CIWEM Chartered Institution of Water and Environmental Management

Urban Drainage Group

Code of Practice for the Hydraulic Modelling of Urban Drainage Systems

Version 01

CIWEM Chartered Institution of Water and Environmental Management
Urban Drainage Group

Code of Practice for the Hydraulic Modelling of Urban Drainage Systems 2017.

www.ciwem.org/groups/udg

Technical enquiries

All technical enquiries and suggestions relating to this publication should be addressed to the Urban Drainage Group mailbox: UDG@CIWEM.org.

The Code of Practice is issued for guidance in good faith following extensive industry consultation. CIWEM cannot accept responsibility for consequences arising from its application. It is intended that the Code of Practice will undergo periodic review to reflect good practice and new technologies as they mature.

This entire document may be freely copied provided that the text is reproduced in full, the source acknowledged and provided it is not sold.

Version Control

Version Number	Description	Date
01	First release to industry	3rd November 2017

Acknowledgments

Authors

Version 1 of this guidance was written by an industry team:

John Titterington	MWH now part of Stantec
Graham Squibbs	MWH now part of Stantec
Chris Digman	MWH now part of Stantec
Richard Allitt	RAA
Martin Osborne	WSP
Paul Eccleston	JBA
Alan Wisdish	Atkins

Project Steering Group

The project was carried out with the guidance and assistance of the Project Steering Group Members, their representatives and colleagues as follows:

Keith Kipling (Chair)	CIWEM UDG and United Utilities
Elliot Gill (Co-Chair)	CIWEM and CH2M
Ed Bramley (Co-Chair)	CIWEM and Yorkshire Water
Nadia Peters	Anglian Water
Phil Hulme	Environment Agency
Francis Finnerty	Irish Water
Nicola Hyslop	Northumbrian Water
Bob Fleming	Scottish Water
Mark McLaughlin	SEPA
David Terry	Severn Trent Water
Marc Barton	Southern Water
Andrew Hagger	Thames Water
Steve Kenney	United Utilities
David Ripley	Welsh Water
David Searby	Wessex Water
Mark Russell	Yorkshire Water

CIWEM also thank the Water Environment Federation (WEF) -Collection Systems Committee Technical Practice Group for their comments.

CIWEM is the leading independent Chartered professional body for water and environmental professionals, promoting excellence within the sector.

© November 2017. The Chartered Institution of Water and Environmental Management (CIWEM).

106 to 109 Saffron Hill, Farringdon, London, EC1N 8QS. Tel: 020 7813 3110.

Charity Registration No. 1043409 (England and Wales) SCo38212 (Scotland)

Contents

1 INTRODUCTION

1.1 Purpose of the Code of Practice

The Code of Practice (CoP) is intended to be a good practice guide to the hydraulic modelling of urban drainage systems. It is primarily based on the modelling practices in the UK and Ireland, and if used outside this geographic area the user must apply judgement in adapting this to local conditions and practices.

The CoP is not software specific, although some examples may use a particular software product. It should be noted that the choice of software to use must be commensurate with the required confidence in the modelling outputs.

It is not intended to be used directly as a specification for modelling and Commissioning Bodies should consider the development of their own more detailed specifications.

1.2 Terminology and language

The CoP uses language and terms predominantly related to the United Kingdom and Ireland, although the practices outlined will be relevant for use internationally. A glossary of terms is included to aid the user who is not familiar with these

1.3 Target audience

The target audience is urban drainage practitioners who are actively involved in the commissioning, development, use and maintenance of hydraulic models in the urban environment. In particular this will include the *Commissioning Body*, the organisation who commissions the work and the *Modelling Team*, those who undertake the modelling work. Examples of a Commissioning Body could be a Government Department, Water Company or a Local Authority. In this CoP, reference is made to the Modelling Team as the ‘Modeller’ for ease of reference, but may refer to the team or an individual from the team.

1.4 Stakeholders

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

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

The stakeholders to be considered include (but are not restricted to):

- External Stakeholders – Government, Regulators, Water Companies, Lead Local Flood Authorities, Local Authorities, Internal Drainage Boards, etc.
- Internal Stakeholders – Any internal department with a responsibility for an aspect of a project (e.g. Asset Planners, Operations Teams)

- Customers and Communities – Should consider all aspects of potential customer interaction through Consumer Organisations (e.g. Council for Water), Local Customer Action Groups, Domestic and Commercial Customers, etc.
- Pressure Groups

It is good practice to develop a Stakeholder Management Plan, identifying systematically the relative importance of stakeholders to the project, and setting out a plan of action to communicate with, engage with and reflect concerns of stakeholders.

1.5 Experience and training of staff

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

Work should be carried out by, or under the day to day direction of, a competent hydraulic modeller who should have a detailed understanding of drainage and sewerage systems and the various processes involved, including (but not limited to):

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

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

1.6 Applying the Code of Practice

1.6.1 What it covers

The CoP covers the hydraulic modelling of both the underground piped drainage systems and the above ground systems, together with their interaction in the urban environment. The below ground systems are typically made up of sewers but could also be culverted watercourses or highway drains. The above ground systems would include watercourses that form the principal drainage pathways for catchments and the overland flow paths on river flood plains and the urban environment.

Elements of the integration of the two systems are considered more fully in the CIWEM UDG (2009) Integrated Modelling Guide.

The CoP does not cover the non-hydraulic elements of water quality modelling, water quality aspects of the impact of urban discharges on the receiving watercourse, or the development of standalone watercourse models for flood risk management purposes.

1.6.2 Modelling process

Figure 1-1 shows a typical high-level sequence of the processes involved in the development of Urban Drainage Models, and this CoP covers all these aspects. Although this shows a linear process, some tasks may run in parallel, such as building or updating a model may occur at the same time as undertaking the flow survey.

Section 8 of the CoP covers documentation for all the sections of the Code. . It should be noted however that the review and documentation process is an ongoing activity which should be carried out throughout the development of the project and not left to the end.

1.6.3 Aligning with other practice

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

Essential:

- Rainfall Modelling Guide 2016, Version 1.0 March 2016
- Integrated Urban Drainage Modelling Guide 2009, V01-001 June 2009
- Competency Framework, Draft November 2015
- Event Duration Monitoring Good Practice Guide, Version 2.2 January 2016
- CIWEM UDG User Notes:
    - User Note 1 – Modelling Vortex Flow Control devices, Version 4, (2009)
    - User Note 2 – Modelling ancillaries and discharge coefficients, Version 3, (2009)
    - User Note 13 – The dangers of force fitting, version3, (2009).
    - User Note 15 – Storage Compensation, version 3, (2009).
    - User Note 22 – Selection of tide levels, version 3, (2009)
    - User Note 27 – Modelling ancillaries: weir coefficients, version 2, (2009)
    - User Note 28 – A new runoff model, version3, (2009)
    - User Note 33 – Modelling dry weather flow, version 2, (2009)

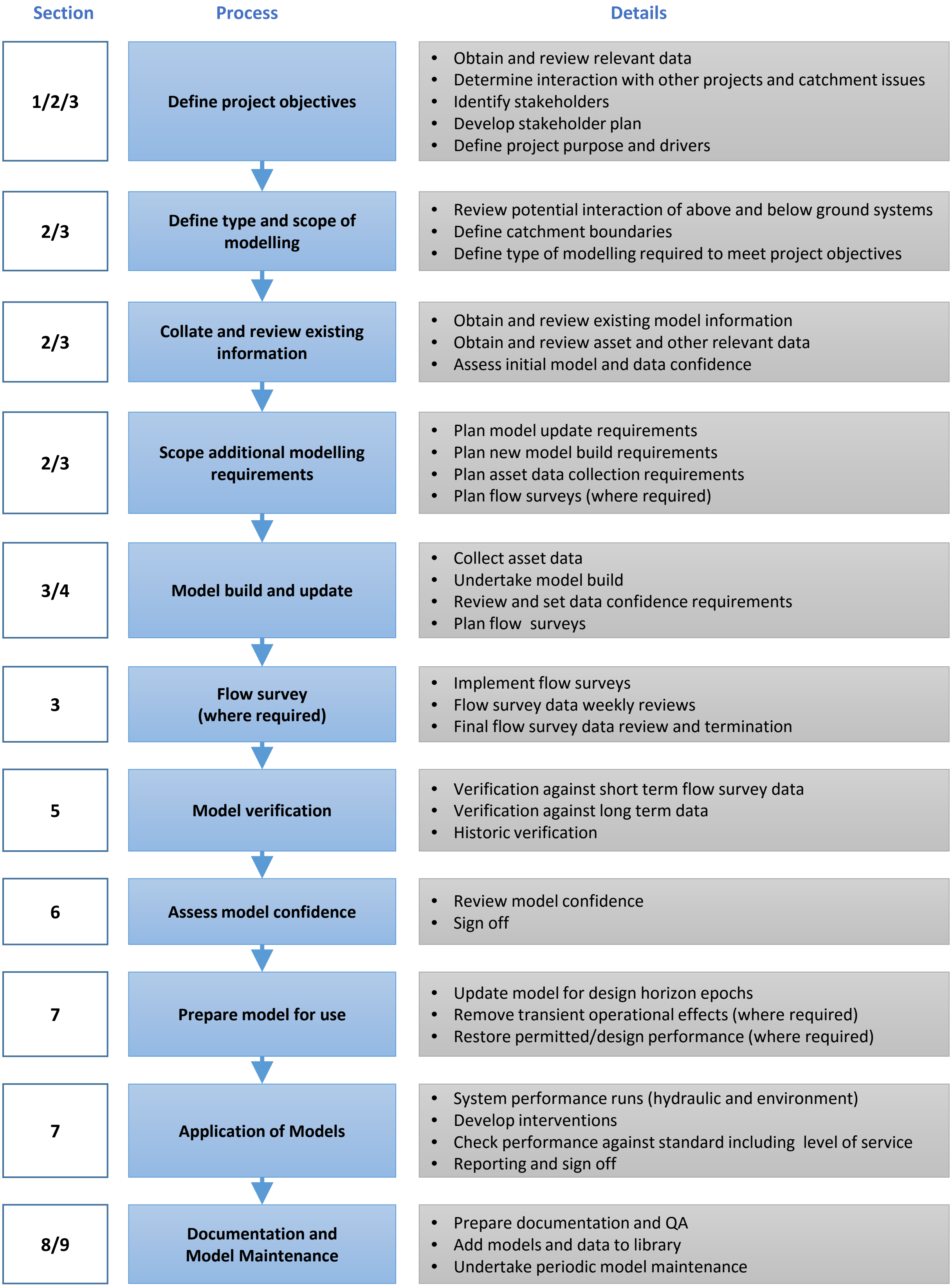
More relevant for Urban Pollution Management (UPM) and water quality modelling by CIWEM DUG:

- Guide To The Quality Modelling Of Sewer Systems, Version 1.0 November (2006)
- River Modelling Guide, Version W01 November (1999)
- River Data Collection Guide, Version W01 November (1999)

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

- C635 Designing for Exceedance in Urban Drainage - Good Practice, (CIRIA, 2006)
- C753 The SUDS Manual, (CIRIA, 2015)
- Drainage Strategy Framework, (Ofwat/EA 2013)
- Flood Estimation Handbook (FEH), issued in a set of five printed volumes (Centre for Ecology & Hydrology, 1999)
- Flood Modelling Guidance for Responsible Authorities Version 1.1, (SEPA, 2017)
- Sewerage Risk Management (SRM), (WRc, 2017)
- Sewers for Adoption 7th Edition, (WRc, 2012)
- Sewers for Scotland 3rd Edition, (Scottish Water & WRc, 2015)
- Surface Water Management Plan Technical Guidance, (Defra, 2010)
- The Fluvial Design Guide, (Environment Agency, 2010)
- Urban Pollution Management (UPM) Manual, (FWR, 2012)

If there is any discrepancy between this Code of Practice and other CIWEM UDG documents, the Code of Practice will take priority unless the CIWEM UDG documents post-date this Code of Practice.



Section	Process	Details
1/2/3	**Define project objectives**	- Obtain and review relevant data - Determine interaction with other projects and catchment issues - Identify stakeholders - Develop stakeholder plan - Define project purpose and drivers
2/3	**Define type and scope of modelling**	- Review potential interaction of above and below ground systems - Define catchment boundaries - Define type of modelling required to meet project objectives
2/3	**Collate and review existing information**	- Obtain and review existing model information - Obtain and review asset and other relevant data - Assess initial model and data confidence
2/3	**Scope additional modelling requirements**	- Plan model update requirements - Plan new model build requirements - Plan asset data collection requirements - Plan flow surveys (where required)
3/4	**Model build and update**	- Collect asset data - Undertake model build - Review and set data confidence requirements - Plan flow surveys
3	**Flow survey (where required)**	- Implement flow surveys - Flow survey data weekly reviews - Final flow survey data review and termination
5	**Model verification**	- Verification against short term flow survey data - Verification against long term data - Historic verification
6	**Assess model confidence**	- Review model confidence - Sign off
7	**Prepare model for use**	- Update model for design horizon epochs - Remove transient operational effects (where required) - Restore permitted/design performance (where required)
7	**Application of Models**	- System performance runs (hydraulic and environment) - Develop interventions - Check performance against standard including level of service - Reporting and sign off
8/9	**Documentation and Model Maintenance**	- Prepare documentation and QA - Add models and data to library - Undertake periodic model maintenance

Figure 1-1 High Level Modelling Sequence and Sections of the Code Covered.

2 PROJECT DEFINITION

2.1 Scope and context

This section covers the scoping of modelling projects, including defining the project purpose and drivers, the types of models required and the confidence in the output required for the project. The process for this section is outlined Figure 2-1.

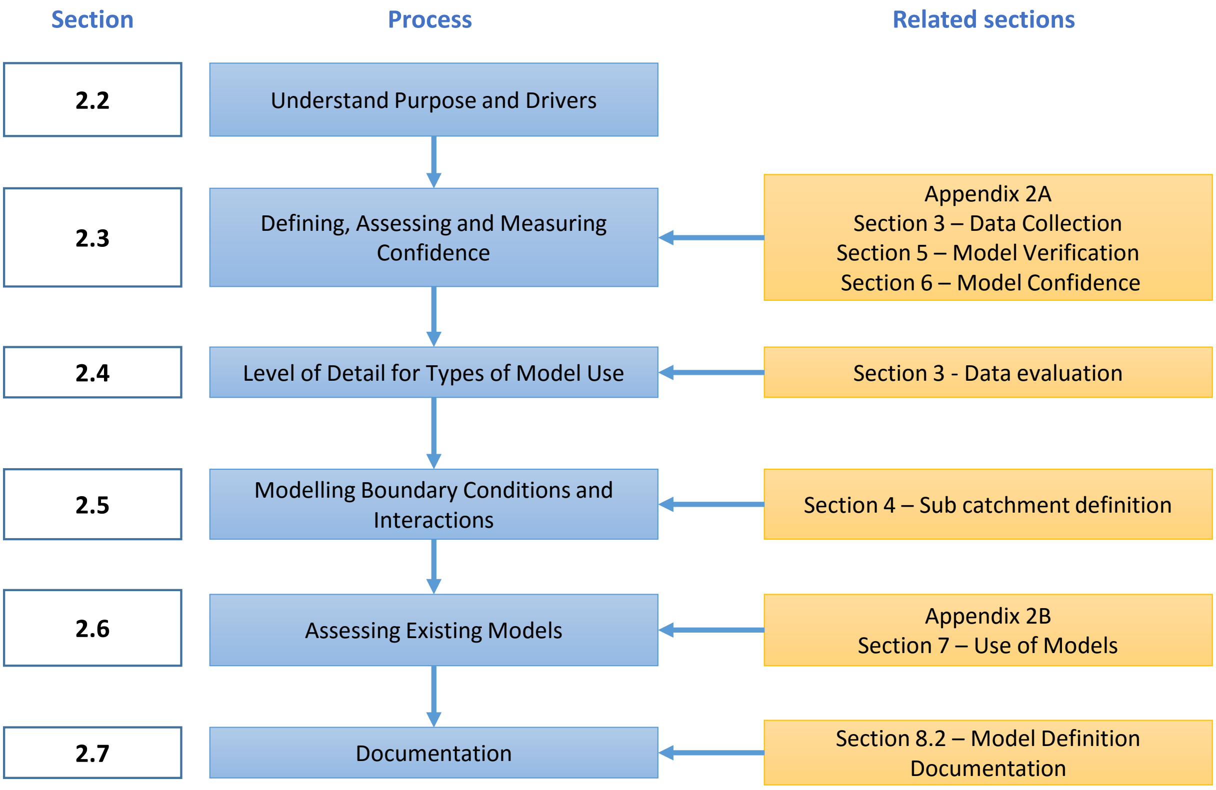


Figure 2-1 Project Definition Overview

2.2 Purpose and drivers

Before embarking on producing a hydraulic model the purpose and required use of the model should be clearly defined.

There are numerous potential reasons for requiring a model, including, but not limited to models needed for general planning purposes, operational use, development control, problem investigation and detailed design of interactions. In each case there is potential for differing requirements in terms of modelling techniques, standards of data collection, modelling detail and verification, leading to varying levels of model confidence.

It is therefore necessary to define the information required from the model, the points at which this information is required and the confidence required in the modelled outputs. The responsibility for defining this would normally rest with the Commissioning Body as the ultimate user and custodian of the completed model, after taking account of the requirements of key stakeholders. In some instances there may be a need for approval of the modelling scope by others, for example by an environmental regulator for a model to be used for an assessment of the impact of intermittent discharges on the receiving environment.

2.3 Defining, assessing and measuring model confidence

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

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

There are five main categories to consider when assessing and measuring confidence. These are:

- Asset data, including real time controls (RTC)
- Subcatchment data
- Flow data
- Flow verification
- Historical verification

Each of these areas will have varying levels of confidence, dependent on the level of detail, accuracy and amount of data used in the model. As a general rule the more surveyed data are used in the model, either from physical surveys or from other reliable sources, the higher the model confidence.

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

The level of detail required for data collection is considered further in **Section 3** of the CoP, and verification is considered further in **Section 5** and associated appendices**. Section 6** and associated appendices provides a framework for confidence to be assessed in a qualitative or quantitative approach.

It is unlikely that there will be a need for a uniform standard of confidence across the whole model. As a Commissioning Body, there will be a need to determine the areas (zones) or elements of the model that require a higher level of confidence, for example in an area of reported flooding or a CSO discharge known to be impacting on the receiving environment with a potential for a scheme. **Appendix A** provides examples of defining model confidence levels qualitatively in different parts of a catchment, and the level of detail for different types of use are considered below.

2.4 Types of model use and levels of detail

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

- The level of detail of the model
- What parameters are modelled? This is limited to hydraulic only in the CoP
- The number of dimensions in which the modelling is undertaken
- The hydrology which has been used in the model

All types of models may contain elements of both the above and below ground drainage systems but the general principles apply in all situations. The CoP provides some guidance for modelling watercourses but other documentation should be consulted as outlined in **Section 1.6.3**.

2.4.1 Level of detail of elements of the model

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

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

Many models built or updated will be a "Hybrid" of the three levels, i.e. they will have a varying level of detail in specific areas or in relation to certain types of assets or features, as detailed in the project scope.

Models typically have two components. These are:

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

As models are generally built from GIS based sewer record databases there has been a progression in the industry towards "all pipe models". These are built from existing records and therefore they will typically be a Type II level of detail.

More information is provided in **sections 4.2** and **4.3**

2.4.1.1 Type I - Simplified

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

- A simulation of the flows and conditions at one or more specific locations (e.g. sea outfall, pumping station, treatment works)
- A simulation of the boundary conditions in a trunk sewer, an intercepting sewer or a watercourse so that more detailed models of connecting sewer systems or smaller watercourses can be modelled with the correct tailwater conditions, etc.
- A simple framework model of a network into which a detailed model can be incorporated, obviating the need for boundary conditions to be deduced

- A reasonably accurate representation of a trunk sewer system, an intercepting sewer system or a watercourse without needing to model exactly the layout of tributaries or contributing sewer networks
- The backbone of a rapid simulation model such as one that might be required for flood forecasting purposes

Flow generation will typically be based on sewer records with no contributing area site surveys, and subcatchments would tend to be larger than in more detailed models.

This type of model detail is not adequate for detailed modelling or for general planning purposes.

2.4.1.2 Type II – Planning

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

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

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

Type II model detail should include all significant ancillaries (although small pumping stations may be omitted) and typically all known problem areas, particularly those of known flooding or surcharge. Simplification of the network in the model is not normally undertaken, although consideration could be given to trimming smaller diameter sewers of 150mm or below from the model, ensuring that all low lying manholes at low points are still included in the model.

Pipe data will typically be based on GIS records with some interpolation of missing data. Asset surveys would be limited to major junctions, assets and areas of significant uncertainty.

Flow generation will typically be based on examination of record plans and experience. For partially separate systems, sample contributing area surveys may be carried out or additional verification undertaken.

2.4.1.3 Type III - Detailed

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

For Type III detail, it is frequently necessary to undertake additional manhole surveys in specific areas of interest to obtain information not held in records and to confirm the accuracy of data, rather than rely on interpolated data.

Type III model detail will typically be within a model of Type II detail but with all known assets (private and adopted) included. For example in the UK Ex-Section 24 sewers, section 105a sewers, and all adopted sewers may be included as well as selected private sewers and drains if there is a need to assess potential flooding in detail. This may entail additional surveys of private drainage systems to ensure all low spots have been identified.

Flow generation will be similar to Type II models, with potentially more focus on sample connectivity and contributing area surveys.

Modelling of watercourses and any 2D elements will generally be the same as for a Type II model but with extra or finer detail included where relevant.

2.4.2 Dimensions

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

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

Guidance on the modelling of interactions between above and below ground systems is given later in **section 2.5** and **section 4.4**.

2.4.3 Hydrology

There are a number of alternative methods for modelling the hydrology of a catchment and the most suitable method to use will depend on a number of factors. In most instances, the Commissioning Body will have specific requirements in respect of hydrology that are usually used for the purposes of consistency. This is considered further in **section 4.2.4**.

2.5 Modelling boundary conditions and interactions

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

Checks should be made at outfall locations against fluvial flood map outlines for the appropriate return period, to identify potential issues with locking of the outfalls.

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

Reference should be made to the CIWEM UDG (2009) Integrated Modelling Guide and the EA (2010) Fluvial Design Guide for more information on these system interactions.

2.6 Assessing existing models

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

Where an existing model is to be considered for re-use a formal assessment process should be carried out, allowing model confidence levels to be assessed in the five areas detailed in **section 2.3**.

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

Appendix B contains a typical list of the items for review. It may be beneficial to carry out a two stage process. This would entail a quick overview assessment to identify if there is any prospect of the upgrade and re-use of the model being economically viable. If the model has good potential for use, the second stage of the process would follow a more detailed examination and assessment of the work required to bring it up to required standards for the current purpose.

2.7 Documentation

Documentation is key to the successful delivery of a modelling project. As a minimum, a scoping or project definition report should be produced the format of which should be set by the Commissioning Body. This would include the project objectives, the extent and type of models to be built, the data collection requirements and the results of any “fit for purpose” reviews outlined.

3 DATA REQUIREMENTS AND DATA COLLECTION

3.1 Introduction

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

This section outlines the data requirements and the processes for planning and implementing a successful data collection programme for an urban drainage project. It includes:

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

Each of these topics is discussed in more detail in the following sections. An overview of the section is shown in Figure 3-1.

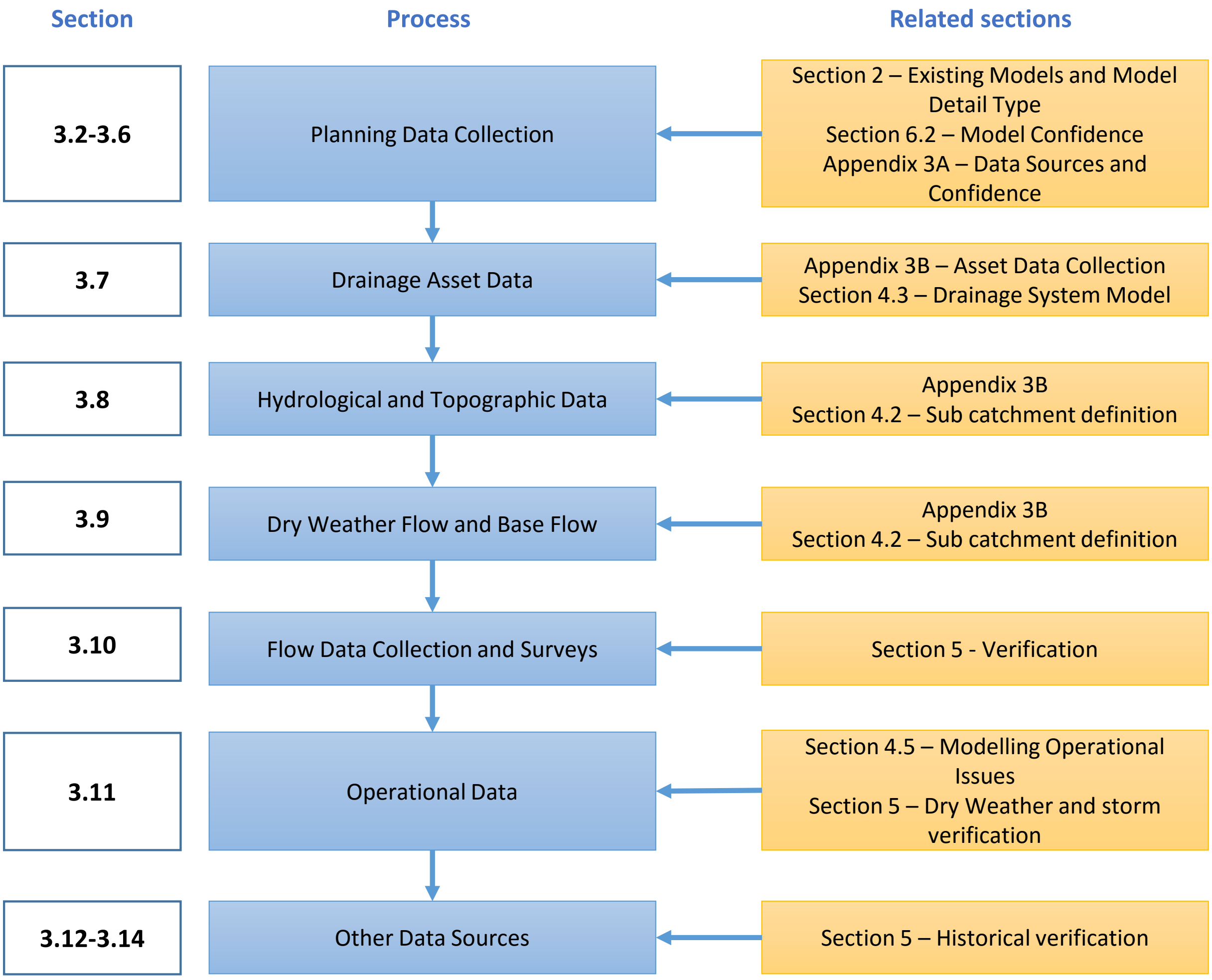


Figure 3-1 Data Requirements and Collection Overview

It should be noted that data collection may be undertaken for a specific project or as part of normal business activities by the Commissioning Body.

When carrying out any data collection activities, Health and Safety should be at the forefront of all activities. Company and Commissioning Body Health and Safety processes and procedures must be followed. Carrying out surveys should be a last resort where alternative methods have been exhausted.

3.2 Principles for data collection

The principles for successful data collection are summarised in Table 3-1.

Table 3-1 Principles for successful data collection.

Category	Principles
Programme	o Obtain data and information in time to avoid delaying the programme. o Anticipate delays in getting data and have contingency plans to resolve these. o If a delay cannot be avoided then inform the Commissioning Body early
Quality	o Check that incoming data matches what is required o Assess Data Confidence and identify any implications for the current project and future model use. o Resolve discrepancies between different information sources so the most suitable values are used in the project o Raise any risks and issues with the Commissioning Body.
Efficiency	o Assess all readily available data and information for re-use before recommending further data collection. o Justify additional data based on its value in reducing uncertainty o Specify that data provided is in a format that requires minimal reprocessing before use; to reduce time, cost and potential errors. o Process data and information efficiently, including developing new methods.
Records	o Keep records of the above for audit. o Provide data back to the Commissioning Body at the end of the project to allow updates to the corporate records and storage for future use.

3.3 Partnership working

Key stakeholders should be identified at the project definition stage, together with the potential opportunities and benefits for collaborative working to assist collecting data. Sharing existing data and collaborative physical data collection can reduce costs, improve the knowledge of the catchment, and provide data from a wider range of sources. Guidance related to data sharing and data from different stakeholders is given in the following documents:

- Drainage Strategy Framework (OFWAT/EA – 2013)
- Surface Water Management Plan Technical Guidance (Defra,2010)
- Integrated Urban Drainage Modelling Guide (CIWEM UDG, 2009)

3.4 Planning Data Collection

3.4.1 Approach

The data collection scope should be defined including both existing and new data. Initially, existing data should be assessed, and its confidence evaluated (see **section 6.2**), including any data collected as part of earlier studies. This should help confirm the new data required and enable a plan to be developed. If doubt exists over the quality of the existing survey data, a partial re-survey may be carried out to establish its quality. This may then be followed by a full re-survey if appropriate.

3.4.2 Sources of data

Table C-2 in **Appendix C** includes a "long list" of the data that may be used in an urban drainage study or project together with the likely primary data sources. The list includes asset data; models; historical records/operational data; flow and other time varying data; hydrological data and mapping/digital terrain data.

3.4.3 Use of existing data

Existing data should be used as much as possible either in building new models or providing extra detail to existing models. Stakeholders who might hold information relevant to the modelling process should be contacted early to assess what is available.

A typical data collection and review process is shown in Figure 3-2.

3.4.4 Data quality, data confidence and uncertainty

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

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

As outlined in **section 2.4**, there are generally three types of model detail, depending upon the proposed use of the model.

Typical data collection levels for use with each type of model detail are given in Table 3 – 1 below, ranging from A to D depending on the level of detail.

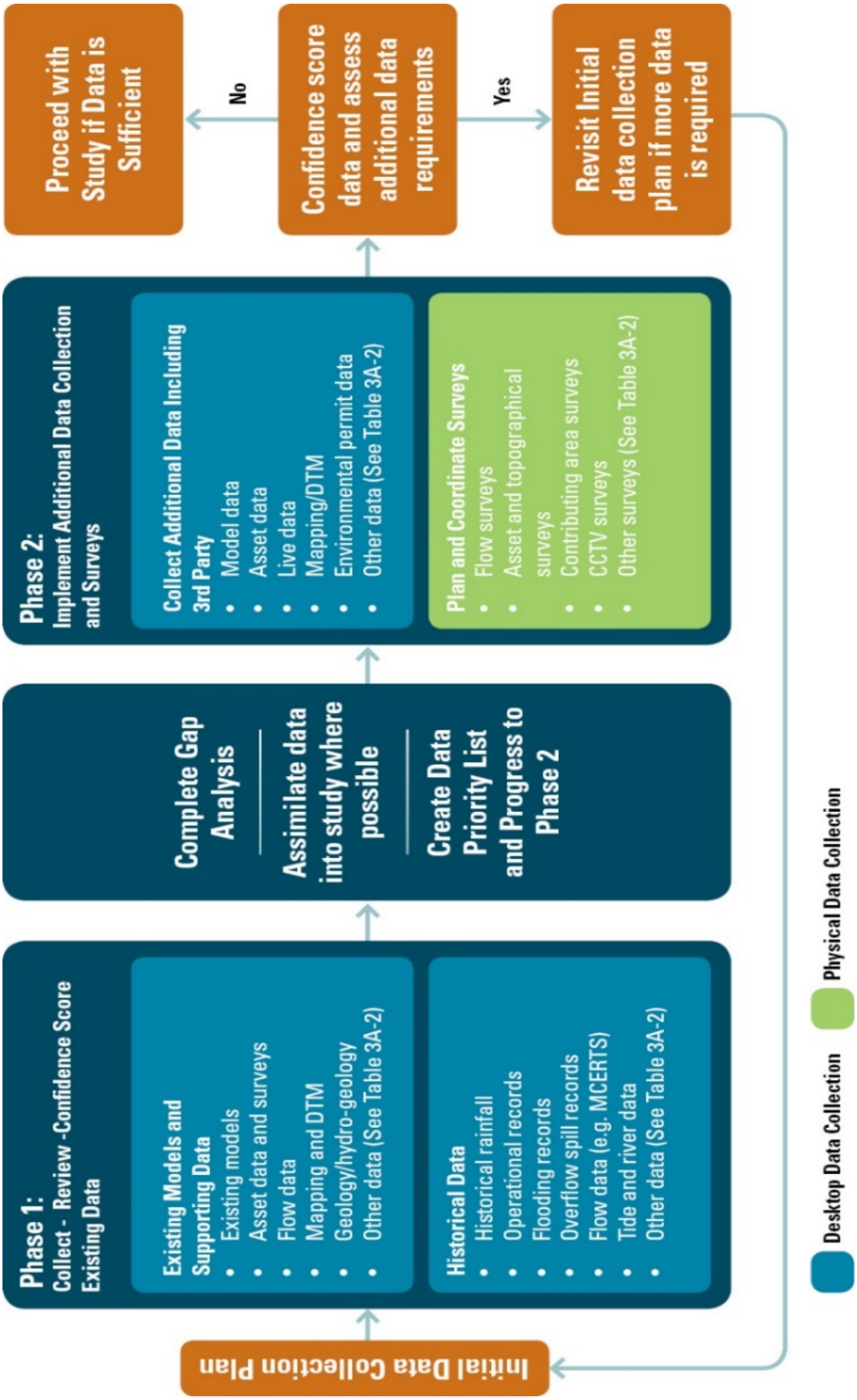


Figure 3-2 Typical Data Collection Process

The suggested data collection and checking methods for each class of data and for each level of detail are summarised in Table C-1 in **Appendix C**. This promotes a tiered process to collect data.

Table 3-1 typical data collection levels.

Model Detail Type	Type I	Type II	Type III
Manhole and pipe data	D	C	B
Checks on urban drainage records	D	B	A
Ancillary data	A	A	A
Contributing area data	C/D	C	B
Operational data	C	A	A
Dry weather flow data	Depends on significance of dry weather flow in total flow		
Infiltration data	Depends on significance of infiltration flow in total flow		
Boundary condition data	Depends on significance of boundary condition		
Pipe roughness data	D	B	B
Sediment data	D	B	B

When lower levels of data collection are applied it should be expected that more data checking will be carried out at the model verification stage.

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

Level A data should be obtained where missing:

- In the location of all project drivers under investigation, for all elements of the hydraulic environments
- In the areas of 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 levels B-C closer to key areas may be considered appropriate, but modellers must understand the uncertainty and risks associated with this. Level D data should be avoided for the key project drivers or interaction areas and but may be considered in areas of less significance.

It is good practice for confidence grades to be assigned to data as this promotes transparency and helps identify risks. In combination with identifying missing data, data confidence scoring should facilitate the compilation of a data priority list to aid the data collection process, particularly where there are budgetary constraints. The priority list will define the data required and its relative importance, together with the potential sources, estimated costs and timescales.

It is generally assumed that a higher detail of information will provide higher confidence in the outputs. The suggested grading system (A-D) can be linked to the detailed confidence guidance included in **Section 6.2**. This is shown visually in Figure 3.3.

Figure 3 – 3 Data Collection Levels A to D

The use of flags and geo-spatial mapping will help assess data confidence as detailed in **sections 2.3, 4.1.3** and **6.2**.

3.5 Survey guidance

Updating or building new models may require further survey work, although this should be minimised as outlined later in **section 3.6.** Commissioning bodies may have their own data collection guidelines to complement or replace industry standard guidance

The main types of surveys and industry standard practice guidance are:

- 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 (2013) Manual of Sewer Condition Classification - 5th Edition, and WRc (2005) Model Contract Document for Sewer Condition Inspection 2nd Edition
- River gauging and cross section surveys – CIWEM UDG (1998) River Data Collection Guide, and Environment Agency (2013) National Standard Contract and Specification For Surveying Services "

Although some of the documents above are quite old, the principles contained within are still valid despite advances in data collection equipment and the data collected.

Useful guidance on data collection for urban drainage projects is included in the CIWEM UDG (2009) IUD Guide and the WRc (2017) Sewerage Risk Management Website. These focus on data collection for flood risk studies and sewerage projects/planning studies respectively.

When additional information is obtained, it is good practice to update any corporate data sources with the new information.

3.6 Existing models

The availability, quality and suitability of existing models should be identified at the start of the project as outlined in **section 2.6**. This should include a review of the confidence in the model or specific data items contained within it for potential re-use.

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, although this is increasing. These models may have been built for a variety of purposes (e.g. drainage area planning, CSOs, or flooding investigations). Environmental Regulators or Flood Authorities often also have models for main rivers and significant watercourses.

In the UK it is rare that a Highways Authority has models of the highway drainage.

New developments that are subject to sewerage adoption procedures by the relevant authority may have models prepared as part of the application process.

Groundwater and coastal models may also be available for some areas, usually from the Flood Authorities or Water Company.

3.7 Drainage asset data

Appendix D gives guidance on the key points to consider and data to collect for all types of assets. It also provides guidance on non-man entry surveys, system connectivity and Real Time Controls (RTC).

3.8 Hydrological and topographic data

3.8.1 Soil data

Soil data are required for many run-off models. The data required will depend on the particular runoff model used.

3.8.1.1 Winter Rainfall Acceptance Potential (WRAP) Classes

The Wallingford Procedure runoff models require the Winter Rainfall Acceptance Potential (WRAP) value. This should be obtained from the Wallingford Procedure and is applicable to the UK and Ireland. However in some cases, due to local variations, the small-scale maps in the Wallingford Procedure contain insufficient detail. Where this is the case the information should be checked using large-scale geological survey information or local knowledge.

3.8.1.2 Hydrology of Soil Types (HOST) Classes

Hydrological analysis for rural catchments in the UK generally now uses the 29 HOST classes. These have associated hydrological parameters defined in detail with maps of superficial deposits and are available digitally from a number of sources including the Flood Estimation Handbook (FEH) website (Centre for Ecology and Hydrology (CEH)).

3.8.1.3 Other soil data

For many non-UK catchments, alternative mapping to HOST and WRAP should be available to derive equivalent soil parameters.

Runoff models such as SCS, Horton and Green-Ampt use parameters which require measurement in the field or estimation from tabulated data for generic soil texture categories.

3.8.2 Contributing area data and connectivity to drainage system

A number of methods of data collection are available for contributing area data. The method selected will depend on the data collection level driven by existing data gaps, the overall required levels of model confidence, and the uncertainties linked to the type of drainage system. For combined and surface water systems, where all properties are known to drain to the sewer system, it is seldom necessary to carry out detailed surveys to determine runoff surface areas/types and their connectivity to sewer system. For partially separate systems, contributing area surveys will almost always be required. For foul systems where there may be a small number of misconnections, the cost of large surveys to determine areas connected may not always be justifiable. In these cases the use of experience together with flow survey data may be appropriate**.**

Methods of data collection include direct measurement, contributing area surveys and comparing to flow survey data. Comments on these are as follows:

3.8.2.1 Direct measurement from background mapping and urban drainage records

Where there is confidence in areas and connectivity, existing urban drainage records and background mapping (including DTM and aerial photography) should be used to determine contributing areas and runoff surface types.

3.8.2.2 Contributing Area Surveys (CAS)

Contributing area surveys (CAS) (sometimes referred to as Impermeable Area Surveys (IAS)) involve the survey of roofs, roads and other paved surfaces, and in some cases permeable surfaces.

Further information on contributing area surveys is included in **Appendix D**.

3.8.2.3 Gullies

Gullies are critical in the detailed coupling of 1D and 2D models. Web based aerial photography and street mapping provide convenient desktop methods of making virtual site visits to identify these. In some cases, the highway authority will hold mapped gully locations.

3.8.3 Topography

3.8.3.1 Surface and terrain

Surface and terrain data are a critical requirement for:

- Above ground (2D) surface flow modelling for flood risk assessments
- Below ground modelling (basements) for flood risk assessments
- Flood hazard mapping

The most convenient source of surface topography data is Digital Terrain Model (DTM) data which provide a fast and convenient way of building large terrain/surface models very quickly. The definition of these terms is included in the glossary.

The above data are available in various resolutions which are defined by the grid size which typically varies from 0.25m to 5m for most areas of coverage in the UK. The best available DTM data should be obtained, at the highest resolution available, subject to limitations of cost. There are limitations with DTM; see **section 3.8.3.2**.

Commissioning Bodies may have their own sources or central storage of DTM data. Alternatively, other stakeholders may hold this data that is freely available. In England and

Wales, DTM data (LIDAR) can be downloaded freely. Similar Government data sources may be available elsewhere.

3.8.3.2 Data concerns and validation

DTM data from UK sources will often have been edited and subjected to a series of validation checks. For river channels, these may include a check to ensure blockages have been removed, such as bridges and vegetation. Manual checks may also have been undertaken using an extreme flood extent to identify and remove any remaining false blockages together with a check at the boundaries of DTM data sets to ensure there are no steps in ground level.

Data should be checked to confirm whether the above validations and corrections have been undertaken and where appropriate the data should be manually edited/corrected.

In addition to the above, the following checks should be carried out:

- The data should be compared (ground truthed) against available information where appropriate (e.g. site data, on-line aerial photography and general observations with local knowledge)
- A geographic query should be run to check the DTM model correlation at nodes with cover levels noting that incorrect plotting of manhole positions my give rise to false differences in levels

Large missing areas of data may be provided by flying the area or ground scanning systems where economically viable. However, if the area of the study is small it may be more appropriate to undertake a topographical survey where coverage is lacking.

3.8.3.3 Additional surface data

A DTM will rarely, if ever, include very detailed features such as fences, walls, dropped kerbs and speed bumps. These subtle changes in local topography can significantly affect the direction of flow and extent of flooding particularly during higher probability events where depths may be low. Typically, it is only necessary to identify and collect this level of detail in specific areas of interest (i.e. where they influence flow paths and flood risk). This information can be gathered from a site visit and survey, but it may be possible to identify some features through aerial photography and street level applications.

3.8.4 Rainfall data

Rainfall and climate change data, where required, should be collected and developed using the guidance in the CIWEM UDG Rainfall Guide. This includes guidance on the generation and application of:

- Rainfall for model verification
- Radar rainfall
- Design Storms (e.g. FEH for UK) including seasonal correction factors
- "Superstorms" (Critical Input Hyetographs)
- Historic and Stochastic Rainfall Series
- Application of antecedent conditions, evapotranspiration and climate change

3.9 Dry Weather and Base Flow

3.9.1 Foul Flows

Dry weather flow is covered in detail in CIWEM UDG (2009) User Note 33 and in the CIRIA (1998) "R177 Dry Weather Flow in Sewers". Data from a number of sources may be used to derive and verify foul flows including:

- Population figures
- Water usage data
- Trade effluent permits and measurements (of water usage or discharge)
- Flow surveys

Other sources of data that may be used include:

- Postal address point data
- Pumping station telemetry
- WwTW flow data – typically recorded is flow to full treatment (FFT) and sometimes also flow to works (FTW)
- Other Long Term Monitoring Data

The accuracy required for dry weather flow data collection will depend on the ratio of dry weather flow to storm flow and the use of the model. Also the purpose of the model and the level of accuracy required should be considered. For example detailed flooding models will require a higher level of accuracy than an SMP. Diurnal, weekly or seasonal variations in dry weather may be significant and should be considered in the data collection. Where measuring dry weather flow to provide a typical per capita diurnal profile, points near the head of the system should be used due to attenuation in larger catchments as described in CIWEM UDG (2009) User Note 33.

3.9.1.1 Domestic Flows

The resident population generate the domestic flows and are the product of the per capita consumption (return to sewer) (G) and the population (P).

Population data for current and future design horizon epochs should be obtained from the Commissioning Body where available. This may be at a political boundary level of detail or at a spatial unit level detail defined by the commissioning authority for example pumping station catchments. Where data are not available from this source, it can be obtained from the Office of National Statistics (ONS) in the UK or other Government sources elsewhere.

Tourist populations should be obtained where required to represent seasonal or transient populations. Water consumption per capita should be obtained from the Water Company.

