Definition
Runoff	Rain and surface water that does not percolate into the ground and flows over the surface to a sink, such as a drainage system inlet, watercourse or surface water body.
SAAR	Hydrological term for Standard Annual Average Rainfall for 1961 to 1990.
SAAR4170	Hydrological term for Standard Annual Average Rainfall for 1941 to 1970.
Scattergraph	A Scattergraph has points that show the relationship between two sets of data. In this case, the comparison of observed depth and flow or velocity and flow. Used in the assessment of the consistency of recorded flow survey data.
Scottish Canals	Scottish Canals is the public corporation of the Scottish Government responsible for managing the country's inland waterways. Formerly a division of British Waterways.
Screen	In a wastewater network, a device used to remove solid material, either from continuation flow at a WwTW or from spill pipes at storm overflows. In a watercourse, used to prevent debris from entering a culvert.
SEPA	Scottish Environment Protection Agency.
Separate Drainage System	A two-pipe drainage system with one pipe taking foul flows and a second pipe taking surface water (storm) flows.
Setting	Continuation flow at which an overflow starts to spill.
Sewer Quality Model	Model that can simulate the flows and the concentrations of various indicators of the pollutant load in sewage as it flows through the sewer system.
Sewerage Management Plan (SMP)	A business plan covering all aspects of sewerage performance related expenditure for a defined number of years, covering a complete drainage area and considering all stakeholders.
Sewerage Risk Manual (SRM)	A web-based process defining a risk based framework to capital maintenance and investment for wastewater network assets. Previously known as the Sewer Rehabilitation Manual (SRM).
Sewers for Adoption	Standard for new drainage systems in England and Wales so that they can be adopted by a WaSC.
Sewers for Scotland	Standard for new drainage systems in Scotland.

Term	Definition
Slow Response flows	Flow entering the sewerage system from pervious surfaces, either directly or as a result of seepage through the ground into the sewerage network. Typically, when water enters the sewer a few hours after the onset of rainfall and persists for a significant amount of time after the event.
Soil Moisture Deficit	The difference between a soil's current moisture content and its moisture content at saturation.
SPRHOST	Hydrological term for standard percentage runoff associated with each HOST soil class.
Stakeholder	An individual or group with an interest in, or having an influence over, the success of a proposed project or other course of action.
Strategic Flood Risk Assessment (SFRA)	Provides information on areas at risk from all sources of flooding. The SFRA should form the basis for flood risk management decisions and inputs into development allocation and control decisions.
Subcatchment	A sub-area of a larger catchment area whose runoff flows into a single drainage pipe or channel.
Subcritical flow	Water depth is greater than critical depth. In practice, this leads to tranquil flow and the depth is controlled at the downstream end of the section.
SuDS	Sustainable drainage systems: a sequence of management practices and control measures designed to mimic natural drainage processes by allowing rainfall to infiltrate, and by attenuating and conveying surface water runoff slowly compared to conventional drainage.
Supercritical flow	Water depth is less than critical depth. High velocity results. Depth is controlled at the upstream end of the section.
Surcharge	Condition in which the hydraulic gradient is higher than the soffit of a pipe. The flow is pressurised.
Surface flooding	Flooding from sewers, drains, small watercourses and ditches that occurs as a result of heavy rainfall and exceedance of the local drainage capacity. May occur from any component of the urban drainage system.
Surface Water Management Plans (SWMPs)	Vehicle through which urban flood risk will be assessed, managed and resolved in the future within England and Wales.
System Storage Compensation	An allowance included in a model for unaccounted for storage in a drainage system, generally from unmodelled local house connections or elements of the system that have been removed as part of a simplification process.

Term	Definition
Time Series Rainfall (TSR)	A series of rainfall data (over a number of years) used with sewer models to analyse the performance of a sewer system. Can be stochastic or historical data.
Topographical Surveys	Manual surveys carried out on surface topography where higher accuracy is required than can be obtained using other digital methods.
Trade Effluent Permit	A permit given to an industrial user for discharging flow to the public sewer or watercourse. Permits usually have a daily maximum flow and a maximum peak flow.
Trade Flows	Flow to sewer from industrial premises, with or without a permit.
TuFLOW	Hydraulic modelling software produced by BMT Group.
UKWIR	UK Water Industry Research. A collaborative research organisation funded by the Water & Sewerage Companies.
Unsatisfactory Intermittent Discharge (UID)	Intermittent discharge considered unsatisfactory by the Environmental Regulator requiring upgrade.
Urban Creep	Urban Creep is the progressive loss of permeable surfaces within urban areas creating increased runoff, generally due to small extensions, conservatories and paving over garden areas.
Urban Pollution Management (UPM)	Urban Pollution Management (UPM) is defined as the management of wastewater discharges from sewer and sewage treatment systems under wet weather conditions such that the requirements of the receiving water are met in a cost-effective way. The 3rd edition of the manual is available from the Foundation for Water Research (FWR).
URBCONC1990	Hydrological term for an index of the concentration of urban and suburban land cover in 1990 expressed as a fraction.
URBCONC2000	Hydrological term for an index of the concentration of urban and suburban land cover in 2000 expressed as a fraction.
URBEXT1990	Hydrological term for an index of urban and suburban land cover in 1990 as a fraction.
URBEXT2000	Hydrological term for an index of urban and suburban land cover in 2000 as a fraction.
URBLOC1990	Hydrological term for an index of the location of urban and suburban land cover in 1990 expressed as a fraction.
URBLOC2000	Hydrological term for an index of the location of urban and suburban land cover in 2000 expressed as a fraction.
Validation	Process of determining the degree to which a model or simulation is an accurate representation of the 'real world' from the perspective of its intended use.

