INTEGRATED URBAN DRAINAGE MODELLING GUIDE 2009

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INTEGRATED URBAN DRAINAGE MODELLING GUIDE

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Amendments

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WaPUG would welcome any comments on this document which is published as a 'living draft'. All comments should be addressed to:

Technical Queries WaPUG Home Page: www.ciwem.org/groups/wapug

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Section A – An introduction to integrated urban drainage modelling

1 Introduction

1.1 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 which contribute to water quality and flooding problems (e.g. diffuse pollution, combined sewer overflows (CSOs), pumping stations (wastewater and storm water), sewage treatment works (STWs), receiving water impacts). However, in the context of this **WaPUG IUD modelling guide** our meaning is restricted to the narrower consideration of **surface flooding**, reflecting the concern of Government to develop a more holistic approach to managing flood risk in urban areas. Hence, this document provides best practice guidance on how to model the interaction of different components to improve understanding of urban flood risk. Surface flooding may originate from any component 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[1] (SWMP). In February 2008 the UK Government's Future Water strategy for England and Wales proposed that SWMPs will be a new vehicle through which urban flooding will be assessed and resolved in the future within England and Wales. The position is similar in Scotland, whereby it is envisaged that SWMPs will be a key element of the implementation of the Flood Risk Management (Scotland) Bill[2]. Formal SWMPs were developed through the Defra IUD pilot projects[3] in 2007/8 and promoted in Sir Michael Pitt's review of the July 2007 floods (Pitt, 2008).

The first SWMPs will be developed in England and Wales through 2009 following guidance published by Defra in January 2009 (Defra, 2009). The Defra guidance sets out a framework within which local partnerships (local government, water companies, the Environment Agency and others) first seek to understand surface water flood risk and then plan a practical, sustainable and cost effective series of measures to reduce it. IUD modelling will be central to the risk assessment (stage 2) and options (stage 3) components of the SWMP framework (see Figure 1-1).

Other applications for an IUD modelling approach include:

- Detailed analysis of the cause, effect and remedy of sewer flooding
- Improved understanding of the impact of watercourse interactions on sewer system performance and the operation of CSOs, pumping stations and other sewer assets
- Development of integrated flood risk plans for essential infrastructure and utility assets
- Strategic Flood Risk Assessments

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[1] http://www.defra.gov.uk/environ/fcd/policy/surfacewaterdrainage.htm

[2] http://www.scottish.parliament.uk/s3/bills/15-FloodRisk/index.htm

[3] http://www.defra.gov.uk/environ/fcd/policy/strategy/ha2.htm

- Detailed Flood Risk Assessments
- Development of emergency response plans
- Understanding pollution impacts on receiving waters (e.g. Urban Pollution Management (UPM) Studies)
- Climate change adaption and carbon reduction strategies (reduced energy use)

1.2 Types of urban drainage

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

- **Minor Drainage Systems** – these are the underground piped drainage systems which are typically sewers but could also be culverted watercourses or highway drains.
- **Major Drainage Systems** – 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.

Consideration should be given at an early stage as to which of these broad types are likely to be an influencing factor in the study purpose. The type of drainage system, and the nature of the dominant or key drainage system in the flooding mechanism under consideration, is one of the key factors influencing the choice of modelling approach and relative levels of detail.

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 CIRIA's C635 Designing for Exceedance in Urban Drainage Systems (Balmforth et al, 2006).

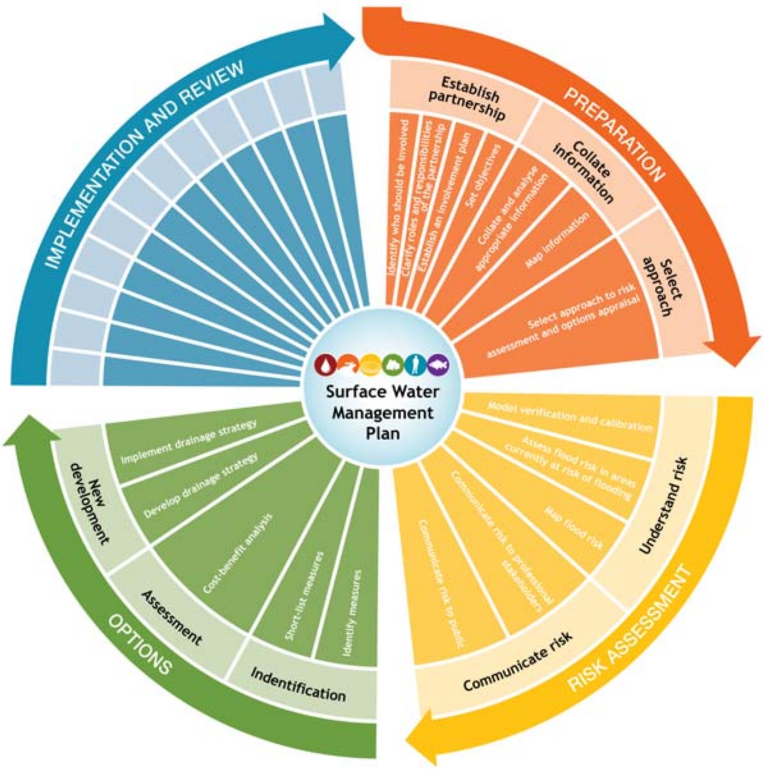

Figure 1-1 **– Surface Water Management Planning Framework (Defra, 2009)**

1.3 What is IUD modelling?

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 assist in developing 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, and river interactions. Less consideration will be given to tidal and groundwater interactions, though these will be commented on, as there may be a need to represent these in some cases.

IUD modelling must be able to replicate historical flood events. It should 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.

There are many software programs which are used to model single systems. Some programs can model more than one type of drainage system and there are procedures and protocols which allow separate models to work together to provide a simulation representing the integrated condition eg Open Modelling Interface (Open MI).

The following examples give an illustration of some of the more common interactions to be modelled.

Example 1 – Sewer discharge to river - This example is where a surface water sewer discharges into a river (ie a minor/major interaction). The sewer contributes flow to the river such that the flow in the river downstream of the interaction point (the sewer outfall) is greater than it was upstream. This increased flow results in a greater depth of flow and the water level in the river is raised which in turn backs up into the sewer raising water levels, possibly causing surface flooding.

Example 2 – Surface inlet to sewer - This example is where surface runoff (which includes fields outside of the urban area) creates flow in the highway. This flow continues to run overland until highway gullies are able to drain the water and discharge into the sewers (i.e. a major/minor interaction). If the sewers or gullies do not have sufficient capacity to accept all of these flows, the flows continue along the highway to the next road gully or further to lower lying areas, possibly causing flooding.

Example 3 – Sewer to surface to watercourse - This example is where hydraulic incapacity in the sewer system results in surface flooding from manholes and gullies. The flooding flows overland following the local topography (i.e. minor/major interaction). This flooding may pond on the ground or may continue to flow to the local receiving water (i.e. an interaction between different aspects of the major system).

Example 4 – Watercourse to culvert - This example is where an open watercourse has a greater capacity than a culverted section. If the flows in the open channel are large enough to take up the full capacity when the flows reach the culvert only part of the flow can be conveyed by the culvert (a major/minor interaction) with the remainder of the flow spilling onto the streets or adjacent open area and finding an overland route (i.e. interactions between the different aspects of the major system). This overland flow may drain back into a local sewer system or the original watercourse downstream (i.e. major/major interaction).

1.4 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.

Over time, different emphasis has been placed on developing certain aspects of the models from different hydraulic environments. As a result, models representing one type of hydraulic environment may much better represent a particular feature than another.

More recently, hydraulic modelling packages that allow greater integration of river, coastal, above ground and sewer environments have become readily available. This enables increasing levels of complexity to be modelled.

In the context of urban drainage systems there are two main modelling approaches:-

- 1D Modelling – this is used where there are sufficient lateral constraints (eg pipe walls, river banks etc) to keep the flows within a specific cross section and there is no variation in direction of flow. This form of modelling does not allow or represent the movement or variation of flow vertically or laterally;
- 2D Modelling – this is used when there can be variations in the direction of flow because of the absence of lateral constraints.

All sewer (minor system) modelling is 1D. Most river (major system) modelling is also 1D. Major system overland flow can either be 1D or 2D. In the case of river modelling it has traditionally been the case that the flood plains alongside a river have been modelled in 1D as a wider river channel cross-section and this is still standard using most commercially available river modelling software.

A comparatively recent development is the modelling of the flood plain flows in 2D and the main river channel in 1D. Commercial software is available that allows this representation to be undertaken in either a single modelling program/environment or a combination of programs. Where combinations of programs are used, data and outputs must be transferred between the programs. There is software available to transfer this data in parallel so that simulations can be undertaken together and the results passed between the different packages on a timestep by timestep basis. The Open Modelling Interface (OpenMI) has recently been developed to provide a standard protocol which facilitates the linking of simulation environmental models. This is discussed in more detail in Section 23.2.2.

The 2D modelling of the major system overland flows is now possible. This can be undertaken in isolation from the minor system modelling, or with the simultaneous modelling of minor system in 1D and overland flows in 2D.

A hierarchical approach to understanding the nature of the flooding problem is appropriate depending upon its scale. More simplified techniques are appropriate for larger areas, whilst greater detail can be used for smaller areas where greater accuracy is required.

1.5 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 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

1.6 Purpose and benefits of IUD modelling guide

IUD modelling is a relatively new field and is not as well developed as its constituent parts such as sewer modelling or river modelling in their own right. However, it is the logical progression of the more established constituent parts. IUD modelling also encompasses the relatively new technique of overland surface water modelling (major system) involving either one-dimensional (1D) or two-dimensional (2D) flow routing models.

The guide illustrates how different modelling approaches can be applied in different circumstances. Many software alternatives are available, but the guide considers generic approaches rather than specific products. The focus is on modelling within a context that is consistent with broader methodologies for SWMPs, Flood Risk Assessments (FRAs) and Drainage Area Studies or Plans (DAS / DAP) etc.

There are significant differences between software packages and in many cases the methods which can be employed 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.

The guide will evolve over time as our knowledge improves and technology advances. New approaches and techniques (often showcased at WaPUG meetings) will be included in regular updates, reflecting and supporting the WaPUG community of modellers. This will also include up to date examples of best practice. As a result, this guide is intended to be a 'living draft', in line with the current SWMP guidance, with regular updates to reflect best practice in IUD modelling approaches.

The primary benefit of the guide will be to improve the consistency and quality of modelling work throughout the UK, to both client and supplier partners. It will also assist with the technical development of individuals working in this specialist area. This guide is aimed at all IUD practitioners, across a range of expertise and experience. It is, however, not a substitute for this expertise and the appropriate level of training.

1.7 Structure of the IUD modelling guide

The presumption in preparing this guide is that the constituent models already exist and the IUD element is primarily the interlinking of these existing models. The data requirements are therefore limited only to the interlinking and enhancement of the component models, not the original model building. If a constituent model does not already exist the following guidance documents should be referred to.

- Minor System Models (sewers and other piped network models) – The WaPUG Code of Practice (2002) provides an industry accepted framework detailing the construction and verification of hydraulic sewer models. The WaPUG website (www.ciwem.org/groups/wapug/) also provides numerous user guides and conference technical articles to assist in the construction of a sewer model.
- Major System In-Channel Models (river models) – There is no definitive industry guidance for the construction of river models though the Environment Agency "Using Computer River Modelling as Part of a Flood Risk Assessment – Best Practice Guidance" provides a useful introduction and references for further reading. In

addition the WaPUG River Modelling Guide (1998) and the WaPUG River Data Collection Guide (1998) are useful reference texts. The WaPUG website (www.ciwem.org/groups/wapug/) provides details of some of these.

- Major System Overland Flow Models – There is no definitive industry guidance detailing the construction of overland flow models. To gain an understanding of the principles and key issues relating to overland and exceedance flows, CIRIA's C635 Designing for Exceedance in Urban Drainage Systems (Balmforth et al, 2006) is essential reading. There are an increasing number of case studies and good practice papers being presented at conferences. The WaPUG website (www.ciwem.org/groups/wapug/) provides details of some of these, for example, Allitt et al (2008), Balmforth et al (2008), Bamford et al (2008), Crowder et al (2006).

Such new model builds must consider how interaction takes place. Information on the requirements for data collection and verification of the interaction is discussed in this guide. Other guidance is provided with books, guides and user manuals specific to each software application being utilised. A reference and further reading list is presented in Appendix A.

This WaPUG IUD modelling guide is split into 5 Sections:

Section A explains the principles of Integrated Urban Drainage and sets it in context. This is followed by guidance on planning an IUD Study.

Section B of the guide describes the data required specifically for IUD modelling, its sources and methods of collection.

Section C details the generic modelling approaches available for the different system types, and how interactions between these may be represented.

Section D of the guide provides information on how IUD models can be calibrated and validated against observed data.

Section E of the guide highlights key reporting considerations.

2 Planning an IUD Modelling Study

The key to a successful IUD study 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.

This section of the guidance has been written to enable an IUD modelling study to be planned, noting that it may form part of a wider project or framework such as for a SWMP. This is likely to include involvement of a number of partners and stakeholders and, due to its integrated nature, a project steering group.

2.1 Project setup and define objectives

The objectives and scope of the IUD study and specifically the modelling work need to be explicitly stated at the beginning to provide a clear focus. The key drivers, required performance standards, levels of service and the scale of the modelling study must be defined. For example, a modelling study designed to assess a local flooding problem linked to sewer and watercourse interactions will be very different to a large scale strategic modelling study.

It is important at this early stage to define the problems within the catchment and understand the flooding mechanism and potential key interactions between drainage systems (i.e. minor or major drainage systems). A large scale plan showing the known problems in the area and the key drainage systems should be produced to aid the planning process. This initial work will enable a programme and resource plan to be developed.

2.2 Identify partners and stakeholders

This phase focuses on drawing together the appropriate partners and stakeholders necessary to define the objectives and implement study.

A **partner** is a person or an organisation with responsibility for some of the decisions or actions that need to be taken. Partners will share responsibility for decisions and actions and it is critical to engage them at the start of the process.

A **stakeholder** is anyone affected by or having a valid interest in the problem or solution. They may be individuals or organisations and include the general public and community bodies.

In order to ensure the study considers all the mechanisms, interactions and necessary integration it is vital to engage with appropriate partners at the outset identifying roles, responsibilities and objectives. Further guidance is available in the first living draft of the SWMP (Defra 2009), with examples of IUD scoping studies and projects on the DEFRA website, and summarised by Gill (2008).

2.2.1 The project steering group

This should involve key stakeholders and will form the basis of the decision making process. Technical reports and modelling outputs may be considered by the group to enable actions to be agreed and implemented.

The project steering group 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.

2.2.2 The modelling team

IUD hydraulic modelling is a complex subject and it is essential that the appropriate skills and knowledge are held within the team. An indication of the experience and training necessary within a team is given in the WaPUG Code of Practice (2002) and throughout the WaPUG Competency Guide for Wastewater Network Planners. This 2002 Code of Practice is focused on sewer systems whereas IUD modelling encompasses all sources and mechanisms of flooding.