3.9.1.2 Consented Trade Effluent Flows (E)

Trade Effluent Consent data and supporting information should be obtained in geo-referenced format, if available, for each trader including:

- Name, and address of trader
- Discharge location

- Consented daily flow volume
- Maximum consented discharge rate
- Daily profile (e.g. 8 hour, 24 hour)
- Weekday and weekend working patterns, where available
- Measured data, where available, for a suitably long period to establish working patterns and ideally to include the flow survey period where carried out

3.9.1.3 Commercial flows (E)

The majority of flows from commercial premises are not subject to Consenting regulations. In these cases metered water consumption and any discharge flow data should be obtained from the WaSC where available. Where this is not available, population data should be obtained or estimated for premises that are likely to generate significant flow in the model context.

3.9.2 Base Infiltration

3.9.2.1 Locating sources of infiltration

Short term sewer flow surveys provide a way of measuring and determining the spatial distribution of infiltration at any given time. These may include "roving" monitors moved periodically to measure major sources of infiltration. These then target other inspection techniques such as CCTV to pinpoint defects as considered appropriate. WaSCs in the UK have recently trialled new developments in infiltration monitoring including:

- Distributed Temperature Sensing (DTS)
- Temperature logging with low cost sensors
- Electrical conductivity testing

3.9.2.2 Seasonal infiltration

Seasonal infiltration may be obtained using long term flow and level records from permanent monitors. For example, this may include certified flows under the Environment Agency's Monitoring Certification Scheme (MCERTS) at WwTWs. Other permanent and long term flow monitors may be installed at key assets or specifically for the measurement of infiltration. Pumping station telemetry data may also provide a good source of infiltration data.

3.9.3 Unaccounted for flows

During dry weather verification, a mass balance check between predicted and observed flows may indicate large missing flows, often referred to as "Unaccounted for flows". These are the residual flows once the known elements have been summed and subtracted from measured flows. These may include:

- Un-measured commercial and trade flows
- Infiltration flows
- Additional areas connected to the system (which may be pumped)

The level of effort required in determining the sources of missing flows will be dependent on their magnitude and relative significance in the context of the study. Methods of determining flow sources may include further desktop data gathering (e.g. metered flows, liaison with operational staff) and as a last resort, surveys including, visual inspections, CCTV surveys, flow surveys and other specialists surveys (e.g. infiltration surveys). Billing data may also be used to identify properties with storm water connections to sewers.

3.9.4 Groundwater

Groundwater levels are the main source of base infiltration into urban drainage systems. The increased use of continuous simulation in modelling requires the representation of time varying (seasonal) infiltration which is critical in predicting inflows. The use of separate groundwater models, as well as those already integrated into urban drainage modelling software, to give greater confidence in predicted infiltration flows is increasing and generating a need to collect live and historical groundwater information for model calibration.

3.9.4.1 Boreholes

The most convenient source of groundwater levels is from existing borehole records and live data feeds in the form of a time series. This information may be sourced by WaSCs, other public water supply companies, the Environmental Regulator, British Geological Survey (BGS) and National Groundwater Level Archive. In some instances, with the agreement of the Commissioning Body, groundwater data may be obtained by installing boreholes at strategic locations in the urban drainage catchment.

Infiltration results from a highly complex mix of above and below ground mechanisms. This includes the impact of interconnected permeable trenches in urban areas including backfill for sewers and those associated with building foundations. These trenches can provide below ground drainage paths which can confound the interpretation of borehole data and groundwater models. For this reason borehole data should be used in conjunction with corresponding sewer flow data to establish a correlation between groundwater levels and inflow to sewers from this source.

3.9.4.2 Groundwater models

Sources of groundwater models include the Environmental Regulator, Flood Authorities and in the UK, the BGS. Section C of the CIWEM UDG (2009) IUD Guide summarises the types of models available including Conceptual and Mathematical Models. It is advisable to seek input from a hydro-geologist when using these models.

3.10 Flow data collection and surveys

3.10.1 Permanent vs short term flow monitoring

Short-term flow surveys are still the most commonly used method to collect flow data to verify and calibrate urban drainage models. However, this may represent a significant proportion of the costs associated with modelling which will still carry a number of risks. The length of the flow survey required is dependent on weather conditions, meaning that there is uncertainty around both duration and cost of modelling projects. Even when completed satisfactorily, short-term flow surveys still have some limitations. These include:

- The short term survey is unlikely to record the more extreme events that cause flooding, leading to uncertainty over extrapolating the model’s results in a design context

- Short-term data in isolation may not show the seasonal variation in base flows that can be a significant factor in system performance
- Short term data in isolation may not show the extent of rainfall induced infiltration in wet periods of saturated soils

WaSCs, Environmental Regulators, Flood Authorities and other urban drainage bodies gather depths and (sometimes) flows via telemetry from drainage systems. The network coverage is increasing over time, and this growing data set should be maximised to:

- Reduce the need for and scope of short term flow surveys
- Provide an additional source of data to overcome some of the limitations (seasonal effects, etc.) of short term flow surveys
- Monitor transient (operational issues) and permanent temporal and spatial catchment changes (development, capital schemes, population change, etc.) so that they can be adequately represented in models over time
- Aid in the planning of short term flow surveys where these are identified as a need
- Drive urban drainage management activities (control or operational maintenance)

When planning the approach to flow surveys, short term and long term flow monitoring needs along with the collection of asset and subcatchment data should be considered in order to achieve the overall target levels of model confidence. They should not be considered in isolation.

3.10.2 Use of historical short term sewer flow surveys

Flow data are only a snap shot of the system performance at the given time. Historical flow surveys may provide a cost effective way of verifying models. As with any existing data, the date of the survey needs to be taken into account, as there may be a need to remove changes in the modelled catchment since the date of the flow survey.

3.10.3 Permanent monitoring data

Permanent monitoring is available for main rivers, WwTWs, key pumping stations and other critical urban drainage assets. However, more recently it has become more common to monitor with telemetry a wider range urban drainage assets. These can be utilised as a source of data or help validate/verify other collected. These include:

- MCERTS and other flow measurement at WwTWs
- Event duration monitoring (EDM) at overflows
- Level monitoring at pumping stations and detention tanks
- Pump flow meters
- Permanent flow monitor sites
- River flow and/or stage monitoring
- Tide levels
- Terrestrial and radar rainfall monitoring
- Soil Moisture Deficit (SMD), temperature and evapotranspiration monitoring

- Borehole level monitoring

This data may be used for historical verification, to monitor seasonally varying parameters such as infiltration and to monitor the impact of ongoing catchment changes such as growth and urban creep. Users of the data should be aware of its limitations and uncertainties.

3.10.4 Short term flow surveys

3.10.4.1 Planning a short term flow survey

The primary source of data for the verification of an urban drainage hydraulic model is the flow survey. Many of the problems with verification arise from poor flow survey data due to inadequate planning. Completing adequate pre-survey planning before commissioning a flow survey can substantially improve the selection of monitor sites and the return of good quality data.

The Guide to Short Term Flow Surveys in Sewers (WRc, 1987) gives detailed guidance on planning and carrying out flow surveys. Model Contract Document for Short Term Sewer Flow Surveys (WRc, 1993) contains a specification for flow surveys. Most WaSCs will have their own updated flow survey specifications.

The planning of a short term flow survey is primarily a desktop assessment of the catchment. This desktop study will typically identify all ancillaries, known hydraulic problem areas and the level of detail required for the survey. The use of telemetered data from other sources should be considered at this stage to minimise monitor requirements. **Section 3.11.3** details the potential sources of this data.

The scope of the survey will primarily depend on the objectives of the study and model purpose.

During the planning phase of a flow survey, a seasonal infiltration check should be undertaken using WwTW inflow MCERTS data (or other long term data) as detailed in **section 4.2.3**. Where seasonal infiltration variation and significant changes in slow response to rainfall are identified, and their representation in the model is critical to the aims of the study, flow surveys should be completed in the winter period with the aim of capturing the spatial distribution and magnitude of the varying flows.

3.10.4.2 Rain gauges and supplementary rainfall data

Guidance on rainfall data for short term sewer flow surveys is included in the CIWEM UDG (2016) Rainfall Guide including:

- Rain gauge density and coverage
- Rain gauge site considerations
- Radar rainfall
- Historical rainfall
- Rainfall data suitability for verification

3.10.4.3 Flow monitors - General

The number of monitors used will depend on the purpose and type of the model and the level of confidence placed in the accuracy of the input data. The choice of monitoring sites is a two stage process. Usually monitors will be chosen first to gain confidence in specific assets or areas of the model driven by the purpose of the model. Following this further monitors may be required to cover areas of the model for increasing general confidence in the model. Figure 3.3 outlines an example flow survey monitor locations to cover various drivers:

3.10.4.4 Selecting flow monitor locations

Flow monitor locations should be chosen to achieve the following objectives of monitoring:

- At the system outfall, to give a check on the overall accuracy of simulation and to enable the significance of inaccuracies at individual monitoring sites to be assessed
- In areas free from known major problems, a single monitor should be placed on significant main sewers. The recorded data should confirm whether the modelled response from the area is accurate
- In areas experiencing known performance problems, where accuracy in modelling is important, monitors should be placed at critical points to enable verification of these areas
- Points along the main trunk sewers or near major junctions where the effects of major connecting flows can be assessed. This may also indicate any major connections or features, such as overflows, that have been omitted
- Upstream and downstream of major combined sewer overflows, bifurcations, loops or specific problem points, in order to define their behaviour, if there is adequate rainfall during the survey. When there are large numbers of combined sewer overflows it may be appropriate to monitor all of them based upon the purpose and objectives. However it may be possible for groups of combined sewer overflows to be monitored upstream and downstream if these are considered of low significance
- Depth monitors should be installed at all significant pumping stations together with pump loggers to monitors pump on/off for individual pumps
- If redundancy is needed in case of problems with a particular site
- In urban watercourses and rivers where these are part of or influence the urban drainage system performance (see **section 3.10.4.7**)

If there is uncertainty over the need for a monitor, it may be appropriate to include it, since the cost of insertion later and the diminished value of other data, can be considerable.

Figure 3.3 shows typical locations for flow monitors within a catchment, together with other data sources.

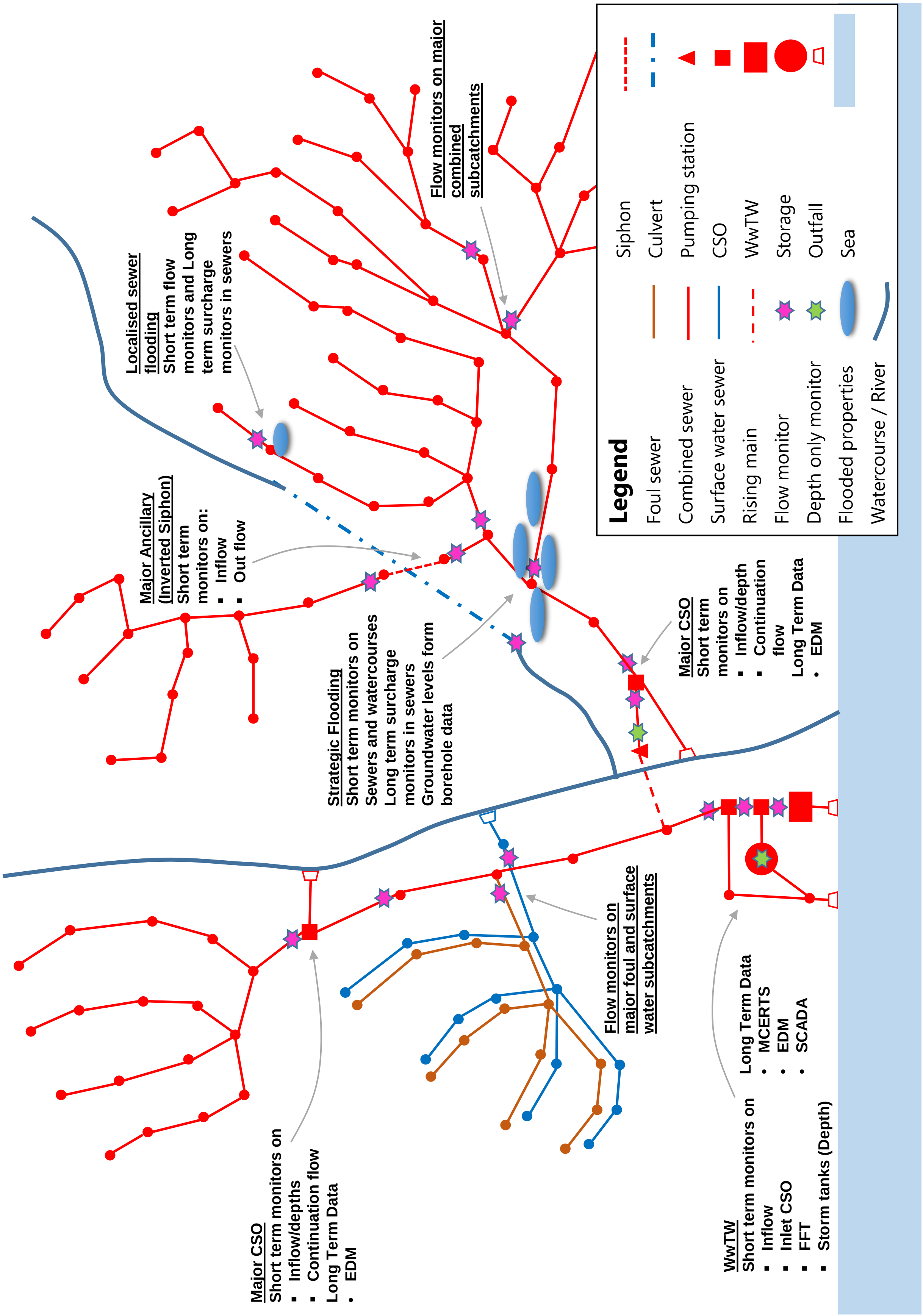


Figure 3-3 Examples of flow survey monitor locations

3.10.4.5 Flow monitor sites selection and inspection

Selection of the most suitable monitoring sites ultimately depends upon the local hydraulic conditions. If available, the model, or an existing model, should be used to predict the range of flow velocities and depths at possible locations. These should be compared with the capabilities of the equipment being used. Ideally, the conditions should be suitable in both dry weather flow and during storms, although in small catchments obtaining suitable dry weather flow conditions may not be possible.

Two or three potential locations should be selected for each flow monitor. Operations staff should be consulted before arranging an inspection of the suitable sites with their knowledge considered in the flow monitor planning. Ideally each site should be inspected with a modeller present and it should be checked that:

- The cover can be accessed safely and is free to lift
- The manhole is safe to enter
- The manhole is on the correct sewer
- There are no features that would cause unstable flow either during dry weather or in high flows:
    - Turbulence near to the sides of the sewer due to high roughness
    - Skewed flow due to a bend in the sewer
    - Turbulence due to the effect of the manhole - particularly in surcharged conditions (the monitor head should be placed in the upstream pipe ideally between 2 and 4 diameters from the manhole)
    - Turbulence due to upstream drop shafts and vortex drops or junctions etc.
    - Turbulence due to overflow weirs - the sensor should be placed at least 2 times the length of the weir upstream of the weir
    - Turbulence due to the continuation orifice or throttle on an overflow - the sensor should be placed at least 10 diameters downstream of the throttle or at the next manhole downstream in the case of a vortex control
- The flow conditions (depth and velocity) are as predicted and are within the capabilities of the monitor and site calibration checks are practicable, for example:
    - There should be sufficient flow for dry weather flow depth to register on the depth sensor to allow calibration
    - Sites should have sufficient depth and velocity during dry weather to be measured by the monitor and to allow independent velocity checks using a hand-held velocity monitor

For the most important locations, it may be worth observing the conditions during storm flow such as by installing a remote camera, if it is possible. Where more than one site is suitable, the site with the most stable flow pattern should be chosen. If there is doubt about the flow conditions, and a more suitable location cannot be found, it may be appropriate to obtain greater detail by using several monitors in upstream or downstream catchments, instead of deploying a monitor at the 'poor site'.

Measurement of flows spilling at combined sewer overflow pipes can be difficult as it is impossible to carry out adequate calibration checks in overflow pipes during dry weather conditions. If spills are small in comparison to the continuation flow, measuring spill by subtracting upstream and continuation flows can also be poor. If the spill is a relatively small proportion of the total flow into the overflow it is still sometimes more accurate to measure flows in the overflow pipe than taking the difference between incoming and continuation flows. Monitoring the depth in the chamber can be useful to indicate when a weir is spilling. However it should be recognised that depth can vary along the length of a side weir.

3.10.4.6 Monitor performance

The weekly interim reports supplied by the contractor should be checked to review the performance of equipment installed as part of the survey. The reports should contain a summary of operability of the equipment and brief comments on the quality of the raw data, which should be reviewed.

During the first few weeks of the survey particular attention should be given to the returned data quality. This should include checks on the degree of data returned as well as data consistency through inspection of the scattergraphs (see **Appendix F**). Sites with low depths of flow or poor data quality should be checked in detail and the monitor type upgraded or site abandoned and the monitor moved to a better site.

The details of manhole numbers and flow monitor locations should be checked to confirm the correct installation location. Pipe dimensions should be checked to confirm measured sizes and that flows are derived from the correct sizes and shapes.

Volume balance comparisons should be completed on all sites as a further check on monitor performance. This may identify any errors on perceived connectivity or omitted ancillaries. Examples may include pumped or gravity inflows from unaccounted for catchments in the model, additional populations which may be transient, loss of flows at intermediate bifurcations or other unaccounted for anomalies.

Regular site calibration checks should be compared with the actual monitored data and significant discrepancies queried with the contractor.

Depth monitors should be checked to ensure correct monitor installation. This will depend on monitor type but the monitor should be located where readings will be obtained over the full range of flows (e.g. for pressure transducers the monitor should always be submerged or for ultrasonic the sensor should not become submerged). The contractor should also provide details of the depth from cover, or another known point, to the sensor location.

3.10.4.7 Rivers and urban watercourses

Where required, flow or depth surveys of open river and watercourse reaches should be carried out in accordance with the relevant guidance from the Flood Authorities or CIWEM UDG / CIWEM Rivers and Coastal Group including:

- CIWEM UDG (1999) River Data Collection Guide
- EA (2013) National Standard Contract and Specification for Surveying Services

3.10.5 WwTWs

Flow data collected for wastewater treatment works should include the historical flow to works, flow to full treatment and spill data to storm tanks where available. Other data that may be relevant could include pump run times for return flows and levels in storm tanks.

Generally, there will be a flow monitor maintained to certified accuracy standards. This will be to monitor FFT against Consent. Sometimes, at larger works, FTW may be monitored as well but may not be certified. The FTW monitor may include recirculating flow. This can sometimes include storm return flow if the FTW flow meter is upstream of the overflow to the storm tank. FFT data should be used in preference to other data, however a limitation of using certified flow data are that they are generally positioned downstream of the FFT control device and therefore will not record any flows from the catchment above this setting. Level data may be available, most commonly at the inlet works.

Where it is necessary to install flow monitoring equipment at WwTWs advantage should be taken of any existing flow measurement structures such as flumes by the installation of depth or ultrasonic level monitors at these locations. The flow should be calculated using the calibration (h/d) data for the flume. In the absence of permanent monitoring data, the flow survey strategy for the WwTW should be to gather the following information:

- Flow to Works
- Flow to Full Treatment
- Flow diverted to storm tanks
- Spill from storm tanks
- Storm tank effluent levels
- Screen headlosses where critical
- Backwater effects from the WwTW in the upstream sewer network

3.10.6 Pumping stations

There are three components to monitoring pumping stations:

- Determining the flow capacities of the pump
- Monitoring water levels in the wet well
- Monitoring when pumps are running

3.10.6.1 Pump capacity

The pump flow capacity should be determined using the guidance in **Appendix D**.

3.10.6.2 Depth monitors in the well

The most common form of monitoring of pumping station operation is to install a temporary depth monitor in the wet well of the pumping station. This is independent of any existing level measurement for pump control and it is not usual to relate the two together. The rise and fall of the level identifies when pumps are running or stopped and can provide an ongoing drop test to help to confirm pump capacities. The wet well depth also identifies when the levels reach any overflow and so allow spill flows to be estimated. The following should be considered:

- Accurately record the datum level of the depth monitor on installation and apply a correction to the results
- Depths are normally recorded at a 2 minute interval to match that commonly used for flow monitors. However for pumping stations with rapidly changing levels this often fails to record the exact top and bottom water levels and so makes interpretation of the results difficult. Recording at 1 minute or shorter timesteps helps to overcome this problem
- In stations with multiple pumps, it can be difficult to identify which pump is running and any differences between them. Pump run time loggers may be required

3.10.6.3 Pump run time monitors

Pump run time monitors should typically be installed on all pumps at ancillaries which are significant in the context of the particular model or study. Pump run time monitors are critical at pumping stations running duty/assist cycles or with more than two pumps in order to understand the recorded operation.

3.10.6.4 Use of telemetry data at pumping stations

Most major pumping stations will have telemetry installed, which will record continuous data, for example, pumping well levels, pump status (on or off) and overflow operation. This data may be used in conjunction with or in place of short term monitors at the pumping station. Where used, liaison with Operations Staff is essential so to understand whether the form and frequency of data archiving will be suitable for verification purposes and possibly whether it might be modified for the duration of the flow survey.

3.10.7 Overflows

An increasing number of overflows will have Event Duration Monitors (EDMs) fitted and this will invariably report via a telemetry system. Where data are available from EDMs, it may be used as a source of data for model verification. However, EDM data may take many different forms and the data, the monitor types and positions should be understood to allow the data to be used effectively.

A key characteristic is the timestep at which the data are recorded. This can range from a report of spill or no-spill every 15 minutes to reporting the start and stop time of spill to the nearest second. The results can be sensitive to small errors in flow that make the difference between just spilling and not spilling. Data from EDMs at different parts of the system should be compared to identify any possible data errors or operational factors. The availability of overflow depth data received via telemetry overcomes some of the limitations of EDM data as it also shows near miss spills and can be used to derive the spill flow rate if the overflow has a free outfall. Different parts of the system can be compared to identify data errors or operational factors.

It may still be appropriate to undertake short term flow surveys around the overflow. However, depending on the location of the monitors, this can result in velocities dropping below the threshold for accurate measurement with a consequent loss of valuable data. It may be more cost-effective overall to locate the flow monitor further upstream of the CSO, and record depth only at the chamber itself to record spill. This also reduces the risk of erroneous velocity recordings due to turbulence and/or complex flow patterns at the CSO inlet. To record CSO pass forward flows, a downstream manhole should be considered for similar reasons.

3.10.8 Evaluating flow survey data and system response

Confidence in flow and depth data measurements is critical to the success of model verification. When assessing the results of a flow survey undertaken for hydraulic and model verification purposes, the calibrated data should be requested from the contractor after each compliant rainfall event. Rainfall data should be simulated and compared with the simulation results if the model has been built.

For each storm:

- The rainfall should be checked against the requirements in Chapter 2 of the CIWEM UDG (2016) Rainfall Guide
- Flow at each site should be high enough to ensure measurements are accurate and within the reliable operating range of the flow monitoring equipment
- The flows should be sufficient for all combined sewer overflows and urban drainage pumping installations to have operated where it is necessary to verify their operation
- Depth response for monitors at known flooding locations should be sufficient to cause surcharge
- There should have been a sufficient flow and or depth response at each site so that measurement errors are not significant

The interpretation of the above requirements and those in the rainfall guide will require experience and judgement, especially in partially separate systems where the response criteria may not always be achievable. It may not prove possible to meet surcharge requirements in short term flow surveys and if this is critical consideration should be given to making use of more permanent monitoring at these locations.

3.10.9 Number of events

In general the flow survey should aim to record three acceptable storm events and some sequence of dry days to capture variation observed in the flow survey period for weekdays and weekends. Where the data captured is not sufficient, consideration should be made to increasing:

- The number of storm events where confidence is affected by the failure to capture the good data across sufficient flow monitors for a the three events
- The duration of the dry weather flow periods or storm events

3.10.10 Supervision of flow surveys

The Model Contract Document for Short Term Sewer Flow Surveys (WRc, 1993) requires the contractor to report to the client after each visit, and may include, any unsuitable sites. The reports should be reviewed and discussed with the contractor throughout the survey. Where required, alternative sites should be used to replace unsuitable sites.

3.10.11 Long term flow surveys

Long term flow surveys may be required to measure seasonal effects such as infiltration or capture events which are more extreme than the minimum event acceptance requirements as outlined in Chapter 2 of the CIWEM UDG (2016) Rainfall Guide. This may be required, for instance, at flooding sites where there is a need to capture events that surcharge or flood the system at historical flooding locations.

It is rare to carry out a long term survey with the level of spatial coverage applied in short term surveys. However, carrying out both types of survey together and leaving a small number of monitors in the network after completion of the main survey should be considered to capture more extreme events at critical locations.

Raingauges should normally be installed for the full period of the long term surveys. However, this may be backed up or merged with radar rainfall to reduce the required raingauge density or improve the spatial accuracy of data.

Flow monitoring technology is continually developing and advice may be sought from flow monitoring contractors regarding the most suitable monitors for long term flow surveys. These may include the use, for example, of depth only monitors with increased battery life, and reduced logging intervals to capture surcharge at flooding locations.

Long term data should be checked in the same way as short term data to avoid data wastage as detailed in **Section 3.10.8**. The acceptance criteria should be agreed for the capture of sufficient events or data to allow termination of the long term survey with the Commissioning Body.

3.11 Operational Data

3.11.1 Liaison with operations staff

Operational records are an important source of information for the model build and verification process.

Operations staff should be engaged throughout the study in order to ensure that relevant information is available including:

- Details of any mechanical or other failures or issues at pumping installations, sewage treatment works, etc.
- Details of any spillages, fires etc. where large volumes of water are used
- Changes in trade effluent discharges
- Operation of penstocks
- Maintenance activities (e.g. sewer cleaning)
- Collapse or partial collapse of sewers

3.11.2 Maintenance activities and systems changes

Operational issues can have a significant impact on an urban drainage system performance. Staff may undertake temporary changes to the system. Operations staff should be aware of when such changes occur, particularly where these are during a short-term flow survey or where they might affect an infiltration investigation for example.

3.11.3 Incident reports

WaSCs and other urban drainage stakeholders keep operational records which are often available in GIS format. These provide date stamped records of operational and hydraulic incidents including for example, flooding; pollution; CSO spills; asset failures (blockages/siltation/roots); pipe collapses and other incidents affecting the urban drainage system.

Incident information should be obtained for the period of any flow survey or of interest for the purpose of the model. Such data may be useful in historical verification. For this purpose, any critical incident (flooding, pollution, etc.) report data (excluding those known to be caused by temporary restrictions) should be analysed to determine the incident location and frequency of occurrence reported in the catchment. Questionnaires to operational staff may be considered to obtain more information on incidents.

3.11.4 Pipe and channel condition data

The condition of the pipe can have a significant impact on the roughness of the sewer. Where important, surveys (e.g. CCTV) to obtain pipe condition data and determine the roughness of pipes should be considered. The Sewerage Risk Manual (WRc, 2017) provides methods of determining pipe roughness. Historic CCTV data are typically available from WaSC or other stakeholders.

3.11.5 Sediment data

Sediments may reduce the cross-sectional area and increase roughness of pipes and channels. Sediment depth data should be obtained from CCTV surveys, flow survey reports, ancillary surveys, or from operational records. Where the model is sensitive to sediment depths, sediment surveys should be carried out at selected time intervals to assess the extent and variability of the sediments. It is important to distinguish between transient silt and that which is always present or builds up gradually. Transient silt would not normally be modelled as an obstruction.

3.12 Non-quantitative data sources

3.12.1 Public engagement

It is important to recognise that the local residents may have a lot of knowledge about the problems experienced in an area. First hand eyewitness reports should be collected using questionnaires and / or through face to face meetings.

Anecdotal evidence or local knowledge can provide a good source of information about the catchment, but should be cross checked with other evidence.

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. C751 Communication and engagement in local flood risk management (CIRIA, 2015) provides further guidance.

This subject is considered further in the CIWEM UDG (2009) IUD Guide, in **sections 5.2** to **5.5**.

3.13 Mapping data, aerial photography and street mapping

Base mapping will normally be available in digital format such as OS MasterMap and web based viewers (e.g. Google and Bing). This data may be used in contributing area take off and in the application of runoff surface types, identified from the base mapping or aerial photography. Street mapping applications such as Google Street View enable virtual site visits to be made from the desktop and may be invaluable in gaining catchment knowledge. Consider backing this up later by a site visit where necessary. When using external website data, commercial restrictions should be abided by and may require a licence fee to be paid and accreditation given in documentation and on drawings.

Base mapping may be linked to digital address point data (such as OS AddressBasePremium) containing useful information on property type, age, number of floors etc.

For detailed and up to date aerial surveys, it may be appropriate to use a licenced drone survey operator.

3.14 Data confidentiality

Urban drainage projects may involve several different organisations, private and public bodies and each will have constraints with regard to the use and availability of data. Where this is the case, each of the stakeholders may want to set out an agreement within the stakeholder group with regard to the data and its dissemination. For example, this may 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.

4 MODEL DEVELOPMENT

4.1 Introduction

4.1.1 Scope

This section provides guidance on building and/or developing a model. All models will have some limitations, regardless of how they are built. The models should be built to meet the confidence requirements and standards set out at the project definition stage. Figure 4-1 outlines the structure of the section.

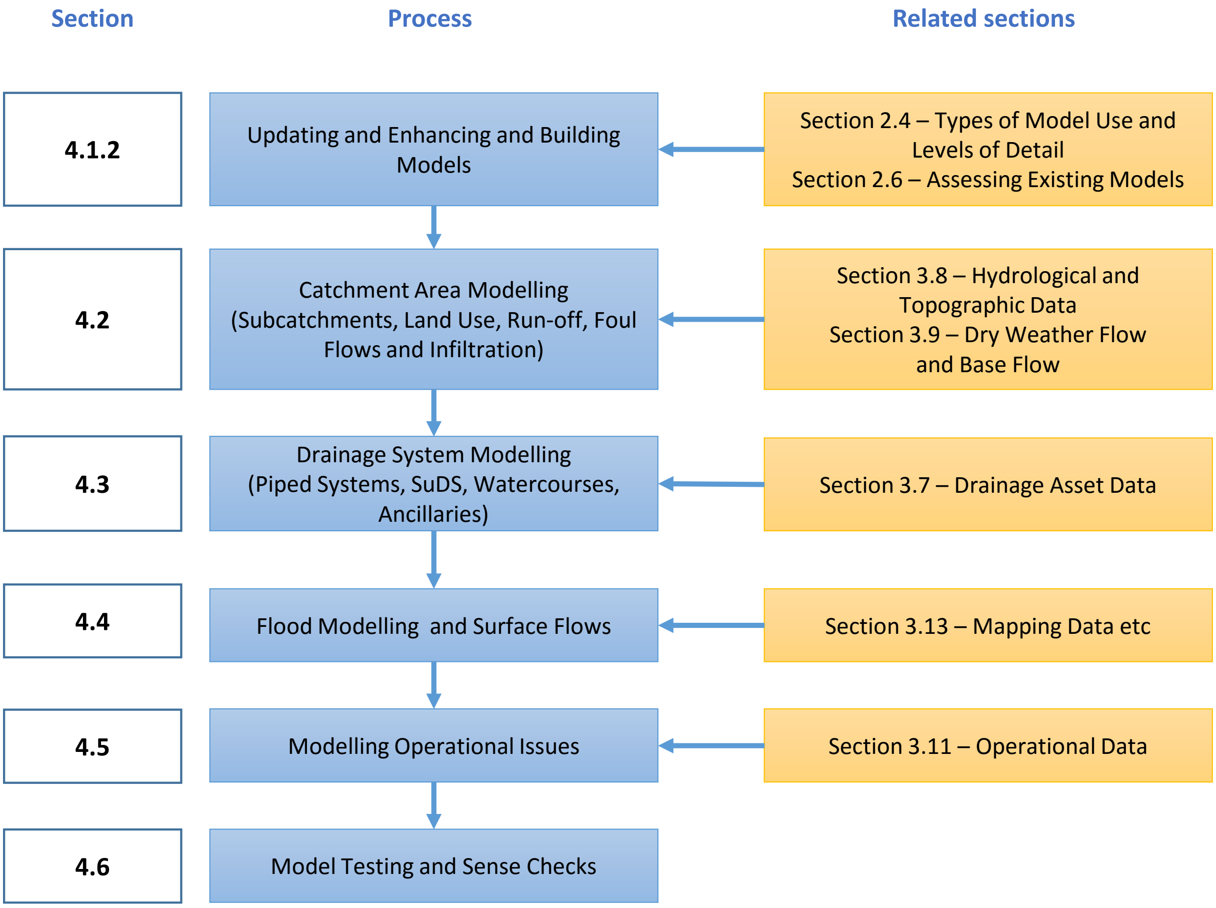


Figure 4-1 Model Development Overview

4.1.2 Updating, enhancing and building models

4.1.2.1 Updating and enhancing existing models

Many urban catchments in the UK already have an urban drainage model of some type. The quality of these models will vary. Some will be to a high standard and quality whilst others may be incomplete, poorly constructed or of uncertain origin, accuracy and robustness (the model's ability to effectively perform while its variables or assumptions are altered).

Updating and enhancing existing models presents many challenges:

- Poor audit trails may make it difficult to assess the model confidence

- The application of temporal catchment changes may be time consuming where the existing model's design horizon is unclear
- Poor modelling practice or modelling errors may not be readily apparent, for example, the force fitting of contributing areas
- Existing models may not be robust across the required range of conditions for their intended use
- Model results may change due to migration to later software versions or the application of revised modelling approaches

The review process is discussed in **section 2.6**.

4.1.2.2 Converting models

It is good practice to use the latest modelling software version for a new project. However, later software versions may generate different results, therefore the model's performance should be checked using comparative hydrographs for storm and dry weather conditions to ensure it is still valid for its purpose. Significant differences in performance should be investigated and understood before correcting the model, if necessary, to restore the original performance or reverting to the original software version.

4.1.2.3 Merging and linking models

When merging models it is important to understand the role of default model parameters/flags and to ensure that these are applied correctly in the merged model. Flags should also be checked for clashes and amended where appropriate before merging.

Dry weather and storm results from the merged model should be compared with those from their individual components. Any anomalies should be investigated and understood before correcting where required. The level of effort will depend upon the error identified and its significance, particularly where detailed models are replacing inflows estimated from measured flows.

4.1.2.4 Model naming and model component naming

There should be a standard naming convention used to identify the status of different versions of the model. There is a need for the Commissioning Body to define a naming and referencing convention for the network (and any scenario sub-models) and their supporting components. This would be expected to cover:

- Catchment name
- Date horizon of the system represented
- Date of the model
- Verification status
- Model Parameters (Generally hydraulic but may include others, Water Quality)
- Dimensions (1D, 2D, 1D-2D)
- Hydrology (Rainfall Runoff (Rural), Rainfall Runoff (Urban), Statistical, Direct Runoff)

The convention may require the use of specific terminology. The systems will vary depending on the software being used.

The convention should be sufficiently robust to allow precise identification of any model and its component parts. The Commissioning Body should also define a naming convention for drainage network assets. This may include:

- Manholes
- Ancillaries
- Dummy nodes (required to model features such as weirs or penstocks)

It is necessary to include the date horizon of the model, as it is frequently necessary to produce models representing different points in time. Examples could be:-

- "Verified yyyy" model to represent conditions at a flow survey in year yyyy
- "Historical yyyy" model to represent conditions appropriate for assessment of historical performance
- "Actual yyyy" model to represent the actual conditions (i.e. including blockages, silt, etc) for year yyyy
- "Cleaned yyyy" model to represent the system with operational issues resolved
- "Future yyyy" model including future development and urban creep for the year yyyy

There will be a need for the Commissioning Body to develop a naming convention and terminology, as without this, references to terms such as "baseline" model could mean a variety of models, ranging from verified, actual or cleaned.

In addition to the above, many hydraulic modelling programs have the function of having "scenario" sub-models that are derivatives of the original model, and these scenario models should be suitably named.

The version of the model should be included in all accompanying documentation.

4.1.2.5 New models

Existing models should be mined for useful information when constructing a new model. It is likely that the existing model will contain corrections to the sewer data which may not have been fed back to the corporate sewer records. This information should be reviewed in an appropriate level of detail to avoid its loss in the new model build, assuming there is some confidence in the information.

Existing models may also include assumptions on the division of contributing areas between different drainage systems. Where appropriate, these should be reviewed to provide guidance for the assignment of contributing areas in the new model.

The time horizon for a new model should be agreed at the project scoping stage. However, where the model results are compared with those from an older model or results from a previous flow survey, it may be necessary to replicate the time horizon of the existing model or the flow survey before the subsequent update to the current or future situation.

4.1.3 Data Flagging

Data-flagging has primarily been used as an indicator of the source of the data used in a model to assist in providing an audit trail. Earlier generations of software required external and independent means to provide this. However, the ability to flag within the model is now available in software commonly used for urban drainage modelling. Knowing the source of data helps to develop confidence in the model by providing the means to assess the likely confidence in the constituent components of the model.

A data-flagging system should be developed with data quality in mind. For example estimated values should be flagged differently from surveyed values. Confidence in the model results will be greater in the knowledge that manhole cover levels in the area of flood risk have been surveyed rather than estimated.

A system of flags should therefore provide the ability to differentiate between data sources and also provide an indication of the relative quality of the data. This should also take into account where possible any indication of quality in the existing datasets. As an example a corporate GIS sewer record system may have fields indicating the quality of the individual components, and where possible this should be carried forward into the model flags.

Table 4-1 shows an example of a flag system for illustrative purposes. This example includes default software specific flags, user defined basic flags, and extended user flags where information is available to include additional data quality information.

Any flag system developed should be flexible to allow additional flags to be created. However, there are difficulties if this is not done in controlled manner therefore:

- The agreement of the Commissioning Body is required so as to ensure that new flags are made available across their model library and not specific to one model
- The form of a flag should be defined, e.g. two characters for Level 1 and 2, three for level 3
- The number of level 2 flags should be kept to a minimum, not least so that their meaning remains memorable to practitioners. (In the table the principle of adding a suffix number (to Level 2 flags) to create Level 3 flags is illustrated)

The role of a default flag (illustrated #D in the table) needs to be understood within the context of the software being used.

The use of system flags for import (illustrated by #I and #V), especially if the modelling software defaults to using these for import, may risk losing data flags already in the source data.

Table 4-1 Example Flag System

Flag	**Description (and notes)**
Level	**Example Software in-built flags**
#A	Asset Data - auto data import from sewer records
#D	System Default
#G	Data from GeoPlan – Use for populations only
#S	System Calculated (e.g. pipe gradient)
Level	**User Defined Flags**
AD	ASSET DATA - from database sources (not picked up by automated import)
AS	ASSUMED - by modeller based on engineering judgement
AT	AREA TAKE-OFF – from OS Mastermap
CA	CALCULATED - Data calculated
CS	CLIENT SPECIFICATION - recommended value in Commissioning Body's
DR	DRAWINGS - Data from Scheme Drawings
DU	DUMMY - dummy asset or value
ES	ESTIMATED - estimated or approximate dimension
IN	INFERRED – Inferred using inference tool in modelling software.
IT	INTERPOLATED - interpolated manually
LI	LIDAR - Cover Level inferred from LiDAR (DTM) data
OP	OPTIONEERING - use while exploring options
SC	SURVEYED - CCTV Survey
SI	SURVEYED – Impermeable (Contributing) Area Survey
SM	SURVEYED - Manhole Survey (including: manhole, CSO, storm tank, pumping
VO	VERIFICATION – Operational issue -blockage /pump not working etc
VF	VERIFICATION - value altered based on flow survey
Level	**Extended User Defined Flags**
AD1	Asset Data – imported with Flags derived from drainage record system (use in
DR1	DRAWINGS – Record
DR2	DRAWINGS – For Construction
DR3	DRAWINGS – Preliminary or Design
DU1	DUMMY – required by modelling software
IM1	IMPORT – of unflagged but verified model which is considered to have a good
IM2	IMPORT – of previous model which is unflagged and is poorly documented
LI1	LIDAR – relatively flat and open areas and high confidence of plotted asset
LI2	LIDAR – significantly sloping ground / heavily vegetated / low confidence in
SC1	CCTV – use for details except pipe size
SC2	CCTV – pipe size (in the absence of pipe sizes from more direct survey sources)
SI1	Sample property surveyed by IAS
SI2	Within IAS area but not explicitly surveyed

4.2 Defining the model catchment and subcatchments

The model catchment boundary should include the entire contributing area for the drainage systems. This will define the model extents which should be checked for potential contributions from upstream rural or urban areas (which may be pumped).

The extent of rural and watercourse catchments may be checked as follows:

- Using the digital terrain model (DTM) directly to identify the catchment extent. Some software will automatically generate the catchment boundary from this data
- Using the Flood Estimation Handbook (FEH) web service
- Using an online “Catchment Finder” tool

4.2.1 Defining subcatchments

The definition of subcatchment boundaries can be a time consuming process that influences the accuracy and usability of the final model. Subcatchments should be set up as follows:

- Foul inflows and base infiltration should be applied by dividing the model into subcatchments with relatively uniform land use
- Storm runoff should be applied by dividing the model into subcatchments with relatively uniform land use
- The subcatchment coverage should include all areas of the catchment that could contribute flow to the modelled drainage systems including foul, combined or surface water sewers, SuDS, and watercourses
- SuDS features should be modelled where they contribute flows to the modelled drainage system
- Subcatchments should be defined to cover one land use type, one drainage system type and one soil type (WRAP, HOST or other)
- Subcatchments should normally be defined using property curtilages
- Large impermeable areas such as car parks, supermarkets, schools or industrial units should be modelled individually to simplify the future representation of surface water removal measures
- Major developments such as hospitals, retail parks and industrial estates, should be modelled explicitly, preferably using private drainage records to avoid problems of unrealistic localised flooding and to assist in identifying the drainage system type
- Large watercourse catchments should be cut down into subcatchments to apply inflows at the appropriate locations
- To prevent dry pipes, a small subcatchment should be included at the head of any pipe run
- Generally roof, road and permeable surfaces are measured and applied separately to the model

For new model builds, after following the above recommendations, a check should be made to ensure subcatchments are not larger than those in the maximum subcatchment sizes in Table 4-2 or in those set in the Commissioning Body’s specification.

Table 4-2 Recommended maximum subcatchment sizes

Drain System type	Max subcatchment (ha)
Separate foul	4
Other urban (e.g. combined, Storm)	2
Large permeable areas	Site specific

An alternative approach to modelling storm flows using direct 2D runoff is described in **section 4.2.9**.

4.2.2 Defining land uses

Standard land use categories provide a useful way of applying default characteristics including dry weather data and storm runoff surface types to subcatchments. Aerial photography such as on-line satellite imagery and digital mapping may be used to assist in this process of identifying land uses.

Table 4-3 provides suggested standard land use definitions to provide a clear audit trail for the application of different system types. Commissioning Body specifications may set their own definitions.

Table 4-3 Suggested land use classifications

Land Use ID	Development Type	Drainage System Type	Notes
FRX	Residential	Foul	Separate foul
SRX	Residential	Storm	Separate storm
PRX	Residential	Partial	Partially separate
CRX	Residential	Combined	Fully combined
ARX	Residential	Attenuated	With permeable pavement or modular storage connected to the sewer
FCX	Industrial / Retail / Business parks	Foul	Separate foul
SCX	Industrial / Retail / Business parks	Surface	Separate storm
PCX	Industrial / Retail / Business parks	Partial	Partially separate
CCX	Industrial / Retail / Business parks	Combined	Fully combined
ACX	Industrial / Retail / Business parks	Attenuated	With permeable pavement or modular storage connected to the sewer
GRX	Greenfield	Large permeable areas	Fields or parks bordering drainage networks, rural subcatchments.

4.2.3 Foul flows and base infiltration

The main sources of inflow to a sewerage network during dry weather are:

- Residential population flows
- Consented trade flows
- Commercial flows
- Base infiltration
- Tidal infiltration

Infiltration in response to rainfall is discussed separately in **Section 4.2.8**.

4.2.3.1 Residential population flows

The population data should be used in conjunction with address data to calculate an occupancy rate to apply populations by subcatchment. A check should be undertaken to ensure that the total model population matches the total in the source data.

The daily water usage is usually available as water provided to the customer and the return to sewer is generated by using an appropriate multiplier (usually 0.9 – 0.95) to allow for water consumed and not returned to the sewer. A single daily average per capita flow rate should be applied across the model unless there is clear evidence of spatial variation, which should be clearly documented and applied where apparent.

It is good practice to check that population and water usage information is consistent with other data sources such as within Water Resource Management Plans.