Term	Definition
Verification	Process of comparing a model against independent data to determine its accuracy. Any changes to the model should be made only where this reflects the physical state of the sewer system and not solely to make the model fit the verification data.
WaPUG	Wastewater Planning Users Group - previous name for CIWEM Urban Drainage Group, with a long history of promoting best practice in the field of urban drainage.
Water and Sewerage Company (WaSC)	Ten regional water and sewerage companies (WaSCs) are licensed for England and Wales, set up under the Water Industry Act 1991. For the purposes of this Guide the term includes any organisation responsible for the management of the sewerage system, including Scottish Water and Northern Ireland Water.
Water UK	A collaborative organisation of the Water & Sewerage Companies.
Watercourse	A natural or artificial channel along which water flows.
Winter Rain Acceptance Potential (WRAP)	A classification system of soils based on their hydrological response, developed as part of the Flood Studies Report. There are five classes of soil.
WwTW	Wastewater Treatment Work (Sewage Works).

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References

Chartered Institution of Water and Environmental Management

REFERENCES

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2. **Competency Framework** Competency Framework, CIWEM UDG, 2015
3. **Rainfall Guide** Rainfall Modelling Guide, CIWEM UDG, 2016
4. **EDM** Event Duration Modelling Good Practice Guide, CIWEM UDG, 2016
5. **Quality Modelling** Guide to The Quality Modelling of Sewer Systems, CIWEM UDG, 2006
6. **CSO Screens** The Design of CSO Chambers to Incorporate Screens, CIWEM UDG, 2006
7. **River Modelling** River Modelling Guide, CIWEM UDG, 1998
8. **River Data** River Data Collection Guide, CIWEM UDG, 1998
9. **UPM** Urban Pollution Management Manual, FWR Version 3.1, 2018, web based
10. **SRM5** Sewerage Risk Management, WRc 2017, web based
11. **FEH** Flood Estimation Handbook, Centre for Ecology and Hydrology, 1999.
12. **FEHweb** FEH web service, Centre for Ecology and Hydrology, (*pay-as-you-go web based*)
13. **SWMP** Surface Water Management Plan Technical Guidance, Defra, 2010
14. **SuDS** The SUDS Manual, CIRIA Report C753, 2015
15. **Drainage Strategy** OFWAT/EA Drainage Strategy Framework, May 2013
16. **C635** Designing for Exceedance in Urban Drainage - Good Practice, CIRIA Report C635, 2006
17. **C738** Managing urban flooding from heavy rainfall – encouraging the uptake of designing for exceedance, CIRIA Report C738, 2014
18. **C786** Culvert, Screens and Outfall Manual, CIRIA Report C786, 2019
19. **SfA-7** Sewers for Adoption 7th Edition, WRc, 2012
20. **SfA-8** Sewers for Adoption 8th Edition, WRc, 2019
21. **Fluvial Guide** The Fluvial Design Guide, Environment Agency (web based).
22. **ReFH** The Revitalised Flood Hydrograph program developed by Wallingford Hydro Systems (Note: there are a number of versions of this program)
23. **Horton** An infiltration methodology ("*An approach towards a physical interpretation of infiltration capacity*", Proc, Soil Sci. Am.) devised by Robert E. Horton in 1933 and used in a variety of hydraulic modelling programs.
24. **WaPUG_UN** A series of "Users Notes" created by members of the CIWEM Urban Drainage Group (previously WaPUG) – these are available on the CIWEM UDG Publications website.
25. **Green-Ampt** An infiltration methodology ("*Modelling Infiltration During a Steady Rain*", Water Resources Research Vol. 9, No 2, April 1973) devised by R.G. Mein and C.L. Larsen in 1973 and used in a variety of hydraulics modelling programs.

26. **UKWIR** A rainfall runoff methodology devised by UKWIR (*"A Guide to the use of the UKWIR Equation"*) Report Ref 14/SW/01/7, UKWIR, 2014.

27. **Joint Prob** The Joint Probability of pairs of variables relevant to flood risk: Dependence mapping and best practice, Proceedings of 40th Defra Flood and Coastal Management Conference, July 2005.

28. **Hazard** Supplementary Note on Flood Hazard Ratings and Thresholds for Development Planning and Control Purpose – clarification of the Table 13.1 of FD2320/TR2 and Figure 3.2 of FD2321/TR1, Defra, 2008

29. **Benchmarking** This refers to the Environment Agency benchmarking tests for hydraulic modelling. https://www.gov.uk/government/publications/benchmarking-the-latest-generation-of-2d-hydraulic-flood-modelling-packages.

30. **DWMP** Framework for the development of Drainage and Wastewater Management Plans, Water UK, 2019

31. **Flood Estimation** The Environment Agency's Flood Estimation Guidelines. The version at the time of writing this Guide was Technical Guidance 197_08 dated June 2020.