It is important in IUD modelling that the lead modeller, who may be expert in one field, has a high level of appreciation of modelling in the other fields 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.

2.3 Collate appropriate existing information

Before undertaking any modelling it is vital to collate existing data. This is to gain the best possible understanding of the existing drainage problems (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 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 Part B.

2.4 Review existing models

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 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 under consideration. 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.

This procedure should start with a review of the documentation and supporting data of the previous model to ensure that any limitations are fully understood. The nature of the work to provide the necessary level of accuracy for the new application should then be established in detail.

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 for 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.

2.5 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 the initial data collection phase (described in Section B) and initial model runs following a model review should enable an early indication of:

- flood mechanisms and interactions between different urban drainage systems;
- scale of the flooding (e.g. localised, town-wide or river catchment wide);
- frequency of the flooding;
- consequence of the flooding (e.g. degree of nuisance, cost).

Initial modelling can be used to help identify and confirm flooding mechanisms so that a detailed IUD modelling plan can be developed. This involves the use of available modelling tools or simplified techniques to rule in or rule out possible flooding causes, either in isolation or through interaction. The level of confidence that should be placed in any outputs from initial modelling investigations should be informed by the outcome of the existing model reviews.

To enable the flooding mechanism and linkages between the systems to be understood and identified, the following questions should be considered:

- From which drainage systems does the flooding originate (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?
- Is the flooding mechanism a localised issue or related to hydraulic influences from elsewhere in the system?
- What range of input or boundary conditions for modelling (eg tide levels) influences the flooding problem?

2.6 Determine 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 programme
- Agree model audit process
- Identify outputs and deliverables

2.6.1 Confirm 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 which are at greatest risk of flooding. Ultimately the modelling approach used should be sufficient to be able 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 which 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. The components of the urban drainage systems which may need to be modelled are illustrated in Figure 2-1, and these have already been presented as minor and major systems. 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. Different drainage systems are represented by contributing catchments of differing sizes. Models should be of sufficient extent or boundary conditions applied to ensure all necessary contributions are included.

The process required to select the modelling tools depends very much on the scale and complexity of the problem under investigation. As with all modelling studies, the modelling approach undertaken must be of the necessary technical standard to represent that problem to a level of accuracy which is acceptable to all individual parties and their own risk profiles. **The approach selected must be fit for purpose** (i.e. sufficiently robust to support decision making).

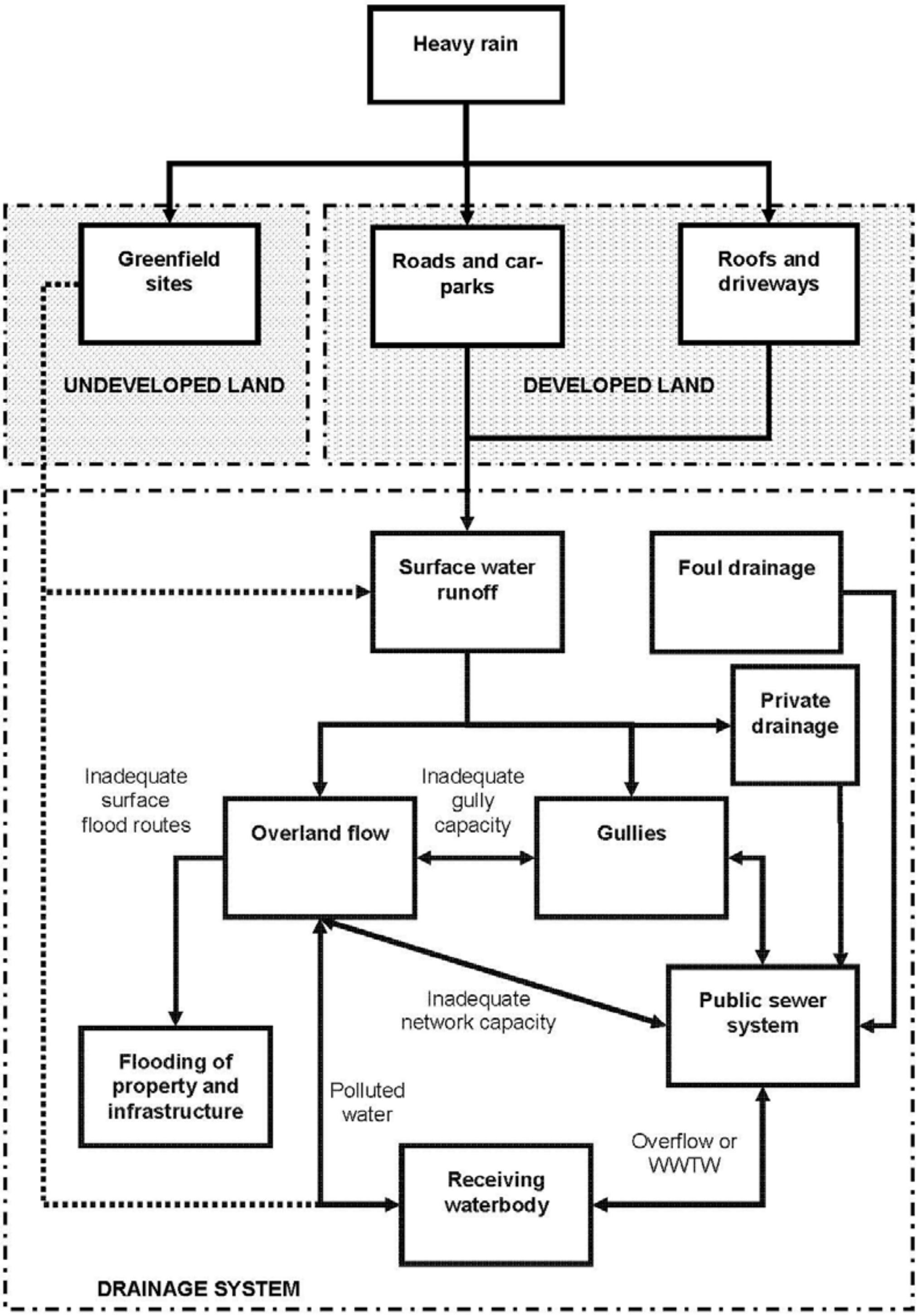

Figure 2-1 – Surface water drainage through the minor and major system (adapted from Future Water, Defra 2008)

An initial staged process is suggested for selecting the modelling approach to use in an IUD study. This approach is iterative, and relies on a continuous assessment of available models and data, model fitness for purpose and further data collection activities to enhance model confidence. This is summarised in Figure 2-2.

As the modelling increases in complexity (i.e. combining different software packages together or trying to represent all of the system in one package) the cost of the modelling will increase.

The modelling approach must also be appropriate to ensure that the study is progressed and solutions designed within an acceptable timescale. There is always a balance to be made between the complexity and accuracy of the modelling process adopted and the time and cost incurred, and this depends on the perception of risk and available budgets of the individual stakeholders involved in the IUD study.

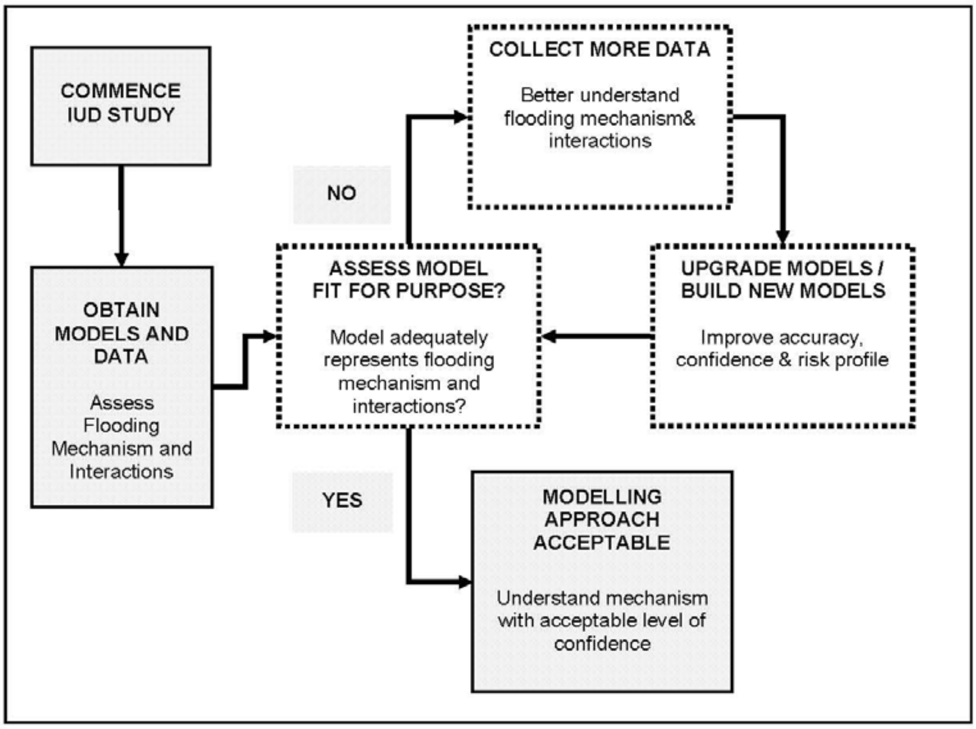

Figure 2-2 – Model Selection Process

2.6.2 Determine data requirements

Constructing IUD models representing the systems under consideration and the various linkages between them is likely to require additional data collection. If an existing model is to be used as a base, then additional data collection activities may be quite localised. Where new model builds are required for a particular drainage system, then the data requirements may be more extensive. Further data collection is likely to focus on the interaction points, including data for further validation or verification if necessary.

Section B discusses data collection activities. This should be referred to for more information relating to the type of data that may be required during an IUD modelling study. The data required to continue with the modelling study may originate from a number of sources, and may require further survey or site works to be undertaken. This may therefore involve a range of further or different stakeholders.

2.6.3 Determine modelling programme

A detailed IUD modelling programme should be developed, covering the key areas of:

- Model assessment
- Data collection
- Verification and calibration
- Analysis (including sensitivity)
- Reporting
- Model build enhancement and extension
- Model interaction
- Simulation
- Checks and reviews

IUD modelling studies are generally more complex than single system modelling applications and this should be considered when developing a programme. Data collection activities can create programme delays, and adequate time should be allowed for this.

The time required to construct the IUD linkage between models or to adapt a single model will vary and depends on a number of factors, especially the model extent, detail and degree of verification, calibration or validation required. Basic and very small, unverified models could be constructed in a matter of days, yet detailed large scale validated models can take a number of months or in some cases, years.

The initial project scope should outline a basic programme of the IUD project and this will initially drive the data collection phase in terms of the time allowed. It is possible that during the initial data gathering phase, knowledge gained can be fed back so as to amend the programme.

2.6.4 Agree model audit process

During the planning phase an appropriate modelling audit trail (especially including data management) and quality system process should be agreed and implemented. This should include a clear scope and definition of the audit linked back to the original objectives. Due to the potentially complex nature of combining models and managing interactions it is imperative that a detailed audit of all modelling and data collection activities is maintained.

Increasingly, the concept of ‘metadata’ is being used in data collection and model build activities, where a detailed log of when individual data was collected, its source and confidence score are kept. This approach is recommended when undertaking an IUD modelling study.

2.6.5 Identify outputs

The modelling strategy should be formally written as a model scope statement which may include:

- Confirming how the models will be used, the modelling objectives and expected outputs
- Confirming the drainage system types that require modelling, and the different system pathways (i.e. minor / major in-channel / major overland)
- Identifying the required modelling standards (confidence) to be achieved
- Defining the quality of existing models, their fitness for purpose and potential improvements needed
- Defining any survey activities required to upgrade the models or better represent interactions
- Confirming how the models are to be interlinked
- Outlining modelling team setup and key roles and responsibilities
- Providing a modelling programme
- Confirming modelling and project outputs and any reporting requirements to steering group

Section B - Data Collection

3 Introduction to data collection

This guide outlines the approach to collecting data specific to an IUD study. When undertaking an IUD study the data collection should be appropriate and relevant. Establishing flooding mechanisms, the causes of flooding and the interaction between the drainage systems is paramount in delivering a successful study. Critically, this should start with the assessment of data previously collected as part of earlier studies.

Data collection should be driven by a clearly defined scope (see Section 2.6). It is often an iterative procedure based on learning from data collected in previous phases and its application to develop greater understanding of the problem.

3.1 Planning of data collection

There are two phases to planning the data collection, as summarised in Figure 3-1:

1. Collate and assess existing data and models from previous studies; and
2. Planning data collection to enable an IUD model to be constructed

Collecting and reviewing the existing data for extent, quality and relevance will allow data gaps to be identified (see Section 2.4). There is likely to be a substantial amount of existing data available, which may be useful in providing greater detail to existing models beyond their original purpose and relating to the interactions between drainage systems. This, for example, could be where flooding has been reported; where known overland flood routes exist. Where greater detail is required existing guidance is available to support this as described in Section 1.7. Compiling a priority list of data is advised as a first step, particularly where there are budgetary constraints.

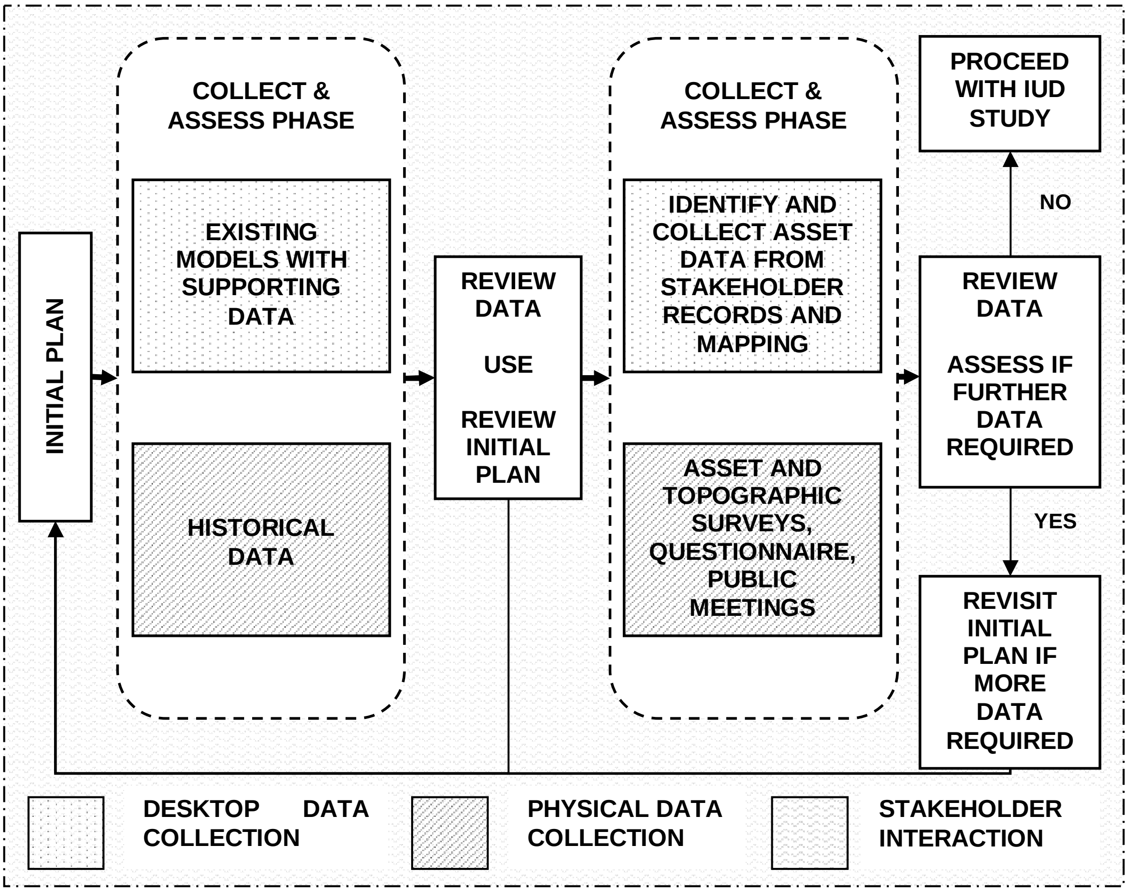

Figure 3-1 - Data Collection Process

4 Desktop data collection

4.1 Existing models and their supporting data

Hydraulic models and supporting data are available from a number of sources. It is likely that the model owners would be the participating stakeholders. The models may have been built for a variety of purposes and should be fully reviewed, assessing their fitness for purpose to use as part of the IUD study.