The default diurnal profile in CIRIA (1998) Report R177 should be applied for UK models, although this, and the per capita flow rate may be adjusted during verification.

4.2.3.2 Measured and Consented Trade Effluent (TE) Flows

Measured and Consented Trade Effluent (TE) flow data should be obtained as detailed in **section 3.9**. TE flows should be applied in the model as summarised below:

- TE flows exceeding 1 l/s are generally applied explicitly at their point of discharge
- TE flows < 1 l/s are generally modelled explicitly if they contribute a significant pollutant load in water quality models otherwise TE < 1 l/s are generally applied with the domestic flows where their sum is significant
- Measured TE flows should be applied for verification where available
- Consented TE flows should be applied in the absence of measured data for recalibration against survey data at the verification stage where applicable
- The traders shift pattern should be applied for explicitly modelled trade flows e.g. an 8 hour 9-5 profile
- A 24 hour flat trade profile or a standard working day profile may be applied in the absence of other data

- Separate profiles should be applied where required for weekday and weekend (if any) discharges. Unless data are available to the contrary the same profile should be applied for both and reviewed during verification

4.2.3.3 Commercial flows of sewage of a domestic nature

Flows from commercial properties, such as shops, offices and schools should be modelled as a population and appropriate per-capita flow rate, or using measured water consumption figures, with an allowance for non-returned flow in either case. CIRIA (1998) R177 provides guidance on flow rates for a wide range of property types.

Separate profiles should be applied where required for weekday and weekend discharges from commercial premises. Unless data are available to the contrary, the same profile should be applied for both and reviewed during verification.

Care should be taken not to double count inflows, for example where a school within a catchment draws students from the immediate vicinity. Conversely, if a school draws students from a wider catchment area, it should be modelled separately. Typically, it is better to model large schools separately in either case.

Transient populations (for example tourists in a holiday resort), should be modelled, where significant. These may be based on metered flows or information obtained from the local tourist board or the Commissioning Body, where available. In the absence of metered flows, a population and estimated per capita rate is the most appropriate way to represent these for confirmation at the verification stage.

4.2.3.4 Base infiltration

Base infiltration responds very slowly to rainfall and is usually seasonally varying. It is possible to model the seasonal variation with an infiltration model driven by the continuous simulation of rainfall. However, this requires calibration against long term measured flows. A fixed seasonal curve is usually simpler and may be adequate for most purposes.

Infiltration should initially be assessed by comparing the total modelled dry weather flow with daily flows from WwTW flow records by analysing the 20%ile (Q80) low flow for each month or season from long-term records (preferably 3 years or more) of daily total flow, and back calculation.

Alternatively a starting figure could be assumed which could be re-assessed during the verification process using WwTW records and flow survey data.

CIWEM UDG (2009) User Note No.33, Modelling Dry Weather Flow gives details on how to disaggregate this flow data to derive base infiltration.

The simplest method of distributing base infiltration is to calculate the required flow rate per hectare of contributing area or per head of population and therefore calculate the flow rate for each subcatchment based on the subcatchment area or population. However, evenly distributing the infiltration over all upstream catchments may lead to the over estimation of hydraulic loading on the upstream sewers and a misunderstanding of the nature of the infiltration problem. Where a very detailed understanding of infiltration is required, infiltration should be assessed taking into account the catchment topography, topology, water table (if information is available) and any structural information available from CCTV surveys.

The application of base infiltration may be refined by comparing and applying the long or short term flow records spatially in the catchment.

4.2.3.5 Tidal infiltration

Tidal infiltration should be modelled as a point source by connecting a notional pipe to the system with a tide level applied to the outfall or by applying a tide level to an infiltration model to distribute the inflow.

4.2.4 Urban runoff models

Urban runoff modelling is a large and complex subject that is not covered in detail in this CoP. A good review of the runoff models currently used in urban drainage modelling is included in the Literature Review and Guide for the UKWIR Project: Development of the UKWIR Runoff Model (UKWIR (2014). These documents include descriptions of the main features of the runoff models, their pros and cons, and the typical ranges for key equation parameters. Equations covered include:

Urban runoff models

- Fixed percentage runoff
- Wallingford Procedure (Fixed) - Old PR model
- New UK (Variable) - New PR model
- UKWIR Runoff Model

Rural / Pervious runoff models

- Green-Ampt
- Horton
- Flood Estimation Handbook Revitalised rainfall runoff (ReFH/ReFH2) Model
- Probability Distributed Model (PDM)
- USA Soil Conservation Service (SCS) method

The choice of runoff model will depend on the type of catchment and catchment's storm response, particularly slow response where present. A brief summary of the most commonly used runoff models is included in Table E-1 in **Appendix E**.

4.2.5 Runoff models for large permeable areas

Modelling runoff from large permeable areas (e.g. fields), can be challenging in an urban drainage context and its incorrect representation and calibration at the verification stage may lead to inaccuracies at extremes (e.g. design storms). This section outlines the suggested approaches for the representation of runoff from large permeable areas. It does not cover slow response from rainfall induced infiltration, which is discussed in **section 4.2.8**.

4.2.5.1 New UK model

The New UK model may be applied and calibrated to represent additional slow response inflow from permeable only areas. These areas may be attached to an urban subcatchment and added using a slow pervious contributing area definition separately from the normal permeable surfaces. Alternatively the area may be applied as a separate subcatchment, noting that it is still good practice to allocate the area to the slow pervious area.

The speed of runoff from these slow response pervious surfaces can be calibrated if necessary by modifying the routing factor in the routing model to achieve the calibration.

It is possible to amend the Soil Storage Depth parameter in the New UK equation to adjust the volume of inflow from these surfaces. However, this should be avoided as it may lead to substantial over prediction at extreme (design) events when reduced and an alternative runoff model should be considered where this becomes necessary.

The calibration of slow response needs careful consideration as there is a significant risk that the model may not accurately predict flows outside the range covered by the flow and rainfall data used for calibration. Models should therefore be sensitivity tested with a range of storms to check the behaviour at extremes. Historic verification is particularly important as an additional calibration check.

4.2.5.2 The Revitalised Flood Hydrograph (ReFH) models

An alternative approach to represent large permeable areas in the UK is using the Revitalised Flood Hydrograph model (ReFH and ReFH2).

This model uses site-specific parameters taken from the FEH Web Service to estimate the runoff hydrograph from the site. ReFH and ReFH2 models may not appropriately replicate rural runoff in Scotland and this should be discussed with Commissioning Bodies and regulators to demonstrate suitability where intended to be used.

The ReFH model is suitable for use in rural and “moderately” urbanised catchments. An urban adjustment should be applied for more highly urbanised catchments.

The ReFH2 model includes two methods “Catchment level” and “Plot level”. Plot level should be used for areas up to 0.5km^2 with Catchment level applied for larger catchments (note the definition of large is often context specific related to the urban drainage system being modelled). Care should be taken to avoid double counting areas already represented in the urban subcatchments.

ReFH models should be considered carefully when used to generate inflow to a piped drainage system as they calculate the maximum runoff possible and this may not all enter the piped drainage system. The model may therefore overestimate inflows.

4.2.6 Defining runoff surfaces

Paved, roof and pervious areas should be applied individually for each contributing area, using area take off from digital mapping (e.g. OS Master Map, DTM and on-line aerial photography). It is preferable to measure and apply areas as absolute values rather than as a percentage of the subcatchment area.

Contributing Area Survey data should be used, where available, to identify the contributing areas for connection to the modelled drainage system.

4.2.6.1 Foul

Some contribution of surface runoff to "foul only" systems should be assumed due to misconnections unless available survey information proves otherwise.

Paved and roof area connected to the foul system is typically between 1-10% of total contributing area with 4% a common starting point for subsequent calibration during verification in the absence of specific data.

4.2.6.2 Surface water

All paved and roof areas contributing to the surface water system should be measured and applied to the model. Typically, all pervious area should be assumed to connect to the surface water system and be applied in the model. Large permeable areas draining to the surface water system should be dealt with as outlined in **section 4.2.5**.

4.2.6.3 Combined

It is seldom necessary to carry out detailed surveys to determine connectivity for properties known to drain to the combined sewer system. The sum of paved, roof and permeable surfaces should be equal to the total contributing area. Large permeable areas draining to the combined system should be dealt with as outlined in **section 4.2.5**.

4.2.6.4 Partially separate

The combined element of a partially separate system in older properties often takes the back roofs and yards with front roofs and road areas draining to a separate surface water system. Partially separate systems may require a contributing area survey to determine the degree of separation of storm runoff in the combined and surface water sewers.

4.2.6.5 Attenuation SuDS

The paved and roof areas should be assigned a large initial loss to represent the attenuation storage. CIRIA's (2015) SuDS Manual provides guidance on this and suggests typical initial losses of 2 mm for permeable pavements without loss to infiltration, 5 mm for permeable pavements with infiltration and 5 mm for localised storage. Further information is provided in **section 4.5.2**.

4.2.6.6 Infiltration SuDS

The paved and roof area should be set to zero percentage runoff so that all surfaces are treated as permeable using the New UK model.

A high initial loss should be applied to represent the attenuation storage, together with a high soil depth to specifically represent the infiltration process as designed. Some runoff from these areas may occur in very wet conditions and should be connected to the sewers or watercourse as appropriate. Further information is provided in **section 4.5.2**.

4.2.6.7 Permeable areas

Small urban and sub-urban permeable areas such as gardens, verges and areas around properties should be applied in the same subcatchment as the corresponding paved and roof areas.

Larger permeable or 'green' areas, such as playing fields, golf courses, parkland or open fields may be modelled using the slow response setups described in **section 4.2.5** and **4.2.8**. Where the drainage of such areas is unclear, local knowledge and GIS data should be checked for evidence of land drainage and stream connections to the sewer system. Where required to verify suspected inputs, site visits and monitoring may be undertaken. DTM data may be used to identify the path of runoff from the area.

4.2.7 Soil types

Soil classes for runoff models should be obtained and applied as follows:

- Winter Rain Acceptance Potential (WRAP) for the UK should be obtained from the Wallingford Procedure Volume 3 (DoE, 1983) to determine individual soil class
- The split between two or more WRAP soil classes in a model may be obtained from geological drift maps or the HOST soil map, where appropriate, to better define the soil class boundary where doubt exists
- HOST Soil classes for use with the UKWIR runoff model and ReFH may be obtained from the FEH Web service
- Soil classes for non-UK locations should be obtained from the local equivalents to the above maps where available

4.2.8 Slow response flows

Slow response flows that occur a significant period of time after the rainfall has ceased originate from a variety of sources including:

- Above ground runoff from large permeable or greenfield areas
- Direct inflow from watercourses connected into the sewer
- Inflow from watercourses or tide through outfalls or faulty sewers
- Long-term seasonal infiltration from high water table
- Infiltration into the sewerage system from saturated ground

Where possible, the sources of these flows should be identified and represented separately by adapting the modelling approach to suit the response characteristics:

- Above ground runoff from large permeable areas and direct inflow from watercourses connected to the sewer may be represented as described in **section 4.2.5**
- Inflow from watercourses or tide through outfalls or faulty sewers may be represented by a notional orifice or small diameter pipe allowing inflow from a modelled watercourse, by applying a level hydrograph or explicitly using a fully integrated catchment model
- Long-term seasonal infiltration from a high water table may be represented using a time varying infiltration rate as described in **Section 4.2.3**
- The representation of Infiltration into the sewerage system from saturated ground potentially requires the use of a specialised ground infiltration model

The above approaches generally require considerable knowledge and experience to apply and should be justified when being applied.

There are particular issues with generating a set of parameters that can represent both the wetting of the catchment to produce slow response and it's drying before the next rainfall event. This causes several problems:

- It is time consuming to adjust parameters to match the catchment response
- A model calibrated against individual events is often incorrect when used for continuous simulation when the drying mechanism is important
- There is poor understanding of how calibration parameters for verification relate to design values for assessing catchment risks

The minimum number of parameters needed to give a robust model should be used. The parameters should be justified based on knowledge of ground conditions, proximity to watercourses and sewer condition. Values should not be selected arbitrarily to achieve an apparent match to measured flow data.

Sense checks should be undertaken by running the model in continuous simulation to ensure that it stays in calibration against the observed flow data. The model should be run with design storm data to check that the hydrographs generated are as expected.

4.2.9 2D runoff models

An alternative approach to representing the runoff from subcatchments is to represent the runoff behaviour of each segment of a digital terrain model by applying rainfall directly to a 2D surface. This is often referred to as a direct rainfall or pluvial modelling approach. This type of approach continues to develop so it is important to seek the latest best practice and guidance.

The benefit of the direct runoff approach is that it can predict the way that the runoff contributes to different drainage systems. The disadvantage is that it requires considerable detail in the definition of the digital terrain model and the location and capacity of gullies and other inlets to the drainage systems.

A simplified approach is to represent the inflow to the piped drainage system as a simple fixed flow rate (or even as zero) and use the model to represent the exceedance flows across the surface. This is particularly useful for large-scale flood risk assessments. Care should be taken here to make sure the assumed flow rate into the piped drainage system represents the flow rate achievable under all of the conditions of interest. An example would be where the piped drainage system may become surcharged and unable to accept flow. Investigating the potentially worst exceedance flow by using an assumption of zero inflow to the piped drainage system is a sensible check.

2D models usually allow the application of a fixed percentage runoff (PR) to runoff surfaces but ideally the runoff should consider variable PR due to the ongoing losses to infiltration through the different surfaces. This may be achieved by pre-processing the rainfall to reduce the intensities to represent the loss to infiltration (net rainfall method) or by using a surface infiltration model built into the 2D software such as Horton or Green-Ampt. However, these models do not include an evapotranspiration component to dry out the soil between events and are therefore not suited to continuous simulation. The soil parameters for these models are not currently mapped in the UK unless using ReFH to generate net rainfall, and should ideally be taken from field studies to represent local soil characteristics. However, this is rarely done in practice and parameters are usually taken from published literature based on soil texture.

4.3 Drainage system model

4.3.1 Piped systems

4.3.1.1 Model detail

Models of piped drainage should be built directly from GIS datasets, where available, using full manhole references from the GIS as node references to provide a clear audit trail. Dummy nodes that do not represent an object in the GIS should be clearly referenced with a clear and consistent naming convention. Nodes that would otherwise overlap in the model should be offset to aid visualisation. All outfalls should be modelled explicitly at their true locations based on survey data.

Pipes upstream of all subcatchment discharge points may be omitted from the model where their connected nodes do not flood to help improve model stability. In areas at risk of flooding it may be necessary to include all pipes (including private laterals) and sub-divide the subcatchments. Models should not be simplified any further by pruning or merging pipes except for exceptionally large models or where only Type I detail is required or where pipes are merged to resolve model instabilities. Where this is the case, a methodology should be documented and agreed with the Commissioning Body.

4.3.1.2 Connectivity check

Models should be checked for connectivity:

- All contributing area in the model should connect to a node and subsequently to an outfall
- Breaks and other errors in connectivity should be corrected using existing GIS or survey data and appropriately flagged with comments added, where appropriate
- The corrected model (hereafter referred to as “the modelled network”) should be reviewed to confirm its adequacy downstream of any contributing areas by overlaying the full system network

4.3.1.3 Assessment of incorrect and missing asset data

The modelled network should be reviewed for missing asset information and errors. A common approach is to divide the modelled network into a series of long sections and to review these in a logical order to ensure that none are missed.

Missing or incorrect data should be replaced with using other information collected during the data collection phase (see **section 3**). It may be necessary to arrange for the collection of additional data such as by survey.

4.3.1.4 Missing pipe lengths

Long section chainages should be reviewed to identify where lengths between nodes are incorrect or missing. Errors here may imply that a pipe length has been omitted, or that node grid references or connectivity are incorrect.

4.3.1.5 Missing pipe sizes

Missing pipe sizes or pipe sizes that reduce downstream on the long sections should be reviewed and corrected where necessary. Non-circular pipes should be checked as incorrect widths are less obvious on a long section. The interpretation of non-circular pipe shapes in the data – e.g. egg, rectangular, barrel, arch should be checked as these sections may be incorrect in the sewer manhole database. These should then be checked to ensure they are correct in the model.

Missing pipe diameters should be derived from known upstream and downstream sizes where available. If there is no change in size between known values, it may be assumed that all pipes between the known values are of that size. Where there is a change in diameter, the network should be checked to identify where branches join the long section under investigation and a junction may be assumed as the location of the size change.

4.3.1.6 Cover levels

Missing cover levels may be in-filled using data from near neighbour manholes on other drainage systems, where available.

DTM data is a rapid and generally accurate method of in-filling missing level data (see **section 3.8.3.1** for guidance on checking the validity of DTM data). Care should be taken in locations such as river banks or other places where rapid changes in levels may not be captured. DTM levels may be compared with "known" cover levels across the whole model to identify localised sections of the model being set to different benchmarks.

As a last resort, cover levels may be linearly interpolated based on known upstream and downstream levels. This should not be done in areas where flooding is known to occur or predicted by the model.

4.3.1.7 Invert levels

Long sections should be checked for negative gradients or upward steps in invert levels. Negative gradients should be checked and corrected by interpolation where appropriate.

Interpolation should be avoided for invert levels at ancillaries or flooding locations and in locations where negative gradients may be a real possibility (e.g. mining areas). Missing data should be obtained by survey or other reliable source (e.g. as constructed drawings) where required.

4.3.1.8 Recording sources of data and assumptions

It is important to ensure that all data used in the model is traceable to its source. This may be done using data flags and (where appropriate) adding relevant comments to the model network where data flags are already used for confidence scoring. Records should be kept of all the changes made to input data in cleaning up the model.

Most long sections should appear correct after data clean up with few negative gradients, upward steps in inverts or reductions in pipe diameter, except where these exist in reality. There may be good reason why some long sections appear incorrect. For example, long sections that include an overflow pipe will appear to show a step up in invert levels, whereas a continuation pipe may appear as a reduction in pipe diameter. Such anomalies should be recorded and described including known negative gradients, diameter reductions etc., and the long section on which they appear.

4.3.1.9 Headloss coefficients

Manhole headlosses are losses in energy as a result of water entering the manhole and exiting the manhole (expansion and contraction), and of a change in direction within the manhole. Losses are higher where there are acute changes in direction, where velocities are high or where manhole benching results in turbulent flow conditions.

Most hydrodynamic modelling software applications include the automated calculation of entry and exit losses at manholes based on the angle of approach of the incoming and outgoing pipes to each node in the model. However, these are based on a standard set of assumptions which may not take into account local conditions and the hydraulics of specific structures, particularly complex ancillaries. Headlosses should be flagged where facilities exist in software to indicate how they have been calculated.

The model should be checked to ensure that inferred headloss coefficients are applied realistically. Particularly high values should be checked and amended where appropriate. Some manual adjustment may be required, for example where side branches join a main pipe run at an acute angle. Headlosses at nodes omitted in any model simplification should be allowed for in this calculation.

Headlosses at complex ancillaries (including SuDS controls) should be calculated by hand or using a steady state hydraulic modelling software package for manual entry or calibration in the hydrodynamic model. All calculations should be recorded and suitable flags and notes added to the model to identify the approach taken.

Checks should be made to identify steep pipes within the model where headlosses may have a major impact on levels in the upstream network. Where these are identified in the vicinity of flooding problems or CSOs then sufficient flow monitors should be installed in order to accurately measure the losses for calibration in the model, where required.

- Pipe entry and exit losses should be allowed for at manholes (although exit losses are usually negligible)
- Headloss coefficient should be increased for the additional losses caused by changes in direction at bends and to allow for the headloss at any intermediate manholes that are not included in the model
- Headloss coefficients should be increased to allow for chamber geometry such as launder channels, and other hydraulic features that affect headlosses
- Suitable headlosses should be allowed for at features such as CSO spill pipes, where entry losses may be relatively high depending on the chamber configuration

4.3.1.10 Additional manhole storage

The calculation and inclusion of additional manhole storage is an important part of the model build process. Even if a simplification process has not been undertaken, the manholes in the model network still require additional storage to account for storage in gullies and private house connections. Where applied in models, the calculation is based on the concept of a notional small diameter connection from each property in the subcatchment directly to the modelled node.

Most hydrodynamic modelling applications include the facility to automatically apply storage compensation based on automated methods which should be agreed with the Commissioning Body where used. These methods normally use population and/or property density to calculate the compensation storage and should not be applied until the final population has been derived and included in the model.

The effect of the Preissmann slot, where used in the model, may need to be taken into account when applying storage compensation, particularly where large sewers are subject to high surcharge

The additional storage method/calculation should be recorded and sense checked to ensure that it has been applied realistically taking account of both simplification and the Preissmann slot where appropriate.

4.3.2 Sustainable drainage systems

Sustainable drainage systems (SuDS) attempt to replicate the natural hydrological response of the catchment and may be applied at a range of scales from individual properties through to large parts of an urban area.

Some SuDS may be represented by modifying the runoff in the hydrological model or by the explicit representation of the individual components as summarised below:

- Surface components such as permeable pavements and green roofs can be applied using a modified hydrological model, but may require explicit representation for detailed design purposes
- Small-scale detention storage or infiltration systems such as water butts, rainwater harvesting and soakaways may be applied using a modified hydrological model or represented explicitly for detailed design purposes
- Larger scale detention storage or infiltration systems such as detention tanks and infiltration basins should be modelled explicitly

The SuDS modelling approach should consider the behaviour of the system at extremes when storage may become full or maximum infiltration rates are exceeded causing a change in the system response / performance. A detailed modelling approach will normally be better at representing a wide range of conditions, in particular the extremes.

The accurate representation of systems incorporating infiltration to the ground may require infiltration tests to determine real infiltration rates, as an alternative to measuring outflows from the system and inferring infiltration rates.

The reasons for selecting the modelling approach should be clearly documented, including discussion of the behaviour in large storms, high groundwater and other extreme conditions.

4.3.3 Watercourses

4.3.3.1 Representation and detail

All significant watercourses included in the model should be visited and, if possible, walked for their entire length within the modelled catchment.

The default representation of watercourses should be to use 1D links to represent the channel up to top of bank and to use a 2D mesh to represent out of bank flows. More complex situations may require a 2D model as described in **Section 4.4**.

The Flood Authorities may already have a watercourse model to incorporate into the model or may provide the base data for a new model. Where models are obtained, the supporting data should be reviewed to determine if they are fit for use. River channels move over time and can be prone to geomorphological changes during flood events. If historical survey data are available, this should be reviewed and the model updated if there are concerns that the river channel may have changed significantly since the previous survey.

The spacing requirement of cross sections in the model depends on the accuracy required of each section of watercourse. Where the channel is simply being used for conveyance, a coarse representation may be satisfactory with cross-sections up to 200m apart.

Cross sections should be no more than 50m apart for key reaches where there is interaction with other drainage systems, known flood risk or where features such as bridges and other structures will influence the performance of the watercourse.

Guidance for modelling of main rivers recommends the section spacing should generally be:

- No more than 20 B apart, where B is the top width of the channel
- No more than 1/(2 S) apart, where S is the mean slope (m vertical to m horizontal) of the watercourse
- No more than 0.2 D / S apart, where D is the typical depth of flow and S is the mean slope

However in small watercourses where the depth of flow is low the final condition may prove too onerous and should be ignored.

Care should be taken to ensure that the intersection of cross sections and 2D surface mesh is correct to prevent loss of water from the model at these points.

4.3.3.2 Naming watercourse cross sections

A systematic naming convention should be used for watercourse cross sections. Section names should incorporate the cross-section chainage and be based on the river length rather than just the section being modelled so that they can be related to other models of the river constructed for different purposes.

The model references for outfalls, flap valves, culvert inlets and outlets should use the same convention as that for the upstream drainage network.

4.3.4 Pipe and channel roughness

In the absence of survey information, pipe roughness should be applied in accordance with the guidance provided in "Tables for the Hydraulic Design of Pipes, Sewers and Channels" (HR Wallingford, 1994) or from other recognised sources. The Commissioning Body may have their own specification for this, in which case it should be used where suitable.

Pipe or channel roughness should be amended to represent operational problems such as sediment and partial blockages. Section 6 of The Sewer Rehabilitation Manual (WRc) contains guidance on the application of roughness including photographs showing suggested roughness coefficients for sewers of various materials and structural/service condition. Further information is covered in **Section 4.5** of this document.

Roughness in watercourses may be affected by bed surface material, channel irregularities, channel alignment and vegetation. It is likely that the roughness will vary by reach. The roughness may also change seasonally due to vegetation growth in summer increasing the roughness. Sensitivity testing should be carried out where appropriate to determine whether seasonal changes in roughness are likely to be significant for water levels and if so separate summer and winter models may be required.

Default roughness values may be adjusted during model calibration / verification where there is robust evidence, preferably photographic.

4.3.5 Ancillary structures

Ancillary structures typically include combined sewer overflows (CSOs), bifurcations, pumping stations, storage tanks, flow control devices and inlet works at wastewater treatment works. In watercourses, ancillary structures may include hydraulic controls such as bridges, weirs and culvert inlets/outlets. Such ancillaries must be represented correctly to ensure that the model functions to an acceptable level of accuracy.

Ancillaries should be modelled explicitly wherever possible using the actual invert levels and dimensions, avoiding the use of equivalent components (unless strictly necessary to reproduce hydraulic behaviour that is beyond the capabilities of the software).

For highly complex structures, Computational Fluid Dynamics (CFD) modelling may be used to analyse hydraulic performance in detail and generate head/discharge curves for inclusion in the urban drainage models. Steady state hydraulic models may also be used for detailed analysis of structures or groups of structures (e.g. WwTWs) and generate head discharge curves for inclusion in the urban drainage models.

All details relating to the modelling of ancillary structures, together with relevant calculations of headlosses, discharge coefficients etc. should be clearly documented and recorded in the modelling process. Key ancillary data should be obtained by survey as outlined in. **Sections 3.10.5** to **3.10.7** where it is not readily available from other robust sources.

4.3.5.1 Overflows and bifurcations

An overflow is defined as a manhole with two or more outgoing pipes with at least one pipe diverting flow from a modelled sewerage network to a receiving water body via directly through dedicated spill pipe or via surface water system. A bifurcation is defined as a manhole with two or more outgoing pipes where at least one pipe diverts flow to another part of the same system.

The following key components/asset data (if present within the chamber) should be included when modelling overflows and bifurcations:

- Invert level of orifice/crest level or weir
- Size of orifice/length of weir
- Orifice type/weir type
- Chamber size and layout
- Details of screens, penstocks, flow control devices, baffles and scum boards
- Details of overflow pipe and receiving water or system
- RTC (Real Time Control)

The relative invert levels of the outgoing pipes are very important in defining flow paths. Therefore, in the absence of supporting data such as drawings and photographs, asset surveys will be required to supplement data in the manhole database. This must include the system downstream of the structure; the accurate modelling of which is essential to the correct simulation of overflow operation.

The individual components of overflows and bifurcations should be modelled based on the guidance below:

Overflow chambers may be modelled as a simple manhole with a uniform plan area or as a bespoke node type to represent more complex chambers taking account of varying chamber plan area with height.

Spill pipes should be modelled up to their discharge location or at least to a hydraulic breakpoint. If the overflow discharges to a watercourse or a surface water system, any potential influence these systems may have on the performance of the overflow should be considered and represented in the model accordingly. Headlosses at the entry to spill pipe must be accurately represented as these can have a significant effect on depths which may be critical in chambers containing screens, especially where velocities are high (>1 m/s).

A spill pipe may run part full if it is steep or if "short pipe" flow conditions occur in it, provided that the outfall of the spill pipe is not surcharged and the design flow is less than the pipe full discharge.

The spill pipe will be steep if the Froude number at half pipe full flow >1. Short pipe conditions occur with mild sloping outfall pipes where the pipe is shorter than the number of diameters specified in Table 4-4. If the outfall pipe runs part full its capacity will be determined by the inlet, which acts as an orifice with a free discharge coefficient.

Table 4-4 Short Pipe Conditions

Pipe Gradient	Length of pipe below which short pipe flow conditions will occur
0	10 diameters
0.002	16 diameters

Pipe Gradient	Length of pipe below which short pipe flow conditions will occur
0.004	25 diameters
0.006	35 diameters

Weirs should be modelled explicitly where present with the following points considered:

1. Weirs should normally be modelled with their true length and true crest level
2. Twin side weirs at the same level may be modelled as a single weir of twice the length, or explicitly as two separate weirs
3. Weirs should be modelled with discharge coefficients applied in accordance with CIWEM UDG (2009) User Note No.27 “Modelling Ancillaries: Weir Coefficients”
4. Discharge coefficients should be modified to reflect the inclusion of scumboards or screens as summarised below
5. Bar screens may be allowed for by applying a proportional reduction to the weir length equal to the ratio of open area of the screen to total area of the screen. In calculating the open area an appropriate allowance for blinding should be made where appropriate
6. Static Screens or Powered Screens (with mesh rather than bars) should be represented by applying the manufacturer’s headloss curve, by calculation or calibration from flow data or by applying an additional headloss for the required design screen rate. The additional headloss can be applied by adjusting the weir coefficient or through a headloss curve. In calculating its performance, blinding should be allowed for, for example by reducing the open area of the mesh
7. Where a screen can be overtopped at high flows, a weir should be modelled at the overtopping level
8. The maximum flow through the screen may become capped or limited when a bypass weir operates so the head discharge curve should allow for this

Pumped overflows may be modelled as fixed or varying discharge pumps. Pumping rates based on measured field data will give more reliable results, however, these are difficult to obtain for pumps that discharge to receiving waters which would be polluted if a conventional pump test were carried out. In the absence of measured data, manufactures pump data should be used. Care should be taken to define correct switch on and off levels.

Pass forward controls at overflows, including throttle pipes orifices, fixed penstocks, vortex controls (see **section 4.3.5.6**) and others should be modelled explicitly with appropriate discharge coefficients or headloss curves applied using manufacturer’s data, calculations or calibration from flow data. The model should be set up to take into account the effects of the control becoming drowned under high flow conditions as this may influence spill performance.

CSOs that Do Not Match Modelling Software Algorithms

The following CSOs do not readily match standard modelling software algorithms in their hydraulic behaviour:

- Siphon
- Low side weir
- Leaping weir
- Vortex

Further guidance can be found in the following CIWEM UDG User Notes:

- User Note 1 – Modelling vortex flow control devices
- User Note 2 – Modelling ancillaries and discharge coefficients
- User Note 27 – Modelling ancillaries: weir coefficients

4.3.5.2 Pumping stations and rising mains

The following guidance is given for modelling pumping stations:

Duty/standby pump arrangements should be modelled as a single pump with justification for the values to use where the capacities of the two pumps are different.

Assist pumps should be modelled as the increase in discharge when both pumps are running, not as the capacity of the second pump alone.

Pumps operating on shared rising mains should be modelled to replicate the performance for the different combination of pumps that may be operating due to the higher headlosses.

Screw pumps may be used in place of fixed pumps in coarse models where the detailed operation of a particular pumping station is not of concern. This can make the model faster and more stable by giving a smooth transition of flow from zero up to maximum capacity.

Where the downstream head, or the number of pumps running, significantly affects pump capacity pumps may be modelled as rotodynamic pumps. This will require the explicit modelling of the rising main which must be modelled as a pressurised pipe with a weir or other device at the discharge point to ensure that the pipe remains surcharged along its entire length throughout the simulation. When modelling rotodynamic pumps it will often be necessary to factor the manufacturer's pumps curve to allow for wear.

Roughness values for rising mains should be based on measured data if available or on Tables for the Hydraulic Design of Pipes, Sewers and Channels (HR Wallingford, 1994).

The node immediately downstream of a pumping station must be large enough to contain the flow pumped between the simulation time steps, otherwise erroneous flooding may occur.

Actual pump configurations (e.g. duty/assist duty/standby etc.) should be recorded in the model documentation.

4.3.5.3 Storage tanks and tank sewers

Storage tanks may be modelled as a simple fixed plan area manhole or as a more complex chamber with varying plan area where required. It is important to be aware that in some software during initialisation, the tank will fill up to the level of the lowest incoming or outgoing link. To ensure that the tank remains empty during initialisation, a dummy closed sluice gate to a dummy node should be modelled at tank floor invert level.

Tank sewers should be modelled explicitly using the actual section properties and levels, including any dry weather flow channels.

The emptying arrangements for tanks back to the sewer network must be modelled explicitly (including RTC where required) especially if it is intended to use continuous simulation in the subsequent model analysis.

4.3.5.4 Wastewater Treatment Works (WwTW)

A model of a foul or combined sewerage system will normally include the inlet works of the WwTW works extending to the Flow to Full Treatment (FFT) hydraulic control. The following elements are commonly modelled and represented in the same way as for the network:

- Overflows
- Screens & Grit Channels
- Pumping stations
- Storm tanks
- Flow control (flumes, penstocks, RTC)
- Recirculation of flows

4.3.5.5 Penstocks and sluice gates

Fixed penstocks should be represented as equivalent orifices or sluice gate controls in the model, with discharge coefficients calculated and applied using the standard orifice equation. Allowance should be made for additional losses resulting from objects protruding into the flow and for any tortuous flow path through the structure. Care should be taken not to double count headlosses which may already be applied by the software at the entry to the downstream pipe.

A penstock/gate may have a fixed opening or height, be adjusted automatically or by operational staff. This information should be obtained from the Commissioning Body as outlined in **section 3.11** as it may be critical to the model performance.

If a penstock/gate is to open or closed during a simulation, real time control (RTC) should be used to replicate the rules under which the penstock/gate operates.

4.3.5.6 Vortex control devices

Information on the head/discharge relationship for vortex control devices (or similar control) should be obtained from the manufacturer. This data should be applied as a head/discharge relationship, noting that depending on the type of device, the relationship may be directional. The following points should be considered in applying the head/discharge relationship:

- A unique discharge value is required for a given head
- Flow cannot decrease with increasing head
- The head/discharge relationship may need modifying where the software uses the differential head across the control rather than a free discharge assumption
- Performance in drowned conditions needs to be understood and allowed for in the model

4.3.5.7 Inverted siphons

Inverted siphons may be modelled explicitly using a pipe, or pipes if the siphon comprises a number of parallel pipes. If the pipe is to remain surcharged throughout the simulation then the pressurised pipe model should be used.

The full length of the siphon including down pipes should be included, so that headlosses are calculated correctly. Additional headlosses should be derived for bends, bell mouths etc. from standard tables.

For complex structures, a head / discharge relationship should be sought in order that a User Control link can be used. The head discharge may be derived from or confirmed by flow survey data.

4.3.5.8 Other sewer ancillary structures

Ancillary structures, such as cascades, flumes, screens, throttle pipes and flap valves for example, may be encountered within the sewer network. These are to be modelled explicitly wherever possible using the actual invert levels and dimensions, avoiding the use of equivalent components (unless strictly necessary to reproduce hydraulic behaviour that is beyond the capabilities of the software). Flumes and screens can be modelled as head/discharge relationships. Throttle pipes and cascades should be modelled as conduits with appropriate dimensions and levels. Flap valves should be included in the model using the appropriate link control.

4.3.5.9 Sustainable Drainage Systems (SuDS)

The catchment may include a range of SuDS and surface water management measures.

Small scale measures installed at a property or a small group of properties may be most easily represented using the hydrological runoff model as outlined in **section 4.3.2**. These measures include: soakaways; permeable paving, rainwater harvesting / water butts, green roofs; disconnecting down pipes; rain gardens; filter strips and geo-cellular storage.

Large scale measures include swales; bio-retention areas; detention basins; infiltration basins; sacrificial flood areas; flow diversion channels. These should be modelled explicitly by identifying their individual components (such as inlets; storage; infiltration; outlets) and representing these in the model in a similar way to other ancillaries.

CIRIA (2015) C753 - The SUDS Manual provides detail on many of these measures.

4.3.5.10 River structures

The watercourse model should include all significant structures, including culverts, bridges weirs, screens and other controls. Structures may be omitted to improve model stability and simulation speed where they do not have a significant impact on the flows and/or depths.

Simple bridge structures may be modelled as culverts to improve model stability, where appropriate. More complex bridge structures or those that may overtop should be modelled explicitly as bridge elements.

4.3.5.11 River downstream boundary conditions

A downstream boundary should be applied, where appropriate, to provide representative flow conditions at the downstream extremity of the model. Alternatively the model should be extended far enough downstream so that any boundary condition does not impact upon the levels and flows at points of interest. The approximate distance for this may be calculated using:

0.7 * depth / gradient (using consistent units of measurement).

A number of methods may be used to apply a boundary condition including normal depth, time varying level and fixed level.

An appropriate tidal boundary should be applied where this influences the downstream boundary.

Further guidance on the application of boundary conditions is included in **section 7.4** and the CIWEM UDG (2009) IUD Guide.

4.3.5.12 Real Time Control (RTC)

RTC rules may be used to represent the normal operation of a system that has automated control of pumps, gates etc., or alternatively to represent the temporary operational issues discussed in **section 4.5.4**. It is important to distinguish between the two types, as they will be treated differently in future models.

4.4 Flood modelling / modelling surface flows

The default representation of flooding in 1D modelling is to store flood water in a notional flood cone at the ground surface and return it to the drainage system when there is sufficient capacity.

A more complex representation of flooding should be considered using 2D modelling where:

- Significant flood water flows overland to enter a different drainage system or a different part of the same drainage system
- Flood water flows overland to impact properties or land in a different subcatchment some distance from the source of the flooding
- Flooding may affect additional properties or land adjacent to those that have already reported flooding
- There is flooding from open channel drainage systems

Detailed 2D modelling can be time consuming, data intensive and slow, and should only be used where required. However, coarse 2D modelling may be considered over the entire catchment area to give an overview of flooding where detailed modelling is not required, for example in strategic flood risk assessments.

It is critical to ensure that the 2D modelled area is large enough to capture all flood flows so that flood water does not run off the edge of the area of interest except to a watercourse or the sea.

Table 4-5 shows the recommended methods to represent flooding.

Table 4-5 Example of flood types

Type	D	Description and use
Stored	1D	Flooded area: Water is retained on the catchment surface, in a user defined flood cone storage volume. Flood water returns to the system when capacity is available. This is the default for 1D flood modelling. Standard parameters for the flood cone are given below.
Lost	1D	Water lost: All floodwater is lost from the system. This may be used where the flood water does not re-enter the system from which it came. For example where flood waters are lost to un-modelled watercourse or sea. Or where floodwaters from combined sewer are lost to a nearby surface water sewer.
Sealed	1D 2D	Sealed manhole: The water level can rise indefinitely without any flooding occurring. These may be used for junction nodes or systems that have been explicitly sealed to prevent flooding. They may also be used at dummy nodes.
2D	2D	The discharge between surface storage (on the 2D mesh) and manhole is calculated using standard weir equations, where the weir width is taken as the circumference of the manhole. This is the default for all manholes in a 2D zone unless the manhole is sealed.

Additional flood types are available in some software applications that may be used for very detailed modelling of flood risk in 2D areas. These include gullies and other flow inlets with flow characteristics defined in a variety of ways.

4.4.1 1D flood modelling

Stored flood cones are the default flood representation for piped drainage systems. These may be composite in models to include a lower part of the cone to represent depths below kerb level and a second wider section of the cone to represent flood area above the kerb level. Table 4-6 shows a typical default flood cone definition, although Commissioning Body's may set their own. This should be reviewed if there is evidence to suggest that the catchment topography requires a different approach.

Table 4-6 Typical definition of flood cone

Type	Depth (m)	Area %
1	0.1	10
2	1.0	100

All manholes that may flood in reality should be modelled to allow flooding.

4.4.2 Level of detail for 2D zones

Where 2D flood output is required to be merged with data from other stakeholders, for example to create surface water flood maps for the National Flood Risk Authority, the level of detail and format of output should be discussed and agreed at the scoping stage. In England, the data may be produced, for example, in line with the EA document "Submitting locally produced information for updates to the Risk of Flooding from Surface Water map" (currently Report version 2 September 2016) or similar guidance elsewhere.

The following text provides guidance that may be followed in the absence of a detailed specification from the Commissioning Body or other stakeholder.

Boundary polygons should be used to define the extents of 2D modelling. Each zone may require different levels of detail and accuracy. Four levels of detail are defined below:

- Rural – varied roughness, no mesh zones, flood defence walls
- Coarse urban – roads mesh zone, single roughness
- Medium – buildings, roads, significant structures such as walls etc.
- Detailed – as medium plus drainage gullies

Starting with a coarse scale grid across wide areas of the catchment allows overland flow paths to be identified before being refined to include more detail locally in areas of flood risk.

Manholes within the 2D zones may be connected to the 2D mesh or sealed where appropriate. Where connected, an appropriate discharge coefficient or head/discharge relationship should be applied to govern the flow between the 1D model and the 2D mesh.

2D zones should be named appropriately, for example after flooding hotspot locations or river reaches to ensure these are easily identified.

4.4.2.1 Rural

A coarse 2D zone should be used to represent the flood plain of a watercourse in rural areas where the impact of flooding on properties is minimal.

4.4.2.2 Coarse

A coarse 2D zone should be used to assess transfer of flood flows between systems and to identify those areas of the catchment where it is appropriate to undertake more detailed 2D modelling.

4.4.2.3 Medium

A medium resolution 2D zone should be used to assess individual parts of the model that are suspected to have interaction between drainage types or overland flow problems. This can help identify and scope areas requiring further investigations and surveys.

4.4.2.4 Detailed

A detailed 2D model should be created to assess known overland flooding problems that affect properties. Zones should be extended if there is a possibility of overland flows between zones as identified using a coarser 2D zone.

4.4.3 Constructing a 2D model

2D zones should be defined using a normal depth condition to represent the boundary edges.

Checks should be completed on the transition zones between the river sections and the adjacent 2D elements to represent the flood plains. These should be tidied where appropriate such problems with LiDAR data and the input of cross sections which may cause gaps, resulting in instabilities and loss of flow. Table 4-7 summarises typical requirements and parameters for different levels of detail.

Table 4-7 2D Requirements and parameters

2D zone type		Coarse - Urban	Medium - Urban	Detailed - Urban	Rural
Max Source Data grid resolution		2 m	1 m	1 m	5 m
Element	Max.	250 m^2	100 m^2	25 m^2	250 m^2
	Min.	75 m^2	25 m^2	25 m^2	75 m^2
Road Element	Max.	No	25 m^2	No	No
	Min.		10 m^2	2.5 m^2	
Lower Road areas		No	150mm	150mm	No
Buildings		>100 m^2 only	All buildings	All buildings	No
Walls, porous		No	Significant	All	No
Other Structures		No	Significant	All	Significant
Gullies		No	Significant	All	No
Site visit needed		No	Probably	Yes	No
Roughness zones min.		1	1	1	As required

4.4.3.1 Surface roughness

The roughness of the surface affects the speed and attenuation of the flood flow on the 2D surface.

Roughness is affected by the surface material, irregularities, alignment, flow depth, discharge velocity and vegetation. A range of roughness values should be applied in the model to reflect any spatial variations in roughness.

Roughness is likely to vary with season. Sensitivity testing of the model should be carried out to determine whether this is likely to have a significant effect on the resulting water levels and, where applicable, it may be necessary to create separate winter and summer models.

Floodplain roughness should be estimated using the tables given in Chow (1959).

4.4.3.2 Surface infiltration

The loss of flood flow through infiltration to the ground should be represented where important. This may be represented as a fixed infiltration rate or using a surface infiltration model such as Horton or Green-Ampt as outlined in **section 4.2**.

4.4.3.3 Walls and other features

For coarse meshes it may be useful to lower the level of the road surfaces by 100 to 150 mm to represent the channelling effect on flow not picked up by the DTM/2D surface.

Buildings have historically been represented as voids in 2D modelling. However, this may cause unrealistic surface ponding and a better alternative is to represent buildings as “stubby” objects (usually 300mm high) or porous objects to avoid this.

Walls and other features should be added to the model in critical areas to contain floodwater and control flood paths in known areas of ponding. These features may be porous with varying crest levels, based on surveys, on-line street mapping or estimates if necessary.

Underground car parks, underpasses and other below ground infrastructure should be investigated where applicable with a site visit as these will not be included in the DTM.

4.4.3.4 Gullies

Gullies may be added in areas of critical detail and at low points away from manholes to allow flood water to drain away. Contributing Area Surveys should be used to assist in the assignment of gully connections where carried out. On-line street mapping and GIS based data held by Highways Authorities may be used to identify road gully locations.

4.5 Modelling operational issues

Common operational problems include worn or faulty pumps, siltation, obstructions by debris, mass root intrusion, structural deformation, collapses, intruding laterals and others.