Water Companies generally have sewer network models available for many foul and combined catchments, though to a lesser extent for the public surface water system. These models may have been built for a variety of purposes (e.g. drainage area planning, CSOs, or flooding investigations).

Environmental Regulators often also have models for main rivers and significant watercourses. Smaller watercourses are frequently not represented. Often these models have been constructed for larger strategic assessments, rather than localised flooding investigations.

Some Local Authorities or Internal Drainage Boards may have models for smaller watercourses. It is rare that the Highways Authority have models of the highway drainage.

Groundwater and coastal models may also be available for some areas. These are usually available from the Environmental Regulator or through Local Authorities.

4.2 Historical data collection and review

Historical recorded data will be held by stakeholders responsible for various different sources of flooding and drainage management. This may be in terms of flow, level, flooding extent and location. This data will assist in understanding the nature of the problem holistically.

4.2.1 <u>Historical base data</u>

Historical data may not be freely and readily available. Some historical data may have already been collected as part of previous investigations and should be reviewed for their suitability for re-use as part of the IUD study. Historical base data is likely to be obtained from the following bodies:

- Environmental Regulators
- Local Authorities
- Local residents
- Internal Drainage Boards.
- Water and Sewerage Company
- British Waterways

Other useful sources include:

- Met. Office
- British Geological Survey (BGS) National Groundwater Level Archive
- Topographic Survey Companies
- Local and national press, including Libraries
- Ordnance Survey
- Centre for Ecology and Hydrology (CEH) - National River Flow Archive
- Internet Ariel Photography and Mapping
- DEFRA and other government and non-government departments

4.2.2 <u>Historical flooding data</u>

4.2.2.1 Environmental Regulators

The Environmental Regulator may have historical flood event data (including flood level, location and time/date stamp). Recently, some Environmental Regulators have produced Post Flood Survey Reports for significant events, containing measured levels, anecdotal evidence, photographs and videos. They may also contain rainfall analysis of the storm event, particularly where the flooding occurred in small, ungauged, fluvial catchments. For England and Wales, indicative flood mapping is available on the EA website, with further historical information being held in local offices. Similar information is available for Scotland through SEPA and Northern Ireland through the NIEA.

River data, if not already available from previous studies (including flow and stage readings, limiting structures, screens, historic flood levels) may also be collected. This data can be obtained via the Environmental Regulator and CEH and is available in an electronic format.

Ground water and geological data can also be obtained from the Environmental Regulator and be stored electronically as a GIS layer. It may be useful to store the ground water level data in date order and be able to cross reference it with known flooding events.

4.2.2.2 Water and Sewerage Companies

Water and Sewerage Companies (WaSCs) maintain historical records of confirmed and reported sewer flooding. The collection of this data is likely to be more complete in recent years, due to the reporting requirements placed on WASCs, and may include the mechanism of flooding. This information is not in the public domain and therefore how this information can be used and shared must be agreed with the WASC. However, it does provide an accurate record of reported sewer related flooding. The WASC may also hold historical rainfall records and data on other sewerage related incidents which may assist in understanding the reasons for flooding.

4.2.2.3 Highways Authorities

Highways Authorities may have registers of flooding incidents occurring with regard to their drainage systems. They may provide information on the location, nature (i.e. - blocked gully) and date of the incident.

4.2.2.4 Local Authorities

Local Authorities generally maintain records of known or reported flooding locations (this may include the Highway Authority).

Drainage departments within a Local Authority are likely to have comprehensive historical records of flooding. This information is likely to have been compiled by operatives who have a good local knowledge of the flooding extents and various mechanisms. In such cases, it may be possible to interview the operatives as part of the data collection process.

Some Local Authorities may have archived records relating to flood events and may be available at the library or county record office. Information on private sewers may be obtained from Local Authority Building Control Records. However, these may be restricted, potentially incomplete and it will probably be a labour intensive exercise if many properties are involved.

4.2.2.5 Local knowledge

There are many other possible sources of information. Residents or resident groups (formed in response to flooding) can often be a source of first hand accounts and photographic evidence. This is discussed in greater detail in Section 5.2. In addition, wildlife groups biodiversity groups, and local parish councillors may often hold valuable information.

4.2.2.6 Emergency Services

For significant flooding events, it may be possible to obtain information from the Police and Fire & Rescue services. Such records can help to validate and complete other sources of this information.

4.2.3 Other sources

CEH can be a useful source of historical hydrological records.

The Met office maintains a record of rainfall and other climatic variables. More recently radar rainfall is now available at increasingly greater detail (Lang and McLachlan, 2008; Neale, 2008).

Ground water information is available from the BGS, including historical groundwater levels and where key underlying geology could render an area more susceptible to flood risk.

Tidal records and tables (UK Hydrographic Office, NP 201-00 vol1) are available for most coastal locations, with local harbour masters often a good source of detailed historical local knowledge and data. Tidal tables generally relate to average meteorological conditions and under extreme conditions (wind or barometric pressure) the differences may be considerable.

Historical mapping, available from the Ordnance Survey, may provide evidence of how the catchment has developed over time to help understand the cause of the flooding.

4.3 Asset data

Information on sewer assets is available from the local WASC and may be available in hard copy or digital format. WaSCs have a duty to provide records of adopted public sewer assets. These records may not be complete.

The Environmental Regulator holds information on their own assets (i.e. – gauging stations weirs, etc). This information may be made available on request.

Records of other important drainage assets should be held by a number of other stakeholders including, but not limited to; Highways Agency, Network Rail, Highways Authority, British Waterways, Internal Drainage Boards, and Local Authorities.

5 Physical data collection

5.1 Surveys

The update, construction or joining of models may require further survey work. The main types of surveys and current best practice guidance is listed below:

- Flow Surveys – WRc (1987) Guide to short term flow surveys of sewer systems, and WRc (1993) Model Contract Document for short term sewer flow surveys (2nd Edition)
- Manhole surveys – WRc (1993), Model Contract Document for Manhole Location Surveys and the Production of Record Maps
- CCTV surveys WRc (2003) Manual of Sewer Condition Classification - 4th Edition, and WRc (2005) Model Contract Document for Sewer Condition Inspection 2nd Edition
- River gauging and cross section surveys – WaPUG (1998) River Data Collection Guide, and Environment Agency "Using Computer River Modelling as Part of a Flood Risk Assessment – Best Practice Guidance".
- Topographic surveys – based on Lidar data, GPS or manual surveys

5.2 Public engagement

It is also important to recognise that the local residents may also have a lot of knowledge about the problems experienced in an area. It is often useful to collect these first hand eyewitness reports by using questionnaires and / or through face to face meetings.

As part of an IUD Study local expertise should be sought to gain a feel for the catchment, it is strongly recommended that if an offer of a 'guided tour' of the catchment is available that it is taken!

In all cases the collection of data and requests for data need to be undertaken within the laws set out in the Data Protection Act (1998), or similar laws if used outside of the UK.

5.2.1 <u>Questionnaires</u>

Questionnaires are a good way to obtain first hand information from the public although caution should be exercised. Stakeholders should be asked if any questionnaires have been completed previously. Some stakeholders may have reservations about questionnaires due to politically sensitive issues. This is an important consideration and all stakeholders should be engaged to understand the benefits and participate in developing its format. Appendix B contains an example questionnaire. Information gained should be summarised and categorised by location and event.

5.2.2 Public meetings

Public meetings are a useful source of first hand experience information when people who are affected are in attendance. These can be sensitive and highly charged events and should be handled sensitively and with appropriate tact. Public meetings need to be very carefully planned, timed and structured, and should be considered during project planning. Frequently, attendees at public meetings expect answers and solutions, therefore managing expectations are critical. Public meetings held at the data gathering stage may need to be approached in a totally different manner to public meetings later in the life of a project.

5.3 Videos and photographs

It is common that photographs and videos of flooding events are taken and are often available from the internet or directly from residents. With such information any ownership or copyright issues must be understood. It is advisable to seek agreement from the owner of the information in writing.

5.4 Media data

Flooding is often reported in the local or national press. Photographs, videos and reports from the media can be useful information especially when piecing together a historical timeline (including newspaper articles usually available in libraries). It is important to record the use of any data ensuring it is referenced and appropriate permissions gained.

5.5 On-site information

The location of the IUD flooding problem should be visited as well as potential points of interaction by the investigating team. During site visits it may be appropriate to make contact with the residents. Anecdotal evidence should be treated with caution, particularly if gathered some years after the event.

6 Data management

Data management is critical for all IUD projects and should follow internal procedures (often in line with ISO9001 or equivalent system). It is especially important for IUD projects as the sources of the data are likely to be more diverse than in a single component modelling study.

It can be beneficial to translate data into a GIS system and geo-referenced so that all information can be readily visualised. A record of the information gathered should be maintained including where it came from, any limitations or requests that may come with the data and any return policy that relates to the data.

As a basic guide to managing data the following are useful ways of recording data and some of the key aspects that may require to be recorded. A digital inputs register, which may be held within the GIS system, can be relatively basic and a suggested structure is shown in Table 6-1.

Table 6-1 – Example of a basic register to record input data

Superseded	Type of Data and summary	Owner of data	Date Received	Checked and Reviewed	Signed (input data received)	Location A	Location B
N	Newspaper report of local flooding in June 1987	Mr Smith (Local Resident)	01/07/07	Yes	TBB	Hard copy in project folder	Scanned copy on server. Location F:\Project\data\Local flooding June 1987.pdf
N	EA River Model	Mr Sheridan (EA Midlands Region)	02/08/07	Yes	JRM	Digital on main server	Backup CD in project folder
N	LA historical flooding	Mr Hirst (LA)	03/09/07	Yes	CJD	Hard Copy in project folder	Scanned copy o server. F:\Project\data\LA flooding

7 Mapping

It is now common to store data in a GIS format to keep track of the data and to visualise its location. The type and level of detail of mapping and topographical data will depend upon the objectives of the IUD study. For example, small localised areas may utilise a topographic survey whereas larger areas may require a Digital Terrain Model (DTM) or Digital Elevation Model (DEM) which depending on the size of the area may have different grid resolutions.

Master Map is the main mapping format available which can provide additional information on each property, including address, land use, owner and value. The topography of the site can be determined from a combination of sources namely:

- Light Detecting and Ranging (LiDAR); and
- Topographic surveys

These methods enables a DEM (contains features such as buildings) and a DTM (has information filtered out and is known as a bare earth model) to be developed. DTM and DEMs can be used to support various levels of urban runoff and flood risk mapping.

LiDAR data can be available from Environmental Regulators, WaSCs, Local Authorities and specialist companies. Available LiDAR coverage extends across much of the country, though the more detailed data is often concentrated around urban areas. LiDAR data can be provided by flying the area or from ground scanning systems, which can be of greater resolution but the quality of the data may be affected by obstacles such as parked cars. Hale (2003), Allitt (2004) and Adams and Allitt (2006) provide useful overviews of the sources of this data and its model applications.

In most of the above cases an associated level or GPS 'ground truth' survey is required to fix this data to known areas on the ground. If the area of the study is small it may be more appropriate to survey or map it.

A topographic survey can pick up all features and their attributes. The locations and shapes of all buildings can be obtained, but not their height. In contrast, line, location and heights of features such as kerbs, road centre lines and hedges will be important when considering overland flow routes. Topographic surveys provide the most accurate but labour intensive method of mapping information. Topographic surveys are more likely to be used as auditing tool or for gap filling rather than the primary data collection method.

With all mapping data the user must ensure the correct licences are gained and also know when the maps were created.

8 Maintenance & operations programmes

Understanding maintenance programmes and operational performance of assets may help to determine their impact on flooding. This may include assets such as pumping stations and sluices indicating the usual mode of operation and their performance during a flood event.

WaSCs' planned preventative maintenance schedules and catchment level investigations (particularly DAP reports) may add value to the investigation.

Maintenance programmes such as the EA's, for example, of watercourse channels and culverts and Local Authority gully cleaning should indicate when these operations were performed in respect to the flood event.

9 Data quality hierarchy

The accuracy of data collected impacts significantly on the model confidence and the fitness for purpose. The WaPUG Code of Practice (2002) suggests four levels of accuracy for collecting data relating to sewer systems. It is suggested that a similar tiered process be applied to data for the other modelling environments and drainage systems. This tiered process to data collection and thus relationship to model confidence is indicated below:

- Type A data should be obtained:
    - In the location of all flooding under investigation, for all elements of the hydraulic environments;
    - In the areas of key interactions between hydraulic environments and thus model linkages;
    - For detailed overland flow modelling studies due to the importance of local topography and;
    - For all key ancillaries that could affect the hydraulic performance.
- Data Types B-C can be used closer to key areas, but users must understand the uncertainty and risks associated with this and;
- Type D data should be avoided in the key flooding or interaction areas and its frequency of use should be higher in areas of less significance.

10 Input formats

Due to the large number of data sources, there is potentially a vast array of data that can be used during the course of an IUD study, available in a number of formats. This in part will also be dependent on the different types of software used.

The current modelling software packages that would be used to undertake an IUD study are able to import a wide variety of file formats making the input of the various datasets relatively straightforward.

11 Confidentiality

IUD projects will involve several different organisations, private and public bodies and each will have constraints with regard to the use and availability of data. Each of the stakeholders may want to set out an agreement within the stakeholder group with regard to the data and its dissemination. This should establish what data will be released and its use by each stakeholder setting out limitations and or confidentiality. This is particularly important with a mixture of private and public stakeholders.