Any operational issues identified in the modelling process should be reported to the Commissioning Body for resolution, where appropriate. A project log of the status of all operational problems should also be kept and updated throughout the project.

Care should be taken when inspecting assets owned and or maintained by 3rd parties to ensure any lack of maintenance is handled tactfully to avoid jeopardising any future cooperation.

4.5.1 Sewers

All available information on operational and structural defects in the sewer network should be obtained from the Commissioning Body (preferably in GIS format from corporate records) and reviewed. Historical databases are particularly useful as they indicate where repeat problems occur.

4.5.1.1 Pumps

Pump failure or poor operation is one of the most common operational problems on sewerage systems. The types of problems include:

- Pumps out of service so that the full station capacity cannot be achieved or so that there is no standby for pump failures
- Frequent pump trips so that the standby pump has to be used
- Pumps not delivering their design flow because of pump wear, blockage or fouling of the rising main
- Poor pump control so that pumps do not start at the optimum time

Pump operational problems are usually identified during (or from) the pumping station survey or from flow survey data. The problems should be reported to the Commissioning Body as soon as they are identified as it may be possible to remedy them quickly.

It may be necessary to use RTC to reproduce the performance of the pumping station during all stages of verification.

4.5.1.2 Sediment (Silt)

Sediment depths and pipe roughness may be derived and added to the model based on CCTV and flow survey information.

Factors to be considered in the application of sediment to the model include:

- Whether the sediment is permanent or mobile
- The extent of any jetting carried out prior to the flow survey or CCTV survey
- Whether sediment is applied only to the surveyed sewer length, or also to adjacent pipe lengths

Flow survey site inspections may assist in determining whether the sediment is transient, as the contractor should measure sediment depths during visits. If the sediment depth varies, an average value may be applied (see application of operational defects below), but it is recommended that the model is sensitivity tested in terms of flooding or CSO operation in order that the results of any needs assessment can be interpreted appropriately. The model can be used to determine if silt is likely to be transient by checking predicted velocity in storm conditions.

Models should be de-simplified where appropriate to allow the correct application of silt depths locally.

The verification of the model against flow survey data may provide evidence suggesting sedimentation or partial blockages. However, these should be confirmed by further investigation.

4.5.1.3 Blockages

Obstructions such as localised blockages (including deformations, collapses and other structural defects) and mass roots should be represented using an appropriately sized orifice (located between 2 dummy sealed nodes) rather than by applying sediment or increased roughness along the full length of a pipe, as that may exaggerate the effect of the constriction. Temporary issues should be documented within the model for later removal.

4.5.2 SuDS

An operational consideration for infiltration SuDS is whether siltation or compaction has reduced the ability of the component to infiltrate flows to the ground. There may also be operational issues with inlets and outlets due to partial or total blockages. Where these have been identified they should be modelled appropriately with a reduced pass forward flow control.

Roughness values may be amended where poor maintenance has taken place or the level of vegetation present is different to that assumed. This may require an increase or decrease in the roughness depending on the issues identified.

4.5.3 Watercourses

As much information as possible should be gathered regarding the maintenance of a watercourse and structures on the watercourse.

Operational issues to represent in the model may include:

- Growth or removal of vegetation (which will affect roughness)
- Dredging
- Implementation of diversion works
- Maintenance and operation of gates, trash screens, weirs, culverts, etc.

All the available information and data regarding operational issues should be included in the model where significant. Sensitivity testing should be undertaken, where necessary, to check the model's response to changes in the operational issues.

4.5.4 Representing temporary issues

Temporary issues may include blockages, faulty pumps, jammed flap valves and temporary sewer diversion works.

Where a significant operational issue develops during the period of verification, it may be necessary to represent the issue with real time control rules to set start and end dates of the problem

4.6 Model testing / sense checks

4.6.1 Overview

The first part of the verification process is to check the model's stability and the credibility of the simulation results. This is done by running standard dry weather events and a few synthetic design storms. The results should be checked for stability and also that the prediction of flooding and overflow spill is not unreasonable for a typical sewerage system.

4.6.2 Preparing the model

4.6.2.1 Model timeline

The current timeline model should be used for the initial stability and sense checks.

4.6.2.2 Model timestep

The model timestep and reporting timestep should be appropriate to the issue being simulated.

4.6.2.3 Reporting

A simulation log should be kept that details all the model runs that have been undertaken, the names of the results files and where they are stored.

4.6.3 Dry weather flow testing

A DWF simulation should be run with a diurnal profile applied. If there is significant seasonal variation of infiltration, the model should be run for both summer and winter conditions. The following key data should be reviewed;

- Check that the simulation has completed and has converged
- Check the flow volume balance overall and at each manhole
- Compare the total daily flow arriving at the treatment works with the values derived from long term flow records
- Check for flooding from manholes. This is not expected during dry weather
- Check the operation of overflows. This is not expected during dry weather
- Check for pumping stations running continuously for a significant part of the day. This is unexpected during dry weather except for large terminal pumping stations with multiple pumps
- Check for surcharged pipes:
    - Only siphons, and possibly pipes upstream of pumping stations, should be surcharged during dry weather conditions
    - Review long sections for peak levels to understand the cause of any surcharge

4.6.4 Storm event testing

A summary of the parameters for sense checking the model is summarised below.

4.6.4.1 Rainfall

Rainfall should be generated in accordance with the CIWEM UDG Rainfall Guide. The Commissioning Body may specify design storm return periods and durations to use for testing. Otherwise the model should typically be run with a full range of storm design events of durations from 15 minutes to 24 hours or using a compound storm with an overall duration of 24 hours. These storms should be of significant magnitude so that the system is widely surcharged for the test runs.

4.6.4.2 Antecedent conditions

Antecedent catchment conditions should be derived to represent typical conditions at the start of a significant rainfall event. This should cover all aspects of the modelling including runoff, infiltration and boundary conditions.

4.6.4.3 DWF multipliers

A constant wastewater flow ignoring diurnal variation is generally adequate for sense checks.

4.6.4.4 River Levels

Where a watercourse has a time of concentration that is similar to the drainage model, the time varying levels should be generated as part of an integrated model.

Levels for watercourses that have a time of concentration which is significantly greater than the drainage model and therefore respond independently should be applied with depth hydrographs generated from a river model or measured data.

4.6.4.5 Tide levels

Tide levels should be applied where appropriate based on an astronomical spring tide starting at mean sea level on a rising tide.

4.6.5 Comparison of results

The output from the sensitivity runs should be checked to ensure the results appear sensible. Typically this would include:

- Checks that the simulation has completed and has converged
- Checks that the volume balance overall and at each manhole
- Checks on the operation of overflows. Most CSOs should operate in this event. Most pumping station emergency overflows should not operate
- Checks on the minimum pass forward flow during spill for each CSO, and the comparison with the Formula A and permit values for the overflow. Any overflows showing pass forward flows much less than Formula A should be reviewed
- Checks on the operation of pumping stations with storm pumps. Some or all of the storm pumps should be running during these events
- Producing long sections through all flooding to understand the cause of the flooding and resolve any errors

5 MODEL VERIFICATION

5.1 Introduction

Verifying the model against measured data and historical observations indicates whether the model is replicating known performance. Verification should take into account the purpose of the model. This can influence the accuracy requirements and the relative importance of different elements of verification. The flow chart in Figure 5-1 provides an overview for this section.

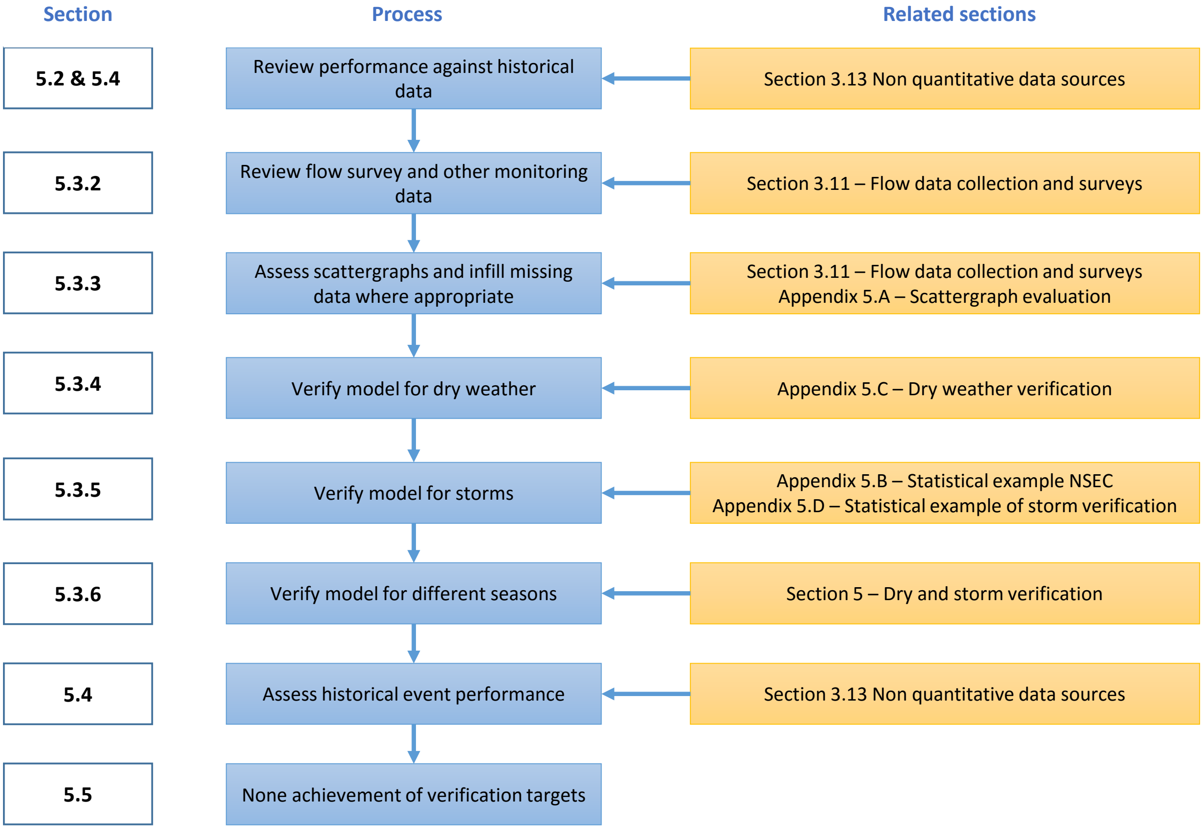


Figure 5-1 Model Verification Overview

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

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

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

Force-fitting is the process of making arbitrary changes to a model to make it fit observed data and should not be undertaken. The dangers of force-fitting are described in CIWEM UDG (2009) User Note 13.

The results of the verification will influence the model confidence within each of the defined confidence zones (see **section 2.3** and **section 6.2**)

5.2 Verification procedure

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

5.2.1 Sewer and Urban Drainage Models

Sewer and urban drainage models should generally be verified for dry weather flows prior to storm verification. The following sequence is commonly used:

- Dry weather flow verification with flow survey and/or telemetry data (see **section 5.3.4** and **Appendix H**)
- Storm flow verification with flow survey data (see **section 5.3.5** and **Appendix I**)
- Verification with long term data sets (such as WwTW certified flows, EDM data or pumping station telemetry)
- Verification with any available major historical event data (see **section 5.4**)
- Historical verification with design events of an appropriate return period and duration or time series (see **section 5.4**). This stage may not be needed if there are several historical events with adequate data

Some modellers prefer to carry out the historical verification before the verification with the events from the short term flow survey, followed by returning to the historical verification. This can be useful to give an indication of the accuracy of the model before the flow survey data are available. This technique is useful when re-using an existing model and can be used as an aid to planning a flow survey.

5.2.2 Pluvial Runoff Models

Verification of pluvial runoff/2D models or the overland flow elements of urban drainage models rarely occurs with flow data because of the relatively rare occurrences of overland flow or flooding. These models should be verified with historical observations with the flooding mechanism and/or flow routing replicated. Historical data can be used to estimate the depth of flooding, flow directions and velocities and be compared with the model prediction.

5.3 Verification with flow data

5.3.1 General

The level of detail, defined purpose and confidence requirements for the model should determine the level of verification required against short term, long term and historical data sets.

Model simulations for the full survey period for the short and/or long-term data sets should pass through the routine stability test requirements given in **section 4.6**.

In looking at the matches (shapes, peaks and tails) between the model and the observed data, the modeller should maintain an overall view of the model. In particular, the modeller should consider whether an observation is supported by data from more than one event and by evidence from more than one monitor site (e.g. an upstream or downstream monitor on the same branch).

The targets given below are a general guide to verification target standards. However, the modeller should always substantiate any claim that the verification is acceptable and record this in the documentation.

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

5.3.2 Reviewing flow survey and other monitoring data

Before using any flow survey or other monitoring data for verification, the data should be carefully reviewed. The flow survey contractor will have carried out a number of checks on the data and will have documented these in the flow survey report. The modeller should review this report carefully before carrying out the verification.

By this stage, the modeller should have a much greater understanding of the system and so can carry out some checks, which the flow survey contractor could not have done. Comparisons should be made between adjacent monitors or groups of monitors on the same branch, for example, to confirm continuity of flow and whether changes in observed volumes are as expected. This should include cross-referencing different additional sources of information such as EDM, pumping stations and WwTW flows and depths with those from short-term flow surveys. Modellers using this data should be aware of its limitations (described in **section 3.10**), for example limitations of measurement parameters, logging intervals and measurement accuracy, which may be lower than those set in the short term flow survey contract. These limitations should be allowed for and targets relaxed where, appropriate when assessing the verification against the targets set in **section 5.3.4** and **5.3.5**. For example verification may be for depth only and be limited by the operating range of the sensor in the case of ultrasonic level sensors (due to drowning under surcharge).

The modeller should then assess whether there is sufficient data to verify the model to the required level of confidence. Good planning, management and checks during the flow survey period should ensure that this is the case as described in **section 3.10.**

5.3.3 Using and developing scattergraphs and infilling missing data

The modeller should review the scattergraphs for each monitor or long-term data set where available. Measured flows should be checked using the Colebrook-White equation (for unsurcharged depths) as a departure from this may indicate inaccuracies in the data such as incorrect invert levels, pipe gradients or pipe sizes. Alternatively, a lack of fit may indicate a transient or permanent issue in the downstream system, for example sediment, an orifice or other hydraulic control. More detail on assessing and classifying scattergraph data is given in **Appendix F**.

The loss of recorded velocity data in sewers is commonly caused by low flows, ragging, or surcharge conditions. With the agreement of the Commissioning Body, the modeller should consider whether it is possible to infill the missing data and, if so, whether the modeller or flow survey contractor should be responsible for doing this. When infilling missing data, it is vital that the depth recording has not been affected if a suitable depth-discharge relationship for a monitor is to be developed. More guidance is provided in **Appendix F** on how these relationships may be developed and applied to non-surcharged conditions.

5.3.4 Dry weather verification

No two dry days are identical, therefore DWF verification should be carried out against data for a number of recorded dry days. This applies to both short term and long term monitoring. The modeller should combine (overlay) daily DWF hydrographs and create minimum and maximum boundary envelopes, for weekdays and weekends. These boundaries may be smoothed and the model predictions compared to them. The boundary lines may be amended to account for:

- Individual days that exhibit unusual conditions caused by operational issues such as pump failure
- Seasonal effects
- Infiltration on longer time series

Care should be taken to exclude periods of missing or inaccurate data as detailed in **Section 3.11**.

The shape including the timings of the peaks and troughs should fall within the boundary envelope.

More guidance is provided in **Appendix H** on how to undertake the DWF verification and how the maxima and minima boundary conditions can be developed and applied.

Where long term data sets are available these should be compared with the simulated performance. This should be for sites where the input data and measurement data including the reading interval is of sufficient quality to be used for comparison.

5.3.5 Storm verification

The predicted and observed flow and depth hydrographs should be compared for the three selected storm event periods from the full flow survey period described in **section 3.10.9**. The hydrographs should closely follow each other both in shape and in magnitude, until the flow has substantially returned to dry weather flow rates. Simulations should be based on full period simulations and not individual events to ensure the appropriate representation of antecedent conditions (hydraulic and hydrological) at the start of the event. The hydrographs should also be reviewed for the full survey period identifying where predictions are poor for events not specifically considered during the verification process and the reasons why.

In addition to the shape, the observed and predicted hydrographs should aim to meet the targets in Table 5–1 for at least two of the three selected storm events. This comparison can be applied to more than three events to improve confidence. At locations that are critical to the use of the model a higher standard of verification should be aimed for as detailed in Table 5-1. Critical locations will be agreed with the Commissioning Body and will typically include flooding locations, CSOs and WwTWs where the accuracy of the model is important in the replication of the system. Modellers should not lose sight of the model's purpose and project scope in undertaking verification against the targets set in Table 5-1. Each site must be viewed in context, and the implications of the achievement or non-achievement of targets should be assessed against the effect that this will have on the model's purpose and use. Implications of non-achievement of targets is discussed later in **section 5.5**.

Table 5-1 Storm Verification Targets

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

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

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

5.3.6 Seasonal Variation

Many catchments exhibit seasonal flow characteristics. The principal causes of these variations may include:

- Changes in populations due to an increased number of tourists in the summer months
- Changes in groundwater infiltration
- Increased slow response run-off due to saturated soils during wetter months
- Snow melt

Seasonal changes, where important, should be included within a single model if possible to avoid the need for different seasonal models.

Model verification should be undertaken over a long period where it is important to capture the seasonal changes in flow. Permanent or long term monitoring data sets (e.g. WwTW measured flow data) can be used, where available, to compare the model performance over different seasons. Using these records may avoid the need for seasonal flow surveys and identify if there is a need in the first place.

Snow melt conditions should be avoided when selecting verification events. The presence of snow melt conditions should be taken into account when analysing continuous verification data that includes the winter period. Specialist modelling techniques for snow melt are rarely required in the UK and Ireland but may be required elsewhere.

5.4 Verification with historical data

Where long term records of historical rainfall information are available, they may be used for historical verification for overflow spills and flooding. The accuracy to be expected from the model depends, amongst other factors, on the rainfall data that is used as input. If the rainfall data are from a single permanent rain gauge the spatial accuracy is likely to be poor for spatially varied events. When combined with radar data, the accuracy may approach that expected from a short-term flow survey.

Where no suitable historical rainfall data are available, design storms (see CIWEM UDG Rainfall Guide) with return periods 1 in 1 years, 1 in 5 years, 1 in 10 years and 1 in 30 years should be tested with the model for flooding. For CSOs, a rainfall time series of 10 years or more should be generated and tested with the model to assess spill frequencies. The whole series should be run where practical, or alternatively a typical year (developed for example based on correlation with the catchment SAAR and the seasonal/monthly rainfall distribution for the full series or long term data) where model run times are prohibitive.

5.4.1 Flooding

Predicted flooding should be compared with reported flooding which should be reproduced by the model in terms of location, magnitude and frequency, insofar as records permit. Where 2D models are run, predicted flood extents may be compared with historical flood outlines or photographic evidence (from various sources as defined in **section 3.13**) with particular regard to matching the overland flow routing.

Significant predicted flooding should be substantiated by evidence of real flooding or by a clear explanation for there being no evidence. However, small predicted volumes may be considered insignificant, since they may not be perceived as flooding on site. For example, in 1D only models, during heavy rainfall on roads, volumes as large as 10m^3 can sometimes be viewed as acceptable standing water or not recognised as flooding. However, inside a building, the smallest volumes are likely to be unacceptable. The modeller should also take into account how the model is built and whether there are limitations that contribute to uncertainty in the prediction of flooding. For 2D models, or coupled 1D-2D models, flood volumes are less relevant and emphasis should be on matching flow routes, velocities, flood depths and extents. For 'conveyance' flooding the flow direction, velocity and flow depth should be considered. For 'ponding' flooding the extents and maximum flood depth should be considered.

Significant discrepancies in reported and predicted flooding should be investigated. Errors identified in the input data should be corrected, or the flooding database updated if further reports of flooding are found. Investigations may include local surveys for evidence of surcharge. Overland flow paths should also be considered as reported flooding might come from remote locations or may be due to runoff that has not yet entered the drainage system.

Below ground flooding to basements may be confirmed by comparing predicted surcharge levels with cellar levels (known or estimated). Alternatively, cellars and connecting pipes may be added explicitly to the model to confirm flooding. Similarly, it is important to check that other low spots in the system where flooding is known to occur have not been simplified out of the model. Where applicable this will include low spots on connected private drainage which should be included in the model.

Operational problems such as sediment, obstructions, pump failures and others can be an influential factor in flooding. The modeller should obtain detailed records of all operational activities undertaken in the local area both before and after the flooding incident.

5.4.2 Overflows

Spill data from Event Duration Monitors (EDMs) and other long term monitors at overflows should be compared with predicted spill data from corresponding rainfall time series where available. This should generate a reasonable correlation subject to the rainfall and EDM data limitations described above and in **section 3.10.7**. The comparison may also be used to identify where overflows may have operational issues that need to be addressed.

5.4.3 Catchment Changes

Urban drainage catchments change over time and it is important that this is taken into account when undertaking historical verification. Running the current timeline model may not reflect the catchment at the time of historical flooding events. It is important, therefore, to establish the catchment state at the time of historical events in order to replicate the historical performance where appropriate or to explain why the current model does not replicate them.

5.5 Dealing with none-achievement of verification targets

Not achieving the verification targets is acceptable, if it is justified by limitations in the flow survey data or is justifiably insignificant in the context of the model purpose.

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

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

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

6 ASSESSING MODEL CONFIDENCE

6.1 Introduction to assessing model confidence

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

Assessing model confidence in a consistent manner helps demonstrate how well models meet their required purpose by providing a system to qualify and/or quantify risk and uncertainty against a range of metrics. This enables confidence to be assessed and compared consistently within a single model or a complete model library.

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

Historically model confidence has been generally based on expert judgement with the use of model "Fit for Purpose" reviews with internal and in some cases external audit. This has taken into account all aspects of the model building and verification process in order to assess the confidence and limitations of the model for use. This is by its nature subjective and relies on judgement. There are attempts being made in the industry to remove some of this subjective, or qualitative assessment and make the process more quantitative. The CoP sets out two possible approaches to the assessment, a qualitative assessment building on historical practice but with more visual reporting, and a quantitative approach based on a scoring system. It should be noted that the use of the quantitative approach is in its infancy and there is too little experience currently available to provide definitive guidance on scores and relative weighting. There will also still be some subjectivity in using a quantitative approach. These approaches could be used independently or to support the expert judgement review.

Figure 6-1 outlines an overall model confidence assessment approach based on suggested standard categories, highlighting links to the relevant CoP Sections where appropriate.

6.2 Developing and applying a model confidence assessment

6.2.1 Confidence assessment general principles

The confidence assessment approach should be transparent, consistent and repeatable. It should enable data to be interrogated, analysed and displayed geo-spatially at an appropriate scale as detailed in **section 6.2.4**.

The Commissioning Body should identify the categories for confidence assessment. Five suggested key categories are listed and described below:

- Asset data confidence
- Subcatchment data confidence
- Flow data confidence
- Flow verification confidence
- Historical verification confidence

For 2D only models or the 2D component of coupled 1D-2D models the flow data and flow verification categories are not relevant and may be omitted.

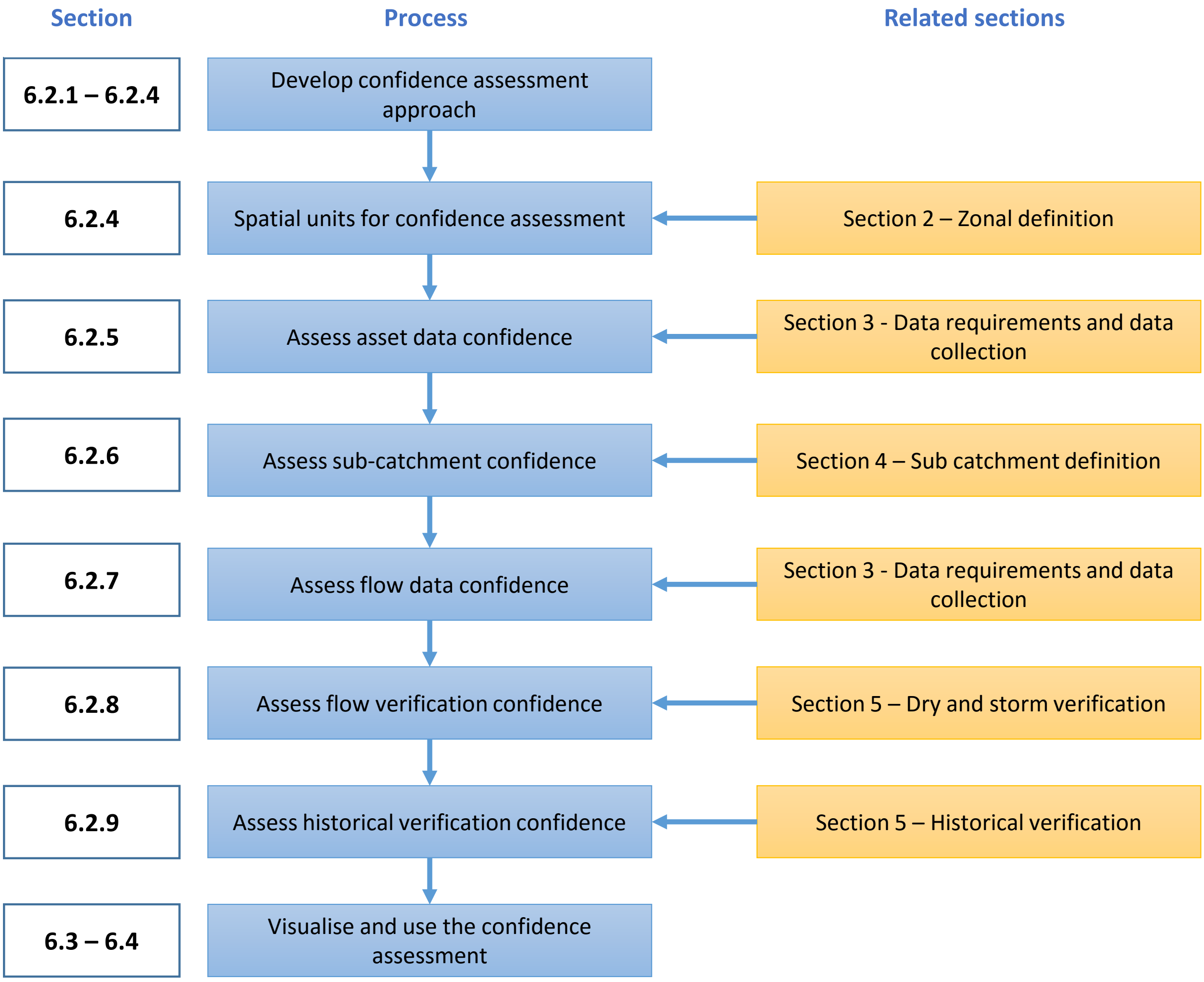


Figure 6-1 Assessing Model Confidence Overview

6.2.2 Evaluation approach

The evaluation approach should clearly set out how to rate or score the individual metrics forming each category. The method applied may be qualitative, quantitative or a combination of both. Most approaches will include an element of subjectivity and judgement that should be minimised as much as possible to achieve consistency.

The Commissioning Body should set the relative weighting or importance of the confidence categories and may omit or add categories as appropriate based on their need and how the output will be used in practice.

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

A **qualitative approach** may vary in detail. In its simplest form, this could be a zonally applied descriptive summary of the data quality and model performance in each confidence category. This approach is subjective and whilst flexible, may be open to inconsistencies when compared with other approaches. Alternatively, increased detail can be applied using metrics with fixed criteria or bands within a rating system, such as Red-Amber-Green (**Appendix J** gives an example of this may be applied). An example of bandings that could be applied to data collection is given in Table 6-1. This shows four different data collection levels of detail, as outlined in Table C-1, together with three different levels of quality. Inherently there is higher confidence in more detailed data, but this can be reduced if the quality of the data is reduced.

Table 6-1 Example Data Quality and Confidence Approach

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

A **quantitative approach** should use a numerical scoring system. Each confidence category and metric would be assessed and a numerical score applied. Each category and metric may be weighted for its relative importance (e.g. if more prominence is placed on replicating measured flow data).

6.2.3 Using data flags in assessing confidence

The use of data flags is discussed in **section 4.1.3**.

A Model Confidence approach based on data flags can be used in both a qualitative or quantitative approach. In a quantitative approach this would assign a score to each flag, depending on the quality of the data. This would be used in conjunction with a weighting system to determine the confidence in either individual assets or asset data as a whole. This is considered further in **Appendix K**.

By thematically mapping the flag scores across the model, the areas of higher and lower scores can provide an understanding of the overall quality of the data used to build it and an indication of risk associated with poor quality data. This could, for example, draw attention to areas where sewer records are poor and there has been an over-reliance on assumed and inferred data.

In a qualitative approach, the number of flags of each type could be assessed to allow a general understanding of the level of detail in the model.

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

6.2.4 Assessing confidence in spatial units

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

- Asset data confidence - Point or zone e.g. project boundary, drainage area or CSO
- Subcatchment confidence - Zone e.g. project boundary, drainage area or CSO catchment
- Flow data confidence - Point or zone e.g. flow monitor location
- Flow verification confidence - Point or zone e.g. flow monitor subcatchment
- Historical verification confidence – Point or Zone e.g. flooding project area or CSO

6.2.5 Asset data confidence

Asset data accuracy has a direct impact on hydraulic model performance and is a key metric in assessing model confidence. Asset data confidence is a function of the quality of that data and its importance in the simulations. For example, pipe dimensions are far more important than the pipe material. **Section 3.7** describes how asset data may be acquired, assessed and categorised when it is entered into the model.

For a qualitative approach, the confidence may be subjective, based on the method of data acquisition, quality control checks and the age of the data. An example structure to rate the data is shown in Table 6-1

For a quantitative approach, it is likely that an assessment of the individual asset elements will be required. Examples of these are summarised in Table 6-2. Each metric should be weighted for its relative importance and a score applied. Alterations made to the asset data without justification and evidence should be highlighted.

Table 6-2 Examples of critical asset data items affecting model performance

Node	Conduit	Weir(s)
Ground level Flood type Benching method Floodable area SuDS parameters (if used for SuDS) Chamber dimensions	Shape Width Length Upstream invert level Downstream invert level Conduit Roughness Headlosses	Crest level Width Discharge coefficient Roof height Notch width (if used) Notch details (if used)
Orifice	**Pump(s)**	**Screen**
Invert level Discharge coefficient Diameter Limiting discharge (if used)	Pump type Switch ON level Switch OFF level Discharge (if used) Head-discharge table (if used) RTC Controls	Crest level Width Height Angle Aperture / openings Head-discharge

Sluice	Flap Valve	Culvert Inlet / Outlet
Invert level Width Discharge coefficient Opening height	Invert level Discharge coefficient Diameter	Invert level Inlet configuration / orientation Reverse flow model

Some of the asset information will be more difficult to assess than others. As an example there are a number of ways that a discharge coefficient could be calculated, with varying levels of confidence. The range could be from CFD modelling in exceptional cases, flow verification, first principles, text book defaults or software defaults.

6.2.6 Subcatchment confidence

Sections 3.9 and **4.2** describe how subcatchment areas should be assessed, surveyed, applied and amended during the model build and verification process. Elements to be considered for a confidence assessment include:

- Area of runoff surfaces
- Connectivity of the area to the drainage system
- Runoff and routing model
- Soil classification
- Rainfall profiles
- Dry weather flow components (population, PCC, trade/commercial flows and infiltration)

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

For a qualitative approach, the confidence may be subjective, based on the method of data acquisition, type of model detail and drainage type. For a quantitative approach, it would be appropriate to develop criteria and scores for each element and consider the weightings to be applied.

Alterations made without justification and evidence should be highlighted.

6.2.7 Flow and depth data confidence

Flow data are generated through the short-term and permanent monitoring of the velocities and/or depths/levels within the drainage system. **Sections 3.10** and **5.3.2** describe how this data should be assessed for quality and accuracy for use in Model Verification. The confidence in the flow data should be assessed during the data collection phase. The following three metrics should be considered.

The quality and accuracy of the monitoring equipment is particularly important for permanent installations where confidence may be categorised using a number of checks, including the amount of lost data, usability of data (ability to understand what the data is saying, knowledge of datum, where the measurement point is, what is being measured), and the record of checks and the accuracy at each site.

Scattergraphs generated for depth and velocity data should be evaluated and categorised for quality on receipt and during model verification. The scattergraph confidence may be considered for dry and storm periods. Assessments will be qualitative, with the quantitative approach placing a score to the qualitative assessment.

Upstream and downstream flow balances should be checked and any issues dealt with where possible during the survey period. Unresolved issues should be identified by the assignment of an appropriate confidence rating or score to the flow data.

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

6.2.8 Flow verification confidence

6.2.8.1 Dry weather verification metric

Section 5.3.4 describes how dry weather flow verification in foul and combined sewers should be undertaken for weekday and weekend profiles. This may be applied to both short-term and permanent monitors subject to limitations in the measured data. The simulated profiles should be compared with the upper and lower bounds generated by the measured data. A qualitative confidence approach may include a description and set ranges for the proportion of the time the profile lies within the two bounds and how far the simulated profile deviates away from these. A quantitative approach may use a statistical calculation that provides a measure of the fit of the simulated profile within the two bounds (**section 5.3.4** and **Appendix H**).

6.2.8.2 Storm verification metric

Section 5.3.5 outlines storm verification targets for a range of metrics including shape, peak depth, peak flows, volume and timing, which may be used to create a confidence assessment approach for storm verification.

A qualitative approach may take the verification targets and develop other bandings (e.g. less or more accurate) to determine the confidence in the simulated performance (with an example shown in **Appendix J**). The procedure should determine how to categorise the overall event performance for each monitor, for example, by averaging the ratings across each target criteria and each storm.

A quantitative approach may use a similar system to the qualitative through scoring each metric or using a statistical approach to evaluate a single composite confidence score (including shape) for depth and flow. **Appendix I** includes an example of this using the NSEC. This method generates a single numerical value for flow and depth comparison for each storm, which may be used to score storm verification confidence. Alternatively, the statistical approach may be used to determine the match of hydrograph shapes only. Depending upon the level of detail forming part of the confidence assessment, it may be appropriate to break storms into smaller sections (e.g. ascension, peak and recession phase) and use the statistical analysis scores for each section. A balance should be considered between the level of granularity and the effort required to evaluate and record the confidence.

6.2.8.3 Seasonal verification metric

Section 5.3.5 outlines the processes for modelling seasonal changes in flows. Seasonal verification confidence should capture how well the model replicates changes in flows over a year or number of years. This may be through a similar approach to the dry weather confidence for overall performance, and through the examination of storm performance for individual events, in line with the storm verification confidence approach.

6.2.9 Historical verification confidence

Section 5.4 outlines the processes for undertaking historical verification. Historical verification confidence may be assessed against flooding or overflow spill performance with ratings or scores weighted depending upon the purpose of the model.

6.2.9.1 Flooding metric

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

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

For historical flooding confidence, where there is frequently less reliable data, it may be necessary to adopt a qualitative approach even when a quantitative approach has been used for other confidence assessments.

A quantitative approach may set defined ranges to rate the model's ability to predict known flooding events in terms of location and magnitude. For example, the metrics may be based on how well simulations and reported event data are matched for:

- X to Y percent of reported flooding locations
- The extent and level of 'ponding'
- The flow routes and depths for 'conveyance' flooding.

A quantitative approach should consider how well the model replicates an observed flooding event and how much predicted flooding was not reported. For the former, a numerical system may be developed to score key metrics such as numbers of flooded locations / properties, flood extents, roads with overland flow etc. confirmed by the model. For the latter an assessment may be based around the likelihood of any flooding being observed or reported at the predicted flooding locations.

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

6.2.9.2 Overflows metric

The assessment of overflow spill performance is highly dependent on the input data quality, including the type of monitoring in place (see **section 5.4.2** and **6.2.7**) and the availability, resolution and spatial/temporal coverage of the recorded rainfall.

Confidence should be linked to the long-term comparison of the predicted and observed overflow performance. The number of predicted and observed spills (calculated using an appropriate spill definition) should be compared and the percentage and/or absolute difference between these used as a confidence metric. The range of the performance or a score (e.g. predicted/measured) may be created based on this approach. The metric should make allowance for data that may have been influenced by operational issues.

6.3 Visualising and using confidence in spatial units

Confidence should be tabulated and displayed geo-visually for the whole model. The visualisation should enable the confidence categories to be viewed in isolation or together, and allow the user to switch between categories.

In order to visualise the model confidence geo-spatially for all categories together, a process will be required to generate composite scores. Where composite confidence values are produced these can be displayed across a range of spatial units, relevant to the purpose of the model. A single confidence score for a whole model would be of limited value due to the level of granularity within a model.

Care should be taken when visualising point confidence. For example verification is carried out at a point and a case can be made for confidence to reduce with distance from the verification point.

6.4 Weightings of categories and “Fit for use” review

As discussed in **section 6.1**, the qualitative and quantitative confidence assessment processes will give an insight into the confidence in the different elements that are included in the completed model. However there is a need to understand the relative importance or weighting of these elements in the assessment of the confidence in the use of the model for a particular purpose.

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

Hence the relative weightings of the different categories will change depending on the projected use of the model. There will still therefore be a need for an expert review process as detailed in **section 2.6** which makes use of the information provided from a qualitative or quantitative assessment of the confidence in the individual elements of the model.

7 Application of Models

7.1 Introduction

Urban drainage models are used for many purposes. Some typical examples are:-

- Development Control and Impact assessment
- Long Term Planning and Management Plans
- Impacts of Intermittent Discharges on the Environment
- Operational purposes
- Live forecasting and management of networks
- Design of Interactions

This section (Figure 7-1) outlines good practice for:

- Preparing the model for use on projects or studies
- Updating the model to include future growth, urban drainage system changes, climate change and the representation of boundary conditions where required
- Developing and running the model for typical post verification uses
- Assessing and documenting key risks and uncertainties in order to consider managing these when using the model and communicating them to future users

Models will normally need updating following a verification process or when making use of an existing model, either to make them representative of drainage system as it is now or to represent the likely conditions encountered during the design period of a project, or the time-period of the project or of a planning study. Changes made for a future time horizon are usually referred to as design horizon changes. A design horizon covers the time periods of the analysis to consider. The Commissioning Body normally sets these, which may be driven by regulatory requirements.

7.2 Model Review

When utilising an existing model it should be reviewed to ensure it is adequate for the purpose it is being used. The level of review will depend on the proposed use of the model and whether the model was built for this purpose.

As a general rule the model should be reviewed using the approach outlined in **Section 2.6**, taking account of any previous model confidence assessments and the checklist in **Appendix B**.

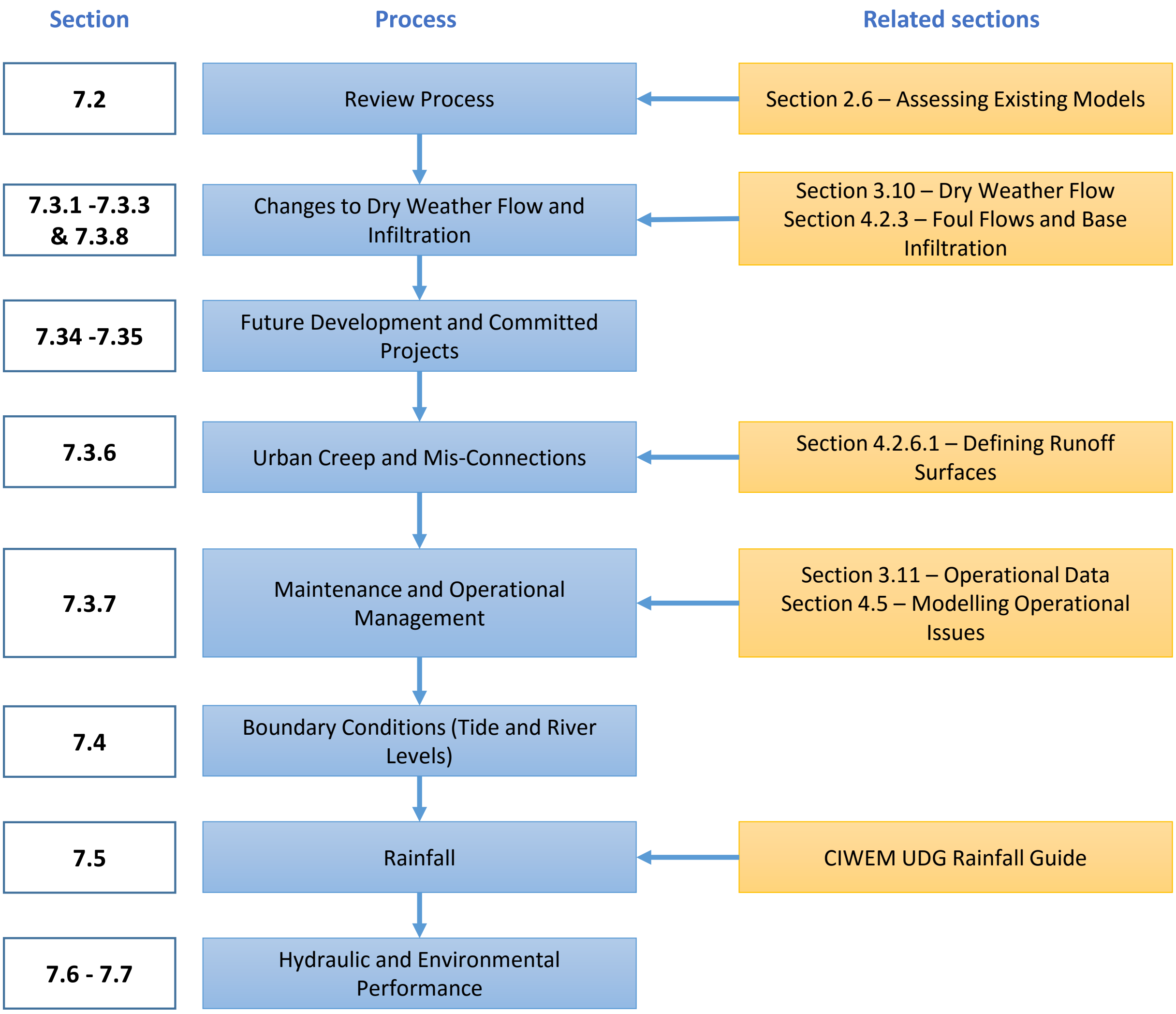


Figure 7-1 Application of Models Overview

7.3 Model preparation

When setting up a model for use, particularly for use in design or long term planning, it is typically necessary to make changes to the model in the following areas:

- Population
- Per capita water consumption (PCC)
- Trade and commercial flows
- Future developments
- Committed urban drainage projects (where data are available)
- Infiltration
- Urban creep
- Maintenance and operational management
- Design and permitted performance at ancillaries and WwTWs

- Possible model adjustments to improve simulation run-times and stability (e.g. pump types)

7.3.1 Population

The Commissioning Body may have a process for calculation of domestic population and future growth. Where this is the case, it should be used. Typically, changes in population over a time horizon will be based on government projections of population changes based on a geographic boundary. These global changes can be transferred to the model as a percentage change to the baseline populations.

Care should be taken when including population data after adding recent and committed developments to the model. The additional population from these developments should be subtracted from the global population changes to ensure there is no double counting.

The global change in population should be calculated by subtracting the modelled development population from the projected change in population. The change in global population may be negative in some circumstances.

Future non-resident populations would generally be considered to be static unless projected figures are available and indicate otherwise.

7.3.2 Per capita consumption (PCC)

The current and future per capita figures for water returned to sewer (consumption figures) for the modelled area should be obtained from the Commissioning Body and applied to the model in accordance with **section 4.2.3**.

In the absence of data from the Commissioning Body the per capita consumption rate for the non-resident population will be less, and a typical value could be a third of resident PCC.

In some situations the per capita consumption may reduce over time, and this should be taken into consideration when assessing performance of the system over the design horizon.

7.3.3 Trade and commercial flows

The current model should include the representation of all significant trade and commercial flows. Any potential changes in the trade effluent permit values should be reviewed.

Verification models will have generally been set up with trade effluent flows set at actual figures if available, or calibrated from flow data, rather than permitted or licenced maximum values. In the UK and Ireland there is nothing to prevent a trader discharging at the maximum in the permit or licence. This should be taken into consideration when representing trade effluent discharges in the model.

A risk based approach should be taken, based on the likelihood of all trade effluent discharges operating at full permit values at the same time. On large WwTW catchments this is unlikely to happen. However, in a catchment upstream of a CSO with a limited number of traders in a catchment, for design horizon purposes consideration should be made to setting the trade effluent discharge at the maximum permitted value. Assumptions should be carefully considered and documented as one approach may not be appropriate for all model applications.

This may require agreement with an Environmental Regulator if the model is to be used for assessing future environmental impacts.

Trade and commercial flow rates for recent and committed developments are considered below.

7.3.4 Future development and redevelopment

The Commissioning Body will normally provide guidance on the types of development to be included in the design horizon model.

Generally for a short term design horizon model, all recent and committed development and redevelopment in the design horizon models will be included. For long-term design horizon models, the future development will not be as well defined, and consideration should be made to the use of local plans to identify potential development. These may carry considerable degrees of uncertainty regarding the likely take up of sites for development, and all assumptions should be documented.

Even in new developments, over time there will be deterioration of the assets, and hence there will need to be an allowance for base infiltration.

Populations for industrial and commercial developments should use the planning data where available. If there is no data available, estimates should be based on similar existing development types with known discharge rates and patterns. In the absence of specific information flow figures may be obtained from the publications "Dry Weather Flow in Sewers" (CIRIA, 1998) and "Flows and Loads – Code of Practice" (British Water, 2013).

Runoff areas for storm discharges to surface water sewer systems, watercourses and SuDS should use information from developer plans where available. Where this information is not available, runoff areas should be based on similar development sites in the modelled catchment or on general policies.

Mis-connections should, in theory, be minimised due to strict building controls. However, over time mis-connections may still occur resulting in an increase in storm response from the foul system. Consideration should be made to modelling some additional contribution of surface runoff to foul systems from separately drained developments.

7.3.5 Recent and committed urban drainage projects

The Commissioning Body will normally advise on projects to be included in the model. Recently completed urban drainage projects should be included in the current model. Committed projects would normally be included where a solution is likely to be implemented within the design horizon timescale for the current project and there is sufficient confidence that the project will be constructed.

7.3.6 Urban creep and mis-connections

It is important to differentiate between urban creep and mis-connections:

- Urban Creep is the progressive loss of permeable surfaces within urban areas creating increased runoff, generally due to small extensions, conservatories and paving over garden areas

- Mis-connections are surface water connections to a foul system or vice versa by householders or commercial premises

Existing mis-connected surface water discharges to foul sewers should already be represented in the current model. No further allowance would generally be included.

Verified models should include existing urban creep up to the date of model verification. In unverified models this would be from the date of the model build.

The urban creep to add should consist of recent creep that has occurred since the model was built or verified, plus additional creep that will occur over the remainder of design horizon period.

UKWIR (2014) "Impact of Urban Creep on Sewerage Systems" defines four methods for calculating urban creep. The simplest method, and the method used widely in the water industry uses defined relationships between property density or property type and the annual increase in impermeable area due to creep. These methods are compatible with GIS based approaches to the application of creep using background mapping and address point data, some sources of which now include property types. Generally urban creep will be assigned to the surface water system and combined systems, and in partially separate areas in the ratio of surface water contribution to systems.

It is good practice to separately identify the additional contributing area assigned as creep in the model for future reference.

A case could be made for limiting the amount of additional urban creep in established urban areas as the majority of the creep may have already taken place.

7.3.7 Maintenance and operational management

Existing models may represent the effects of sediment and other operational and structural defects for verification purposes. An assessment should be made of whether these are likely to be permanent, or of a temporary nature which will have been resolved. In the latter case these defects should be removed from the model, as long as there is a programme of work in place to rectify the issue. If there is any doubt, the defects should be left in.

There are particular issues in open channels and vegetated SuDS as there are significant seasonal variations in roughness as vegetation grows in spring and summer and dies back in the autumn and winter. This may require different seasonal models being developed.

7.3.8 Base Infiltration

Infiltration in verified models, particularly in older models, often represents a snap-shot of the infiltration rates that occurred during the period of the flow survey. This may not take into account seasonal (or yearly) variations in infiltration that occur in reality.

Infiltration should be calculated using a long observed record of flow data, as outlined in **section 4.2.3**, where DWF is taken as the 20%ile (Q80) flow. This should preferably be done using a time series of measured flow, ideally from certified flow measurement available at a WwTW, but other data could be used if the accuracy can be confirmed.

If there is sufficient data, it is good practice to check the variability of base infiltration. In some circumstances an annual figure may be suitable, but if there is significant variation a summer and winter value may be required, or even monthly data if the modelling software allows.

If no flow survey was undertaken, and there is no other long term data available from similar local catchments, an average infiltration value could be used as a default.

7.4 Boundary conditions

7.4.1 Tides

Tide levels can affect many urban drainage systems at the main outfall, at overflows and at surface water outfalls. The following factors should be considered in potential tidal situations:-

- Daily tide cycle - Daily tide variations
- Spring neap cycle - Monthly tide variations between high spring and low neap tides
- Surge - The irregular increase in tide level due to low atmospheric pressure or decrease due to high atmospheric pressure
- Wind set - An irregular increase in tide level due to onshore winds and decrease due to offshore winds

CIWEM UDG (2009) User Note 22 describes the simplest and most commonly used approaches to modelling the impact of tides on urban drainage systems. This outlines joint probability methods for considering tide level and rainfall for flooding and overflow spill performance. It also provides guidance on surge and wind set. The guidance includes the assumption that the variables involved are independent.

A more robust (but more involved from a modelling viewpoint) method for joint probability analysis in the UK is described in the Defra / Environment Agency (2005) Technical Report "Use of Joint Probability Methods in Flood Management: A guide to best practice". This guide 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. It includes the correlation of tidal surge and rainfall.

Tide levels may lock outfalls which can cause a reduction in spills from overflows, and it is common practice to use a worst case approach by omitting tide levels when assessing spill frequency, duration and volume. However, care should be taken with this approach as the locking of an outfall may have upstream or downstream effects causing increased spills elsewhere.

7.4.2 River Levels

River interaction affects many urban drainage systems at the main outfall, at overflows and at surface water outfalls. As in the tidal situation an assessment of joint probability is likely to be required.

The application of river boundary conditions and joint probability is considered further in the CIWEM UDG (2009) Integrated Modelling Guide.

There are three general methods of applying river boundary conditions in urban drainage models, depending on the level of river detail already included:

1. For fully integrated urban drainage models there will normally be no requirement to apply boundary conditions for rivers as they will be included explicitly within the model
2. For partially integrated models that represent watercourses by an integrated model for the urban component of flow in the river, a steady state inflow hydrograph at the upstream boundary could be used based on flows generated from a stand-alone river model or provided by an external source
3. For non-integrated models that consider the response for watercourses to be independent of the modelled urban drainage catchment, their influences are adequately represented using level files. Typically these could be represented as a steady state boundary condition derived from a stand-alone river model or levels provided by an external source

For 2 and 3 above, joint probability should be considered when applying boundary conditions due to the potentially differing times of concentration of the river and urban drainage network, which in the case of 3 above would mean varying the height of the level files used. This may over predict the impact if the same storms are used for each system as peaks may not be coincident in the two systems. Figure 7-2 outlines an approach to assess the impact.

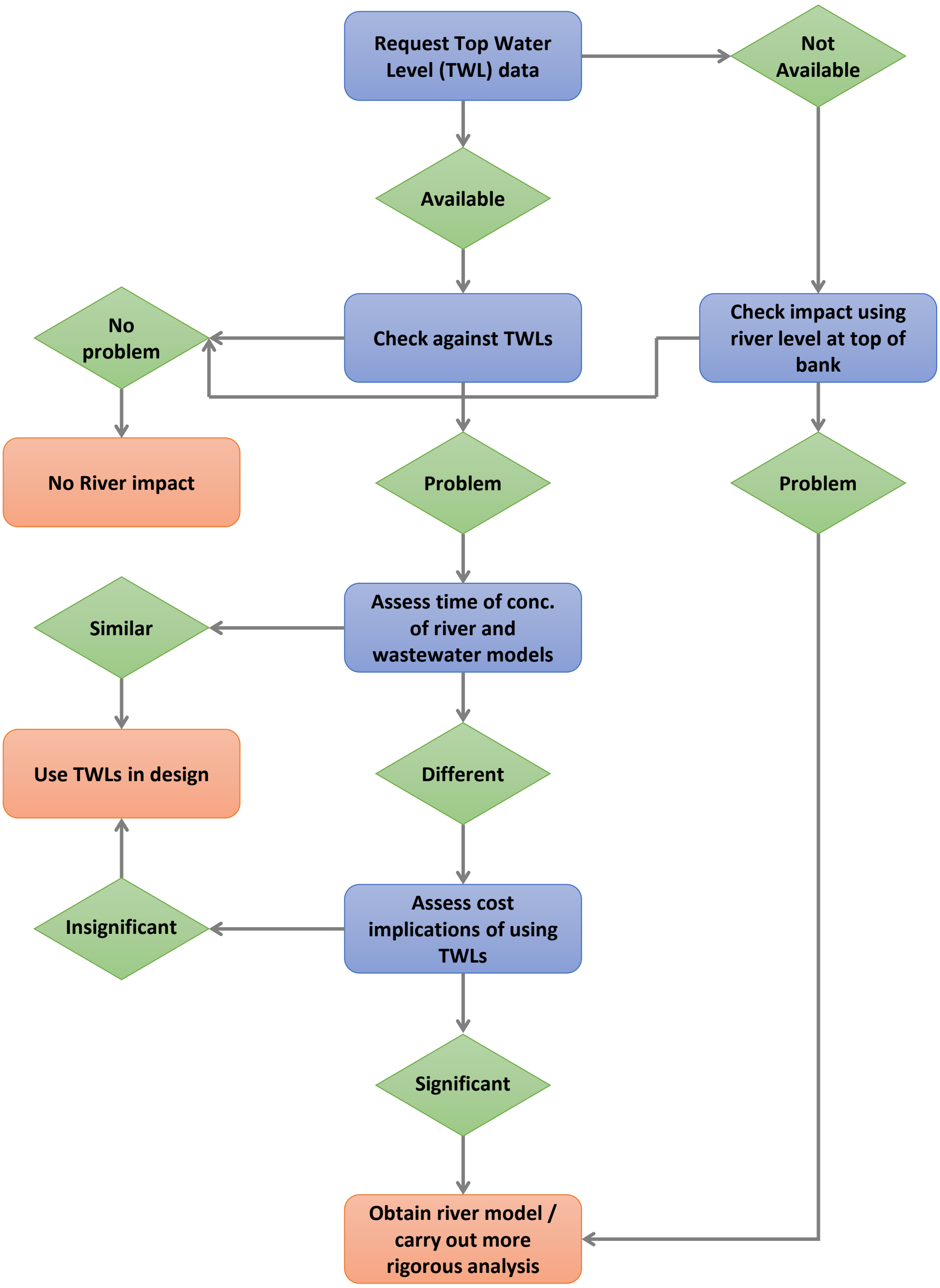


Figure 7-2 Possible approach for considering river impact

7.4.3 Climate Change

In the UK, Regulators publish ranges of recommended climate change uplifts for river flows and sea level rise. These should be tested for the appropriate future scenario timescale.

7.5 Rainfall

Rainfall data and antecedent conditions, including climate change where required should be developed using the guidance in the CIWEM UDG (2016) Rainfall Guide, sections 3, 4 and 5 which includes generation and application of:

- Design Storms (FEH, FSR) including seasonal correction factors
- Superstorms (Critical Input Hyetographs)

- Historic and Stochastic Rainfall Series
- Antecedent conditions, evapotranspiration
- Climate changed rainfall

It is usual when modelling the sewerage system for climate change effects to be modelled by making amendments to future rainfall only, with no changes being made to the runoff processes.

7.6 Assessment of hydraulic and environmental performance

The general principles and procedures for the development of sewerage management plans using a risk based approach are covered in the Sewerage Risk Manual (SRM) http://srm.wrcplc.co.uk/. This outlines a high level approach to a needs (risk) assessment and interventions development for flooding, environmental, structural and operational issues, including growth and climate considerations. Whilst it is not the intention to provide detailed guidance on interventions development in this CoP, it is useful to outline the general intervention types that may be developed for urban drainage needs and the key issues to be considered when modelling these. Interventions should be developed using the general guiding principles in the SRM and within this CoP.

Table L-1 in **Appendix L** summarises common types of interventions to consider for urban drainage needs.

After major changes to the model, stability checks should be carried out.

The Commissioning Body should provide guidance on the performance standards to be used for intervention design. When developing interventions care should be taken to test the impact of the solutions on other areas of the model to ensure any changes are acceptable.

7.7 Developing the model for real time data, live running and forecasting

Urban drainage models are being increasingly used in a live and predictive context for real-time operational forecasting, system management and early warning. These provide Commissioning Bodies with timely, accurate and reliable forecasts of what will happen within a catchment, based on past and current observations of a multitude of parameters, including rainfall.

Speed can be critical in any early warning and emergency process. Models forming an integral part of these systems therefore need to run as efficiently as possible. The following approaches should be considered when developing models for this purpose:

- Critical points for measurement/forecasting in the model should be determined, for example at individual nodes, CSO spill pipes, specific 2D flood locations etc
- All critical nodes or links where there are monitors or which are used in forecasting should be retained in the model with no simplification in their immediate vicinity
- The model should be checked and resolved for any issues that may affect model stability and therefore model speed
- The model should be simplified where possible without compromising its accuracy at critical measurement points by for example:
  - o Simplifying complex RTC arrangements where they slow the model down

    - Simplifying complex pump arrangements where possible
    - Avoiding the use of soil and ground store models where these are not needed for the specific period to be simulated
- 2D modelling should only be applied where essential to the forecasting output and should be simplified where possible by setting an appropriate minimum element size and by the simplification of map object shapes
- Where models include significant watercourses that have a longer time-to-peak than the urban area, an assessment should be made as to whether the fluvial inputs can be derived from another source (e.g. EA fluvial forecasting model), or acceptably simplified using a single subcatchment

7.8 Documentation

Changes made to the model, and the sources of additional data must be documented to provide a clear audit trail for future users. Where applicable, key decisions should be summarised and model changes included in the model using comments, notes and data flags (where software facilitates).

Key residual model risks should be documented for future users.

8 DOCUMENTATION

8.1 Introduction

In order that future users can properly assess the confidence in a model for a particular purpose and to allow for updating and upgrading, it is essential that the work involved in building and verifying a model is properly documented. As well as providing essential information to future users of the model, the documentation is also a basis for both internal and third party reviews of the work. This documentation is not to be confused with the requirement from a Commissioning Body for a final report, which may be significantly less detailed. The following should be considered as a minimum requirement for significant new model building projects. However, not all sections will be relevant for all modelling projects, particularly for a small project making use of an existing model and the user's discretion should be applied.

Documentation can be in many forms. Some documentation may be in the model itself, either by user text or by the use of flags if the modelling software allows it. Other documentation may take the form of calculation sheets, review spreadsheets, or reports at various stages of the model development. Regardless of the format, it is essential that the documentation produced is available for all users of the model and when changes are made to the model the associated documentation is also amended.

For the purposes of this guide, documentation has been considered under the section headings of the guide, being:

- Model definition
- Data collection
- Model development
- Model verification and confidence
- Model application
- Quality assurance and review

It should be noted that the review and documentation process is an ongoing activity which should be carried out throughout the development of the project and not left to the end.

8.2 Model Definition Documentation

8.2.1 Introduction

The Model Definition stage is essentially the scoping stage of hydraulic model development. Documentation should include some or all of the following elements depending on the nature of the model purpose:

- Purpose and drivers of the project
- Catchment description
- Catchment issues / problems
- Previous studies and existing models
- Details of any model reviews

- Definition of modelling requirements

8.2.2 Purpose and drivers of the project

This should include the objectives, purpose and confidence levels required by the Commissioning Body.

8.2.3 Catchment description

Details of the catchment, including the existing above ground and below ground drainage systems, ancillaries, area, population, types of development, ground, topography and potential interactions between the above and below ground systems etc.

8.2.4 Catchment issues / problems

For both the above and below ground systems, this should include the documentation of (but not limited to):

- Future development
- Hydraulic deficiencies and known flooding
- Environmental deficiencies
- Operational deficiencies
- Structural deficiencies

8.2.5 Previous studies and existing models

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

Any existing models should be reviewed in accordance with **Appendix B**, and the results of the review documented, including confidence scoring.

8.2.6 Definition of modelling requirements

This should include:

- The extent and type of models to be developed
- The level of detail to be included in models
- The extent of additional surveys required
- Any additional data requirements

8.3 Data Collection Documentation

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

8.3.1 Existing data

Section 3.4.2 details the potential sources of existing data. All data should be collated and logged and a schedule of data used should be set up. This could include:

- A summary of the data

- Reference to the source of the data
- Issue number and date
- Location of data in archive system
- Confidence assessment if any

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

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

8.3.2 Data from surveys

There are a number of surveys that will produce data, typically manhole surveys, flow surveys, contributing area surveys, topographical surveys, watercourse cross section surveys, CCTV surveys, operational inspections and ancillary surveys.

Details of any specific surveys carried out should be included in the data schedule with reports included as an appendix to the schedule or hyperlinked. This would include details of any checks carried out on the data.

8.4 Model development

It is imperative that the model development process is adequately recorded and documented. This may be by means of data flags, user notes in the model and by external recording. Typically, this would include some or all of:

- Details of any assumptions made, including interpolated data
- Changes made to the data with the justification for the changes
- Details of any simplification carried out
- Allowances for un-modelled storage and Preissmann slot
- Run-off surfaces and sub catchment boundaries
- Soil classes
- Area take-off, impermeability and runoff modelling
- Results of any validation checks and changes made
- Long sections review
- Dry weather flow and infiltration
- Details of ancillaries included and omitted from the model, including calculation sheets
- Pipe and channel roughness
- Headlosses
- Silt and obstructions;
- Flooding types;
- Topography and 2D surfaces.

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

8.5 Model Verification and Confidence Documentation

8.5.1 Model Verification

There would generally be a verification report produced. This can take many forms and does not have to be in a specific reporting format. However the following information should be provided:

- A summary - outlining the main conclusions, including recommendations for future use of the model and unresolved issues
- Details of the flow survey locations and how they were selected:
  - Listing the locations chosen and any alternatives considered
  - The reasons for the selection of each monitor and rain gauge location
  - For flow/depth monitors this should include their intended role in the verification process
- A copy of the sewer flow survey contractor's report, including any updates during the verification process
- A copy of any supplementary comments from the modeller of the performance of the flow and depth monitors
- Comments on the dry weather and storm events with relation to the criteria set out in paragraphs 3.11 and spatial distribution of the rainfall on an event by event basis. The basis for the selection of the event should be included
- Plots of the first fits of the model with the flow survey data
- A detailed description of any changes made to the model during the course of the verification and the justification for making these changes together with making appropriate amendments to data flags
- The final verification plots together with an indication of the verification confidence, and explanation of the results
- A commentary on the initial comparison and a description of how well the model is considered to be verified. Any judgements taken or weaknesses should be highlighted and any sensitivity analysis reported
- Copies of the files on suitable media
- Copies of relevant flow survey and rainfall files on suitable media
- Details of Historical Verification against reported flooding, surcharge, CSO performance and long term monitoring, including a comparison with predictions using design storms and/or times series rainfall

8.5.2 Confidence reporting

The results of the confidence analysis should be reported using the guiding principles set out in **section 6**. If using a quantitative process, this lends itself to geo-visual analytics which may be used to display the confidence scores at a variety of spatial scales. This may be separately for each confidence category, or compositely with an overall score which can be weighted where required. This may be done either within the model by using data flags or externally.

8.5.3 Conclusions and recommendations

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

8.6 Model Application

Documentation should incorporate the following:

- Outputs from any fit for purpose review of the model(s)
- Details of any different versions of the model created
- The time horizon of the future model(s)
- Details of any design horizon changes made to the verified model as outlined in **section 7.1**
- Details of any calculations made and references to any source data or assumptions

For each intervention developed, a list of the detailed changes made to the model should be documented, supported by any calculations made and references to any source data or assumptions. Changes made to the model should be suitably flagged.

This should include the associated files used in the design, for example: rainfall used, any allowances for climate change, antecedent conditions.

As well as the detailed description in the documentation, a note with a cross reference should also be incorporated in the comment fields in the data files.

8.7 Quality assurance and review including audit

Throughout the development of the modelling process there should be documented evidence of a sign off and review process involving suitably qualified staff. This could be an internal review or, if required by the Commissioning Body, could also be an independent audit of the model and the modelling process. **Appendix B** has a checklist of elements that would typically be assessed.

Any audit carried out should take into account any specification and the Commissioning Bodies expectations and should be specific to the proposed use of the model. Although this is generally an independent review it should include discussion with the modellers carrying out the modelling project, and may occur at stages during the project.

9 MODEL MANAGEMENT

9.1 Introduction

There is a significant cost involved in the development of hydraulic models. In 2014, a UK WaSC estimated that the cost to re-build all their hydraulic models would be in excess of £45 Million. Extrapolation across the UK would suggest the total model stock would be in the order of £400 Million. These are significant assets to organisations once built, and without adequate maintenance over time these will become useless or a liability if for example perceived headroom is used more than once for new developments.

From a Commissioning Body's perspective, the benefits of maintaining models are (but not limited to):

- Use in the Capital Delivery programme
- Use of models for operational purposes (e.g. incident management, flood forecasting);
- Network maintenance
- Development and Updating of Sewerage Management and Drainage Area Plans
- Development and update of Surface Water Management Plans
- Development Control enquiries
- Regulatory requirements regarding asset performance
- Live use of the models

In addition, there may be instances where a model is used for more than one purpose by different modellers. In order to reduce the risk of errors being made then adequate management systems will be required.

9.2 Model libraries

A key component of any model maintenance process is the development of a model library.

The library may include the following:

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

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

9.3 When to update or maintain models

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

- Population changes
- Per Capita Consumption Rate
- Measured Commercial Flow
- Measured and Permitted Trade Flows
- Infiltration
- Recent Development
- Changes in ancillary operation
- WwTW Changes
- Revised asset data
- Recent and Committed Capital Schemes
- Operational changes and repairs

There are various triggers to update or maintain a model. Some examples of specific triggers could be flooding in an area not predicted by the model, EDM results conflicting with model predictions, significant new development in an area, or a driver to update models in a library to achieve a minimum or uniform confidence standard.

The four alternatives methods of determining whether to update a model generally available would be to:

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

Table 9-1 outlines the advantages and disadvantages of the various approaches.

There is no definitive guidance to which of the above methods is best. This will depend on the potential use of the models, the frequency of use of the models and the confidence required in the models. If using models for operational purposes, there is more of a need for regular maintenance and update of the models.

For all of these maintenance methods there is a need to have processes in place for identification of changes in the modelled catchments, so that when future updates are required, the data will be available for the update.

Table 9-1 Model Maintenance Approaches

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

APPENDICES

APPENDIX A – EXAMPLES OF DEFINING MODEL CONFIDENCE LEVELS

This appendix contains two examples[1] of defining model confidence levels.

Example 1:

The areas where the highest levels of confidence are required are shown in green with the areas with intermediate confidence shown in amber.

In this hypothetical example, there is a major watercourse flowing through the middle of the city catchment (Figure A-1).

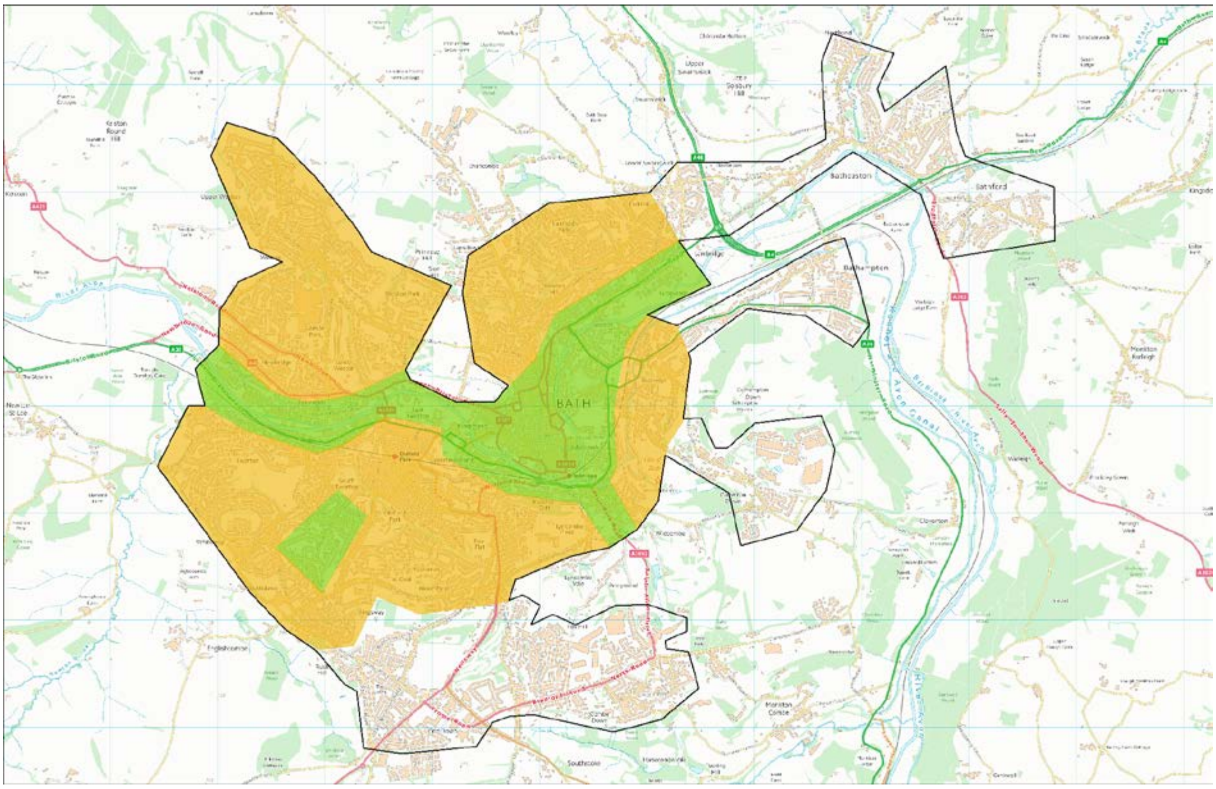


Figure A-1 Example of differing confidence levels defined by a Commissioning Body

This is an example of what a WaSC as the Commissioning Body may specify. The nature and historical development of the city means that there are a significant number of CSOs along both sides of the river and it is important in terms of the Water Framework Directive and permitting of the CSO discharges that there is a high degree of confidence in the area of the model alongside the river (shown in green). The commercial centre of the city is also defined as an area where a high degree of confidence is required.

There may be an area where there are flooding problems (shown hypothetically) that also requires a high degree of confidence. The other parts of the model can have intermediate levels of confidence (shown in amber) and the outer lying parts of the model could have lower levels of confidence.

---

[1] *Contains OS data © Crown copyright and database right (2017)*

Example 2:

In example 2 (Figure A-2) he areas where the highest levels of confidence are required are shown in green with the areas intermediate confidence shown in amber.

The same catchment as that for example 1 is used but the background image is the National Flood Risk Authority's surface water flood risk map

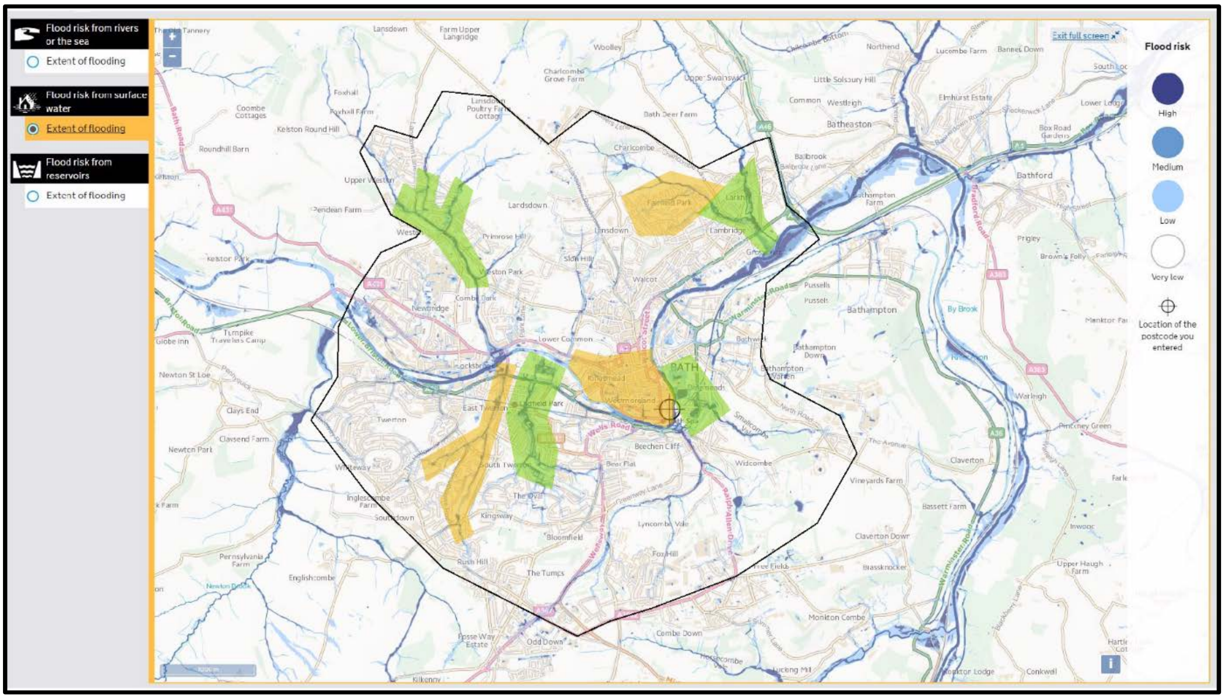


Figure A-2 Example of differing confidence levels defined by a Commissioning Body

This example is typical of what a Local Flood Authority as the Commissioning Body may specify. The National Flood Risk Authority has already undertaken some high level and relatively coarse direct runoff modelling to derive their surface water flood risk maps.

In the example, the Commissioning Body is assumed to require direct runoff modelling to a finer resolution and maybe taking full account of the sewer network. The National Flood Risk Authority's modelling may have identified a number of areas with a high flood risk confirmed by reported flooding. These areas may be defined as requiring the highest confidence levels (shown in green). Other areas, perhaps identified as overland flow routes, may require an intermediate confidence level (shown in amber) whilst the remainder of the catchment within the defined boundary could have a lower confidence level requirement.

In this example, the defined boundary may also define the extents of the required model.

APPENDIX B – ITEMS TO CONSIDER FOR A MODEL ASSESSMENT OR MODEL AUDIT

Model Assessments or Model Audits usually comprise a standard list of formal checks to be undertaken. A typical list of these items is:

- Assessment of sufficient data for review
- Model history and purpose
- Model extents & connectivity and level of detail
- Network validation (if software allows)
- Model stability and volume balance check
- Subcatchment data
- Contributing areas and impermeability
- SOIL type (Class)
- Node data
- Flooding representation
- Manhole headlosses
- Storage compensation
- Conduit data
- River cross-sections
- Bank levels
- Backfalls
- Sediment depths and roughness coefficients
- Inclusion and representation of ancillaries including bridges, weirs, inlet structures, CSOs, Pumping stations
- Population figures
- Domestic wastewater profiles
- Trade flows
- Commercial flows
- Base infiltration
- Runoff modelling and slow response
- Rainfall
- Changes in catchments since the model was developed
- Urban creep
- Previous model verification
- Inclusion of major systems
- Model detail in vicinity of critical locations
- Interactions with watercourses and other systems
- Sensitivity to local baseflow infiltration and rainfall induced infiltration
- Historical verification
- Overland flow paths

APPENDIX C – DATA COLLECTION LEVELS

Table C-1 Data Collection Levels

Data	**Data Level A**	**Data Level B**	**Data Level C**	**Data Level D**
Manhole, pipe, culvert and channel data				
Data sources	A complete survey or resurvey of the manhole dimensions, ground levels and pipes/channels dimensions and invert levels should be carried out.	Pipe/channel dimensions, ground and invert levels should be taken from existing records as far as possible.	Pipe/Channel sizes, ground and invert levels should be taken from existing records as far as possible.	Pipe/Channel sizes, ground and invert levels should be taken from existing records as far as possible.
Dealing with missing data	Surveys should be carried out to provide the missing data	Surveys should be carried out to provide the missing data.	Missing pipe/channel dimensions or levels may be estimated or interpolated from neighbouring manholes or pipes subject to a maximum of two consecutive manholes and a maximum of 5% (for guidance) of the total data. Ground levels may be applied using DTM data where available subject to the appropriate checks. Where no DTM data are available, missing ground levels may be estimated or interpolated from other known levels.	Missing pipe/channel dimensions or levels may be estimated or interpolated from neighbouring manholes or pipes. Ground levels may be applied using DTM data where available subject to the appropriate checks. Where no DTM data are available, missing ground levels may be estimated or interpolated from other known levels.
Data checks	A complete consistency check should be carried out on the input data and a sample manhole survey carried out to check the accuracy of the data supplied. Resurveys should be organised in any areas where significant errors are found.	A complete consistency check should be carried out on the input data. Surveys/resurveys should be organised in any areas where significant errors are found.	A consistency check should be carried out on a representative sample of the data used in the model to check its accuracy. Any obvious discrepancies should be checked on site.	No routine data checks need to be carried out unless problems are highlighted by the model software.

Data	Data Level A	Data Level B	Data Level C	Data Level D
Ancillaries and Structures (CSOs, Pumping Stations, WwTWs, Watercourse Structures)				
Data Sources	Surveys should be carried out at all significant ancillaries and modelled watercourse structures. Data gathered should include RTC and Long Term measured data (e.g. Carts, EDM) and operational data where relevant.	Data for ancillaries and modelled watercourse structures should be obtained from existing urban drainage records, as constructed drawings, previous surveys, previous models or other reliable data sources. Surveys should be organised where there is insufficient data to model ancillaries/watercourse structures with the required accuracy structures Data gathered should include RTC and Long Term measured data (e.g. MCERTS, EDM) and operational data where relevant.	Data for ancillaries and modelled watercourse structures should be obtained existing urban drainage records, as constructed drawings, previous surveys, previous models or other reliable data sources. Surveys should be organised where there is insufficient data to model ancillaries/watercourse structures with the required accuracy structures Data gathered should include RTC and Long Term measured data (e.g. MCERTS, EDM) and operational data where relevant.	Data for significant ancillaries and modelled watercourse structures should be obtained existing urban drainage records, as constructed drawings, previous surveys, previous models or other reliable data sources Surveys should be organised where there is insufficient data to model significant ancillaries/watercourse structures with the required accuracy structures Other ancillary and watercourse structure data may be estimated. Data gathered should include RTC and Long Term measured data (e.g. MCERTS, EDM) and operational data where appropriate where relevant.
Pipe Roughness Data				
Source and application	Information on roughness, and hydraulic problems should be obtained from available CCTV records.	Where sewer condition is known to be poor, available CCTV records should be inspected and the result used to assess roughness.	Global roughness values should be assumed.	Global roughness values should be assumed.
Sediment Level Data				
Source and application	Information on sediment depths should be obtained from available CCTV records.	Information on sediment depths should be obtained from available CCTV records where there are known sediment problems.	Assumed sediment depths should be included where there are known sediment problems.	Sediment depths should not be included.

Data	**Data Level A**	**Data Level B**	**Data Level C**	**Data Level D**
Contributing area data				
Determining contributing area boundaries and connectivity	Detailed surveys should be carried out to determine connectivity. Boundaries should be determined from mapping and/or DTM data.	For separate and combined systems connectivity should be determined from a sample survey. For partially separate systems detailed surveys should be carried out to determine connectivity. Boundaries should be determined from mapping and/or DTM data.	For separate and combined systems connectivity should be determined from urban drainage record plans by judgement. For partially separate systems sample surveys should be carried out to determine connectivity. Boundaries should be determined from mapping and/or DTM data.	Connectivity should be determined from urban drainage record plans by judgement. Boundaries should be determined from mapping and/or DTM data.
Identifying impermeable areas	The determination of which areas are impermeable should be carried out by detailed survey	The determination of which areas are impermeable should be carried out from urban drainage record plans, digital mapping and on-line aerial photography/street mapping with sample surveys where in areas of	The determination of which areas are impermeable should be carried out from urban drainage record plans, digital mapping and on-line aerial photography/street mapping.	Impermeable areas may be estimated using flow survey data.
Calculation of contributing area data	Contributing areas should be determined from GIS.	Contributing areas should be determined from GIS.	Contributing areas should be determined from GIS.	Contributing areas should be determined from GIS.
Calculation of impermeable area data	Paved and roofed areas should be determined from GIS.	Paved and roofed areas should be determined from GIS.	Paved and roofed areas should be determined from GIS.	Paved and roofed areas should be determined from GIS.

Data	Data Level A	Data Level B	Data Level C	Data Level D
Operational data				
Temporary changes to the system	Data should be obtained from operations staff, operational records and/or data from permanent monitors.	Data should be obtained from operations staff, operational records and/or data from permanent monitors.	Data should be obtained from operations staff, operational records and/or data from permanent monitors.	Data should be obtained from operations staff, operational records and/or data from permanent monitors.
Flooding and surcharge data	Detailed data on flooding and surcharge should be obtained from flooding records, including third party sources. Long term surcharge surveys should be carried out where appropriate.	Detailed data on flooding and surcharge should be obtained from flooding records, including third party sources.	Detailed data on flooding and surcharge should be obtained from flooding records, including third party sources.	Detailed data on flooding and surcharge should be obtained from flooding records, including third party sources.
Other incident data	Data should be from operations staff, operational records and/or third party sources.	Data should be from operations staff, operational records and/or third party sources.	Data should be from operations staff, operational records and/or third party sources.	Data should be from operations staff, operational records and/or third party sources.
Boundary Conditions				
River levels	Time varying river levels should be obtained using data from continuous level monitor.	Time varying river levels should be obtained using data from continuous level monitor.	River levels may be applied using periodic (e.g. daily) level measurements.	River level may be applied as exceptional levels recorded otherwise normal levels may be assumed.
Tide levels	Time varying tide levels should be obtained using data from continuous level monitor. (e.g. the national tide gauge network (UK))	Tide levels may be inferred from tide tables – adjusted from peak level measurements.	Tide level may be inferred from tide tables – adjusted from level measurement elsewhere.	Tide levels may inferred from tide tables with no adjustment.
WwTW inlet water levels	Level should be applied using data from a continuous level monitor.	Level should be applied using data from a continuous level monitor.	Levels may be applied as peak recorded levels.	Not used

Data	Data Level A	Data Level B	Data Level C	Data Level D
Dry weather flow data				
Daily per capita values	Data should be estimated from flow measurements within the catchment including metered water supply data.	Data should be applied standard values of water usage (e.g. from WRMP).	Data should be applied standard values of water usage (e.g. from WRMP).	Data should be applied standard values of water usage (e.g. from WRMP).
Geographic distribution of populations and flows	Geographic distribution should be applied using detailed population data and address points, metered water supply and trade effluent data.	Geographic distribution should be applied using population estimates and address point data and information from major trade effluent sources.	Population may be distributed pro-rate base on length of pipe or connected areas.	Population may be distributed pro-rate base on length of pipe or connected areas.
Diurnal flow variation	The diurnal profile should be derived and calibrated from detailed flow measurements.	The diurnal profile should be derived and calibrated from detailed flow measurements.	The default diurnal profile in CIRIA 177 should be applied.	The default diurnal profile in CIRIA 177 should be applied.
Infiltration data				
Fixed element	Infiltration rates should be obtained from a detailed infiltration survey and from long term records at the system outfall (e.g. MCERTS at WwTW).	Infiltration rates should be obtained from a detailed infiltration survey and from long term records at the system outfall (e.g. MCERTS at WwTW).	Standard values of infiltration should be applied. (e.g. from WaSC specifications)	Standard values of infiltration should be applied. (e.g. from WaSC specifications)
Seasonal variation	Seasonal variation should be determined from a detailed infiltration survey and from long term records at the system outfall (e.g. MCERTS at WwTW).	Seasonal variation should be determined be from a detailed infiltration survey and from long term records at the system outfall (e.g. MCERTS at WwTW).	Seasonal variation should be determined from long term records at the system outfall (e.g. MCERTS at WwTW). .	Not included.
Rainfall induced variation (RII)	RII should be determined from detailed infiltration survey and from long term records at the system outfall (e.g. MCERTS at WwTW).	RII should be determined from long term records at the system outfall e.g. (e.g. MCERTS at WwTW).	Not included.	Not included.
Geographic distribution	Geographic distribution of infiltration should be determined from a detailed infiltration survey across the system.	Geographic distribution of infiltration should be determined from available CCTV data and from short-term sewer flow survey used for verification.	Geographic distribution of infiltration should be determined from available CCTV data and from short-term sewer flow survey used for verification.	Infiltration should be distributed uniformly.

Table C-2 Typical Data Sources for UK Urban Drainage Projects

Category	Sub- Category	Likely Source (UK)
Sewers – Existing Models	Hydraulic models and supporting data	WaSC
Sewers – Existing Asset Data	Sewers and manholes	WaSC
	Overflows	WaSC
	Pumping stations	WaSC
	Detention Tanks	WaSC
	Wastewater Treatment Works (WwTWs)	WaSC
	Other ancillaries - pipe bridges, Anti-Flood Devices (AFDs), Inverted Siphons etc.	WaSC
Sewers – Existing Survey data	Manhole and asset surveys	WaSC
	Topographical surveys	WaSC
	CCTV Surveys	WaSC
	Sewer flow surveys	WaSC
	Infiltration surveys	WaSC
	Contributing area surveys (CAS)	WaSC
Sewers - Live data	Live Data: MCERTS, EDM, SCADA, Permanent flow/depth monitors	WaSC
Sewers - Operational data	Historical wastewater flooding records	WaSC
	Blockages / siltation / tree roots etc.	WaSC
	Sewer collapses / rising main failures	WaSC
Sewers - Previous reports and outputs for historical and committed schemes	Previous and committed wastewater solutions data (reports, models, as-constructed drawings, detailed and outline design drawings	WaSC
Sewers - Current and historical reports and outputs for planning studies, flood risk assessment etc.	Previous study outputs – DAPs, SMPs, FRAs, UPMs, etc.	WaSC
Tides	Tide level data	Tide Tables Harbour Chart Online services National tide gauge network (UK)
Rivers	River models River cross sections and control structures River levels and flows – live and historical	Environmental Regulator Flood Authority CEH (FEH)
Geology and Hydrogeology	Geological maps	BGS
	Hydrogeological maps	BGS
	Borehole data	BGS / Site Investigations / Environmental Regulator/ WaSC
	Groundwater flooding data	BGS, Flood Authority
	Groundwater models	BGS, Environmental Regulator
	Springs	BGS
	Historic groundwater levels	BGS
	WFD groundwater monitoring points	Environmental Regulator
Soils Data	Soil data (WRAP/FSR, HOST, University of Cranfield)	University of Cranfield, IOH, FSR
DWF and Design Horizon Data: Population, PCC, Trade, MCERTS, Development	Population data	WaSC, ONS, Planning Authority
	Per Capita Consumption (PCC)	WaSC
	MCERT Final Effluent Date	WaSC
	Trade effluent data	WaSC
	Commercial flow data	WaSC

Category	Sub- Category	Likely Source (UK)
	Recent and planned development	WaSC
Rainfall and Climate Change	Existing rainfall series	WaSC
	Flood Estimation Handbook (FEH) design rainfall	WASC Existing Models, FEH Website (CEH)
	Historical rain gauge and radar data	Environmental Regulator, Meteorological Office
	UK Climate Projections 2009 (UKCP09) / Department for Environment Food and Rural Affairs (Defra) guidance	Defra
Environmental Data: Pollution, WFD, Environmental permits, Sensitive areas	Pollution incidents	WaSC, Environmental Regulator
	Environmental permits for discharges (intermittent and continuous)	WaSC
	River classifications (WFD)	Environmental Regulator
	River status (main river / ordinary watercourse)	Environmental Regulator
	Bathing Water and Shellfish Waters data	Environmental Regulator
	Environmentally sensitive areas [Sites of Special Scientific Interest (SSSI), Special Areas of Conservation (SAC), Special Protection Areas (SPA) and Ramsar, etc.]	Defra
Background mapping and DTM	OS master map	Ordnance Survey
	LiDAR / Next Map DTM	Environmental Regulator, WaSC, Commercial websites
	Address points and postcodes	WaSC/Ordnance Survey
	Land use data	Ordnance Survey
Flood Risk	Fluvial and pluvial flood maps and historical flood outlines	Environmental Regulator, LLFA
	Strategic Flood Risk Assessment (SFRA), Local Flood Risk Assessment (LFRA), Surface Water Management Plan (SWMP), Preliminary Flood Risk Assessment (PFRA)	Lead Local Flooding Authority (LLFA) and District Council (DC) Websites
Highways drainage, land drainage and private drainage assets and performance	Highway drainage information	Highways Authority, Highways agency
	Land drainage information	Land Drainage Authority
	Railway drainage information	Network Rail, London Underground
	Internal Drainage Board (IDB) information	Flood Authority and IDBs
	Private drainage and wastewater treatment	Private land owners
Canals, Navigable rivers, harbours	Canal information	Canal and Rivers Trust (UK)
	Navigable Rivers information	River navigation authorities
	Harbours and ports information	Harbour authorities
Anecdotal data, primary and secondary evidence	Eye witness accounts	Public websites (Facebook, newspapers, etc.)
	Social media accounts	

APPENDIX D - ASSET DATA COLLECTION

Asset record data

Commissioning Bodies generally hold urban drainage asset record data in digital format. However, it may be necessary to obtain other stakeholder data to build the model to an appropriate level of detail. The data are usually available in the form of databases which may be accessed through Geographical Information Systems (GIS). Older records may be held in hard copy formats. Note that these records will rarely be complete.