When using third party data (for example Mapping Data) consideration must be given to the terms of the licence agreements, in particular with the data being made available to multiple stakeholders. The relevant third party should be approached and an agreement should be in place before proceeding with the work.

Section C – Integrated Modelling Methods

12 Introduction to integrated modelling methods

The key focus of this guide is to advise how to integrate different models of the minor and major drainage systems. This is required as a result of different modelling components being developed in isolation and not holistically (Crowder et al, 2006). This guide does not advise how to build and verify individual component models (see Section 1.7).

This section of the guide is split into two distinct parts. The first part is an overview of the individual component models that are available with an outline of benefits and limitations. The second part addresses the concept of linking different component models and key influencing factors.

13 Model types and selection

Hydraulic modelling can be classified into the following model types, which interact:

- **Input Models** – These typically include rainfall and hydrological models (generally built into software programmes) that generate flow for the minor and major system hydraulic models.
- **Minor System Models** – These would represent the piped and culverted networks, or small open channels. Sewer models are generally the most advanced at representing these systems, though many river modelling programs have the facility to represent small sections of piped network.
- **Major System Models** – These can be split into two broad types:
    - **Overland Models** - A number of specific overland flow packages are available, that replicate flow paths in the urban area. Recently, sewer and river modelling packages have also developed this capability, allowing the interactions between different system types within the same platform.
    - **In-Channel Models** – These represent river and minor watercourse systems, and also the large scale movement of floodwaters across floodplains. Coastal and groundwater models have also been included in this category, though less attention will be paid to these.

14 Input models

Rainfall and hydrological models are generally the most common types of input to the physical urban drainage models, and these are discussed in detail below. In addition, groundwater sources can input flow. The modelling of groundwater flows is discussed in its own context in Section 19, due to the other interactions possible.

14.1 Rainfall data

Rainfall data can be grouped into three general types and used for a range of applications:

- ➢ verification of the individual models against observed data,
- ➢ validation of the integrated or individual component model against flooding events, or
- ➢ design analysis for performance testing, optioneering and design.

These rainfall types generally include:

- Design rainfall data – This involves the generation of a synthetic, symmetrical profile of various return periods and durations, based on depth, intensity and duration statistics from historical datasets across the UK (e.g. FSR, FEH).
- Time series rainfall data (TSR) – These are long series of historical or synthetic rainfall data that is more representative of real storms with a range of event

characteristics. Whilst traditionally used for annual CSO performance analysis, long series containing extreme events can be used for flooding investigations. They also allow better representation of successive storms and antecedent conditions. TSR may be based on local data, or extrapolated from a donor or adjacent site.

- Specific historical event data – This includes detailed measurements of rainfall for a specific event or series of events in the catchment. This data is generally used to verify individual models or validate the performance of an integrated model to a known flood event. This data may be from raingauges and / or radar data.

The choice of input data is important, and the following issues are critical for IUD applications:

- Spatial variation across large catchments
- Variations in critical duration for different system types and model scales
- Importance of antecedent conditions
- Potential climate change adjustments
- Joint probabilities with other input boundary conditions

14.2 Hydrological models

Hydrological modelling estimates runoff that could enter a system, either from empirical rainfall and runoff models or statistical methods using measured data from the catchment or similar donor catchments. All the approaches have been derived directly or indirectly from gauge data.

The approach to representing hydrology and runoff is often different between minor and major systems. Almost all minor system models allow rainfall to be applied to inbuilt hydrology volume and routing models, which converts the rainfall into a series of inflows. These hydrological models often determine the percentage runoff (e.g. Wallingford Procedure) and are generally based on flow response data collected in urban catchments. This is also often applicable for smaller urban watercourses, where the peak flow response is dictated by the minor drainage system inputs and therefore modelled as part of the minor system.

Many major system models utilise statistical techniques to convert rainfall to runoff. Additional models then route the volume to the major drainage system (e.g. FEH). This better represents rural flow responses. An un-urbanised watercourse or one with upstream rural subcatchments should be represented in this way.

Recently, direct 2D runoff modelling approaches have been developed. Whilst this technology is in its infancy, it has the potential to offer improvements to the representation of runoff volume and routing, and also help represent more localised inlet incapacity (e.g. Bailey and Margetts, 2008).

Difficulties occur when assessing flows in urban watercourses using statistical methods. If a natural watercourse has been heavily modified and piped, its natural catchment boundary may have been significantly amended (Figure 14-1). Scenario A shows natural drainage catchments with defined boundaries. Flow is passed from the upstream to the downstream end of the catchment. In scenario B, an urbanised watercourse has been introduced which conveys flows across catchments and amends the natural drainage characteristics. It is advisable that detailed topographical data is obtained to understand the full impact on the catchment characteristics and boundaries, and if they need to be altered.

If two models are integrated care must be taken with the contributing area to ensure that runoff from the same area is not double counted. For example, the flow inputs in a semi-urban area may have been allowed for in two component models representing the sewers and a watercourse respectively.

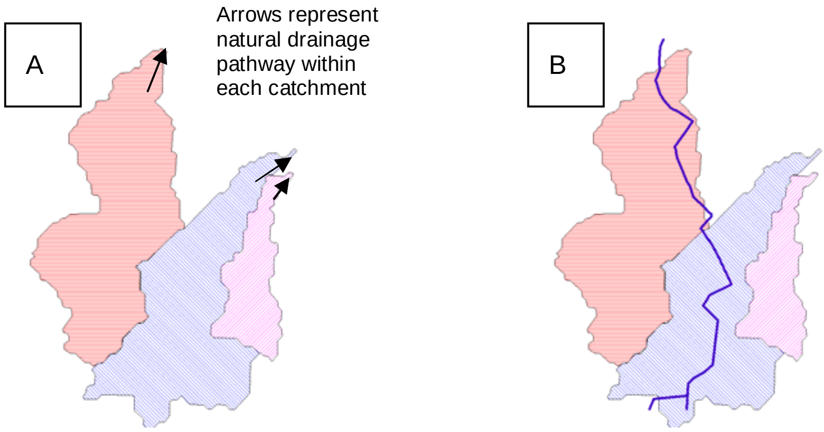

Figure 14-1: Natural catchment boundaries (A) being significantly changed (B) as a result of an urbanised watercourse (blue line) crossing catchment boundaries

15 Minor system models

The expertise in minor system drainage modelling is generally associated with the approaches developed through sewer modelling.

Dynamic 1D hydraulic sewer models can be considered industry standard within the UK for most minor drainage system applications. They may include basic representations based on observed data inputs or simple models. The expertise, software and data sets are readily available to construct the models. Detailed procedures exist (WaPUG, 2002) outlining the construction and verification of these models.

15.1 Minor system model IUD detail

The majority of sewer models readily available within the UK are Type II Drainage Area Planning Models (WaPUG, 2002), and some with localised additional detail (Type III) in areas where the model may have previously been used for analysis and optioneering.

At an early stage, the level of detail required for representing the minor drainage system in an IUD study should be identified. There may be justification to upgrade the existing model with additional detail in particular where interactions may occur (overland flow routes, or outfalls to major drainage systems). The model purpose and complexity of interactions should be considered in the modelling strategy, as demonstrated in the following examples:

Example 1 – Minor system required to input urban flows into a watercourse to assess flooding downstream in the watercourse. In this case, additional detail would be required to ensure the interactions (outfalls to the watercourse) are represented, though less detail may be necessary for most of the minor system.

Example 2 – As example 1, but backing up from the watercourse occurs through the outfall and causes some flooding from the minor drainage system. In this case, some further detail may be necessary to represent flooding points from the minor system.

Example 3 – As example 2, but overland flows due to flooding from the minor system also occur causing larger scale flooding. In this case, much more additional detail will be required to represent the linkage points, e.g. gullies and flooding manholes. Greater detail of a ground model and overland flow routes to allow the transfer of flows over the surface.

There are a large number of minor system models (predominantly owned by WaSCs) within the UK. Many of these models will have been built for specific purposes, with a specific level of detail. They are predominantly focused on the foul or combined sewer systems, with a lower representation of surface water systems and to an even lesser extent highway drainage. Any model that is used must be assessed for its fitness for purpose.

15.2 Minor system model IUD limitations

Limitations in minor system models exist with the individual equations and how various processes are represented. These are detailed further in numerous WaPUG papers covering such topics as runoff modelling, flooding mechanisms, and ancillary modelling.

The extent of any limitations within minor system models generally relates to the level of data collection and their original purpose. Section 3 of the WaPUG Code of Practice applies confidence grades to different types of data to reduce limitations in the minor system model in the area of IUD consideration.

Verification of the simulated against measured flows can help to quantify the extent of model limitations. Verification is normally based on low return period events. When a model is used to simulate extreme events the level of extrapolation from the verification can lead to low confidence results. This effect is exacerbated if the model has been calibrated.

It is important that all data issues, assumptions and associated limitations in the sewer model are well documented.

16 Major system (overland flow) models

16.1 Major system (overland flow) model types

A range of overland flow modelling approaches exists. Different approaches relate to the degree of interaction with other system types. Overland flow models either exist as stand-alone programs or as modules added to minor or the major system packages.

Major system overland flow models can take the form of simple 1D flow path models or more complex 2D approaches. The key element to all these models is the DTM, and this dictates the scale to which the modelling can be undertaken, the detail and the output accuracy. High level / strategic assessments may utilise DTMs with a 10m resolution or coarse topographic survey data. In contrast, detailed assessments where a defined flow path is required on a street or property level may use a DTM down to sub-metre resolution. Identifying the areas where detailed 2D modelling is necessary is often an iterative process, based on the results of previous coarser assessments.

Overland flow models have been grouped into flow path approaches and 2D overland flow approaches. This is an emerging area in the UK with a number of examples presented by Balmforth et al (2006), Allitt (2006), Dow et al (2008), and Allitt et al (2008).

IUD studies may wish to consider a tiered approach, using coarser or more rapid modelling (i.e. lower resolution flow path modelling or coarse 2D modelling) to identify the areas of highest flood risk, then highly detailed 2D overland flow modelling studies are undertaken (Bamford et al, 2008; Balmforth et al, 2008).

16.1.1 1D flow path approaches

A number of GIS and modelling approaches exist which utilise topographic survey data or DTM data to plot linear flow paths of water on the surface using a number of computational techniques. These approaches are often used at an initial stage to predict where water is likely to accumulate or the main flow path.

The most common is the ‘rolling ball’ approach. This plots a preferred flow path based on the steepest gradients down a slope. An advance in this technique is a ‘bouncing ball’ approach which maintains some of the momentum and allows the ‘ball’ to bounce out of a low spot in the same way that water will form a pond and then overflow should it fill. The use of detailed DTM data, including buildings added, would produce the most accurate linear flow path predictions. These can be used for 1D modelling with 1D defined pathways.

The main advantage of the 1D approach is the simulation speed. Where overland flows are constrained by kerblines or other features it maybe entirely adequate to model in 1D.

The main disadvantage of the 1D approach is that it confines the overland flow to linear channels on the surface and does not account for varying water depth creating a change in flow route. The approach also ends at any sink point in the DTM and only the most advanced procedures will include for the filling of sinks (ponds) with further overland flow downstream.

In recent years, the 1D approach has gradually been superseded by 2D overland flow modelling.

16.1.2 Dedicated 2D overland flow approaches

2D overland flow approaches use topographic data or a DTM, but allow for multiple flow paths in a number of directions, in response to changing water depth on the surface. The topography, slope and surface characteristics (e.g. roughness) are used to calculate how water will flow and spread across the surface.

2D overland flow modelling in urban areas has become increasingly reliant on highly detailed DTM data, down to 1m or sub-metre grid resolution, for two main reasons:

- In order to replicate overland flows in urban areas it is essential that the vertical accuracy is between ± 50mm and ± 150mm. This can only be achieved with one metre or sub-metre resolution. The DTM data should be based on the highest possible available survey accuracy.
- The route of flow paths in urban areas may be dictated by changes in the topography (e.g. dropped and raised kerbs, alley ways between houses, sloping driveways, walls and even street furniture). Using 2m to 10m resolution data as typically used for larger scale river flood mapping studies is not of sufficient resolution and detail for urban areas.

In steeper catchments flow on the highway will be shallow and fast and in many cases could be supercritical flow. In these situations the flow depth is most likely to be less than the height of the kerb face and in many locations the flows will be constrained between kerbs. At road junctions, entrances and at dropped kerbs it is possible for the overland flows to deviate from the road.

In flat catchments flow depths are deeper but slower and in these situations the flow could take a variety of routes depending upon the precise circumstances. Topography is represented by a 2D mesh. How the 2D simulation mesh is created, the influencing parameters and mesh resolution must be understood to achieve representation of the surface topography.

It is important to gain an intimate knowledge of the catchment which can only truly be achieved by a site walkover. Crowder et al (2006), Williams (2008) and Allitt et al (2008) give a good account of the issues affecting the detailed drainage routes of overland flows and how these should be considered as part of an IUD modelling study.

In an urban environment, small changes in surface topography can significantly alter flow paths. It is important that a combination of site visits, available photography, mapping and detailed topographic data are used to identify surface features such as:

- Gully location
- Walls
- Hedges
- Retaining walls
- Railway and road embankments
- Bridges
- Kerbs and dropped kerbs
- Fences
- Buildings
- Street furniture
- Speed humps / berms
- Gates (and degree of opening)

Kerbs will constrain flows in a similar fashion to channels, yet dropped kerbs and pedestrian or vehicle crossings may allow flow to leave the highway and take an alternative path. Walls, fences and hedges also constrain or redirect flows to varying degrees. Some software packages allow these features to divert part of the flow, yet allow some flow to pass through the feature, or overtop the feature. Retaining walls must also be identified, as the failure to represent the steep or vertical slopes can distort the application of the mesh and drainage paths in the area below the wall.

It is often necessary to detail buildings based on the mapping data, rather than only DEM data. This allows the sharp wall features to be better represented.

16.1.3 Hybrid overland flow modelling

It is possible to simulate 1D and 2D overland flow models together. It is important that this is not mistaken for coupling minor and major system models. In this approach all the water remains on the surface and none is discharged to gullies, manholes or watercourses.

The principal advantages of hybrid 1D-2D models is that in the steeper parts of the catchment where flows are constrained the use of 1D achieves faster simulation times. In the flatter areas where the flows can take different routes the 2D approach is better. The way in which the 1D and 2D elements interact varies depending upon the modelling program.

16.2 2D mesh sizes

The computational speed of 2D overland flow models is greatly influenced by the size of the elements within the 2D simulation mesh, and other software features to represent obstacles, voids and breaks in topography. Mesh size will depend upon the specific project requirements. A series of tests should be undertaken on a trial area to determine the most appropriate mesh sizes. Mesh sizes will typically vary depending upon the topography with steeper slopes typically requiring smaller mesh sizes. In most cases a model will contain a series of different mesh sizes with the smallest being in high flood risk areas. Identifying the areas requiring small mesh sizes is often an iterative approach.