Asset Surveys

Asset surveys record the main structures which influence the catchment's flow conditions whether in drainage networks, rivers or at coastal locations. The extent of asset surveys required will largely depend on the confidence requirements linked to the use and purpose of the model. Budget constraints, identified and agreed with the Commissioning Body at the model definition phase of the project will influence the extent of such surveys.

Surveys involving underground structures will require confined space entry in dangerous environments (mechanical equipment, power supplies, dangerous atmospheres, etc.). These assets should only be surveyed where absolutely required and all other alternative sources of information have been investigated and found unsuitable for use. At times it may be appropriate to apply sensitivity testing rather than placing someone in a potentially life threatening environment.

Typically, assets requiring surveys may include, but not be limited to, manholes and key ancillaries such as overflows, bifurcations, dual manholes, pumping stations, detention tanks, outfall structures, inverted siphons and other control structures.

The locations for manhole surveys may also include:

- Flow monitor locations
- Immediately upstream and downstream of ancillaries and flow monitors
- Major junctions
- Low spots
- Areas of known hydraulic deficiencies
- Areas with specific drivers for investigation

The aim of any surveys should be discussed with the survey contractor so that any relevant information can be collected at the same time as the asset survey.

Pipes, channels and manholes

The pipe data needed to build a model is as follows:

- Details of the drainage network and connectivity
- Ground levels
- Dimensions and shape

- Invert and other key levels
- Material

Typically, most of this data apart from levels will be available from existing urban drainage records. This should be used to define the nodes and links. The pipe material may help in defining the roughness and condition.

Where data are missing, surveys may be required, depending on the location and purpose of the model. . In less detailed models, surveys may sometimes be avoided by making best use of other level data such as mapping spot heights, DTM, or by calculating invert levels from known depths, or by interpolation from levels at adjacent manholes.

This inferred data may sometimes be used in Type I, or in limited cases, Type II models directly, or it may be used to assist in any simplification process adopted, reducing the requirement for surveys. An assessment should be made as to whether the inferred data are critical to the location, or requirements of the study, in which case appropriate surveys should be undertaken.

Manhole surveys should be carried out in accordance with the Commissioning Body standard specification/framework documentation where available. In the UK these are usually based on the “Model Contract Document for Manhole Location Surveys & Production of Record Maps” (WRc, 1993).

The purpose of manhole surveys is twofold. Firstly, to gain an understanding of the quality of the existing commissioning authority asset data and secondly, to enhance the detail of the model for the intended purpose. Focus should remain on what is needed rather than what would be ‘nice to have’ to limit the extents of such surveys. For model enhancement projects the manhole surveys will be targeted at adding additional detail to an existing model but there is still a requirement to check existing data to ensure data sets have the same relative datum.

If a manhole survey is requested, the following information should normally be obtained:

- Full Grid Reference
- Manhole number (Unless already currently referenced in which case that reference will be retained. Where new manhole references are to be given to manholes these will be numbered using the system as instructed by the Commissioning Body)
- Location (OS Plan containing the existing sewer record)
- Function/Use
- Cover level
- All pipe depths to invert
- Upstream/downstream manhole references
- Materials
- Backdrop depth
- All pipe sizes and diameters
- Evidence of surcharge

The survey should include also an assessment and comments on the service condition of pipes (e.g. sediment, encrustation and other internal issues which may influence flows). These observations can only hope to pick up issues in the immediate vicinity of manholes. CCTV and or man-entry surveys will be required for a more comprehensive full length survey of the structural and service condition of pipelines.

Rising mains

Data collection requirements for rising mains will depend on the modelling approach in the specific software. However, for most models and the associated reporting, typical information to record or collect can include:

- Diameter
- Length
- Starting asset reference
- Finishing asset reference
- Material
- Locations and sources of connections

Other information required may include valves and other flow control or operational devices (air valves, reflux valves, surge controls). For most drainage models, these will not be implicitly included but their impact may need to be considered as part of any operational verification or calibration, especially when investigating a problem.

Ancillaries

Introduction

Data for ancillary structures, such as combined sewer overflows, bifurcations, on-line and off-storage tanks, control structures and pumping stations, can profoundly affect the results of a sewer model. Ancillary data may already exist and the availability of the following should be checked prior to surveying, including:

- Existing models and accompanying reports
- Historical surveys
- As constructed drawings
- Telemetered operational information

Ancillary structures should normally be identified for a full survey where they have a significant effect on the flow conditions and existing data are of insufficient quality for modelling purposes. It is useful for the modeller to attend complex surveys to ensure that all necessary data are retrieved and to observe any issues that may assist later in the modelling process.

Overflows

Overflows within the study area, or within the influence of a study area, should be surveyed where good quality information is not available from previous surveys or record drawings. The surveys should identify the key hydraulic components and be detailed enough to enable these to be included/represented within the model.

The following information will generally be measured and recorded, if applicable:

- Chamber dimensions and levels
- Benching details
- Incoming and outgoing pipe dimensions and levels
- Flow control type and dimensions
- Weir length, crest level and width
- Weir orientation (side or transverse)
- For elevated channels with weirs: dimensions of under channel return to spill pipe
- Screen details and dimensions
- Scum board details and dimensions
- Spill pipe and outfall details including flap valves
- Outfall screen details
- Monitoring details (e.g. EDM)

Head discharge relationships for screens and proprietary control devices should be obtained from manufacturers. In some cases a national database is available for these (e.g. Hydro-Brakes).

Pumping Stations

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

- Number of pumps
- Pump type
- Pump characteristics
- On/off levels
- Nominal capacity
- Pump curve/head-discharge relationship
- Pump arrangement – duty/standby or duty/assist
- Pump control philosophy (RTC)
- Wet well dimensions
- Rising main details
- Emergency overflow and CSO details

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

Depending on the configuration of the station, Real Time Control (RTC) may be required to control pump start and stop and/or pump rates. Understand the current operating conditions to avoid lengthy verification using incorrect/out of date conditions.

Pump capacities are normally determined by carrying out a "drop test". This involves measuring the plan area of the wet well and then measuring the change in water level for a cycle of the pump running and stopped. It assumes the inflow to the wet well remains constant over the cycle and calculates the pump capacity from the difference between the rise rate and fall rate of the water level. This process should be repeated for each pump individually and for each combination of pumps that may operate together.

There are several precautions that are required to ensure that accurate results are achieved. These include:

- Any pumping stations upstream that could cause rapid changes in the inflow rate should be switched off for the duration of the test
- The test should be carried out over a large enough depth range so that the measurements are accurate
- The test should be carried out at least three times to ensure repeatable results
- The depth range should not include low depths where the pump casing or the benching reduce the cross sectional area, nor high depths where the incoming pipes increase the area
- Pump combinations that do not operate should not be tested and reported. This is a particular concern where duty and standby pumps are both run together with the potential to damage the rising main. It is also a significant cause of confusion in modelling correct operation
- Results should be sanity checked so that notionally similar pumps should give similar capacities and two pumps always give more flow than one pump

Due to some uncertainties over pump tests, if not undertaken or interpreted correctly, an alternative is to back calculate from depth monitor results. However, there are benefits to carrying out drop tests:

- They accurately relate capacities to pump combinations without requiring run time monitors
- They allow the pumps to be modelled correctly before the flow survey is carried out
- They can identify pump faults that could be remedied before the flow survey is carried out, so giving better survey results

Where the rising mains combine with flows with other pumping stations, then this will require a different testing regime due to the potential different pumping heads. Ideally, multiple pumps and combinations should be tested running simultaneously.

Other Ancillaries

Other hydraulically significant ancillaries with missing data should be identified for a survey, where key data are not available from other sources or is of insufficient quality, including. These may include:

- Detention Tanks (including upstream and downstream manholes)
- Inverted Siphons (including upstream and downstream manholes);
- Outfall structures including screen and flap valves
- Other significant ancillaries affecting hydraulic performance

WwTW

There are many components in a WwTW that may require representation in a hydraulic model. It is common practice to represent the WwTW as far as the FFT control. In cases more detail may be added to represent downstream processes; in other cases less detail is needed, and the requirement is merely to represent the boundary condition created by the WwTW. Typically, the following components may be represented explicitly necessitating the collection of specific data:

- Inlet (6DWF) and Storm Tank Overflows (3DWF)
- Inlet Screens
- Works Pumping Stations
- Flow channels
- Flow controls
- Online storage
- Offline storage - Storm Tanks including overflow and storm return
- Outfall channels pipes including flap valves
- FFT
- Operating manuals and control rules for FFT, pumping stations, storm tank returns, etc.

It is recommended that a site visit is undertaken if the WwTW is to be included in the model. Inlet arrangements at WwTWs can vary widely and hydraulic controls/influences cannot always be seen from record drawings. Site visits are essential to understand individual hydraulic structures/controls and any interactions between them. It is important to obtain as much information from site operatives as possible to fully understand current operating regimes and such information should be recorded and documented clearly. Collection of as built information may be required to determine the extents of survey requirements to check the quality of as built information and ensure any modifications are captured and included in the model.

Where surveys are required, overflows and pumps within the WwTW should be surveyed the same as the catchment's other CSOs and PSs where site constraints allow.

Other data requirements include the WwTW permit information, inflow data (e.g. MCERTS (UK)), EDM spill data and other monitoring data which should be obtained for the full period of record where available. Care should be taken to ensure that the correct units for any flows are reported as well as their monitoring locations. For example, FTFT can be reported downstream of the storm tanks and include elements of storm return flows. Consideration may need to be given to the wastewater treatment biological process to ensure that there are no unexpected impacts on the hydraulic representation.

Real Time Control (RTC)

Control philosophies and logic for complex pumping stations, controlled overflows etc.; should be downloaded from control panels and analysed where possible for inclusion in the model. If this is not possible, the RTC rules may be obtained from O&M manuals, existing models and/or estimated by reviewing records of flows from long or short-term flow data. This data should be supported by detailed discussions with operational staff to understand how the controls operate in extreme events

Sustainable drainage systems

A detailed site walkover should be carried out where SUDS require modelling to assess their operational condition. Key issues to consider include outfall/overflow condition, level of maintenance and siltation levels. Data requirements for SUDS essentially follow the same principles as for other ancillaries, but the data may be harder to determine or establish. The aim of the model is to represent the features hydraulic performance. This can be done as part of an explicit representation of flow paths and in some instances it may be appropriate to represent their impact by other modelling approaches. The representation of SUDs and data collection should consider the following components:

- Source control – area affected and exceedance needs, runoff factors
- Infiltration – area and ground conditions
- Conveyance – channel dimensions, vegetation types
- Storage – dimensions, soil, lining, flow controls, exceedance routes

Depending on the complexity of the modelling software and approach being applied, a more detailed list of data that could be collected is summarised in Table D-1.

Table D-1: Typical SuDS Data Collection Requirements

Parameter	**SuDS Component**			
	Source Control	***Infiltration Devices***	***Conveyance***	***Storage***
Ground Level (m AOD)	Y	Y	Y	Y
Invert Level (m AOD)	Y	Y	Y	Y
Dimensions (Length, Width, Depth) (m)	Y	Y	N/A	N/A
Plan area at all depths (where composite) (m^2)	N/A	N/A	N/A	Y
Cross section area (shape and dimensions) (m^2)	N/A	N/A	Y	N/A
Length (m)	Y	N/A	Y	N/A
Roughness (mm)	N/A	N/A	Y	N/A
Porosity %	N/A	Y	Y	Y
Groundwater level (m AOD)	N/A	O	N/A	N/A
Initial Water Level (m AOD)	N/A	O	O	O
Vegetation Level (m AOD)	N/A	N/A	N/A	O
Liner Level (m AOD)	N/A	N/A	N/A	O
Time of Entry (mins)*	Y	N/A	N/A	N/A
Evapotranspiration/Initial Loss (m)	Y	N/A	N/A	N/A
Depression storage (m)	Y	N/A	Y	N/A
Infiltration rate (Base) (mm/hr) (if applicable)	O	Y	O	O
Infiltration rate (Sides) (mm/hr) (if applicable)	O	Y	O	O
Flow control (type, diameter, level, coefficient, etc.).	Y	Y	Y	Y
Overflow arrangement (Y/N)	Y	Y	Y	Y
Maximum discharge rate (l/s)	Y	Y	Y	Y
Clogging factor	N/A	O	N/A	N/A
Safety factor (applied on the infiltration rates)	N/A	Y	N/A	N/A

Y = Mandatory O = Optional Software considerations should be reviewed.

* While most software can calculate the time of entry to the structure using the network details, some software applications calculate the flow from rainwater when and where it falls and hence the "Time of Entry" is important.

Watercourses and open channels

Watercourses should be considered in similar way to any other part of the urban drainage system where included in an urban drainage model. The following data requirements will apply where watercourses are modelled:

- River cross-sections should be taken at all significant changes in channel form, and in most urban contexts at least every 100m. Data requirements will be sections (x, y and z) with banks defined looking downstream
- Details of river control structures such as bridges and weirs will be required where they could be expected to impact the model results within the scenarios the model is designed to represent

Open channels are classified by the flow having a free surface and are sub-divided into two groups:

- Natural Channel (Irregular Shape)
- Artificial Channel (Regular Shape)

Cross section and control structure data for rivers may be obtained from existing river models or historic survey data where available. Where Open channel or river control structure surveys are required the EA (2013) National Standard Contract and Specification for Surveying Services and the CIWEM UDG (1999) River Data Collection Guide provides further guidance.

Particular care is required when considering exceedance flows and extreme events to ensure that all flow routes are represented. It should be noted that a flood risk model may contain many more structures than a model solely looking at water quality.

System Connectivity

Where the connectivity of urban drainage systems is uncertain from asset records then further investigations on site may be undertaken to gather the required information. Methods of connectivity testing include:

- Sound testing
- Dye Tracing
- Smoke testing
- CCTV survey

Real time controls (RTC)

It can be difficult to understand the operating rules for complex pumping stations, overflows, storage tanks and other ancillaries merely by observing or surveying their operation. It is therefore important to obtain control philosophies and operating manuals for these and to understand that they may not be operated as designed. It is often beneficial to obtain a download of the operating logic from the control device so that this can be analysed to understand the real operation. This task should always be undertaken with the system operator's approval and carried out by instrumentation specialists, as there is a risk of disrupting the operation of the controls when downloading the control logic. Site operatives should be consulted where ancillaries are suspected to be operating outside their control rules. In some cases this may be due to manual interventions.

Non Man Entry Surveys

In addition to physical attributes, the operational and structural condition of urban drainage systems are very important factors that can be the main cause of issues such as flooding in a catchment. The condition of the pipes, for example, can have a significant impact on the pipe roughness and sediments may reduce the cross-sectional area of the pipes and increase roughness.

To better understand the condition of the pipes in a catchment the existing CCTV surveys should be collected from the commissioning authority if available. Depending on the age/availability of such information it may be necessary to undertake further CCTV surveys for the study. This should be planned an undertaken in line the commissioning authority's own specification or where this is not available, the Model Contract Document for Sewer Condition Inspection (WRc, 2005).

Contributing Areas Surveys (CAS)

Contributing area surveys (CAS) involve the survey of roofs, roads and other paved surfaces, and in some cases permeable surfaces in order to:

- Establish the general patterns of drainage within the survey area
- Quantify and qualify the different types of runoff areas within the survey area
- Establish the connectivity of the runoff areas to the urban drainage system(s)

This type of survey usually depends on the Commissioning Body's requirements and budgetary constraints. Specific development types should therefore be targeted (partially separate systems, separate systems, large industrial areas or commercial developments) where records are not available or storm contribution is uncertain and could influence the model's performance. The results of the CAS will assist in the calibration of runoff in areas where the degree of separation between foul and surface water is unclear and so provide some level of validation to the parameters included in the model. In some cases, it may be necessary to undertake further surveys where the model cannot replicate measured flows.

The sampling rate for CAS will vary depending on the age and type of development but in general the overall property sampling rate is typically in the range 10 - 15 %. However, in urban or sub-urban areas where properties are of a similar age and design, the sampling rate may be reduced to as low as 5%...Conversely in areas where there exists a wide variation in the age and/or design of properties, an increased the sampling rate may be required especially in established rural catchments. Where there is an intention to undertake surface water disconnections from combined systems, it may be necessary to target even more properties, although this may be undertaken at a later stage.

Contributing area surveys are particularly useful where there are either small pipe sizes (<225mm) or very steep pipes that create hydraulic conditions unsuitable for conventional flow monitoring. In particular, this may include separate or partially separate systems.

CAS results should ideally be created in a GIS format to enable all the survey findings to be imported directly into the preferred modelling software. A suitable colour coding system for GIS output showing the means of surface water disposal is also beneficial in visualising the data. Table D-2 presents example colours and application.

Table D-2 Possible colours for CAS output

Surface Water Disposal Method	**GIS Display Colours for Flow Sources**	
	Pitched Roof	**Paved Areas and Flat Roofs**
Soakaway and permeable areas	Yellow	Yellow
Foul/combined sewers	Red	Brown
Surface water sewers	Blue	Green
Direct to road or pavement	Mauve	N/a

APPENDIX E - Runoff Models

This note summarises the following rainfall-runoff models including their characteristics, calibration and use in urban drainage modelling.

- Fixed percentage runoff
- Wallingford Procedure (Fixed) - Old PR model
- New UK (Variable) - New PR model
- UKWIR Runoff Model

Rural / Pervious runoff models

Each of the following models is described in more detail in the Literature Review and Guide for the UKWIR Project: Development of the UKWIR Runoff Model (UKWIR (2014).

- Green-Ampt
- Horton
- Flood Estimation Handbook Revitalised rainfall runoff (ReFH/ReFH2) Model
- Probability Distributed Model (PDM)
- USA Soil Conservation Service (SCS) method

Table E–1 summarises the key attributes of each model.

Table E–1 Runoff models and their characteristics

Runoff Model	Application	Comments
Fixed percentage runoff	Primarily Impervious areas but may applied to pervious areas	Mainly used for impervious surface runoff only. Typical parameter values well understood in the UK. Percentage runoff values are generally not varied between storms or during a storm. Not suited to continuous simulation series or long storm durations
Wallingford Procedure (Fixed) – Old PR model	Impervious and pervious surfaces in an urban setting	Correlation equation based on soil type, wetness and proportion of paved surface. Superseded by New PR equation, but still in use in some models. Parameter values easily measured and well understood in the UK. Percentage runoff does not vary during each storm so not suited to long storm durations. Theoretically can be used for continuous simulation as wetness can be updated for the start of each event.
New UK (Variable) - New PR model	Impervious and pervious surfaces in an urban setting	Suited to impervious and pervious surface modelling. Typical parameter values well understood in the UK. Percentage runoff varies over time through the storm
UKWIR runoff model	Impervious and pervious surfaces in an urban setting	Developed to address perceived limitation of New UK runoff model Suited to impervious and pervious surface modelling The paved runoff has a wetting effect to increase runoff with rainfall depth;

Runoff Model	Application	Comments
		Paved areas which are not directly served with drainage can be treated as different paved surface types with their own runoff characteristics; Includes the facility to use HOST categorisation of soils as well as WRAP soil classes; Facilitates the ability to meet the differences in runoff between winter and summer conditions; Pervious runoff has been shown to not exceed rural runoff predictions from ReFH – therefore addressing concerns of over-prediction of runoff volume.
Green-Ampt infiltration model	Pervious surfaces (esp 2D)	Physically based model. Intended for modelling runoff from pervious surfaces. Parameter selection relies on knowledge of physical soil properties Percentage runoff varies over time through the storm Soil drying represented to allow continuous simulation Does not include evapotranspiration
Horton infiltration model	Pervious surfaces (esp 2D)	See comments Green-Ampt above.
Flood Estimation Handbook Revitalised rainfall runoff model (ReFH)	Rural catchments hydrology	Extreme events runoff Part of hydrological model for flooding in rural catchments Parameters can make use of readily available Flood Estimation Handbook catchment descriptors Designed for rural rivers rather than small pervious catchments in the urban environment
Probability Distributed Model (PDM)		Extreme events runoff Part of hydrological model for flooding in rural catchments Parameters require calibration from observed data Designed for rural rivers rather than small pervious catchments in the urban environment
USA Soil Conservation Service method (SCS)	Pervious surfaces – normally rural catchments	Designed for modelling runoff from pervious surfaces and rural catchments Commonly applied outside UK (mainly US). Parameter selection relies on land use classification to select curve number Percentage runoff varies over time through

APPENDIX F - SCATTERGRAPHS

The recorded flow data for each monitor should be reviewed by plotting scattergraphs. This may be done for different storm events or different interim data periods using different colours. The scattergraphs should also show the Colebrook-White line for the pipe in which the monitor was installed.

Where a flow monitor is installed in an incoming pipe into a manhole it is useful to add the Colebrook-White line for the outgoing pipe also. It is possible that the outgoing pipe is governing the flow conditions at that flow monitor.

Ideally the scattergraph should be plotted to a log-log scale and can either be flow/depth or velocity/depth. The illustrations shown later are for flow/depth plots and these help the quality of flow survey data to be assessed. Interpretation of velocity/depth scattergraphs is more difficult but can be a useful means of understanding the flow conditions during the flow survey. Velocity/depth scattergraphs may only be needed where a greater understanding is required to adequately classify the quality of the flow survey data.

Scattergraphs for dry weather periods can often be affected by the monitoring equipment interfering with or partially obstructing the flow, especially where the flows are shallow. It is recommended that dry weather scattergraphs are only plotted and assessed at a selection of the monitoring sites where the flows are sufficient to enable meaningful assessment.

The data should be classified by means of a visual observation of the consistency of the data and the closeness of the fit to the Colebrook-White line. This can use a subjective classification of as “very good”, “good”, “fair” or “poor”. The interpretation and classification of the scattergraphs should consider if there are inaccuracies in data used to calculate the flows and depths. For example, a departure from the Colebrook-White line may indicate that the invert levels, pipe gradient or pipe size might be incorrect in the model, there may be sediment in the downstream pipes or the system has a downstream control causing for example an increase in depth.

Examples of scattergraphs plotted for storm conditions are shown below. An example of a scattergraph is shown in Figure F.1 and the flow survey data for this monitor (M140) has been classified as ‘Very Good’. Further examples of scattergraphs are given in Figure F.2 (good data), Figure F.3 (fair data) and Figure F.4 (poor data).

Verification of a flow monitor should only use data considered to be ‘very good’ or ‘good. Depth data from sites classed as ‘fair’ may still be used as depth data are typically more reliable than flow or velocity. ‘Poor’ data should not normally be used for model verification.

The scattergraph for Figure F.5 is an example of a flow monitor installed a short distance upstream of a CSO. Initially, this may be classified as ‘poor’. However, further examination reveals the data are very good. It departs from the Colebrook-White line when the flow is backed up by the flow control at the CSO (depth increases with no increase in flow) until such time as the water level reaches the overflow weir. At this point there is an increase in flow rate with very little increase in depth then finally a second curvilinear relationship is noted which is governed by the capacity of the CSO spill pipe. In this example the data would be classified as ‘very good’.

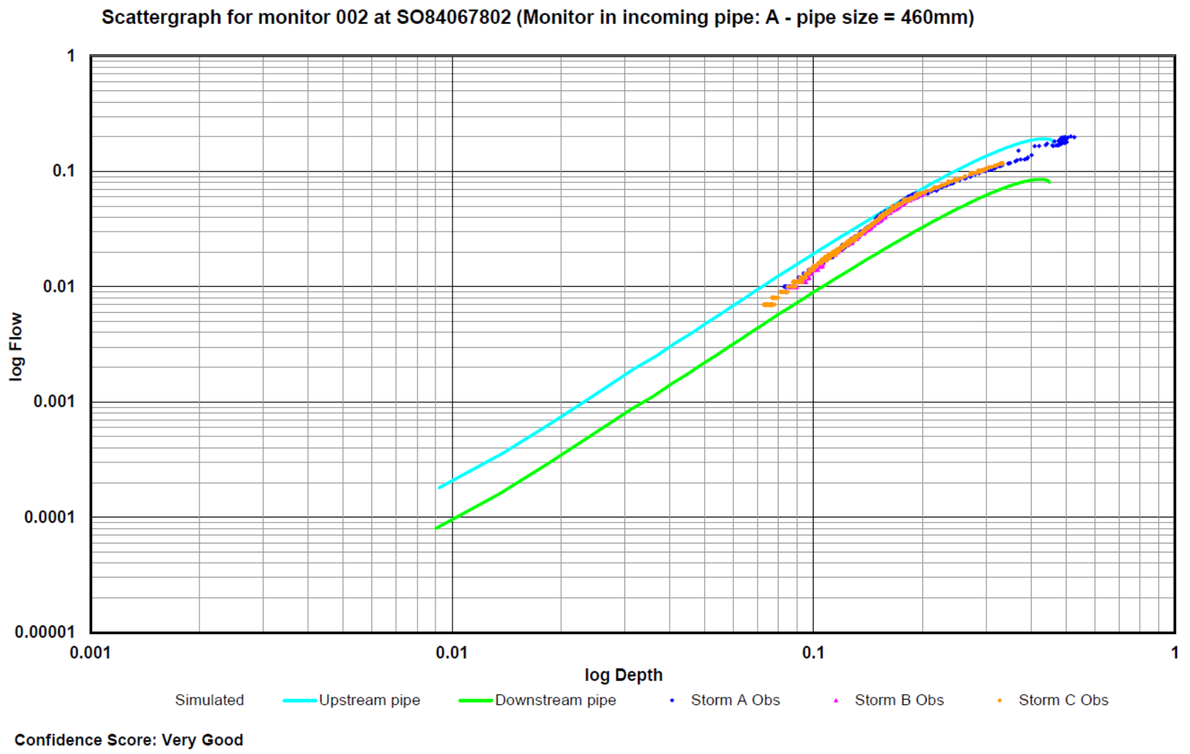


Figure F.1: Example scattergraph for very good measured flow depth relationship

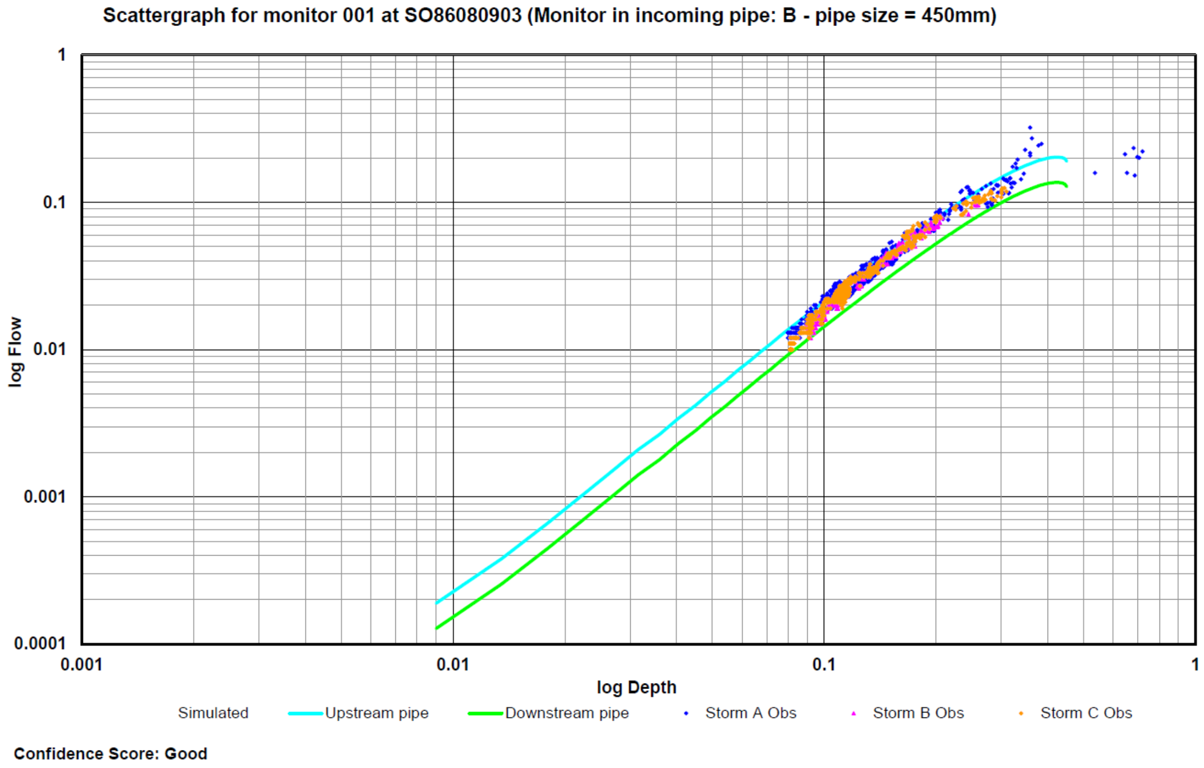


Figure F.2: Example scattergraph for "good" measured flow depth relationship

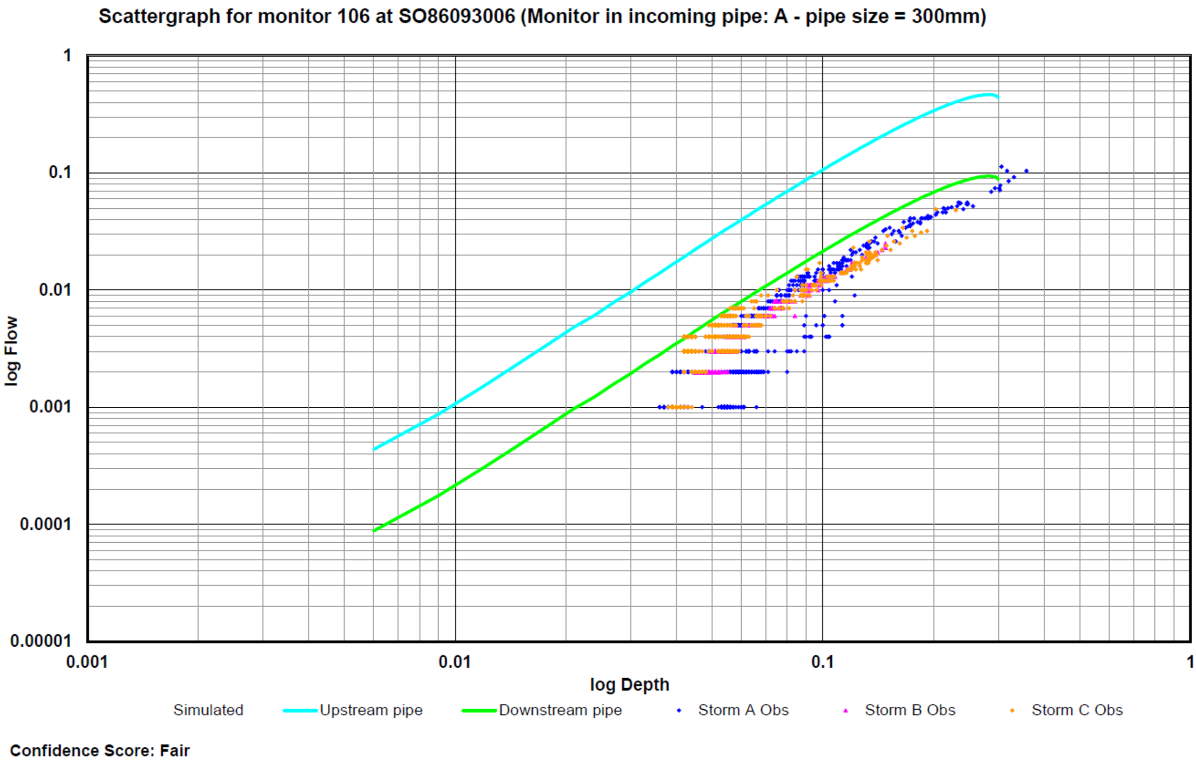


Figure F.3: Example scattergraph for "fair" measured flow depth relationship

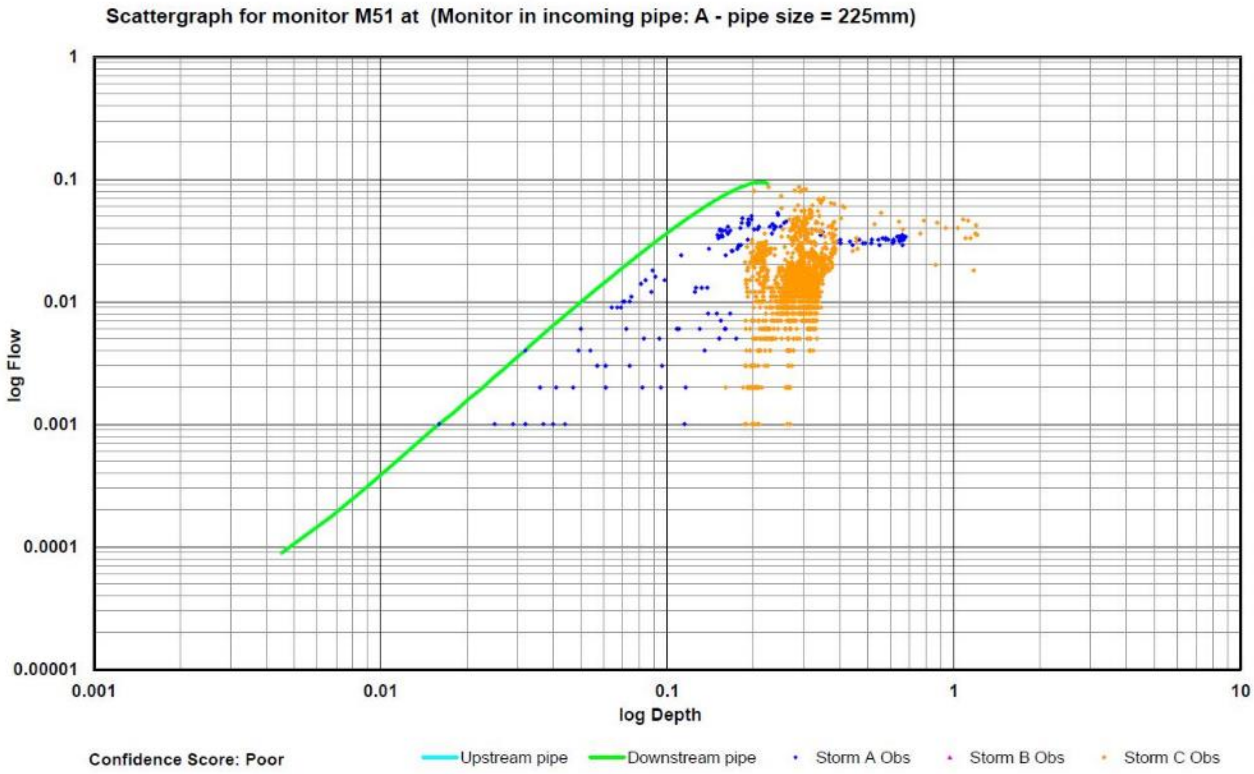


Figure F.4: Example scattergraph for "poor" flow depth relationship

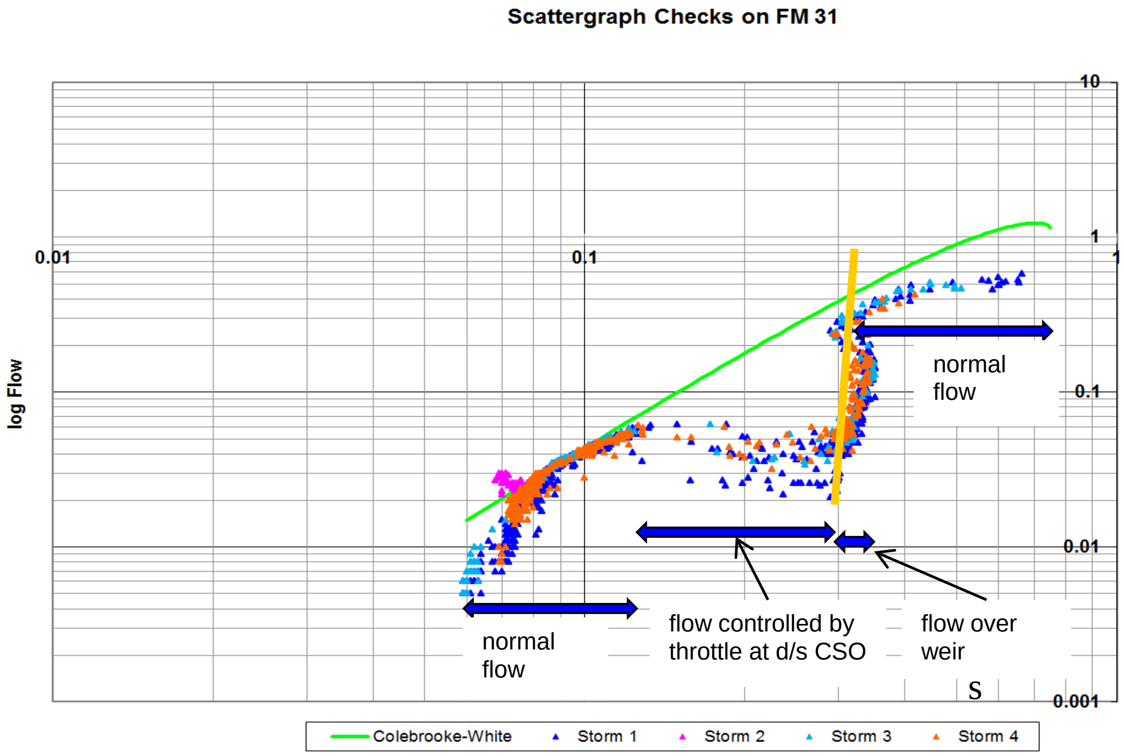


Figure F.5 Example Scattergraph where analysis of the relationships between flow and depth in the local context is important to understand its quality

APPENDIX G – EXAMPLE OF STATISITICAL METHOD FOR STORM VERIFICATION: THE NASH-SUTCLIFFE EFFICIENCY COEFFICIENT

The Nash Sutcliffe Efficiency Coefficient (NSEC) formula shown below is a normalised statistic used to assess how well two graphs (observed and predicted) match one another:

$$\mathrm{NSEC} = 1 - \frac{\Sigma_{\mathrm{t}=1}^{\mathrm{T}}\left(\mathrm{Q}_{\mathrm{o}}^{\mathrm{t}} - \mathrm{Q}_{\mathrm{p}}^{\mathrm{t}}\right)2}{\Sigma_{\mathrm{t}=1}^{\mathrm{T}}\left(\mathrm{Q}_{\mathrm{o}}^{\mathrm{t}} - \overline{\mathrm{Q}}_{\mathrm{o}}\right)2}$$

Where Q_o is observed discharge and Q_p is predicted discharge.

When using the statistical approach it should be applied to graphs for flow and depth separately. The formula calculates residual variance by comparing model predicted data with observed data at every available time-step. It provides an assessment of the closeness of the match between peak values and the closeness of the fit in respect of shape and timing.

The overall NSEC score can range between +1 and negative infinity, with a perfect match between predicted and observed data returning a score of 1. Research by Moriasi *et al.* (2007) states that a NSEC score of 0.5 is a 'satisfactory' replication of observed data.

NESC criteria and scores should be set by Commissioning Bodies. The scores should be calculated for depth and flow at each monitor.

For depth, NSEC should be applied where water depth is greater than 10% of the pipe height or 100mm whichever is the greater. This accounts for a simulation programme that may artificially add flow to dry pipes for stability and monitors may not accurately record levels below this threshold.

APPENDIX H – EXAMPLE APPROACH TO DRY WEATHER VERIFICATION

This appendix sets out a procedure for dry weather verification.

Weekday and weekend dry weather profiles whilst different do not capture the variations observed. This procedure uses all or a large number of dry days within the survey period. All DWF day hydrographs should be combined to create maximum and minimum boundary hydrographs, so creating a window of acceptability. This should be completed for weekday and weekend. Dry days can be defined as a day of zero rainfall that follows a day of less than 1mm of rain. Dry weather verification should be considered 'good' if the predicted hydrograph lies between the boundaries.

In some instances where the flow survey data are over a long period and there has been a significant change in baseflow infiltration it may be necessary to remove the baseflow element prior to plotting the DWF day hydrographs.

A simplified version of this approach is shown in Figure H.1. At each time-step, the plotted maximum (in red) and minimum (in blue) values create boundary hydrographs.

A more advanced approach involves smoothing the lines to give more defined boundaries. This helps spiky hydrographs or those which are heavily influenced by upstream or downstream pumping stations as the pump cycles tend to be dampened out. An example of a smoothing method for this is the Savitzky-Golay filter which is shown below.

$$Y_j = \sum_{i=1(m-1)\div 2}^{i=(m-1)\div 2} C_i y_{i+1}$$

$$\frac{m+1}{2} \leq j \leq n - \frac{m-1}{2}$$

Where: x is an independent variable,

y_j is an observed variable and

m and C_i relate to "convolution coefficients.

The Savitzky-Golay filter works in a similar way to a moving average, but uses 'convolution coefficients' and low-degree polynomials. It retains the exact peak and trough times and does not distort the shape of the data. For the values to be generated it uses data from outside of the 24-hour period of the individual dry day. At maximum, 42 minutes of data (at 2-minute intervals) from each of the two adjoining days need to be used.

Figure H.2 shows the Savitzky-Golay filter in use. The base data are the same as for Figure H.1, but the Savitzky-Golay filter smoothes the underlying five DWF days used with the minimum and maximum lines taken from these smoothed lines. Individual dry days which exhibit unusual characteristics (e.g. high depth and low flows due to pump failure downstream) should not be used and removed.

When using long time-series or extended data, only dry days should be used where the recession from preceding storms has fully receded. This for example may be 36 to 48 hours after rainfall has ceased.