17 Major system (in-channel) models

17.1 Major system (in-channel) model types

In-channel flow modelling programmes are generally classified to the number of dimensions in which they represent the spatial domain and flow processes. For particular problems a 1D, 2D or even 3D model may be most appropriate. In the context of IUD modelling, major system in-channel models are generally 1D, with flood plain modelling perhaps in 2D. The key approaches to representing the major in-channel drainage system are detailed in the following sections:

17.1.1 Historical river flow and level data

There is a network of river level and flow gauges in the UK and data is readily available from the Environmental Regulator. Various statistical analyses can be undertaken to provide levels and flows for various return periods.

Historical gauge data is specific to the point of measurement. Extrapolating levels between gauges is fraught with error due to the effects of weirs, gates and bridges. There are standard approaches for interpolating river flow data between river gauges and on ungauged catchments outlined in FEH. Consideration should be given to the routing of flows if the gauge point is a distance away from the point of interest. These flows can then be applied to simple river models to estimate level data, although care should be taken to ensure that the river model is long enough to properly model the downstream boundary condition, and that adequate consideration is given as to whether the flow is in or out of bank.

The role of historical river flow or level data in IUD studies is often to set downstream boundary conditions at minor system outfalls.

17.1.2 1D river models

1D river models do not represent turbulence and secondary circulation, but do represent to a good degree the bulk properties of river flows (propagation and attenuation of the flood wave, and backwater effects). The channel geometry is represented as a series of irregularly spaced cross sections perpendicular to the 1D flow. Water levels calculated at each cross section are considered horizontal and constant across the section. Boundary conditions typically consist of an inflow hydrograph at the upstream cross section and, if the flow is sub-critical, a stage hydrograph at the downstream boundary.

1D River models can be applied as steady state or unsteady. Steady state models utilise a constant flow at the upstream boundary, calculating the corresponding level through the river profile for that flow. These are relatively simple to construct and generally stable, though the model assumes an infinite volume of water and does not represent the filling of storage. Steady state models also tend to over predict peak levels and should be avoided where there is excessive storage available (flat flood plains) or where there are variable downstream boundary conditions and backwater effects.

Unsteady modelling approaches allow for time varying flow input at the upstream boundary (i.e. flood hydrograph) and a time varying downstream boundary condition. The time varying nature of these means that storage is better represented. Simple techniques exist for representing flow on the floodplains, such as 1D reservoir filling techniques or parallel channel conveyance. More advanced techniques exist where the 1D channel model is coupled to a 2D model of the floodplain to represent flow conveyance. These models are discussed later but require more time and effort to ensure stability, though are considered more accurate at representing flows and levels across a variety of reach types.

The data used to represent the channel cross sections and flood plains can range from simple topographic surveys at predefined intervals to using detailed DTM data. Depending upon the software program used secondary processing is sometimes required to extrapolate predicted peak levels from river cross sections to a DTM to allow flood mapping to be undertaken.

17.1.3 2D river models

2D river and flood plain models provide an improved representation of river hydraulics. This includes the continuous representation of topography and roughness and does not require secondary processing to determine flood inundation. These approaches make optimal use of high resolution DTM data.

Complete 2D river modelling approaches utilise a much more complex set of hydraulic equations than 1D approaches. They are well suited to overbank flood flows in compound channels, and better represent turbulent mass and momentum exchange between channel and flood plain flows.

The main draw back with this approach is the computational cost of utilising a detailed 2D model to represent the flow in the channel and the flood plains during periods of inundation.

17.1.4 Coupled 1D-2D river models

Although 1D approaches are computationally very efficient, they suffer from a number of drawbacks when applied to floodplain flows. The computational cost of running very detailed full-2D simulations at the river reach scale may be prohibitively high. Consequently, research and commercial organisations have recently begun to develop complimentary 1D-2D software tools that seek to combine the best attributes of each model class. In summary:

- 1D models are best suited for describing flow within channels, confined valleys and through hydraulic structures,
- whereas 2D models are best suited for describing the lateral diffusion of shallow water flows over low-lying areas.

Linked 1D-2D major system models aim to reduce the representation of river hydraulics to an appropriate level to achieve acceptable, computationally affordable predictions of flood extent.

18 Coastal models

Coastal models are unlikely to be simulated dynamically in an integrated manner to assess urban drainage flooding problems, as most tidal influences on minor drainage systems can be represented as level based boundary conditions. In many cases the use of historical data will be adequate to represent coastal boundary conditions. There are, however, a number of coastal and estuarial models available which also provide predicted boundary condition data.

Where there is a risk of coastal inundation the potential flood volumes greatly exceed the contributions which any sewered or even natural river drainage system can make. The methodology for modelling flooding from the sea is therefore outside the scope of this guide.

19 Groundwater models

Groundwater can influence flooding, as it can dictate soil saturation or contribute to river levels. It is unlikely that groundwater models would need to be integrated into IUD models for most studies. Groundwater can be considered an infinite source, and from an IUD modelling perspective is likely to only produce an inflow to a system based on level.

Variations in ground water generally occur over long timescales. There may be a need to assess groundwater levels or models to identify where inflows to the minor or major systems occur. High ground water levels may lead to an increase in baseflow or direct flooding. A brief summary of the key groundwater models available is presented below.

Conceptual Models – This brings together all available information in the groundwater zone under consideration (solid geology, drift geology, solid, hydraulic conductivity and storage, surface water hydrology, river levels and flows, historical data relating to groundwater levels etc). This allows a broad understanding of groundwater interactions, and the historical data may be adequate to set boundary conditions if necessary.

Mathematical Models – A number of equations exist to describe the flow of groundwater through a porous medium, and these may be steady state or transient (time variant), and may be 1D, 2D or 3D in nature. The solution to these equations gives the hydraulic head as a function of space and time. Standard numerical codes and user friendly interfaces are commercially available to allow complex modelling of groundwater flows and levels.

20 System interactions

There are numerous types of interactions between the different modelling environments. The complexity of the interaction will depend on a range of issues including: the significance of the flooding problem and mechanism, the models to represent this interaction and the sensitivity of the flooding problem to the interaction.

The type of interaction can be broadly categorised as to whether it is **one-way** or **two-way**. This complexity of the interaction and the selected linkage method has important implications on the type of model integration and simulation set up required. Consideration should be given at a very early stage as to the type of interaction that will be required:

One-way interactions are likely to necessitate the integration of different sets of historical data and model results. This is relatively straightforward.

Two-way interactions are likely to necessitate the integration of different models and model environments. This can lead to highly complicated modelling studies.

21 One-way (series) interactions

One-way interactions occur when only one system influences a second system. In its simplest sense, the first system influences the second, but the second system does not influence the first. This type of interaction has been dealt with in many modelling studies in the past as a boundary condition, as demonstrated by Figure 21-1.

One-way system interactions are likely to be simplest and examples of these include:

- Flow inputs from minor systems that have a permanently free outfall into a major system (e.g., a surface water outfall to a river),
- Downstream level boundaries from a major system affecting a submerged minor system outfall (e.g. high river or tide levels at the downstream end of a sewer outfall),
- Inflows to major overland systems that remain on the surface and do not re-enter the minor or major in-channel system (e.g., flood flows from minor systems that drain overland locally to low spots or depressions).

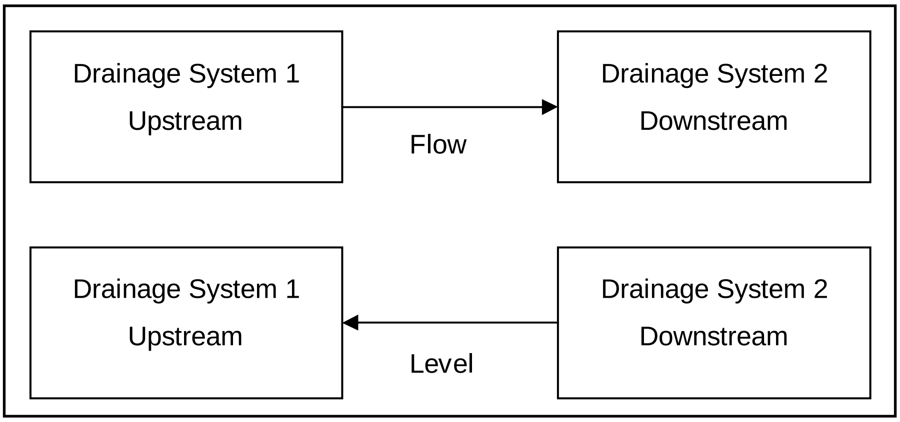

Figure 21-1 – Two Different Examples of One-way Interactions

One way interactions involve obtaining data on the input boundary under consideration and applying this to the model that is being used to predict flooding. This boundary condition data may originate from a number of sources including:

- Historical gauge or measured data
- Model outputs
- Fixed or design estimates

21.1 Use of historical gauge or measured data in series

Historical data (e.g. time varying measured sewer flows, tidal data or river levels) sets are often time varying. The level of detail applied to the input boundary data will be related to the measurement resolution. This can also be affected by the simulation timestep resolution of the model which uses the data. For example, daily historic depth data for an urban watercourse would be of too large a timestep to model the interaction when investigating sewer flooding in a short duration event.

This approach is commonly used to verify and validate individual component models where there is a known interaction with an adjacent minor or major drainage system. The main disadvantage when using historical data is how to determine a value to use in design, large return period, time series or scenario testing analyses.

21.2 Use of fixed or design estimates in series

This approach utilises a fixed value that does not vary with time throughout the whole simulation. These are generally utilised in design conditions when the IUD study is concerned with maxima or worst case extreme scenarios.

21.3 Use of model outputs in series

Series interactions allow one model environment to be simulated first (e.g. a river model to provide level data along the reach) with the results input into the second hydraulic model as a boundary condition (e.g. the time varying river level data at the outfall of the sewer system). Many simple IUD studies use steady state river or coastal models to predict the peak level for a given return period at a minor system outfall where historical data is not available.

Many simplified IUD overland flow models utilise predicted flood volumes from minor and major system models. Overland flow is simply applied to the surface as a fixed boundary condition, (a known volume of rainfall or floodwater from fixed points, e.g. rivers or manholes). These flow inputs can be time varying. No flow is lost from the 2D grid surface to other hydraulic environments or drainage system types. This is often known as a De-Coupled 1D & 2D modelling approach.

The main advantage with using modelled boundary conditions is the degree of flexibility afforded that historical or design approaches do not allow. The first model can be simulated as any scenario and the boundary condition applied to the second model simulations.

21.4 Application of one-way (series) approaches

Whilst there are true one-way interactions in the urban drainage environment, the majority of interactions are two-way to some degree, with one system being more dominant. These have historically been treated as one-way interactions for modelling purposes, due to the different system type models not being able to pass results between each other on a timestep by timestep basis. In a series approach, two-way interactions can only be represented through a laborious iterative process.

Recent advances have meant that different systems can be represented in a single software application or by tools allowing data transfer between the different software (e.g. Open MI). The need to utilise series interactions due to software compatibility issues has become less, and the series approach is now used when appropriate, not when software limitations dictate.

Series interactions may be used where one system is dominant and important (e.g. river level on the sewer system) but the reverse interaction is not represented as it is less significant (e.g. sewer flows on river flows and level). Often this applies to highly localised investigations of a single flooding location. This highlights the importance of understanding the flooding mechanism prior to selecting modelling tools and approaches. This has important consequences on the complexity of the modelling exercise, cost and programme.

22 Two-way (parallel) system interactions

Parallel simulation techniques recognise that the urban drainage system does not comprise of distinct independent units, but form part of an all encompassing urban drainage network. Two-way parallel interactions occur when two or more systems influence each other, with feedback between each system as demonstrated simply by Figure 22-1. In this case, flow is passed from the upstream minor drainage system to the downstream major system. This in turn causes the level to increase in the downstream system, which then reduces the flow input from the outfall from the upstream minor system.

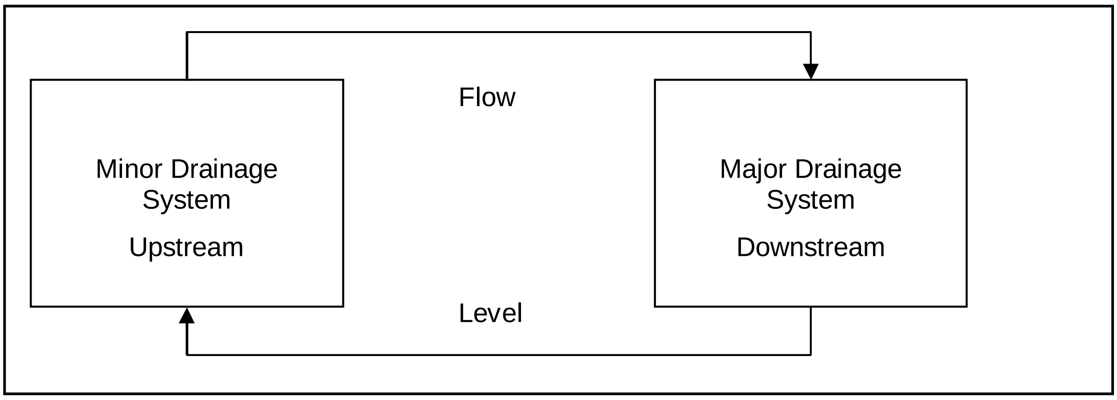

Figure 22-1 – Example of Two-way (Parallel) Interactions

The key factors to consider when representing two-way interactions are:

1. Available models for each individual drainage system component (i.e. a river model, a sewer model, and an overland flow path model),
2. The ability and method to pass data at the interaction point between the individual component models on a time step by timestep basis.

As data is exchanged on a timestep by timestep basis between models, any variations in the magnitude or effect of interaction due to changing conditions over time is better represented.

These are often referred to as Coupled modelling approaches, allowing continuous interactions between hydraulic environments and drainage system type.

In reality, the term two-way is an oversimplification and multidirectional is more appropriate. This is because numerous minor and major systems may interact in a typical IUD study. All the different system types have the ability to receive flow from another system, transfer flow to another place over time, and then input that flow to another system. As demonstrated in Figure 22-2.