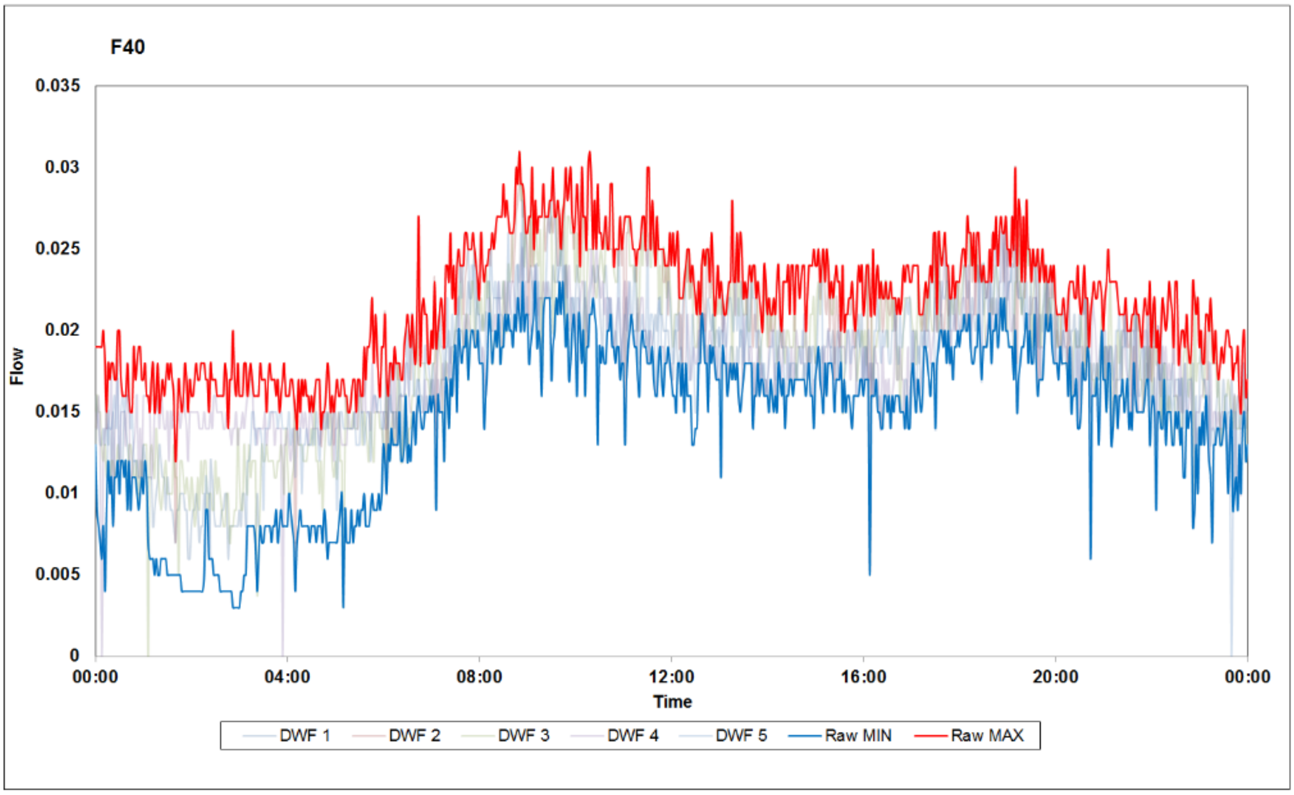


Figure H.1 - Maximum and Minimum Boundary Hydrographs

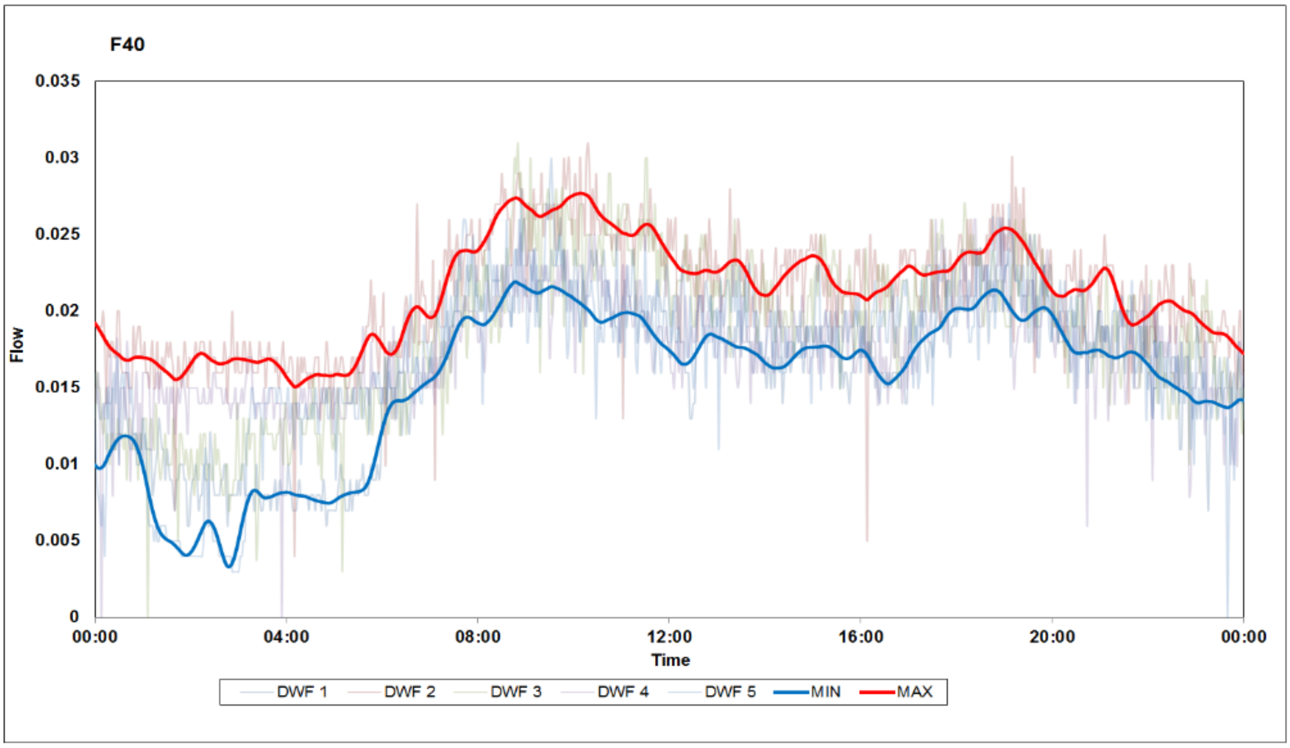


Figure H.2 - Smoothed Maximum and Minimum Boundary Hydrographs using Savitzky-Golay Filtering

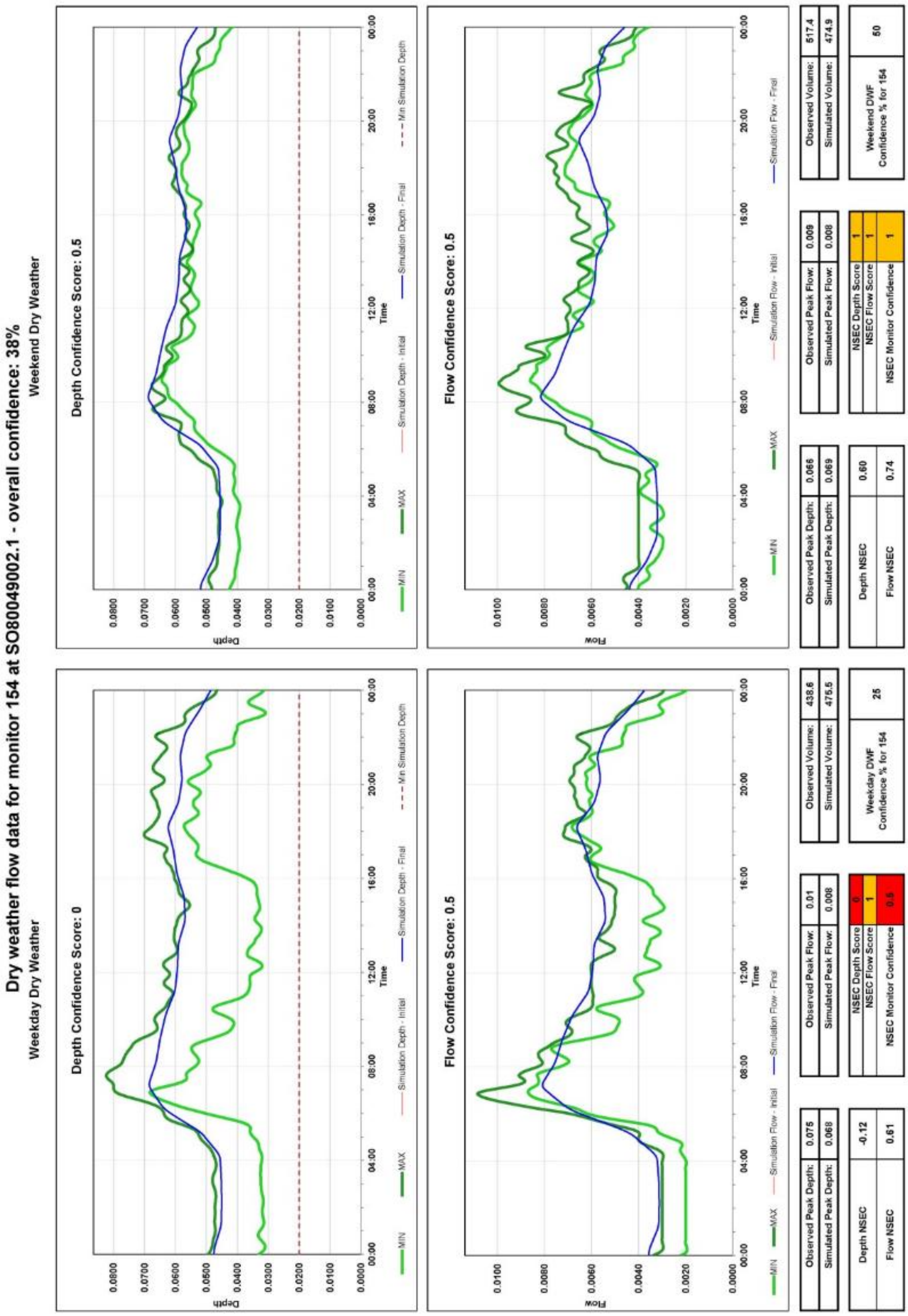
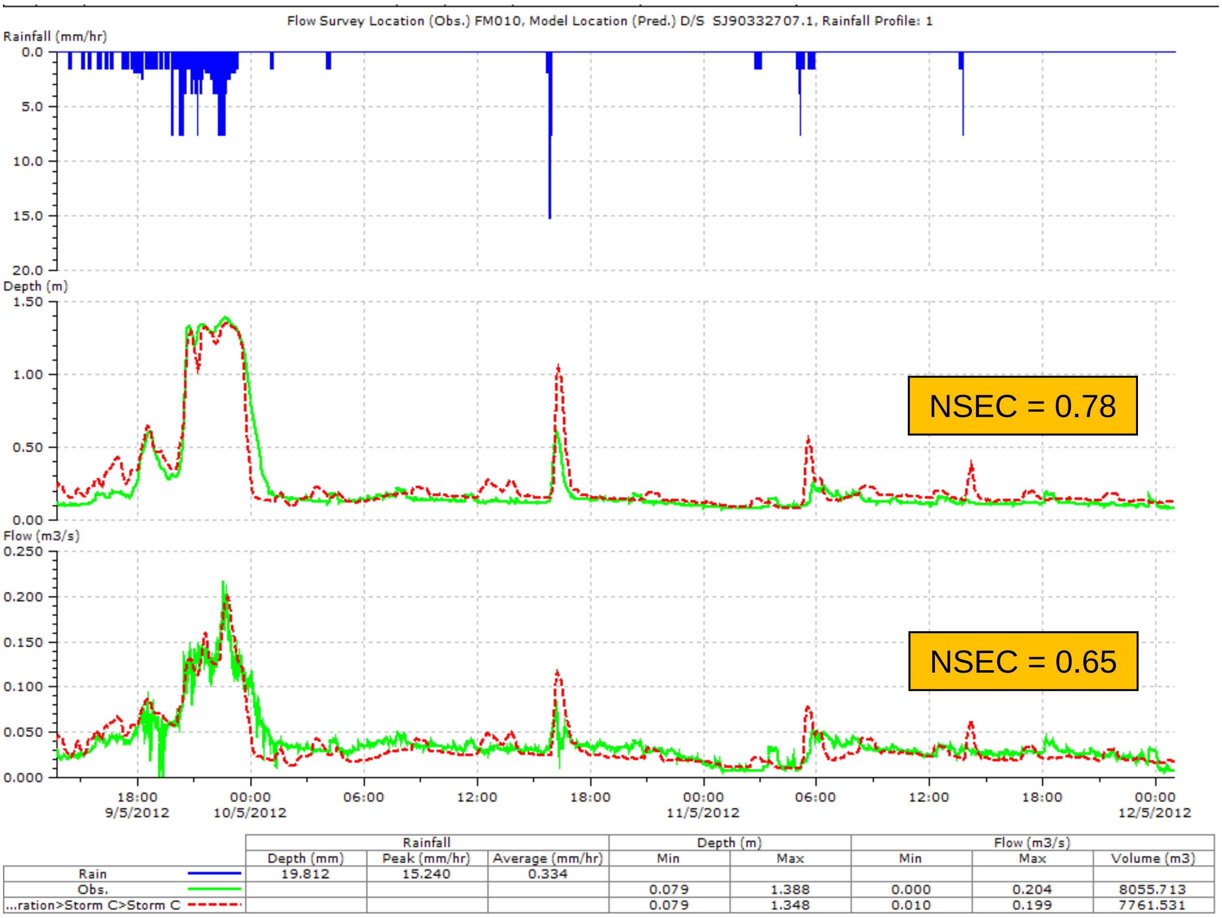


Figure H.3 - Example of Dry Weather Verification Plots with NSEC and Confidence scores

APPENDIX I – EXAMPLE OF APPLYING THE NASH-SUTCLIFFE EFFICIENCY COEFFICIENT FOR STORM VERIFICATION

The application of the NESC is shown in Figure I-1. There is a good match in the first peak but an over prediction in the second peak. This causes the NSEC values to drop. These values are above 0.5 and indicate an acceptable verification. Further investigation of the under predicted peaks might be considered to improve the overall NSEC values.



	Rainfall			Depth (m)		Flow (m3/s)		
	Depth (mm)	Peak (mm/hr)	Average (mm/hr)	Min	Max	Min	Max	Volume (m3)
Rain ——	19.812	15.240	0.334					
Obs. ——				0.079	1.388	0.000	0.204	8055.713
...ration>Storm C>Storm C - - - -				0.079	1.348	0.010	0.199	7761.531

Figure I-1 Depth and Flow Hydrographs (observed in green, predicted in red) with calculated NSEC scores

Figure I-2 shows an example of the storm verification for a flow monitor FM015 for 3 storms. The plots are for depth and flow. The dashed red horizontal line in the depth plots represents 10% of the conduit height and the depth remained above this level throughout the storms.

It contains a summary of key values (see Table 5-1) and the NSEC values beneath each pair of hydrographs.

The filtering system used for the recorded dry day data should not be used for the storm data as the comparison needs to be against the recorded data for that storm event as opposed to a 'typical' dry day.

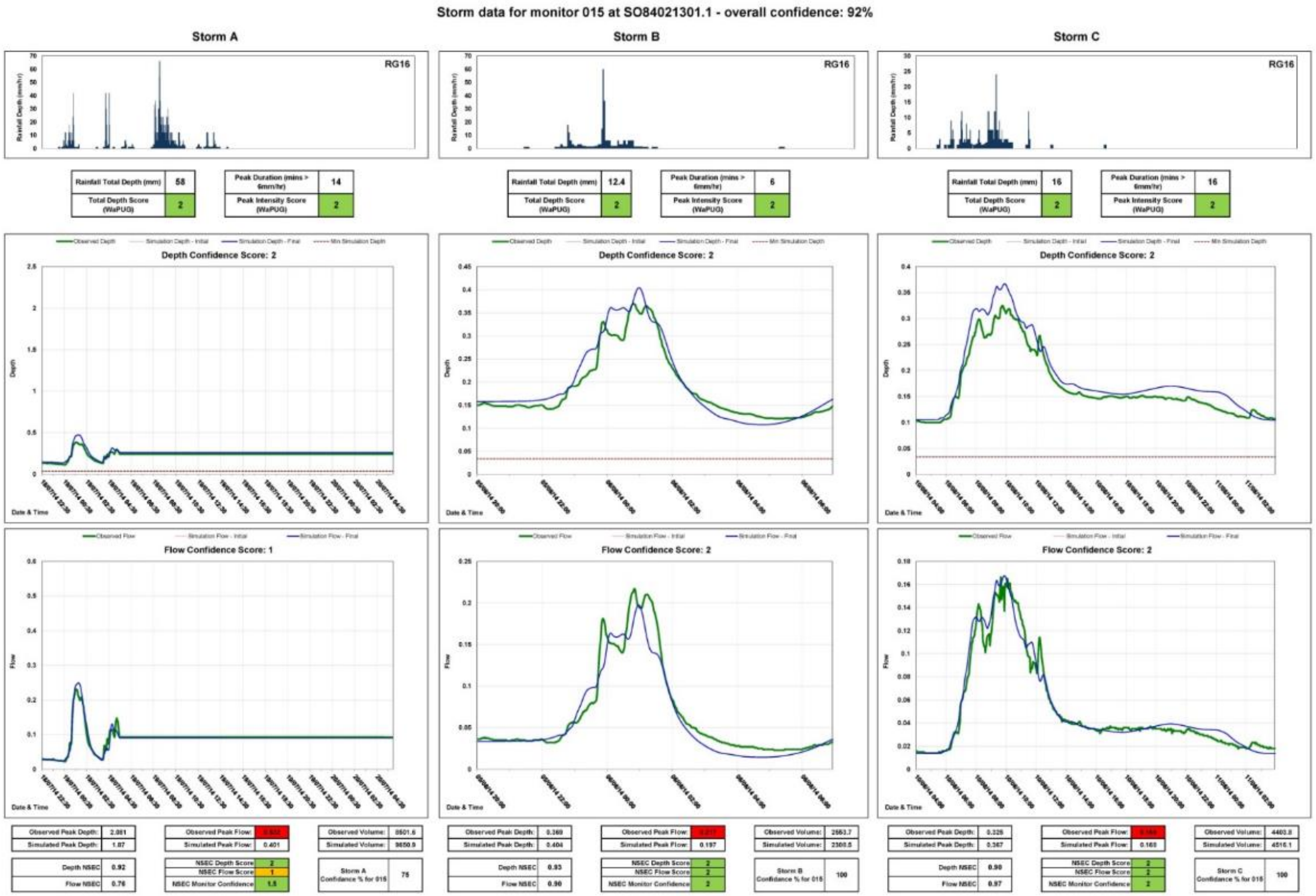


Figure I-2 - Storm Verification Plots with NSEC scores

APPENDIX J – EXAMPLE OF QUALITATIVE SCORING APPROACH

This appendix contains an example of how a qualitative (R-A-G) scoring approach can be applied. This is not intended to be a definitive scoring system but serves to illustrate how such a system might be developed. This example is for the storm verification of a partially separate catchment which has a mixture of foul, combined and storm sewers. For simplicity foul and combined sewers are treated as being the same.

Verification Assessment Spreadsheet

The storm verification targets as set out in Table 5.1 are used in this scoring system. The assessment is set up in a simple spreadsheet where the observed and simulated data for each of the 3 verification storms are entered. If the match between the observed and the simulated is within the target criteria the cell is coloured green, if it is marginally outside it is coloured amber and if it is further outside it is coloured red.

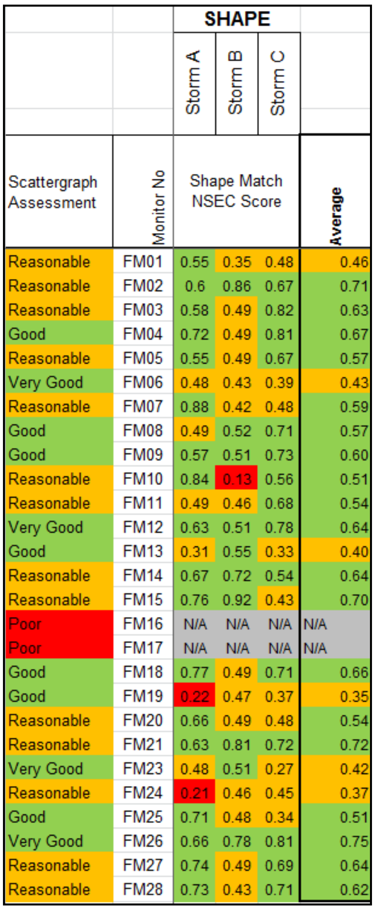
On the left hand side of the spreadsheet the assessment of the scattergraph quality (poor, reasonable, good or very good) is included and colour coded.

The full spreadsheet is shown in Figure J-4 to illustrate the 4 different sections of the spreadsheet (shape, peak flow, volume and depth) each section is discussed separately below. Separate assessments are done for each storm and then the results in each section are then averaged to give an overall indication.

The following images illustrate the different sections of the spreadsheet.

This section of the spreadsheet (Figure J-1) deals with how well the shapes of the hydrographs match. This is primarily based on the flow hydrograph but the depth hydrograph can be used when there is extensive ragging or poor velocity measurement.

For each of the 3 storms the degree of match has been assessed using the Nash Sutcliffe Efficiency Coefficient (NSEC) which has a range of +1 to -∞. A score higher than 0.5 is considered good and has been colour coded in green, between 0.4 and 0.5 is coloured in amber and lower than 0.4 is coloured red. The average values are coloured in the same way.



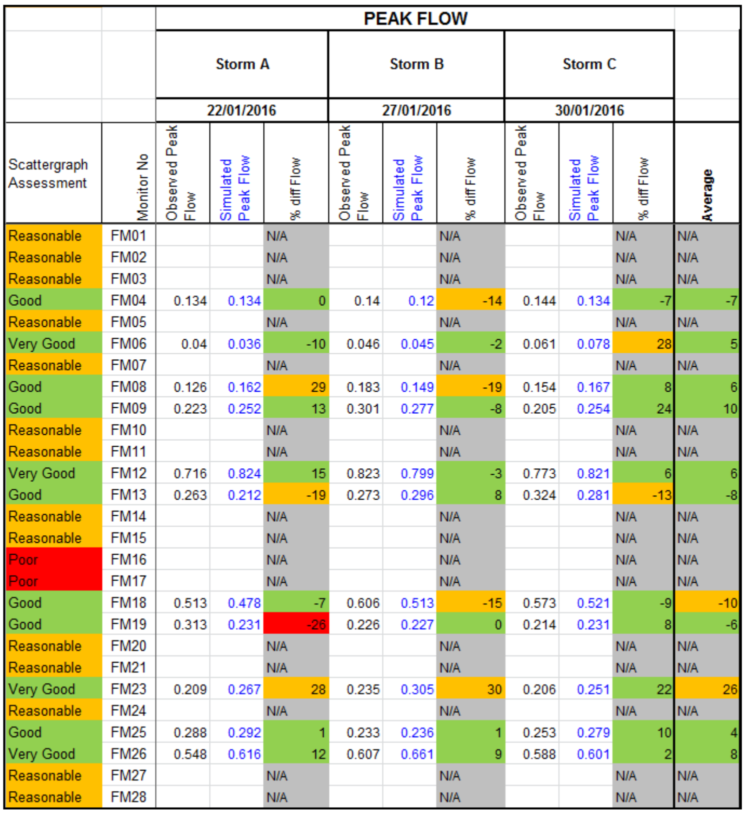
		SHAPE			
		Storm A	Storm B	Storm C	
Scattergraph Assessment	Monitor No	Shape Match NSEC Score			Average
Reasonable	FM01	0.55	0.35	0.48	0.46
Reasonable	FM02	0.6	0.86	0.67	0.71
Reasonable	FM03	0.58	0.49	0.82	0.63
Good	FM04	0.72	0.49	0.81	0.67
Reasonable	FM05	0.55	0.49	0.67	0.57
Very Good	FM06	0.48	0.43	0.39	0.43
Reasonable	FM07	0.88	0.42	0.48	0.59
Good	FM08	0.49	0.52	0.71	0.57
Good	FM09	0.57	0.51	0.73	0.60
Reasonable	FM10	0.84	0.13	0.56	0.51
Reasonable	FM11	0.49	0.46	0.68	0.54
Very Good	FM12	0.63	0.51	0.78	0.64
Good	FM13	0.31	0.55	0.33	0.40
Reasonable	FM14	0.67	0.72	0.54	0.64
Reasonable	FM15	0.76	0.92	0.43	0.70
Poor	FM16	N/A	N/A	N/A	N/A
Poor	FM17	N/A	N/A	N/A	N/A
Good	FM18	0.77	0.49	0.71	0.66
Good	FM19	0.22	0.47	0.37	0.35
Reasonable	FM20	0.66	0.49	0.48	0.54
Reasonable	FM21	0.63	0.81	0.72	0.72
Very Good	FM23	0.48	0.51	0.27	0.42
Reasonable	FM24	0.21	0.46	0.45	0.37
Good	FM25	0.71	0.48	0.34	0.51
Very Good	FM26	0.66	0.78	0.81	0.75
Reasonable	FM27	0.74	0.49	0.69	0.64
Reasonable	FM28	0.73	0.43	0.71	0.62

Figure J-1 - Example of confidence assessment for hydrograph shape match

The next section of the spreadsheet (Figure J-2) is for the comparison of peak flows with the observed data shown in black and the simulated values shown in blue. For each storm the values are compared and then on the right hand side the comparison values are averaged.

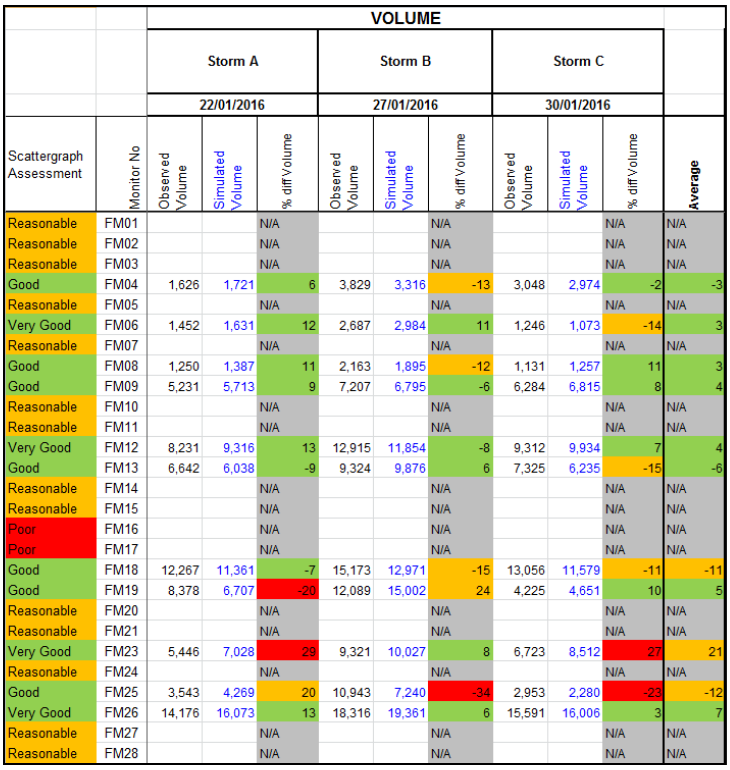
Where no comparison is made (in this example for any sites with a 'reasonable' or 'poor' scattergraph assessment) the cells are left blank.

The colour coding used is:
+25% to -10%: green
+30% to -15%: amber
>30% or <-15%: red.



		PEAK FLOW									
		Storm A			Storm B			Storm C			
		22/01/2016			27/01/2016			30/01/2016			
Scattergraph Assessment	Monitor No	Observed Peak Flow	Simulated Peak Flow	% diff Flow	Observed Peak Flow	Simulated Peak Flow	% diff Flow	Observed Peak Flow	Simulated Peak Flow	% diff Flow	Average
Reasonable	FM01			N/A			N/A			N/A	N/A
Reasonable	FM02			N/A			N/A			N/A	N/A
Reasonable	FM03			N/A			N/A			N/A	N/A
Good	FM04	0.134	0.134	0	0.14	0.12	-14	0.144	0.134	-7	-7
Reasonable	FM05			N/A			N/A			N/A	N/A
Very Good	FM06	0.04	0.036	-10	0.046	0.045	-2	0.061	0.078	28	5
Reasonable	FM07			N/A			N/A			N/A	N/A
Good	FM08	0.126	0.162	29	0.183	0.149	-19	0.154	0.167	8	6
Good	FM09	0.223	0.252	13	0.301	0.277	-8	0.205	0.254	24	10
Reasonable	FM10			N/A			N/A			N/A	N/A
Reasonable	FM11			N/A			N/A			N/A	N/A
Very Good	FM12	0.716	0.824	15	0.823	0.799	-3	0.773	0.821	6	6
Good	FM13	0.263	0.212	-19	0.273	0.296	8	0.324	0.281	-13	-8
Reasonable	FM14			N/A			N/A			N/A	N/A
Reasonable	FM15			N/A			N/A			N/A	N/A
Poor	FM16			N/A			N/A			N/A	N/A
Poor	FM17			N/A			N/A			N/A	N/A
Good	FM18	0.513	0.478	-7	0.606	0.513	-15	0.573	0.521	-9	-10
Good	FM19	0.313	0.231	-26	0.226	0.227	0	0.214	0.231	8	-6
Reasonable	FM20			N/A			N/A			N/A	N/A
Reasonable	FM21			N/A			N/A			N/A	N/A
Very Good	FM23	0.209	0.267	28	0.235	0.305	30	0.206	0.251	22	26
Reasonable	FM24			N/A			N/A			N/A	N/A
Good	FM25	0.288	0.292	1	0.233	0.236	1	0.253	0.279	10	4
Very Good	FM26	0.548	0.616	12	0.607	0.661	9	0.588	0.601	2	8
Reasonable	FM27			N/A			N/A			N/A	N/A
Reasonable	FM28			N/A			N/A			N/A	N/A

Figure J-2 - Example of confidence assessment for peak flow



		VOLUME									
		Storm A			Storm B			Storm C			
		22/01/2016			27/01/2016			30/01/2016			
Scattergraph Assessment	Monitor No	Observed Volume	Simulated Volume	% diff Volume	Observed Volume	Simulated Volume	% diff Volume	Observed Volume	Simulated Volume	% diff Volume	Average
Reasonable	FM01			N/A			N/A			N/A	N/A
Reasonable	FM02			N/A			N/A			N/A	N/A
Reasonable	FM03			N/A			N/A			N/A	N/A
Good	FM04	1,626	1,721	6	3,829	3,316	-13	3,048	2,974	-2	-3
Reasonable	FM05			N/A			N/A			N/A	N/A
Very Good	FM06	1,452	1,631	12	2,687	2,984	11	1,246	1,073	-14	3
Reasonable	FM07			N/A			N/A			N/A	N/A
Good	FM08	1,250	1,387	11	2,163	1,895	-12	1,131	1,257	11	3
Good	FM09	5,231	5,713	9	7,207	6,795	-6	6,284	6,815	8	4
Reasonable	FM10			N/A			N/A			N/A	N/A
Reasonable	FM11			N/A			N/A			N/A	N/A
Very Good	FM12	8,231	9,316	13	12,915	11,854	-8	9,312	9,934	7	4
Good	FM13	6,642	6,038	-9	9,324	9,876	6	7,325	6,235	-15	-6
Reasonable	FM14			N/A			N/A			N/A	N/A
Reasonable	FM15			N/A			N/A			N/A	N/A
Poor	FM16			N/A			N/A			N/A	N/A
Poor	FM17			N/A			N/A			N/A	N/A
Good	FM18	12,267	11,361	-7	15,173	12,971	-15	13,056	11,579	-11	-11
Good	FM19	8,378	6,707	-20	12,089	15,002	24	4,225	4,651	10	5
Reasonable	FM20			N/A			N/A			N/A	N/A
Reasonable	FM21			N/A			N/A			N/A	N/A
Very Good	FM23	5,446	7,028	29	9,321	10,027	8	6,723	8,512	27	21
Reasonable	FM24			N/A			N/A			N/A	N/A
Good	FM25	3,543	4,269	20	10,943	7,240	-34	2,953	2,280	-23	-12
Very Good	FM26	14,176	16,073	13	18,316	19,361	6	15,591	16,006	3	7
Reasonable	FM27			N/A			N/A			N/A	N/A
Reasonable	FM28			N/A			N/A			N/A	N/A

Figure J-2 - Example of confidence assessment for volume

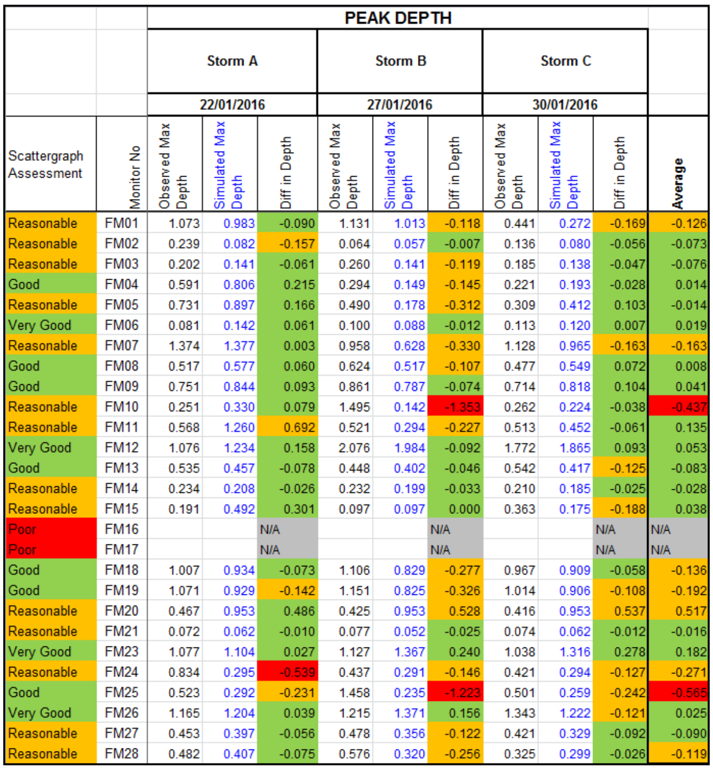
The next section of the spreadsheet is for the comparison of volumes with the observed data again shown in black and the simulated values shown in blue. For each storm the values are compared and then on the right hand side the comparison values are averaged.

As with the peak flows where no comparison is made (in this example for any sites with a 'reasonable' or 'poor' scattergraph assessment) the cells are left blank.

The colour coding used is:
+20% to -10%: green
+25% to -15%: amber
>25% or <-15%: red.

In Figure J-3 the peak depths are compared. For simplicity in this example the depths are treated the same irrespective of whether the sewer was surcharged or not and were also not considered as 'critical locations'. In practice it is likely that greater account will need to be taken of whether the sewer was surcharged or not and whether the monitor was at a 'critical location'.

Those monitors (in this case FM16 & FM17) with a scattergraph assessment of 'Poor' are not used for any verification assessments whereas those assessed as 'Reasonable' are assessed for peak depth only; this is why in this image there are only two lines with no data.



		PEAK DEPTH									
		Storm A			Storm B			Storm C			
		22/01/2016			27/01/2016			30/01/2016			
Scattergraph Assessment	Monitor No	Observed Max Depth	Simulated Max Depth	Diff in Depth	Observed Max Depth	Simulated Max Depth	Diff in Depth	Observed Max Depth	Simulated Max Depth	Diff in Depth	**Average**
Reasonable	FM01	1.073	0.983	-0.090	1.131	1.013	-0.118	0.441	0.272	-0.169	-0.126
Reasonable	FM02	0.239	0.082	-0.157	0.064	0.057	-0.007	0.136	0.080	-0.056	-0.073
Reasonable	FM03	0.202	0.141	-0.061	0.260	0.141	-0.119	0.185	0.138	-0.047	-0.076
Good	FM04	0.591	0.806	0.215	0.294	0.149	-0.145	0.221	0.193	-0.028	0.014
Reasonable	FM05	0.731	0.897	0.166	0.490	0.178	-0.312	0.309	0.412	0.103	-0.014
Very Good	FM06	0.081	0.142	0.061	0.100	0.088	-0.012	0.113	0.120	0.007	0.019
Reasonable	FM07	1.374	1.377	0.003	0.958	0.628	-0.330	1.128	0.965	-0.163	-0.163
Good	FM08	0.517	0.577	0.060	0.624	0.517	-0.107	0.477	0.549	0.072	0.008
Good	FM09	0.751	0.844	0.093	0.861	0.787	-0.074	0.714	0.818	0.104	0.041
Reasonable	FM10	0.251	0.330	0.079	1.495	0.142	-1.353	0.262	0.224	-0.038	-0.437
Reasonable	FM11	0.568	1.260	0.692	0.521	0.294	-0.227	0.513	0.452	-0.061	0.135
Very Good	FM12	1.076	1.234	0.158	2.076	1.984	-0.092	1.772	1.865	0.093	0.053
Good	FM13	0.535	0.457	-0.078	0.448	0.402	-0.046	0.542	0.417	-0.125	-0.083
Reasonable	FM14	0.234	0.208	-0.026	0.232	0.199	-0.033	0.210	0.185	-0.025	-0.028
Reasonable	FM15	0.191	0.492	0.301	0.097	0.097	0.000	0.363	0.175	-0.188	0.038
Poor	FM16			N/A			N/A			N/A	N/A
Poor	FM17			N/A			N/A			N/A	N/A
Good	FM18	1.007	0.934	-0.073	1.106	0.829	-0.277	0.967	0.909	-0.058	-0.136
Good	FM19	1.071	0.929	-0.142	1.151	0.825	-0.326	1.014	0.906	-0.108	-0.192
Reasonable	FM20	0.467	0.953	0.486	0.425	0.953	0.528	0.416	0.953	0.537	0.517
Reasonable	FM21	0.072	0.062	-0.010	0.077	0.052	-0.025	0.074	0.062	-0.012	-0.016
Very Good	FM23	1.077	1.104	0.027	1.127	1.367	0.240	1.038	1.316	0.278	0.182
Reasonable	FM24	0.834	0.295	-0.539	0.437	0.291	-0.146	0.421	0.294	-0.127	-0.271
Good	FM25	0.523	0.292	-0.231	1.458	0.235	-1.223	0.501	0.259	-0.242	-0.565
Very Good	FM26	1.165	1.204	0.039	1.215	1.371	0.156	1.343	1.222	-0.121	0.025
Reasonable	FM27	0.453	0.397	-0.056	0.478	0.356	-0.122	0.421	0.329	-0.092	-0.090
Reasonable	FM28	0.482	0.407	-0.075	0.576	0.320	-0.256	0.325	0.299	-0.026	-0.119

Figure J-3 - Example of confidence assessment for peak depth

The colour coding used is:

- +0.5m to -0.1m : green
- +0.75m to -0.35m : amber
- >0.75m or <-0.35m: red.

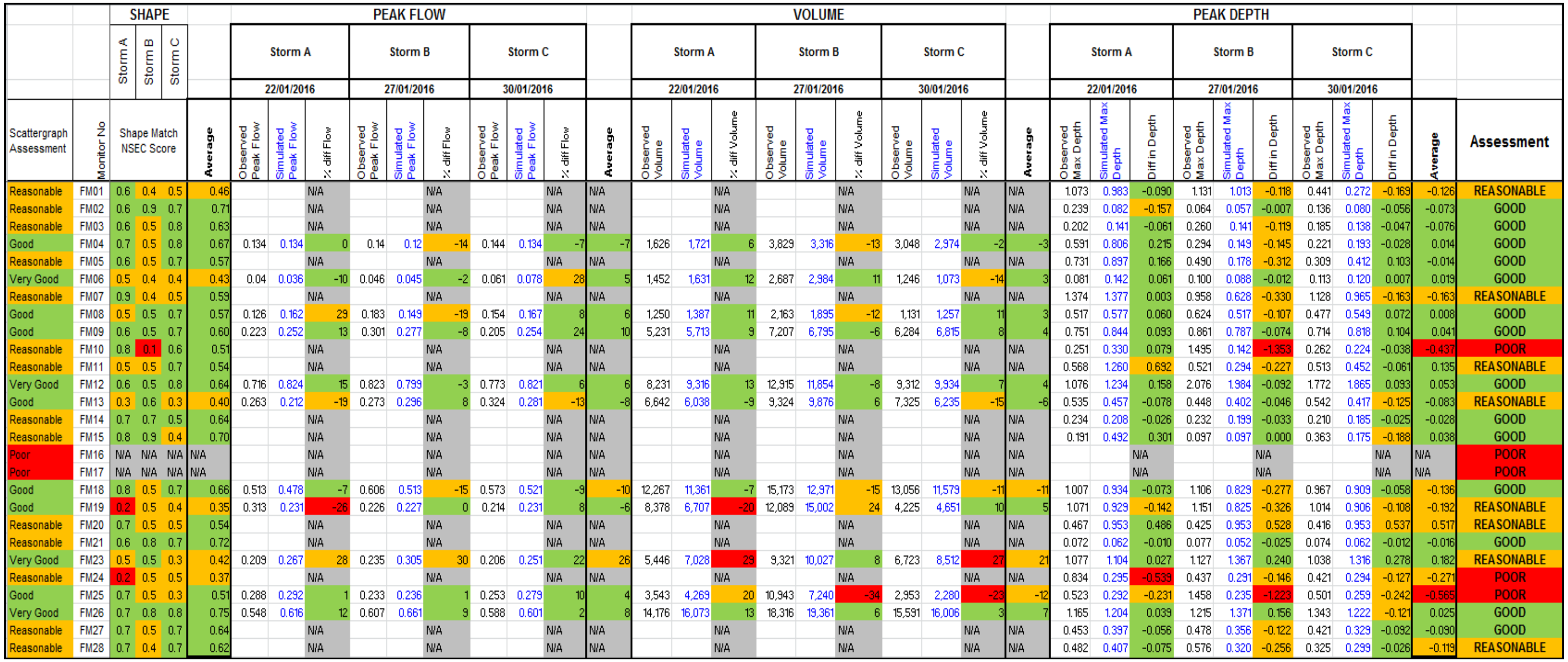
Figure J-4 shows the whole spreadsheet. At the right hand end of the spreadsheet (in this case at the top of the image) is a column for an overall assessment to be made. This is a largely subjective judgement but it is reasonably transparent how it has been arrived at by means of looking across the rows in the spreadsheet.

There are only 3 categories given:

- Good : green
- Reasonable : amber
- Poor : red

These final assessment can then be visualised within the modelling program by means of giving all of the subcatchments upstream of each monitor that assessment. Figure J-5 shows the foul & combined system with the subcatchments colour coded to reflect the confidence assessment and Figure J-6 the shows similar for storm system. Care should be taken with this approach as verification is at a point and a case can be made that confidence will reduce with the distance from the monitoring point.

It is particularly clear in the visualisation for the storm system that large parts of the catchments could not be assigned a confidence because there were no flow monitors installed covering those areas.