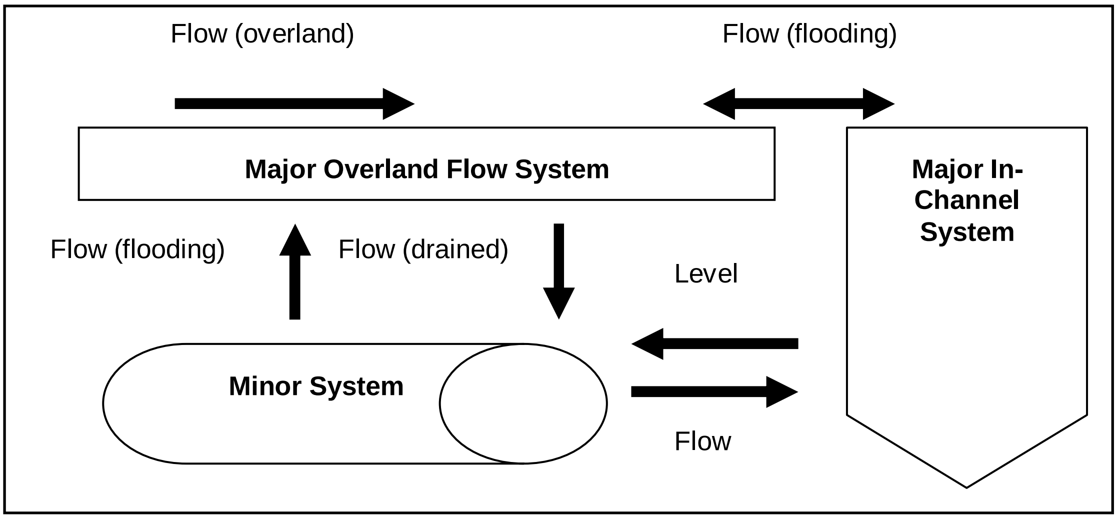

Figure 22-2 – Multidirectional Interactions

22.1 Application of two-way (parallel) interactions

Two-way system interactions are by far the most complicated as a number can occur at any one time. Examples of the common interactions that may be represented within an IUD modelling study are highlighted in Table 22-1.

Recently, linkages between tools and platforms have significantly improved and now allow user specific linkages to be created between very different and independent modelling tools (e.g. OpenMI). In addition, some software packages are now integrated themselves, and provide a full suite of different drainage system modelling tools. These have the ability to interlink and exchange data and simulation results. Also, experience over the last few years has shown that in certain circumstances it may be appropriate to use more simplistic alternative modelling packages, such as the simplified representation of watercourses as 'open' channels or simplified river sections in sewer modelling software.

Parallel interaction approaches are by far the most complex, as they require some form of time varying model for each drainage system type. However, they are generally the most appropriate way to represent all hydraulic interactions that may influence a complex IUD study.

Full parallel simulation of interlinked models will require greater integration of model disciplines. Model users will need to have an understanding of a number of modelling disciplines and be part of a cross discipline team.

Table 22-1 – Examples of Two-way Interactions

System Interactions	Example of two-way interaction
Minor / Minor	Combined sewer overflowing into a surface water sewer or culverted watercourse at a CSO
	Surface water sewer or culverted watercourse overflowing into the combined sewer at a storm sewer overflow (SSO)
Minor / Major In-Channel	Sewers discharging flow to watercourse through outfalls River systems influencing downstream level in sewer system at outfall
	Rivers / open watercourses discharging into culvert systems Culvert system influencing downstream level in river system at culvert inlet Influence of screens on inlet to culvert sections
	Culvert systems discharging into rivers / open watercourses River system influencing downstream level in culvert system at culvert outlet
Major Overland / Minor	Runoff, sewer flooding or overland flow entering gullies and discharging into minor system Incapacity of inlets restricting flow into the minor system Incapacity of the minor system restricting inflow or causing flooding NB In the case of sewer flooding, flood waters may flow overland, re-enter the sewer, then flood again downstream, creating a cycle of interactions.
Major Overland / Major In-Channel	Runoff, flooding or overland flow to the receiving watercourse River system incapacity causing out of bank and overland flow over flood plains.
Minor / Major Overland and Major In-Channel	Incapacity of the sewer system causing flooding, overland flow and discharge to the watercourse, with the additional flood flows in the watercourse exacerbating watercourse flooding.
	Incapacity of the watercourse causing flooding, which discharges overland and enters an adjacent sewer system, exacerbating sewer flooding.

23 Integrated modelling environments

The choice of modelling approach is dependant on the type and complexity of interaction and the available modelling software.

23.1 Series model simulation

When using a series approach, the modelling methodology is relatively straightforward. This will involve identifying the dominant modelled system (e.g. where flooding originates) which will be the platform for the main hydraulic analysis. The boundary data at the point of interaction will be applied. A summary of this approach is highlighted in **Figure 23-1**.

Confirming the location of all significant interactions is a key step. Many series applications will involve a small number of interactions (e.g. inflow points from minor systems into major systems, or application of major system levels on minor system outfalls). In some cases, there may be a high number of series interactions such as when flood volumes from a minor system are applied to an overland model at each flooding manhole.

The temporal and spatial resolution of the boundary data is a key parameter. It must be suitable to be applied to the dominant model with respect to the IUD study aim. Wherever the temporal or spatial resolution of the boundary data is inadequate, then more complex parallel modelling is likely to be required.

- **Temporal resolution** – the data used to formulate the boundary condition should have an adequate resolution or timestep. Low resolution boundary data (e.g. daily) should not be used to assess flooding that occurs over the space of an hour.
- **Spatial Resolution** – The boundary condition data should be applicable to the interaction location. Often measured data (particularly river data) may be applicable for a location away from the interaction point. Interpolation or extrapolation of these to the point of interaction can be undertaken, though this can be fraught with error, due to features such as weirs, bridges and restrictions, which prevent linear interpolation.

Application of the boundary data to the dominant system model is generally applied as a time varying file at the interaction location. Measurement units of the boundary data must be consistent with the dominant modelling software package.

This approach may result in a quicker simulation time than if parallel model simulations were undertaken (as one side of the interaction is input as time varying data).

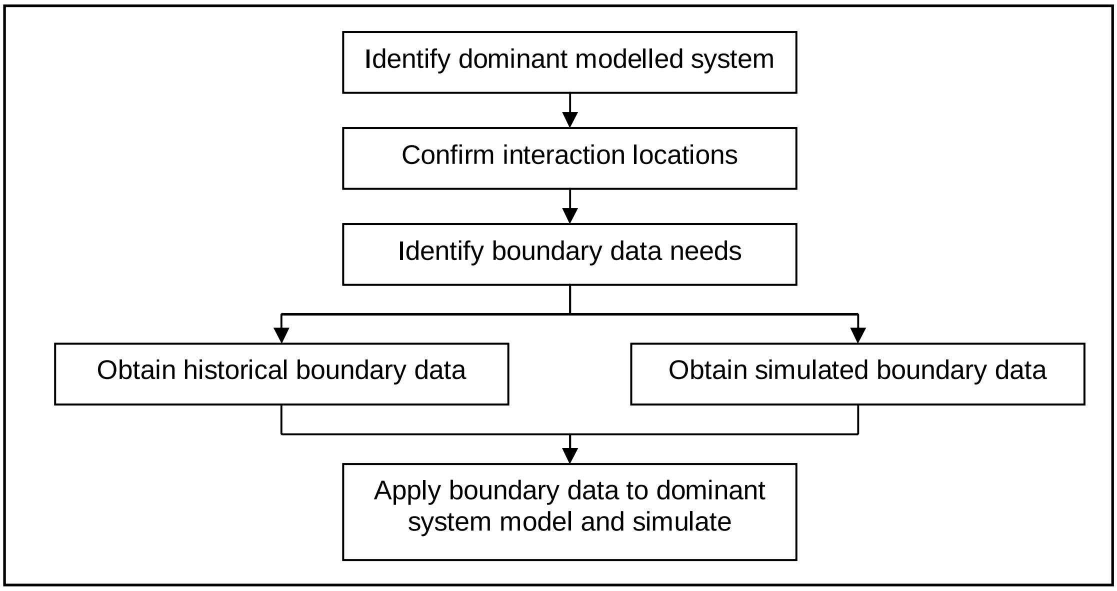

Figure 23-1 – Outline Process for Series Simulation

23.2 Parallel model simulation

A number of alternative approaches are available when undertaking parallel modelling investigations, influenced by the capabilities of the various software packages commercially available. These are summarised in **Figure 23-2**.

23.2.1 <u>Model representation of interaction</u>

In order to accurately represent all interaction locations within the parallel model environment it is necessary to consider:

- The hydraulic regime(s) at the interaction
- The type of interaction point and linked system types
- The number of linkage points
- The location of linkage points

For example, minor and major in-channel interactions may be concentrated around a single or a few specific outfall locations. Interactions with major overland systems are often greater in number due to the high frequency of gullies and manholes, or spill points to flood plains.

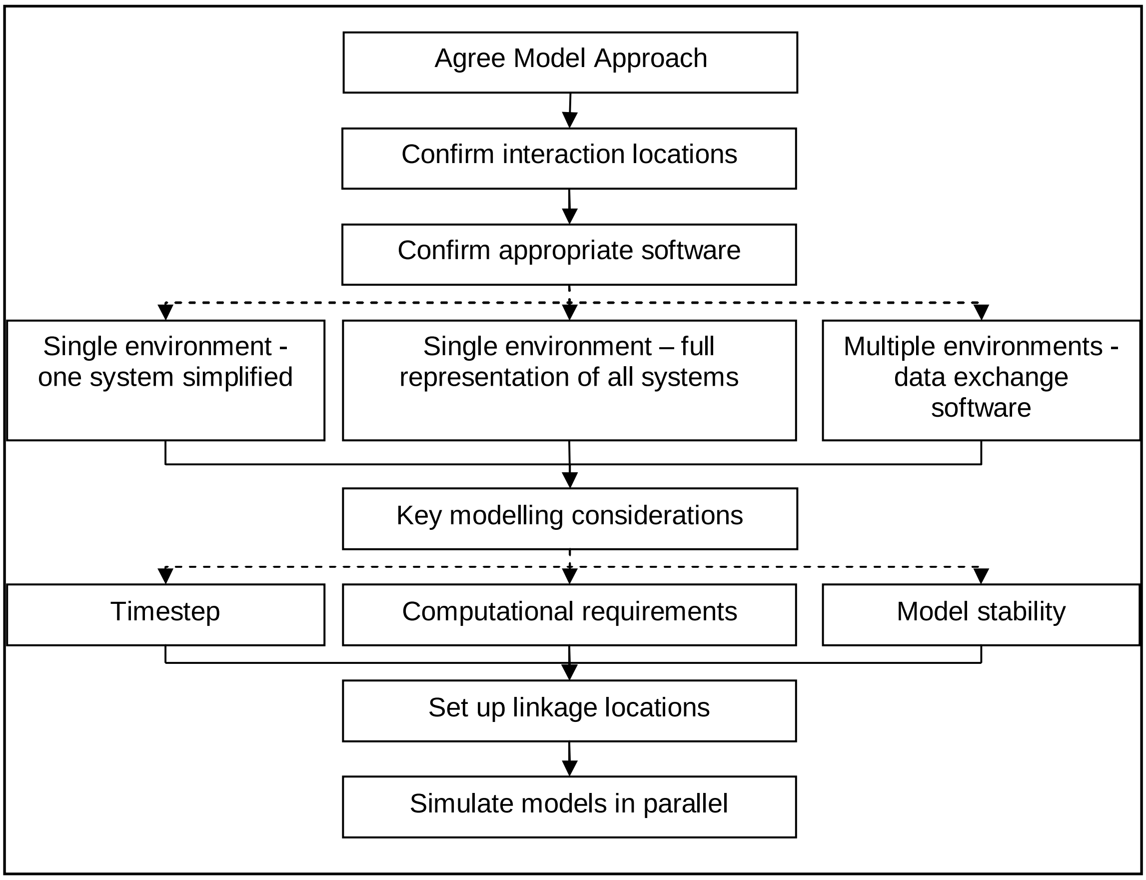

Figure 23-2 – Outline Process for Parallel Simulation

How a model represents a type of interaction is influenced by its physical characteristics. These may be initially identified from desk based exercises, though site visits are strongly recommended to identify key physical aspects.

Outfalls and outlet structures

The quality or asset condition of an outfall or outlet affects the transfer of flows or degree of interaction between systems (e.g. a partial collapse or silting). In addition, features such as flap valves or screens (clean or ragged, free or stuck) will influence the passing of flow or level. Many modelling packages allow these interactions to be represented, which are commonly between piped systems and watercourses.

Inlet structures

These generally enable flow from the major system to enter the minor system. Some modelling packages allow specific inlet structures to be represented, with discharge coefficients controlling capacity or inflow rates. Alternatively, orifices or weir units can be used. The capacity of these is also often influenced by screens, debris and the structural condition, which must be taken into account.

Gullies

Gullies are the main two-way interaction point between the overland and minor system and are a complex feature to model. It is often difficult to obtain an accurate gully dataset. The large number of gullies in a given area adds to the complexity.

Historically, gullies have been rarely represented within models, and including these represents a step change in the level of model detail.

Gullies are typically modelled using simple representations, such as weirs or orifices, or by head discharge relationships. Weirs can be used to represent the gully perimeter or gully pot circumference, although experience has shown this can allow too much flow to pass through the structure. If a weir is to be used, careful consideration should be given to its appropriate application. Orifices with limiting discharges may be used in preference.

Head discharges are a more sophisticated approach, and require a detailed understanding of the factors influencing flow through gullies. The flow passing through a gully can vary significantly with increasing head; and may use a different relationship when operating in reverse, due to minor system exceedance. Flow through an individual gully is more influenced by the design of the grate, and less by the capacity of the gully pot or pipework. HA102/00 – Spacing of Road Gullies (HA, 2000) has useful information on these factors, with Allitt (2006) providing further information on key modelling considerations.

Accurate representation of gully interactions must consider the following:

- Spacing between gullies
- Gully grate spacing / opening
- Direction of grill
- Gully condition (blocked with leaves, litter or plant growth)
- Area drained to each gully
- Gully size
- Connection to minor system
- Local topography and impact on head / discharge relationship

Manholes

Manholes may act similarly to gullies as key interaction points between overland and minor systems, although differ as they are notionally covered. Minimal overland flow may enter the minor system through gaps in the cover. Exceedance flow from manholes onto the overland system may occur in times of surcharge. In extreme cases, bulk flows may pass from the minor system to the overland system when the manhole cover is raised or blown. These interactions can be modelled using orifices and weirs with differing discharge coefficients. Careful consideration should be given to how this interaction is modelled with the appropriate evidence base.

Out of bank spill points

When major systems reach capacity flow spills onto the flood plain. Channel to flood plain interactions must be specified (e.g. between 1D in-channel river models and 2D overland flow models). Low bank level spill points to the flood plain can be identified from topographical data and represented by weirs or spill units. Spill locations may also allow flow to return back to the channel (e.g. around embankments and flood defences).

Model stability and flow balances must be ensured across these 1D and 2D interaction points.

23.2.2 Modelling software environments

Parallel integrated modelling software approaches fall into three main categories: single model (simple), single model (full integration), multiple models (with linkage software).

Single model (simple)

This involves modelling the different system types within a single environment, but where the software may not be the most appropriate for representing one of the systems. For example, many sewer modelling packages can represent urban open channel features. These are not dedicated to river modelling but do allow a basic representation of urban watercourses (where the modified and part culverted nature is similar to sewer hydraulics).

Many sewer interactions with highly urbanised watercourses have been modelled in this way. This requires only a single software package, which is beneficial for compatibility across system models and representing interactions. This approach does have disadvantages. The hydraulic code and software features may not be fully applicable to the simplified system. For example, sewer packages may allow the representation of river channels, but pay less attention to the detailed channel profile and hydraulics.

This should only be undertaken when the benefits of modelling one system outside of the dedicated software outweigh any uncertainty introduced by the simplified representation.

Single model (full integration)

Packages exist specialising in the full detailed modelling of numerous system types and interactions within the same modelling environment. This is an improvement on the single environment (simplified) approach as each system is represented by dedicated algorithms and models. These packages frequently couple 1D and 2D models.

Coupled 1D-2D major in-channel and overland models

1D models are best suited to represent flow in channels, confined valleys and at hydraulic structures, and 2D models are best suited for the lateral diffusion of flows. This combination of 1D and 2D approaches offer the following benefits:

- Improved accuracy and detail of flood plain / overland modelling compared with the whole system modelled in 1D,
- Faster simulations than if the channel and floodplain was entirely modelled in 2D.

Coupled 1D-2D minor system and overland models

Minor system packages exist with inbuilt major system overland flow models, which have developed specifically for improved urban drainage flood modelling. These have linkage features allowing flood waters from manholes and gullies (represented as 1D sewer models) to discharge onto the surface and flow using 2D hydraulic codes. More advanced minor system applications also exist allowing the surface flow to drain back into the sewer system, resulting in a fully integrated minor and major overland system model. These models manage to achieve a volume balance between the two systems, which is an important stability issue.

The computational requirements of these fully integrated coupled models can be relatively high, especially where very detailed 2D overland flow models are required, which use a much larger number of computational points than 1D models.

In both cases, whilst the two systems are integrated within the same software, the identification of linkage points between the 1D and 2D models is still vital. Adequate consideration must be given to the resolution and location of all potential linkages.

The choice of whether to use a minor or major system model to simulate overland flow and flooding can only be made when there is adequate knowledge of the catchment and flooding mechanisms. Where flooding is predominantly linked to rivers, then the major system model may be most appropriate to represent overland flow; but if flooding is predominantly pluvial or sewer related, the minor system model for overland flow modelling may be most appropriate.

<u>Multiple models (with linkage software)</u>

Software packages exist that control the simulations of two or more hydraulic models in their different modelling environments. These pass the necessary data across the interaction locations on a timestep by timestep basis. This software allows full parallel simulation in the original individual component modelling environments. Integration software that links different environments does not change the base data held in the original component models, acting only as a facility to exchange data between models.

Open MI

The Open Modelling Interface (OpenMI) aims to deliver a standardised way of linking related models. The OpenMI standard defines an interface that allows time-dependent models to exchange data, be simulated simultaneously and share information at each timestep. The development of the software was funded by the EC's Fifth Framework HarmonIT Project, and is now being sustained by the EC's LIFE Environment Programme.

OpenMI defines a standard integrated model interface that has three functions:

- Model definition – Allow various linkable components to identify what items the model can exchange in terms of quantities and locations.
- Configuration – Defines what will be exchanged when two models have been linked for a specific purpose.
- Run-time operation – To enable the model to accept or provide data at run time.

When models have been made OpenMI compliant, their overall structure remains unchanged, but each simulation engine becomes linked to the OpenMI interface. This allows the model components to exchange data (flow, level, etc) between different locations.

Open MI is interface based. It is not a common data-model specification nor is it an integrated modelling system. OpenMI is open, is publicly available via the internet (www.OpenMI.org), and the source code is open and available under Lesser GPL licence conditions.

The OpenMI Association has been set up as an open group of organisations dedicated to taking OpenMI into the future. It is an independent not for profit organisation, with primary objectives to develop, maintain and promote OpenMI.

Many of the commercial hydraulic modelling packages available in the UK and Europe are part of the OpenMI association and the software is OpenMI compliant. In addition, more bespoke hydraulic modelling software applications can be made OpenMI compliant. OpenMI has been used successfully in a number of integrated modelling studies within the UK (Fortune, 2006; Hale and Anderson, 2006; Margetts and Rayner, 2006, Ayoung et al, 2006).

23.2.3 Parallel simulation - key modelling considerations

Specific attention should be paid to the following issues when parallel modelling is to be undertaken, as they may affect the choice and viability of software platform or approach.

Model stability

Instabilities in the hydraulic mathematical calculations can cause flow to be generated or lost, resulting in erroneous model predictions. The linking of independent component models potentially increases the risk of instabilities due to increases in size and complexity. Models utilising 2D hydraulic calculations are often more likely to be unstable than 1D models, due to the complex computational wetting and drying of cells on the 2D mesh.

Most independent component models assess model stability during a simulation (e.g. volume balance through space or time), and procedures exist to check simulation outputs for spurious data and instabilities. Some of the integrated modelling software undertakes volume balance and stability checks across the linkage locations. The results of these should be reviewed for all simulations to ensure stability. Model users should ensure that stability is maintained both within each component model and also across the linkage locations.

Should instabilities be identified, then users should check the detailed set up of the model components, the timestep set up, and the hydraulic calculation parameters, as detailed in Section D.

Simulation timestep

As models become increasingly integrated and complicated, the timestep required to achieve stability and successful simulations decreases significantly. Many minor and major system 1D models perform adequately with timesteps of a minute. In contrast, detailed 2D models may require timesteps in terms of seconds to achieve stability.

Users should consider the impact of joining models using very different timesteps. Where 1D and 2D models are joined, the timesteps used may be very different. The time required to undertake a simulation of all component models at the lower timestep may be prohibitive. Some of the integrated modelling software available allows for the individual component models to be simulated with different timesteps to improve run time efficiency.

Simulation times and computational requirements

The simulation times and computational requirement of a parallel approach is generally greater than a series approach due to:

- Larger models
- Larger results files
- Increased processing
- Additional linkages
- Smaller timesteps
- Increased stability checking

Model users should consider the implications of the increases in simulation time and computational requirements, as this may influence the number of interactions modelled, the level of detail in which these are represented, and the software used to undertake the modelling. This issue should be considered at the planning phase, due to the implications on software selection and potentially study programme.

Real Time Control

A number of integrated modelling studies have utilised Real Time Control (RTC) between different models or software representing the different drainage systems (Margetts and Long, 1999; Margetts and Rayner, 2006). For example, a variable structure (i.e. penstock, gate) within a sewer system may be controlled by the characteristics in a receiving major system. In such cases, full parallel simulation with full integration between the different models is necessary to adequately allow the RTC 'sensor' to feedback and activate the 'control' on a timestep by timestep basis. The timestep required to allow stable RTC operation is likely to dictate the timestep used to simulate all components models within the integrated model.

24 Joint probability

Joint probability refers to the likelihood of two or more scenarios or conditions occurring at the same time. For example, flooding may only result when a one year storm occurs on the minor system and the major system at the same time. Understanding the real likelihood of this is important to understand flood risk predicted by an IUD model. Factors affecting IUD studies include flows and levels in sewers and rivers; tidal conditions including sea level and wave height; and groundwater levels. Serviceability considerations including the degree of blinding at screens and temporary blockages within sewers and culverts may also be important, but are generally considered to be independent of other environmental variables.

When considering the interaction of flood regimes, the combined probability of different systems responding differently to rainfall should be considered carefully. The extreme critical storm for a minor urban drainage network is likely to be a shorter duration high intensity event. Major systems are likely to be at their highest level during longer duration events, and after large storms that occurred across the whole catchment area.

The approach taken will depend on the choice of one-way (series) or two-way (parallel) interactions. However, in either case it is unlikely that all the parameters can be varied simultaneously.

Joint probabilities do not just relate to rainfall or flow across different areas and times within a catchment, and it may be necessary to consider the coincidence of previous rainfall and antecedent ground conditions.

Defra and the Environment Agency have produced a Technical Report "Use of Joint Probability Methods in Flood Management: A guide to best practice" (R&D Technical Report FD2308/TR2) which provides a good overview of appropriate analysis methods, principally for combinations of:

- Wave height and sea level, for coastal flood defences
- River flow and surge, for river flood defences
- Hourly rainfall and sea level, for coastal urban drainage
- Wind-sea and swell, for coastal engineering.

The report provides a desktop approach to generating a matrix of combined probabilities. This can be a good basis for examining how various flood and rainfall regimes interact and understanding how to develop the modelling approach if necessary. The desktop method uses the value of each variable at a number of return periods and a "correlation factor" indicating how independent the variables are, to estimate pairs of each variable having a desired joint exceedance period. Tables of pairs for certain return periods are given in section 3.5.2 of FD2308/TR1, and values for other return periods can be estimated by interpolation. It should be noted that the correlation factors vary depending on return period and that an allowance for increased dependence as a result of climate change may be necessary.

Probabilistic modelling is becoming increasingly important to test the impact of different influencing factors occurring coincidently. A series of simulations may be carried out, based on numerous probability analyses and sensitivity tests, for the different locations and influencing factors of the model. The outputs are then amalgamated to identify worse case scenarios and parameter risk banding.

When trying to decide which various flood, rainfall return periods or design scenarios to integrate, there are a number of factors to consider:

- Joint probability of different return period events occurring on each of the drainage systems under consideration, for instance a combination of high tides with high rainfall.
- Joint probability of the same return period event occurring across the whole of any of the drainage systems under consideration, i.e. spatial variation.
- Joint probability of serviceability issues affecting each system simultaneously

A general approach may be to

- Decide which variables are likely to be most critical to the situation under consideration
- Establish a “normal” combination of serviceability and boundary conditions, hence reducing the number of variables being considered at once
- Either:
    - estimate the cumulative probability of combinations of remaining variables, and run scenarios of suitable combinations amounting to each target probability, or
    - run a sufficiently large number of combinations of parameters, or a sufficiently long time series of simultaneously varying parameters, that the frequency of failure can be estimated
- Carry out sensitivity testing to demonstrate the impact of other variables

Throughout this process it should be born in mind that

- The critical duration of each of the drainage systems differs significantly across system types and location within the catchment. Upstream areas often have a shorter critical duration than downstream areas.
- Any probability analysis refers to the probability of the flow/level at a single location, and not necessarily for the whole catchment.

25 Climate change

It may be necessary to account for climate change in IUD modelling studies. There is guidance available on climate change and often this relates to adjusting the model input parameters (rainfall or river flood flows) for various areas of the UK. It is generally documented that changes in rainfall intensity will occur as a result of climate change, a factor which could have a significant effect on minor drainage system flooding. The advice for changing rainfall for sewer systems is not the same as the rainfall change applied to river models. The degree of change predicted in rainfall depths and intensities varies across the UK.

The following documents should be referred to for guidance on how climate change will affect rainfall and runoff inputs (e.g. Defra, 2003 Supplementary note on climate change considerations for flood and coastal management).

Section D – Verifying and Validating an IUD Model

26 IUD model verification and validation

The performance of hydraulic models should be compared to measured or observed data to quantify the confidence in the predicted results. Different terminologies exist for the process of ensuring the model matches reality.

Validation is the 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.

Verification is the 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 a drainage system and its components. Changes must be evidence based when attempting to make the model match verification 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 (normally with events of different magnitude and duration).

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 WaPUG Usernote 13.

The individual component models are likely to have undergone a process of verification or calibration, which will ultimately affect the fitness for purpose and accuracy of the model for the IUD study. This Section deals with the verification and validation of the integrated flooding mechanism and flooding predictions by the IUD model.

This section can be broadly split into two parts. The first deals with the potential need for further **verification** of the different components within the IUD model to represent the interaction (e.g. backing up from a major system into the minor system). The second relates to the **validation** of the extent and impact of the above ground flooding predicted by the model.

During the project planning stage, the following key considerations relating to model validation should have been identified:

- Definition of the problems, modelling objectives and required performance standards to tailor the IUD model validation to the specific requirements of the project.
- The level of detail, further verification or calibration, or level of validation required in the areas relevant to the IUD project.

26.1 Further verification of the interaction between component models

26.1.1 <u>Verification of new models</u>

If it is necessary to build new models for the IUD study these should be built and verified / calibrated in accordance with the guidance available, as highlighted in Section 1.7.

With major overland flow drainage systems there is currently no standardised procedure for verification, particularly where these are integrated with minor or major system models. The verification process described below for integrated models is considered good practice for verifying overland flow models.

One key difference between the verification of minor system models and major system models is the degree to which the comparison between simulated and observed flows and depths is used to ‘verify or calibrate’ the model. Major system models often cover large areas and the hydrology can be complex. It is normal to adjust the percentage runoff values to achieve a satisfactory calibration at a few strategic locations. By contrast in minor system models the hydrology is relatively fixed and the extents of impermeable areas are adjusted to represent observed flows at more measured locations. In more complex minor system catchments, models may represent a variety of permeable and delayed infiltration responses with more complex approaches.

26.1.2 Differences in verification / calibration methodology

There are differences in the methodology and standards of verification / calibration for different system types. Validation of minor system models is generally based on flow measurement from three or more storms and comparison with flooding records for extreme events. It focuses on the connectivity of the network, the extent of contributing areas and the performance of ancillary structures.

By contrast, major system models generally have few issues with connectivity and routing. Validation or calibration generally focuses on adjusting the catchment hydrology so the model better represents recorded gauged flows and flooding incidents. Validation of major system models tends to be based on more extreme storm events which cause flooding.

26.1.3 Verification of existing models following integration

There may be a need to further verify the performance of the different component models, in an integrated manner. The first step to be taken when verifying or calibrating existing models is to establish whether the original model is deemed fit for purpose and constructed to the required level of detail, as discussed in Section 2. With all IUD projects it is important that the confidence in the final integrated models is greater than the confidence in the individual component models, in relation to the integrated driver. Therefore the change in the level of verification between the individual component and integrated model should be checked. For example, if the depth match in an individual minor system model was poor due to the interacting river system not originally represented, then this should improve in the integrated model when the sewer system and river system are linked.

The verification of the original models should not be compromised through integration. If this occurs, further verification or calibration of the integrated model should be undertaken. It is necessary to check that following model integration, the results obtained from the new model are sensible, and demonstrate a match with recorded information. Where this is not achieved, a further process of verification must be undertaking, and this may include collecting further flow or level data for each component model in a similar manner to the verification of individual component models as detailed in other guides.

As well as considering the inter-linking of the models in respect of relatively small storms as part of the verification process (when flows remain below ground in the case of minor system models or remain within bank in the case of major system models), a check should be completed on the performance of inter-linking locations when more extreme storms are simulated and overland flow occurs. This involves identifying all possible interactions at the planning stage (Section 2), and ensuring they perform in a sensible and expected manner under extreme event conditions.

Checks need to be undertaken to ensure that there is no double counting (ie areas included in both models) and also that there are no omissions or missing areas.

Models can in some circumstances give significant over-predictions when running simulations with synthetic design storms. It is important to understand from the model documentation how the verification of the model has been achieved, and what issues may exist causing any over-prediction. If there is uncertainty in the magnitude of the integrated model predictions, the model should be run in isolation using synthetic design storms to gauge the usefulness and reliability of the model when it is integrated with other models.

If validation of the integrated model uses recorded rainfall, then that recorded data should reflect the rainfall occurring across the whole modelled drainage systems, especially as river catchments are likely to be larger in extent than minor systems in urban areas.

26.1.4 Further flow / depth measurement

When verifying or calibrating an integrated model further it is preferable to use recorded flow and depth data for the minor and major system. Any permanent or long term flow gauging stations in these systems should be identified, as should any short and long term sewer flow monitoring. Ideally data from an extreme event will be available. Some of this data may be available from the initial individual model build and verification study.

Depending upon the data already available and the manner of the interactions it may be necessary for further flow or depth measurement, which should be sufficiently ensure that the interactions between component models can be simulated. The need for this would be identified in the planning phase.

26.1.5 Key model points

Key model points within the integrated model should be identified during verification of the integrated model. For example, such points are where there are interactions between the different systems, or known flooding problems. These points should be used to check that the integrated model is giving improved results as the original component models and that the models are stable at the point of interactions. This includes comparing the data at previous flow survey points and that the verification is of the same level or improved.

Key points should be used to obtain a direct comparison between the individual models and the integrated model to check performance.

Where depth of overland flow or extent of surface flooding data is available, key points should also be identified for comparison purposes at the validation stage to compare model predictions against the observed data.

26.2 Validation of flooding extent and impact - methodology

This section details the process involved in validating the model predictions in terms of extent and impact of above ground flooding. Determining the method of validation of the integrated model is best undertaken in a series of stages:

Stage 1 – Obtain performance data

Obtain copies of all flooding records (including details of which properties were flooded and the depth, start time and duration of flooding). This would include photographs, videos and CCTV evidence of the flooding (often by residents), as identified in Section 3. The availability and suitability of any flow survey data and rainfall data should be established. This may be river gauging data, previous sewer flow surveys or rainfall data.

Stage 2 – Review original model validation / calibration

Review the validation or calibration of the individual component models, assess the adequacy and accuracy of this and understand all steps taken to achieve the final validation or calibration. It is important to understand any steps taken to account for factors not specific to the individual model (e.g. details of river levels used to validate a sewer model; or urban areas included within a river model). The implications of these must be understood so that when the models are integrated they can be removed and replaced with the model interactions.

A review of existing models should be undertaken at the planning stage so that a model update programme can be scoped. If model limitations remain, these must be understood and its implication on the study and future use recorded.

Stage 3 – Confirm performance data to use in integrated model validation / calibration

Determine which historical events or flow surveys can be used for the integrated model validation or calibration. For catchments subject to significant recent population growth or network changes, then a review must be undertaken to ensure this performance data can be used or should be updated. It may be necessary to use various models representing different dates or discard some earlier flooding incidents initially intended to be used for validation.

Stage 4 – Prepare models for integration

Update and upgrade the component models based on Stage 2 and 3 to prepare various models representing different dates and different networks.

Stage 5 – Obtain validation data for specific events

This differs from Stage 1, where all flooding related data is identified. It is necessary at this stage to identify all the relevant specific catchment data for the selected validation events, including rainfall data, flow data, catchment wetness data, tide level data and details of any interventions (eg temporary barriers, sandbags etc). Records of any flooding or overland flows should also be obtained from local residents or other stakeholders (photos, videos, witness statements etc), which will be useful to check the simulated overland system flows are a reliable representation. This will be used in the following specific validation checks.

Stage 6 – Define key points

Establish the key points to be used for gauging and comparison of the integrated model against observed flow and level data. Key points may also be identified at flooding properties to represent threshold levels of the properties and allow the comparison of modelled and observed flood depths within the properties for each of the relevant events. Key points may be within the piped or channel network, or on the surface to assess overland flow routes.

Stage 7 – Confirm simulation durations

Identify the durations over which the individual models and the integrated models should be simulated, recognising that the time of concentration and critical duration for a major system is considerably different to a minor system. Normally all the models should be simulated for the same duration.

Stage 8 – Model Testing

Model testing should be undertaken with synthetic design storms and recorded rainfall data. Checks should be carried out on the simulations from the individual component models and the integrated model to identify instabilities, volume imbalances and that the integration points are performing satisfactorily. Volume balances between the integrated drainage systems are particularly important.

Stage 9 – Identify validation parameters

The recorded information from witness statements, photographs and videos should be reviewed to enable the historical performance (flood depths, flow direct etc) to be confirmed. Consideration should be given as to how the simulation outputs are to be presented (e.g. flow hydrographs, depth hydrographs, thematic plans etc) at each of the key points identified, for comparative purposes with the recorded data.

Stage 10 – Validation simulations

Simulate the original baseline or verification events in the individual component models, any updated individual component models and the integrated model for all of the validation events.

Stage 11 – Validation of integrated model

Compare the model outputs at each key point. These comparisons should include the output from all individual and component models and the recorded information. These comparisons determine:

(i) if the integrated model is providing better results than the original or component models and,

(ii) if there is a satisfactory match or correlation between the recorded data and the results from the integrated model.

This assessment should correlate model predictions with the reported flooding and flow routes. The degree to which these correlate dictates the confidence that can be placed in the new model to predict flooding.

Demonstration of confidence in the integrated model outputs is very important when the results are to be released to local residents with detailed knowledge. In the past, the results of some complex 2D IUD modelling studies have been discredited by local stakeholders with a detailed knowledge of the flood routes, which was contrary to the model predictions demonstrated to them.

Stage 12 – Review detailed overland flow representation

This stage is specific to 2D modelling of the overland system and is to ensure that the representation of surface features that dictate surface flow routes is accurate. Further detailed site inspections may be undertaken at this stage to identify all details and features (potentially at a small or micro scale if this is the purpose of the study) which influence or control the overland flow routes. There is further guidance available in other documents on this matter, such as Allitt et al (2008), and a WaPUG User Note is intended for 2009, outlining current best practice in this emerging field, using common modelling software.

Stage 13 – Improve integration representation

Adjust each of the component models as necessary (with evidence based reasoning) and then repeat stages 10, 11 and 12 until such time as a satisfactory match between model outputs and recorded data is achieved. Further site investigations may be necessary at this stage to identify issues with the representation of the individual component drainage systems or the integration points.

Stage 14 – Extreme event performance test

Simulate the validated integrated model for more extreme events and check that the interactions between the component models continue to perform satisfactorily for these events. It may also be necessary at this stage to undertake some sensitivity assessments to identify whether any particular attribute of the model or any particular data input has a dominant effect on the results.

Unlike the verification of minor systems or the calibration of major system models, there are currently no industry guidelines or standards available for the validation of integrated models and the accuracy to which they predict flooding. It is important that the individual component models meet the necessary standards for verification and calibration, particularly in terms of the criteria relating to flooding. The degree of validation necessary for the integrated model should be agreed between all project stakeholders.

SECTION E – Reporting

26.3 Reporting

As with all model building and validation it is necessary to maintain documentation throughout the IUD project to record the work undertaken, the data used and its origin, any assumptions or inferences and the model outputs and level of validation achieved. It is necessary to record details of the interactions between the models and whether the modelled interaction links perform satisfactorily. Section 8 of the WaPUG Code of Practice provides further details on model reporting (WaPUG, 2002).

The model documentation should be sufficient for a new user to fully understand the work that was undertaken to integrate the models, what changes were made to the component models and what level of validation was achieved. Clear guidance should be given for future model use (this should include how to interpret model results/ outputs).

In addition to the detailed technical reporting of the model validation it will also be necessary to provide reports setting out the results of the modelling. These reports may be aimed at a less technical audience and should be in accordance with the project objectives.

In summary, any IUD model reporting should include:

Study scope

- Project definition
- Stakeholders and modelling team
- Initial understanding of problem

Existing component models

- Confirmation of individual component models used
- Summary of reviews or audits of individual component models
- Original fitness for purpose of the individual component models
- Details of model upgrades and surveys undertaken to improve the individual component models
- Summary of new model builds necessary

Model integration

- Details of model integration approach
- Model platforms used
- Confirmation of overland flow modelling approach, identifying and detailing key linkages between models
- Details of site investigations
- Model upgrades in area(s) of integration

Model Validation

- Historical or recorded data used for IUD model validation
- Details of key points and gauges
- Commentary of key changes to achieve validation
- Model validation comparisons to recorded data, including statistics, tolerances and visual flooding extent outputs
- Summarise any limitations on model use and/ or particular uncertainties (generally and locally)

Glossary

British Waterways	British Waterways is the organization responsible for 2200 miles of Britain's canals and rivers.
Calibration	Process of adjusting model parameters to make a model fit with measured conditions (usually measured flows). This process should be followed by verification
Catchment	An area of land where rainwater drains into a single watercourse.
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.
Combined Sewer Overflow (CSO)	The direct discharge wastewater from a sewer system that carries both foul and storm water (combined system) during rainfall. The CSO acts as a point of relief as the system becomes overloaded, discharging wastewater to an adjacent surface water sewer or watercourse.
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 work towards securing a sustainable society and a healthy environment.
Designing for Exceedance	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.
Digital Elevation Model (DEM)	A digital map of the elevation of the ground surface and includes building, vegetations etc.
Digital Terrain Model (DTM)	A digital map of the elevation of the earth's surface without additional surface features ('bare earth')
Drainage Area Plan (DAP)	A full assessment of a sewer systems performance and condition made by the water company, investigating hydraulic, operational, structure and environmental performance. It also proposes a strategy to achieve the desired levels of service.
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 the Environmental policies of Central Government and the Welsh Assembly.
Environmental Regulator	In England and Wales: the Environment Agency (EA), in Northern Ireland: the Northern Ireland Environment Agency (NIEA), in Scotland: the Scottish Environment Protection Agency (SEPA)

Exceedance Flows	Excess flow on the surface once the capacity of the below ground drainage system is exceeded.
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.
Floodplain	Flat, low-lying area adjacent to a watercourse and prone to flooding.
Flood risk	Likelihood of flooding occurring and its consequences of happening.
Flood Risk Assessment (FRA)	An assessment of the likelihood and consequences of flooding in a development area, with recommendations of any mitigation measures.
Floods and Water Bill	The draft bill will create a simpler and effective means of managing the risk of flood and coastal erosion. It will also help improve the sustainability of water resources and protect against potential droughts.
Flood Studies Report (FSR)	Provides techniques for design flood and rainfall estimation in the UK.
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.
Future Water	The Government's water strategy for England, Future Water was published in February 2008. This strategy sets out the Government's long-term vision for water and the framework for water management in England.
Geographical Information System (GIS)	A mapping system to analyse and display geographically referenced information.
GPS	Global Positioning Satellite, used to determine geographical location and elevation.
Groundwater flooding	Flooding caused by increases in the water table to above ground level, due to rainfall.
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 which are not under the responsibility of the Highways Agency

Integrated Urban Drainage (IUD) Pilots	15 Defra funded studies which ran from 2007-2008 to test new approach to working in partnership to improve management or urban drainage.
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.
Integrated Urban Drainage (IUD)	Approach to planning or managing an urban drainage system which leads to an understanding of how different physical components interact
Joint Probability	Analysis of the probability of two or more conditions which affect risk occurring concurrently.
Main River	Main rivers are usually larger streams and rivers, but also include smaller watercourses of strategic drainage importance. The EA has responsibility for main rivers and are designated by Defra.
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.
Major drainage system	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.
Minor drainage system	The underground piped drainage systems which are typically sewers but could also be culverted watercourses or highway drains.
Ordinary Watercourse	An ordinary watercourse is any other river, stream, ditch, cut, sluice, dyke or non-public sewer which is not a Main River. The local authority or Internal Drainage Board has powers for such watercourses.
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.
Return Period	The expected average time between the exceedence of a particular extreme threshold. Frequently used to express the frequency of occurrence of an event e.g. rainfall or flooding.
River flooding	Occurs when river flow exceeds the channel capacity due to rainfall, covering the adjacent floodplain with water.

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 of surface water body.
Surface flooding	Flooding from sewers, drains, small water courses and ditches that occur as a result of heavy rainfall and exceedence 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.
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.
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.
Urban Pollution Management (UPM)	The UPM procedure adopts a risk-based approach to assessing the impact of intermittent discharges on receiving water quality.
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.
Verification	Process of comparing a model against independent data to determine its accuracy.
Water and sewerage company	Ten regional water and sewerage companies (WaSCs) are licensed for England and Wales, set up under the Water Industry Act 1991.
WaPUG	CIWEM's Urban Drainage Group, with a long history of promoting best practice in the field of urban drainage.
Watercourse	A natural or artificial channel along which water flows.

Appendix A – References and Further Reading

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Useful Links

IUD Projects - www.defra.gov.uk/environ/fcd/policy/surfacewaterdrainage.htm

Making Space For Water - http://www.defra.gov.uk/Environ/Fcd/policy/strategy.htm

http://www.defra.gov.uk/Environ/Fcd/policy/strategy/bestpract.htm

IUD Pilots - http://www.defra.gov.uk/environ/fcd/policy/strategy/ha2.htm

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Appendix B – Example Questionnaire

Sewer Flooding Questionnaire

Property Details

Flooding Property Reference:

Details of owner if different:

Tel:

email:

Tel:

email:

Section 1 – The Property

Type of property (Industrial, Residential, please specify)

Time at the property (years)

Record of dates on which flooded (dd/mm/yyyy)

Was it rainwater or sewage flooding?

Describe if necessary/available photographs\video?

How extensive was the flooding?

External only?

Internal (ground) ?

Garage?

Other out buildings?

Garden?

Road/Path?

Basement?

Joined or detached?

Front?

Back?

If external please indicate percentage covered

Does the property have a basement?

Is it in use?

What for? Does it have a drainage connection? Sink, toilet etc.

Section 2 - The Flooding

Do you know where the flooding came from?

Manhole in road?

Manhole on property?

From under and edges of doors/air bricks, from external

Ditch or watercourse?

Water not able to drain from garden?

Gully in road?

Through toilet bath etc?

Cracks or through floor?

Drains/basement connection?

Other (please detail)

Were you told what caused the flooding?

Yes

No

What was the reason given?

Heavy Rainfall

Broken/problem pipe

Blockage on your drain

Blocked gully

Other (details) [ ]

Do you agree? Do you have an opinion on the cause? Yes [ ] No [ ]

Your view

Would use of the toiled or sink/bath resulted in overflowing? Yes [ ] No [ ]

Details

During flooding could you always exit and enter your property through normal routes? Yes [ ] No [ ]

Details

Have you needed to vacate your property because of a flooding? Yes [ ] No [ ]

Details

Section 3 Mitigation and cleanup

Have any professionally fitted flood defence measures been fitted to address the flooding? Yes [ ] No [ ]

Pumps, barriers etc.

Details

Have you put in place any preventative measures? Yes [ ] No [ ]

Sandbags/landscaping/walls/barriers etc.

Details

How did you undertake the cleanup?

- Used a self selected professional company? [ ]
- Professional company selected for you? [ ]
- (If so by who?) [ ]
- No company used [ ]

I confirm that the above information is to the best of my knowledge accurate

Name

Signature

Date