		SHAPE				PEAK FLOW										VOLUME										PEAK DEPTH										
		Storm A	Storm B	Storm C		Storm A			Storm B			Storm C				Storm A			Storm B			Storm C				Storm A			Storm B			Storm C				
						22/01/2016			27/01/2016			30/01/2016				22/01/2016			27/01/2016			30/01/2016				22/01/2016			27/01/2016			30/01/2016				
Scattergraph Assessment	Monitor No	Shape Match NSEC Score			Average	Observed Peak Flow	Simulated Peak Flow	% diff Flow	Observed Peak Flow	Simulated Peak Flow	% diff Flow	Observed Peak Flow	Simulated Peak Flow	% diff Flow	Average	Observed Volume	Simulated Volume	% diff Volume	Observed Volume	Simulated Volume	% diff Volume	Observed Volume	Simulated Volume	% diff Volume	Average	Observed Max Depth	Simulated Max Depth	Diff in Depth	Observed Max Depth	Simulated Max Depth	Diff in Depth	Observed Max Depth	Simulated Max Depth	Diff in Depth	Average	Assessment
Reasonable	FM01	0.6	0.4	0.5	0.46			N/A			N/A			N/A	N/A			N/A			N/A			N/A	N/A	1.073	0.983	-0.090	1.131	1.013	-0.118	0.441	0.272	-0.169	-0.126	REASONABLE
Reasonable	FM02	0.6	0.9	0.7	0.71			N/A			N/A			N/A	N/A			N/A			N/A			N/A	N/A	0.239	0.082	-0.157	0.064	0.057	-0.007	0.136	0.080	-0.056	-0.073	GOOD
Reasonable	FM03	0.6	0.5	0.8	0.63			N/A			N/A			N/A	N/A			N/A			N/A			N/A	N/A	0.202	0.141	-0.061	0.260	0.141	-0.119	0.185	0.138	-0.047	-0.076	GOOD
Good	FM04	0.7	0.5	0.8	0.67	0.134	0.134	0	0.14	0.12	-14	0.144	0.134	-7	-7	1,626	1,721	6	3,829	3,316	-13	3,048	2,974	-2	-3	0.591	0.806	0.215	0.294	0.149	-0.145	0.221	0.193	-0.028	0.014	GOOD
Reasonable	FM05	0.6	0.5	0.7	0.57			N/A			N/A			N/A	N/A			N/A			N/A			N/A	N/A	0.731	0.897	0.166	0.490	0.178	-0.312	0.309	0.412	0.103	-0.014	GOOD
Very Good	FM06	0.5	0.4	0.4	0.43	0.04	0.036	-10	0.046	0.045	-2	0.061	0.078	28	5	1,452	1,631	12	2,687	2,984	11	1,246	1,073	-14	3	0.081	0.142	0.061	0.100	0.088	-0.012	0.113	0.120	0.007	0.019	GOOD
Reasonable	FM07	0.9	0.4	0.5	0.59			N/A			N/A			N/A	N/A			N/A			N/A			N/A	N/A	1.374	1.377	0.003	0.958	0.628	-0.330	1.128	0.965	-0.163	-0.163	REASONABLE
Good	FM08	0.5	0.5	0.7	0.57	0.126	0.162	29	0.183	0.149	-19	0.154	0.167	8	6	1,250	1,387	11	2,163	1,895	-12	1,131	1,257	11	3	0.517	0.577	0.060	0.624	0.517	-0.107	0.477	0.549	0.072	0.008	GOOD
Good	FM09	0.6	0.5	0.7	0.60	0.223	0.252	13	0.301	0.277	-8	0.205	0.254	24	10	5,231	5,713	9	7,207	6,795	-6	6,284	6,815	8	4	0.751	0.844	0.093	0.861	0.787	-0.074	0.714	0.818	0.104	0.041	GOOD
Reasonable	FM10	0.8	0.1	0.6	0.51			N/A			N/A			N/A	N/A			N/A			N/A			N/A	N/A	0.251	0.330	0.079	1.495	0.142	-1.353	0.262	0.224	-0.038	-0.437	POOR
Reasonable	FM11	0.5	0.5	0.7	0.54			N/A			N/A			N/A	N/A			N/A			N/A			N/A	N/A	0.568	1.260	0.692	0.521	0.294	-0.227	0.513	0.452	-0.061	0.135	REASONABLE
Very Good	FM12	0.6	0.5	0.8	0.64	0.716	0.824	15	0.823	0.799	-3	0.773	0.821	6	6	8,231	9,316	13	12,915	11,854	-8	9,312	9,934	7	4	1.076	1.234	0.158	2.076	1.984	-0.092	1.772	1.865	0.093	0.053	GOOD
Good	FM13	0.3	0.6	0.3	0.40	0.263	0.212	-19	0.273	0.296	8	0.324	0.281	-13	-8	6,642	6,038	-9	9,324	9,876	6	7,325	6,235	-15	-6	0.535	0.457	-0.078	0.448	0.402	-0.046	0.542	0.417	-0.125	-0.083	REASONABLE
Reasonable	FM14	0.7	0.7	0.5	0.64			N/A			N/A			N/A	N/A			N/A			N/A			N/A	N/A	0.234	0.208	-0.026	0.232	0.199	-0.033	0.210	0.185	-0.025	-0.028	GOOD
Reasonable	FM15	0.8	0.9	0.4	0.70			N/A			N/A			N/A	N/A			N/A			N/A			N/A	N/A	0.191	0.492	0.301	0.097	0.097	0.000	0.363	0.175	-0.188	0.038	GOOD
Poor	FM16	N/A	N/A	N/A	N/A			N/A			N/A			N/A	N/A			N/A			N/A			N/A	N/A			N/A			N/A			N/A	N/A	POOR
Poor	FM17	N/A	N/A	N/A	N/A			N/A			N/A			N/A	N/A			N/A			N/A			N/A	N/A			N/A			N/A			N/A	N/A	POOR
Good	FM18	0.8	0.5	0.7	0.66	0.513	0.478	-7	0.606	0.513	-15	0.573	0.521	-9	-10	12,267	11,361	-7	15,173	12,971	-15	13,056	11,579	-11	-11	1.007	0.934	-0.073	1.106	0.829	-0.277	0.967	0.909	-0.058	-0.136	GOOD
Good	FM19	0.2	0.5	0.4	0.35	0.313	0.231	-26	0.226	0.227	0	0.214	0.231	8	-6	8,378	6,707	-20	12,089	15,002	24	4,225	4,651	10	5	1.071	0.929	-0.142	1.151	0.825	-0.326	1.014	0.906	-0.108	-0.192	REASONABLE
Reasonable	FM20	0.7	0.5	0.5	0.54			N/A			N/A			N/A	N/A			N/A			N/A			N/A	N/A	0.467	0.953	0.486	0.425	0.953	0.528	0.416	0.953	0.537	0.517	REASONABLE
Reasonable	FM21	0.6	0.8	0.7	0.72			N/A			N/A			N/A	N/A			N/A			N/A			N/A	N/A	0.072	0.062	-0.010	0.077	0.052	-0.025	0.074	0.062	-0.012	-0.016	GOOD
Very Good	FM23	0.5	0.5	0.3	0.42	0.209	0.267	28	0.235	0.305	30	0.206	0.251	22	26	5,446	7,028	29	9,321	10,027	8	6,723	8,512	27	21	1.077	1.104	0.027	1.127	1.367	0.240	1.038	1.316	0.278	0.182	REASONABLE
Reasonable	FM24	0.2	0.5	0.5	0.37			N/A			N/A			N/A	N/A			N/A			N/A			N/A	N/A	0.834	0.295	-0.539	0.437	0.291	-0.146	0.421	0.294	-0.127	-0.271	POOR
Good	FM25	0.7	0.5	0.3	0.51	0.288	0.292	1	0.233	0.236	1	0.253	0.279	10	4	3,543	4,269	20	10,943	7,240	-34	2,953	2,280	-23	-12	0.523	0.292	-0.231	1.458	0.235	-1.223	0.501	0.259	-0.242	-0.565	POOR
Very Good	FM26	0.7	0.8	0.8	0.75	0.548	0.616	12	0.607	0.661	9	0.588	0.601	2	8	14,176	16,073	13	18,316	19,361	6	15,591	16,006	3	7	1.165	1.204	0.039	1.215	1.371	0.156	1.343	1.222	-0.121	0.025	GOOD
Reasonable	FM27	0.7	0.5	0.7	0.64			N/A			N/A			N/A	N/A			N/A			N/A			N/A	N/A	0.453	0.397	-0.056	0.478	0.356	-0.122	0.421	0.329	-0.092	-0.090	GOOD
Reasonable	FM28	0.7	0.4	0.7	0.62			N/A			N/A			N/A	N/A			N/A			N/A			N/A	N/A	0.482	0.407	-0.075	0.576	0.320	-0.256	0.325	0.299	-0.026	-0.119	REASONABLE

Figure J-4 Example of a confidence assessment sheet for storm verification

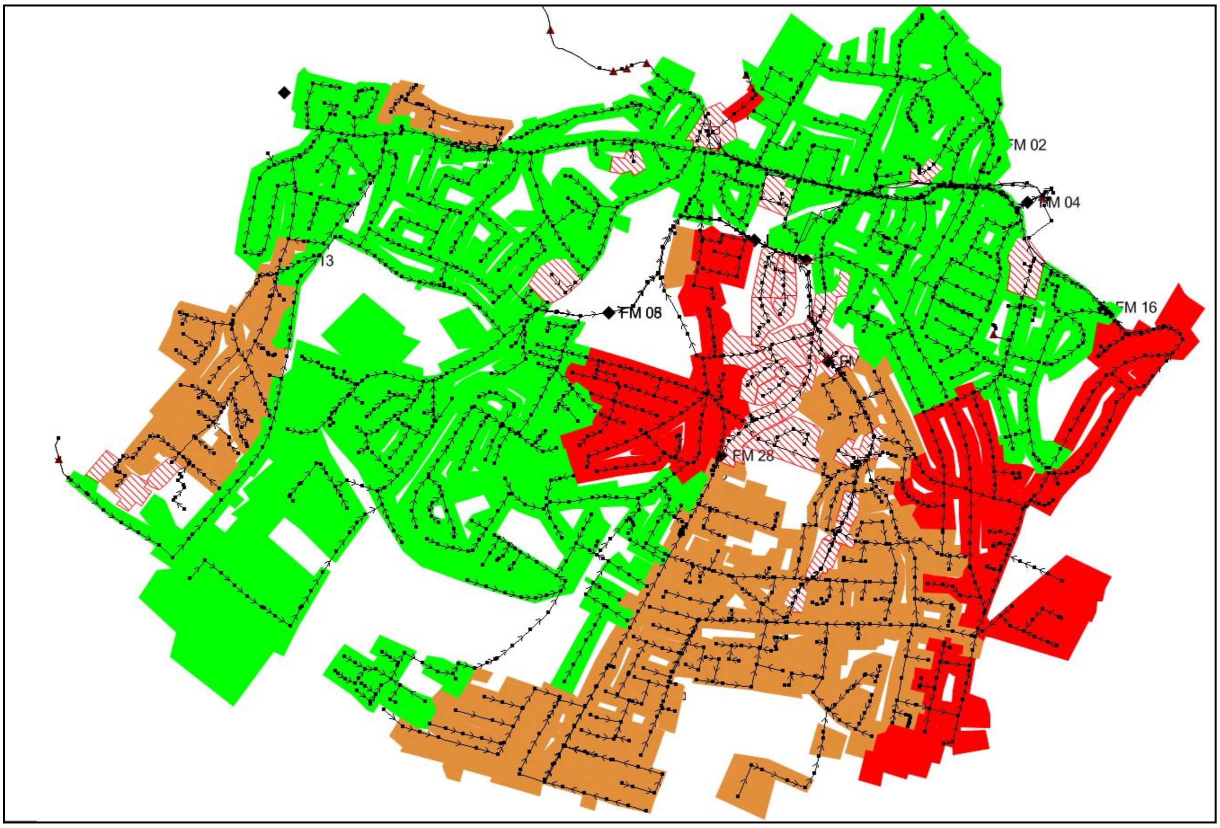


Figure J-5 Storm Verification Visualisation for Foul & Combined System

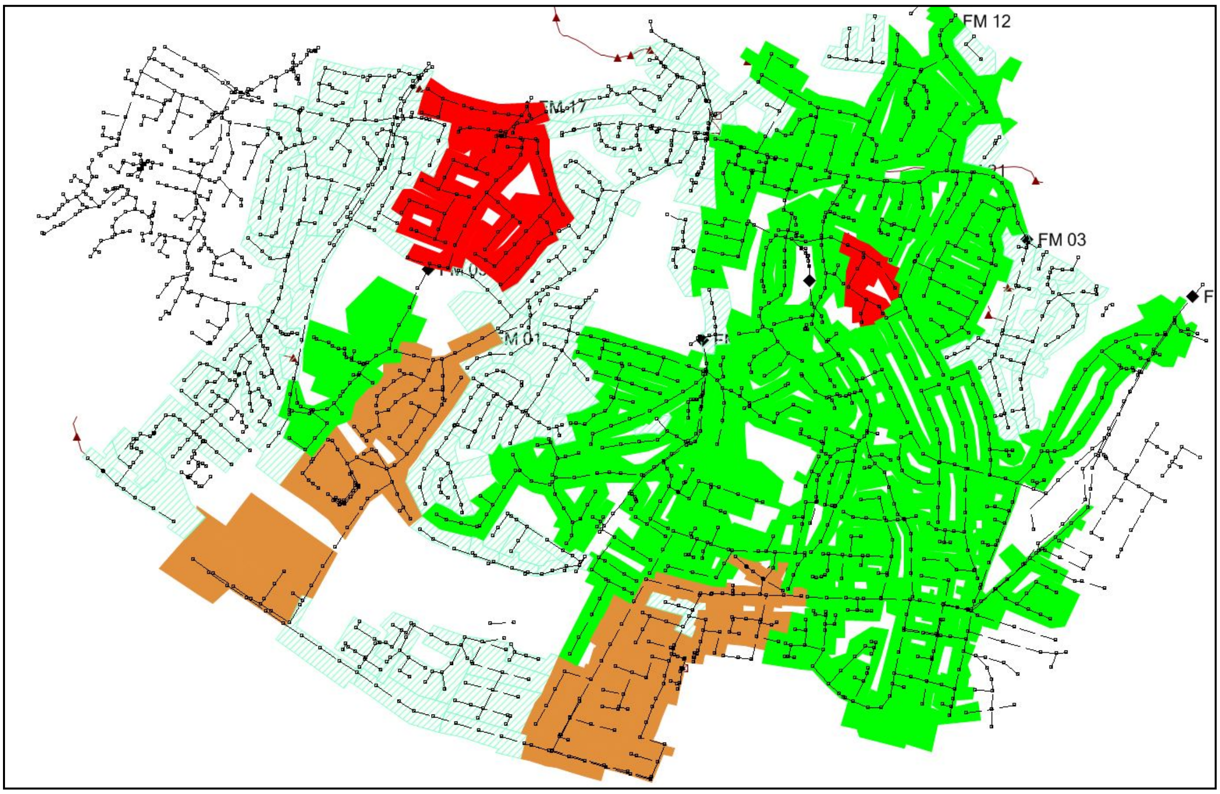


Figure J-6 Storm Verification Visualisation for Storm System

APPENDIX K – EXAMPLE OF NUMERICAL SCORING APPROACH

This appendix contains an example of how a numerical scoring approach can be applied. This is not intended to be a definitive scoring system but serves to illustrate how such a system might be developed. Values used in the examples for scores and weightings are therefore only included for illustration purposes and are by no means recommendations.

This example is for a conduit and a similar approach can be taken for all aspects.

Scoring Data Flags

The first aspect is to decide on a scoring system for the data flags used in the modelling. This scoring system would need to be applied throughout the model and for all aspects. A score should be determined for data flags that might be used and it is therefore simpler if the number of data flags used is kept to a minimum. Difficulties will arise if modellers are permitted to introduce additional data flags.

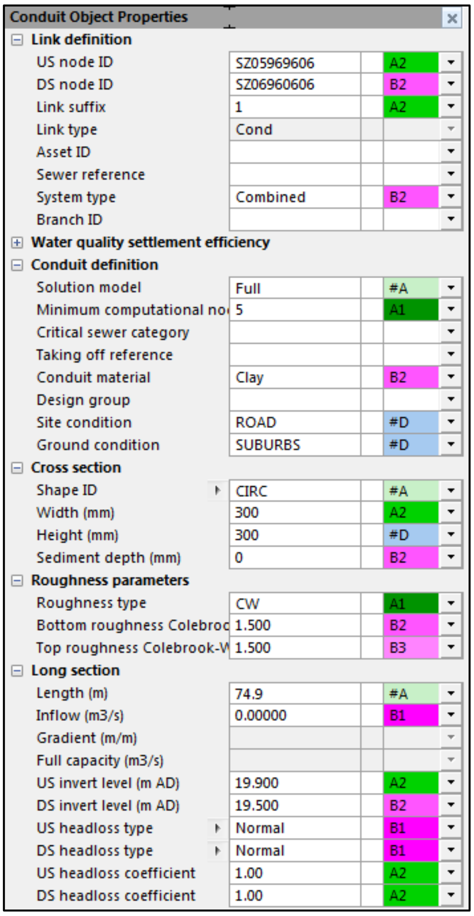
Table K-1 gives an example of the data flags that follow an alphanumerical approach with the letter denoting the method of collection and the number denoting a quality assessment.

Table K-1 Example of data flags and scoring

Name	Display Colour	Description	Score
#A		Asset Data	7
#D		System Default	0
#G		Data from GeoPlan	1
#I		Model Import	6
#S		System Calculated	1
#V		CSV Import	6
A1	🟩	A1 Quality	10
A2	🟩	A2 Quality	9
A3	🟩	A3 Quality	8
B1	🟪	B1 Quality	8
B2	🟪	B2 Quality	7
B3	🟪	B3 Quality	6
C1	🟦	C1 Quality	7
C2	🟦	C2 Quality	6
C3	🟦	C3 Quality	5
D1	🟥	D1 Quality	6
D2	🟥	D2 Quality	5
D3	🟥	D3 Quality	4

The # data flags that exist in some modelling programs are also scored and it is notable that the #D flag is scored at zero, which is intended to encourage modellers to make a conscious decision about all the data used in the model. Scores for #A, #I and #V are relatively high as they are likely to be used for data imported from GIS data or previous models.

The example in Figure K-1 shows how the data flags might appear for a pipe conduit.



Conduit Object Properties

Link definition		
US node ID	SZ05969606	A2
DS node ID	SZ06960606	B2
Link suffix	1	A2
Link type	Cond	
Asset ID		
Sewer reference		
System type	Combined	B2
Branch ID		
Water quality settlement efficiency		
Conduit definition		
Solution model	Full	#A
Minimum computational no	5	A1
Critical sewer category		
Taking off reference		
Conduit material	Clay	B2
Design group		
Site condition	ROAD	#D
Ground condition	SUBURBS	#D
Cross section		
Shape ID	CIRC	#A
Width (mm)	300	A2
Height (mm)	300	#D
Sediment depth (mm)	0	B2
Roughness parameters		
Roughness type	CW	A1
Bottom roughness Colebroc	1.500	B2
Top roughness Colebrook-W	1.500	B3
Long section		
Length (m)	74.9	#A
Inflow (m3/s)	0.00000	B1
Gradient (m/m)		
Full capacity (m3/s)		
US invert level (m AD)	19.900	A2
DS invert level (m AD)	19.500	B2
US headloss type	Normal	B1
DS headloss type	Normal	B1
US headloss coefficient	1.00	A2
DS headloss coefficient	1.00	A2

Figure K-1 Example of data flags for a pipe conduit

Weightings

Each aspect of the model (Asset data, Subcatchment data etc) will need to have a set of weightings applied, which are based on the relative importance of each item of data to the overall confidence which can be attributed to that asset or subcatchment. The example in Table K-1 gives an illustration of the weightings that might be applied to a conduit in the model.

It will be necessary for the personnel developing the scoring system to have a detailed understanding of hydraulics and how the modelling program utilises the data, in order that appropriate weightings can be determined.

If the scoring system is based upon a series of SQL's which can be embedded in the model it will be necessary for the weightings for each aspect of asset data etc to be hard coded into the SQL.

Table K-1 Example of weightings for links

Link Definition	Weighting
US Node ID	10
DS Node ID	10
Link Suffix	3
Link Type	10
Asset ID	-
Sewer Reference	-
System Type	5
Branch ID	-

Conduit Definition	Weighting
Solution model	5
Minimum computational nodes	5
Critical sewer category	-
Taking off reference	-
Conduit material	4
Design Group	-
Site Condition	-
Ground condition	-

Cross section	Weighting
Shape ID	10
Width (mm)	9
Height (mm)	9*
Sediment depth (mm)	8

* In some programs data flags cannot be assigned to the Height when the shape is circular

Roughness parameters	Weighting
Roughness type	7
Bottom roughness	7
Top roughness	7

Long Section	Weighting
Length (m)	8
Inflow (m3/s)	10
Gradient (m/m)	-
Full capacity (m3/s)	-
US invert level (m AD)	10
DS invert level (m AD)	10
US headloss type	6
DS headloss type	6
US headloss coefficient	2
DS headloss coefficient	2

Example for Circular Pipe

The percentage score for this pipe is based on comparing the actual score with the maximum attainable score, assuming the maximum score can be achieved for every item. In this example the percentage score is 80.6% which signifies a high degree of confidence (Table K-2).

This example is presented in a spreadsheet format and whilst a quantitative scoring system could utilise a spreadsheet or database it is more likely to be developed as a series of SQL's which automatically calculate the total score and add the answer to a 'User Number' field. In this way the confidence can be displayed within the geoplan view (Figure K-2) of the modelling program as illustrated below.

In this example both the pipe size and the quantitative score are displayed for each pipe in the network. The pipes are also colour coded according to their quantitative score banding. The foul and combined sewers are shown as the solid lines and the storm sewers are shown as dashed lines.

Table K-2 Example of calculating the confidence score for a pipe

Link Definition	**Weighting**	**Data Flag**	**Data Flag Score**	**Weighted Score**
US Node ID	10	A2	9	90
DS Node ID	10	B2	7	
Link Suffix	3	A2	9	27
Link Type	10	A1	10	100
Asset ID	-			
Sewer Reference	-			
System Type	5	B2	7	35
Branch ID	-			
Conduit Definition				
Solution model	5	#A	7	35
Minimum computational nodes	5	A1	10	50
Critical sewer category	-			
Taking off reference	-			
Conduit material	4	B2	7	28
Design Group	-			
Site Condition	-	#D	0	
Ground condition	-	#D	0	
Cross section				
Shape ID	10	#A	7	70
Width (mm)	9	A2	9	81
Height (mm)	9*	A2	9	
Sediment depth (mm)	8	B2	7	56
Roughness parameters				
Roughness type	7	A1	10	70
Bottom roughness	7	B2	7	49
Top roughness	7	B3	6	42
Long Section				
Length (m)	8	#A	7	56
Inflow (m3/s)	10	B1	8	80
Gradient (m/m)	-			
Full capacity (m3/s)	-			
US invert level (m AD)	10	A2	9	90
DS invert level (m AD)	10	B2	7	70
US headloss type	6	B1	8	48
DS headloss type	6	B1	8	48
US headloss coefficient	2	A2	9	18
DS headloss coefficient	2	A2	9	18
			Total	**1161**
			Maximum attainable score	1440
			Percentage Score	**80.6%**

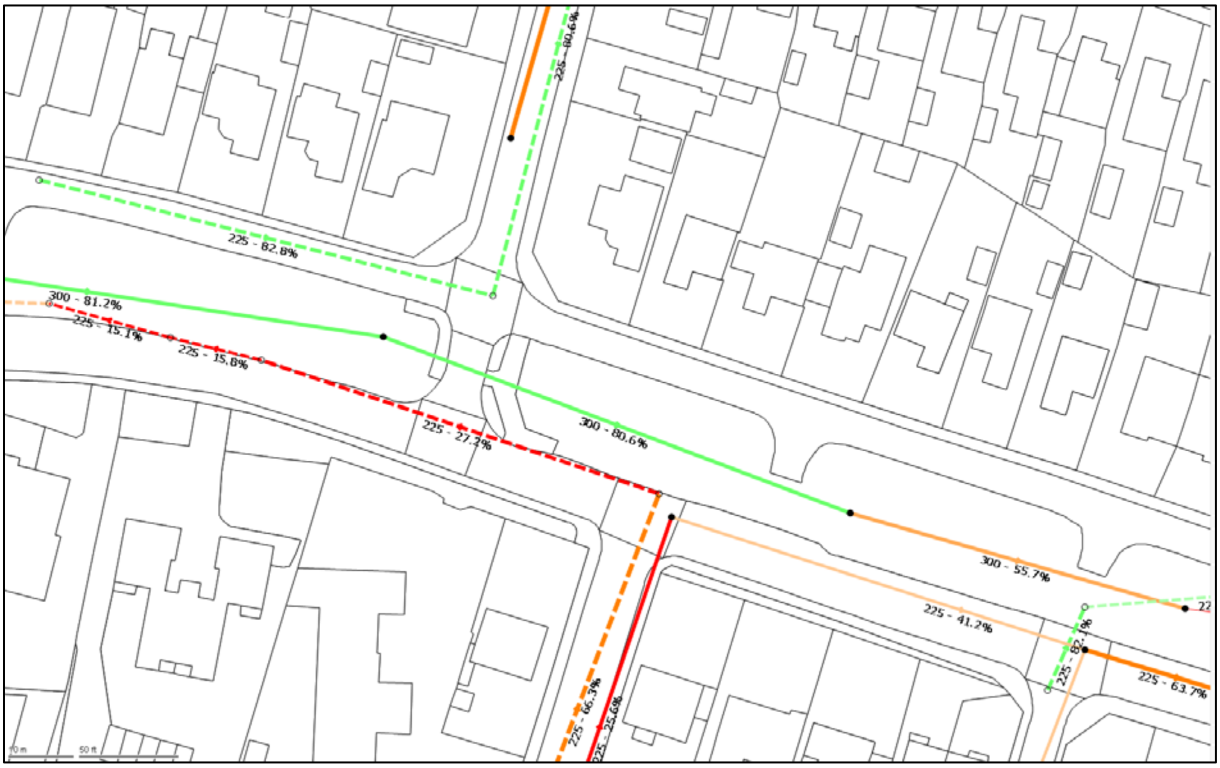


Figure K-2 Example of displaying the model confidence for the pipes geospatially

APPENDIX L - Types of Intervention

Table L-1 below summarises the common types of interventions to consider for urban drainage needs.

Table L-1 Typical Urban Drainage Interventions

Generic Intervention	Brief Description
Maximise existing capacity – System optimisation	Reconfigure hydraulic structures
	Remove isolated throttles
	Install hydraulic controls
	Real Time Control (RTC)
	Flow transfer (to area with headroom in the same or other network)
Disconnection and anti-flood devices – (AFDs)	Anti-flood devices or pumps at single properties
	package pumping stations to disconnect groups of properties from surcharged sewers
Separation of foul and surface water flow	Separate foul and surface water flows e.g. new SW sewers, correct wrong connections in sewer or domestic networks etc.
Structural rehabilitation	Sewer lining or other rehabilitation techniques including trenchless technologies
Mitigation and resilience	Property Level Protection (PLP) including flood gates, air-brick covers, resilience measures etc.
Design for exceedance	Manage flows on surface e.g. sacrificial flood areas, raise kerbs to direct flow down minor roads to receptor etc.
Conveyance	Sewer upsizing/reinforcement
	Increased pump capacity
	Relief sewers
Storage	Online tanks
	Off-line tanks
Sustainable Drainage (SuDS)	SUDs or other techniques to attenuate or eliminate/reduce storm flows to major or minor systems: See susdrain.org
Static or mechanical screens	Screen to reduce aesthetic pollution to the environment
Non-structural measures	These include measures which aim to change customer behaviour for example around water consumption, disposal of FOGs etc.
Operational Maintenance	Carry out appropriate levels of operational maintenance to prevent problems occurring e.g. jetting, root cutting etc.

REFERENCES AND BIBLIOGRAPHY

British Water, (2013) Flows and Loads – Code of Practice

Centre for Ecology and Hydrology (2017) Flood Estimation Handbook (FEH) website

Chow (1959) Open channel hydraulics

CIRIA (1998) Dry Weather Flow in Sewers, R177

CIRIA (2006) Designing for Exceedance in Urban Drainage - Good Practice, Report C635

CIRIA (2015) Communication and engagement in local flood risk management, report C751

CIRIA (2015) Communication and engagement techniques in local flood risk management, companion guide report C752

CIRIA (2015) The SUDS Manual, Report C753

CIWEM UDG (1999) River Data Collection Guide, Version 01

CIWEM UDG (1999) River Modelling Guide, Version 01

CIWEM UDG (2006) Guide to the Quality Modelling Of Sewer Systems, Version 1.0

CIWEM UDG (2009) Integrated Urban Drainage Modelling Guide version 1.0

CIWEM UDG (2009) User Note 1 – Modelling Vortex Flow Control devices, Version 4

CIWEM UDG (2009) User Note 13 – The dangers of force fitting, version3

CIWEM UDG (2009) User Note 15 – Storage Compensation, version 3

CIWEM UDG (2009) User Note 2 – Modelling ancillaries and discharge coefficients, Version 3,

CIWEM UDG (2009) User Note 22 – Selection of tide levels, version 3

CIWEM UDG (2009) User Note 27 – Modelling ancillaries: weir coefficients, version 2

CIWEM UDG (2009) User Note 28 – A new runoff model, version3

CIWEM UDG, (2009) User Note 33 – Modelling dry weather flow, version 2

CIWEM UDG (2015) Competency Framework

CIWEM UDG (2016) Event Duration Monitoring Good Practice Guide, Version 2.2

CIWEM UDG (2016) Rainfall Modelling Guide, Version 1.01

Defra / Environment Agency, (2005) Use of Joint Probability Methods in Flood Management: A guide to best practice (R&D Technical Report FD2308/TR1 and TR2)

Defra, (2010) Surface Water Management Plan Technical Guidance

DOE (1983) Wallingford Procedure for design and analysis of urban storm drainage

Environment Agency (2010) The Fluvial Design Guide, Environment Agency (web based).

Environment Agency, (2013) National Standard Contract and Specification for Surveying Services

FWR (2012) Urban Pollution Management (UPM) Manual, Version 3, web based

HR Wallingford, (1994) Tables for the Hydraulic Design of Pipes, Sewers and Channels

Institute of Hydrology, (1999) Flood Estimation Handbook (FEH)

Moriasi, D.N., Arnold, J.G., Van Liew, M.W., Binger, R.L., Harmel, R.D. and Veith, T.L. (2007) Model evaluation guidelines for systematic quantification of accuracy in watershed simulations, American Society of Agricultural and Biological Engineers, Vol 50(3) 885-900

Natural Environment Research Council, (1975) The Flood Studies Report

OFWAT/EA (2013) Drainage Strategy Framework

SEPA, (2017) Flood Modelling Guidance for Responsible Authorities Version 1.1

UKWIR (2012) Strategic Infiltration, UKWIR Reference 12/SW/01/1

UKWIR (2013) Development of the UKWIR Runoff Model UKWIR Reference 14/SW/01/6)

UKWIR (2014) Wastewater supply-demand framework, UKWIR Report Ref. No. 14/RG/08/6

UKWIR (2014), Impact of Urban Creep on Sewerage Systems, UKWIR Reference: 10/WM/07/14

WRc (1987) Guide to short term flow surveys of sewer systems

WRc (1993) Model Contract Document for short term sewer flow surveys (2nd Edition)

WRc (1993), Model Contract Document for Manhole Location Surveys and the Production of Record Maps

WRc (2005) Model Contract Document for Sewer Condition Inspection 2nd Edition

WRc (2013) Manual of Sewer Condition Classification - 5th Edition

WRc (2017) Sewerage Risk Management (SRM), web based

WRc, (2012) Sewers for Adoption 7th Edition

GLOSSARY & ABBREVIATIONS

Glossary

Term	Definition
Ancillary	Non pipe and conduit devices forming part of a sewerage and watercourse system, e.g. CSOs, pumping stations, flow controls
Antecedent Conditions	The condition of a catchment before a rainfall event
Backwater	Build-up of flow in a pipe due to a restriction downstream
Bifurcation	A location where part of the flow is diverted to another part of the same system type. This could be either sewers or watercourses. In a sewer this would be a chamber with two or more outgoing pipes where at least one pipe diverts flow to another part of the sewer network.
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 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
CIWEM UDG	CIWEM Urban Drainage Group.
Colebrook-White	An empirical equation relating flow to roughness and gradient of a conduit and the viscosity of the fluid.
Combined Drainage System	A single pipe drainage system where both foul and storm runoff are conveyed in the same pipe.
Combined Sewer Overflow (CSO)	A relief structure allowing the discharge of diluted untreated wastewater from a combined sewer during a rainfall event, when the flow exceeds the wastewater network capacity.
Commercial Flow	Flows from commercial premises whose effluent quality does not require consenting as trade effluent.
Commissioning Body	The organisation commissioning the modelling project.
Conduit Headloss	Energy losses in pipes and channels generally due to friction.
Confidence	A measure of how confident a modeller is that either an element of a model or the whole model matches reality
Confidence - Qualitative	A measure of confidence based on expert judgement.
Confidence - Quantitative	A measure of confidence based on a numerical scoring system with pre-set scores to be achieved.
Connectivity - assets	The connectivity of the physical assets in a drainage system.
Connectivity - surfaces	The connectivity of the runoff surfaces to modelled nodes.

Term	Definition
Continuous Simulation	A simulation run that extends over more than just a single rainfall event, and includes the intervening dry weather periods.
Contributing Area	The total area of a subcatchment which can contribute runoff to a point in the drainage system
Contributing Area Survey (CAS)	Surveys carried out to identify the nature and connectivity of surfaces to the respective sewerage systems.
Critical Duration Storm	The duration of design storm necessary to produce the maximum flow or volume at a specific location in a drainage system.
Culvert	Conduit used to direct the flow of water, usually below a structure such as a building, road or railway
Curtilage	The open space situated within a boundary belonging to dwelling house.
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.
Depression Storage	Rainfall retained in surface hollows which does not contribute to runoff.
Depth - Discharge relationship	A relationship between depth of flow and the associated discharge rate.
Design Storm	A rainfall hyetograph of a specific duration whose total depth corresponds to a particular storm return period or recurrence interval, usually chosen from an IDF curve.
Designing for Exceedance	Designing for Exceedance an engineering philosophy for the design and management of urban sewerage and drainage systems to reduce the impacts that arise when flows occur that exceed their capacity. Guidance published by CIRIA.
DG5 Register	A WaSC held register of properties which have experienced sewer flooding due to hydraulic overloading or are at risk of sewer flooding.
Digital Elevation Model (DEM)	A digital map of the elevation of the ground surface and includes building, vegetation etc.
Digital Terrain Model (DTM)	A model of the terrain of the earth’s surface (bare earth), which excludes buildings and vegetation.
Diurnal profile	The temporal variation in dry weather flow during the day, generally expressed as a multiplier of average dry weather flow.
Drainage Area Plan (DAP)	A full assessment of a sewer systems performance and condition, investigating hydraulic, operational, structure and environmental performance. It also proposes a strategy to achieve the desired levels of service
Drainage Strategy Framework	A good practice guide for the development of WaSC drainage strategies
Dry Weather Flow	The continuous discharge of domestic, commercial and trade wastewater directly into the sewer system together with base infiltration.

Term	Definition
Economic Regulator	The economic regulator of the water industry. (In England: Ofwat, in Scotland: the WIC, and in Northern Ireland: The Utility Regulator)
Environment Agency (EA)	An Executive Non Departmental Public Body tasked to protect and improve the environment, and to promote sustainable and improve the environment, and to promote sustainable development. The EA plays a central role in delivering the Environmental policies of Central Government in England.
Environmental Regulator	The Environmental Regulator for the water industry (In England: the Environment Agency (EA), in Northern Ireland: the Northern Ireland Environment Agency (NIEA), in Scotland: the Scottish Environment Protection Agency (SEPA), in Wales: Natural Resources Wales (NRW))
Ex Section 24 Sewer (UK)	Former private sewers serving more than one property that were transferred to public ownership in 2011.
Exceedance Flows	Excess flow on the surface once the capacity of the below ground drainage system is exceeded.
Fast Response	Flow entering the sewerage system as a result of direct links between the stormwater collection system and the sewer system, generally from impervious areas. This has a very short response time to rainfall on the catchment.
FEH Web service	www.fehweb.ceh.ac.uk. The FEH Web Service, launched on 9 November 2015, updated and replaced the FEH CD-ROM application. The FEH Web Service provides the data at the heart of the flood estimation procedures, including the release of the new FEH13 rainfall model.
Fit for Purpose	A model that has been considered suitable for the purpose it is required to be used for, taking into account of the uncertainties in the development of the model and the associated risks in the use of the model.
Flags	A notation system allowing the source of information to be traced and the confidence to be assigned to the data.
Flood	Temporary expanse of water that submerges land not normally covered by water.
Flood Estimation Handbook (FEH)	Gives guidance on rainfall and river flood frequency estimation in the UK.
Flood risk	Likelihood of flooding occurring and 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.
Flood Studies Report (FSR)	Provides techniques for design flood and rainfall estimation in the UK and Ireland. This has been superseded by the Flood Estimation handbook.
Floodplain	Flat, low-lying area adjacent to a watercourse and prone to flooding.
Flow Survey	A survey carried out over a period to monitor the response of a drainage system to measured rainfall and dry weather conditions.

Term	**Definition**
Flow to Full Treatment (FFT)	Rate of flow that receives treatment at a Wastewater Treatment Works. This is usually controlled flow with diluted flows above this rate discharged to the environment following settlement through storm tanks.
Flow to Works (FTW)	Rate of flow arriving at the inlet of a Wastewater Treatment Works.
Fluvial flooding	Same as river flooding.
Force-fitting	Process of making arbitrary changes to a model to make it fit observed data. Should not be undertaken
Foul Flow	Wastewater from domestic, commercial and industrial premises
Froude Number	A dimensionless parameter which represents the ratio between inertial and gravity forces in a fluid.
Geographical Information System (GIS)	A mapping system to analyse and display geographically referenced information.
GPS	Global Positioning System, used to determine geographical location and elevation.
Greenfield runoff	The natural rate of runoff which would occur from a site that is undeveloped or undisturbed.
Groundwater flooding	Flooding caused by increases in the water table to above ground level, due to rainfall.
Gully	A structure to permit the entry of surface water runoff into a sewerage system. It is usually fitted with a grating and a grit trap
Headloss	Energy lost due to resistance to flow, due to friction in pipes, bends and manholes etc.
Highways Agency	Executive Agency of the Department for Transport (DfT), responsible for operating, maintaining and improving the strategic road network in England.
Highways Authority	Local authority responsibility for managing, maintaining and improving England's roads which are not under the responsibility of the Highways Agency
Hydraulic Model	A mathematical model developed to represent the physical characteristics of a drainage system, including assets, topography and hydrology.
Hydrology	The scientific study and practical implications of the movement, distribution and quality of freshwater in the environment
Hydrology of Soil Types (HOST) – (UK)	An improved system of soil classification based on more detailed analysis of the hydrological parameters of soils. There are 29 HOST classes.
Impermeable area	See Impervious surface
Impervious surface	A surface that does not allow infiltration of rain water, such as a roof, road or hard standing.

Term	Definition
Infiltration - Hydrology	The process by which rainfall penetrates the ground surface and fills the pores of the underlying soil.
Infiltration - Sewers	The entry of groundwater into a sewer system through the pipe work, It may also include the entry of unplanned flows into a sewer system via manholes or misconnections.
Integrated Urban Drainage (IUD)	Approach to planning or managing an urban drainage system which leads to an understanding of how different physical components interact
intensity-duration-frequency (IDF)	The relationship between rainfall intensity (amount per unit of time), rainfall duration (total time over which rainfall occurs) and frequency (return interval) at which the intensity-duration relationship is expected to recur.
Intermittent Discharge	Non continuous discharge from the Wastewater Network to a watercourse. This will include discharges from a CSO, EO or a storm tank.
Internal Drainage Boards (IDBs)	Independent bodies responsible for land drainage in areas of special drainage need that extends to 1.2 million hectares of lowland England.
Inundation	The flooding of an area with water.
Joint Probability	Analysis of the probability of two or more conditions which affect risk occurring concurrently.
Land Use	Catchments zoned based on ergonomic, geographic or demographic use of land, such as residential, industrial, agricultural and/or commercial, together with the drainage system type.
LiDAR	Light Detection and Ranging. Ground elevation data
Link	An element of a model linking two nodes. This could be a conduit or a feature, for example a weir or a control.
Main River	Main rivers are usually larger streams and rivers, but also include smaller watercourses of strategic drainage importance. The Environmental Regulator has responsibility for main rivers and are designated by Defra.
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.
Manhole Headloss	Energy losses at a manhole.
MCERTS (UK)	Environment Agency Monitoring Certification Scheme for equipment, personnel and organisations. In this case certified flow monitoring at WwTW
Minor drainage system	The underground piped drainage systems which are typically sewers but could also be culverted watercourses or highway drains.
Misconnections	Mis-connections are surface water connections to a foul system or vice versa by householders or commercial premises;
Model	A numerical representation of physical assets and processes
Model Maintenance	The process of maintaining hydraulic models for future use on

Term	Definition
Modelling Team	Team responsible for carrying out the modelling project
Nash-Sutcliffe Efficiency Coefficient (NSEC)	The Nash–Sutcliffe model efficiency coefficient is used to assess the predictive power of hydrological models.
Flood Authority	Bodies having overall for flooding, e.g. in England this would be the Environment Agency at a National Level and Local Authorities and Internal Drainage Boards at a local level.
Node	A point in a modelled drainage system that receives runoff and other inflows, that connects links together, or that discharges water out of the system. Nodes can be manholes, junctions, storage units or outfalls. Every modelled link is attached to both an upstream and downstream node.
OFWAT	Economic Water Industry Regulator for England and Wales
Operations	The process of operating and maintaining a drainage system, and the part of an organisation that undertakes this.
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.
Overflow	A point where excess flow can spill from one drainage type to another.
Overland Flow Path	The path that runoff follows as it flows over a surface until it reaches a collection channel or drain.
Partially Separate Drainage System	A drainage system where there is a mixture of a combined system and a separate system, usually with the inclusion of separate surface water sewers.
Pass Forward Flow (PFF)	Flow that continues on through the network after passing through a network ancillary
Pass forward flow at first spill	Continuation flow from a CSO at the moment the overflow spills
Per capita consumption (PCC) (G)	The amount of domestic and unmeasured commercial water returned as flow to sewer, generally expressed as units of litres/head/day.
Pervious (Permeable) Surface	A surface that allows water to infiltrate into the soil below it, such as a natural undeveloped area, grass verges or a gravel roadway.
Pluvial Flooding	Flooding that results from rainfall-generated overland flow, before the runoff enters any watercourse or sewer.
Postal address point data (PAF) – (UK))	The Postcode Address File (PAF) is a database which contains all known "Delivery Points" and postcodes in the United Kingdom
Preissmann Slot	The Preissmann slot is a fictitious slot above the soffit of a pipe to allow the use of open channel flow methods to simulate pipe flow in surcharged conditions. As this introduces additional conduit area in the model, there needs to be a reduction in system storage to compensate for the slot.

Term	Definition
Rainfall Induced Infiltration	Non-continuous storm flows that enter a sewer due to inflow from land drainage as well as increased infiltration from subsurface flows through cracked pipes and leaking joints etc.
Return Period	The expected average time between the exceedance of a particular threshold. Frequently used to express the frequency of occurrence of an event e.g. rainfall or flooding.
Revitalised Flood Hydrograph Models (ReFH2)	A model to generate flood peak flows and hydrographs from given rainfall events for both catchments and development sites.
River flooding	Occurs when river flow exceeds the channel capacity due to rainfall, covering the adjacent floodplain with water.
RTC	Real Time Control
Runoff	Rain and surface water that does not percolate into the ground and flows over the surface to a sink, such as a drainage system inlet, watercourse or surface water body
Scattergraph	A Scattergraph has points that show the relationship between two sets of data. In this case the comparison of observed depth and flow or velocity and flow. Used in the assessment of the consistency of recorded flow survey data.
Screen	In wastewater network a device used to remove solid material, either from continuation flow at a WwTW or from spill pipes at CSOs. In a watercourse used to prevent debris from entering a culvert.
Section 105a Sewer (England and Wales)	Previously private sewers and drains that became vested in the Water Utilities under the "Water Industry (Schemes for Adoption of Private Sewers 2011)"
Separate Drainage System	A two pipe drainage system with one pipe taking foul flows and a second pipe taking surface water (storm) flows.
Setting	Continuation flow at which an overflow starts to spill.
Sewer Quality Model	Model which can simulate the flows and the concentrations of various indicators of the pollutant load in sewage as it flows through the sewer system.
Sewerage Risk Manual	A web based process defining a risk based framework to capital maintenance and investment for wastewater network assets. Previously known as the Sewer Rehabilitation Manual (SRM)
Sewerage Management Plan (SMP)	A business plan covering all aspects of sewerage performance related expenditure for a defined number of years, covering a complete drainage area and considering all stakeholders
Sewerage Risk Manual (SRM)	A web based process defining a risk based framework to capital maintenance and investment for wastewater network assets. Previously known as the Sewer Rehabilitation Manual (SRM)
Sewers for Adoption	Standard for new drainage systems in England & Wales so that they can be adopted by a WaSC.

Term	**Definition**
Sewers for Scotland	Standard for new drainage systems in Scotland
Slow Response flows	Flow entering the sewerage system from pervious surfaces, either directly or as a result of seepage through the ground into the sewerage network. Typically when water enters the sewer a few hours after the onset of rainfall and persists for a significant amount of time after the event.
Soil Moisture Deficit	The difference between a soil's current moisture content and its moisture content at saturation.
Stakeholder	An individual or group with an interest in, or having an influence over, the success of a proposed project or other course of action.
Strategic Flood Risk Assessment (SFRA)	Provides information on areas at risk from all sources of flooding. The SFRA should form the basis for flood risk management decisions and inputs into development allocation and control decisions.
Subcatchment	A sub-area of a larger catchment area whose runoff flows into a single drainage pipe or channel.
Subcritical flow	Water depth is greater than critical depth. In practice this leads to tranquil flow and the depth is controlled at the downstream end of the section.
SuDS	Sustainable drainage systems: a sequence of management practices and control measures designed to mimic natural drainage processes by allowing rainfall to infiltrate, and by attenuating and conveying surface water runoff slowly compared to conventional drainage.
Supercritical flow	Water depth is less than critical depth. High velocity results. Depth is controlled at the upstream end of the section.
Surcharge	Condition in which the hydraulic gradient is higher than the soffit of a pipe. The flow is pressurised.
Surface flooding	Flooding from sewers, drains, small water courses and ditches that occur as a result of heavy rainfall and exceedance of the local drainage capacity. May occur from any component of the urban drainage system.
Surface Water Management Plans (SWMPs)	Vehicle through which urban flood risk will be assessed, managed and resolved in the future within England and Wales.
System Storage Compensation	An allowance included in a model for unaccounted for storage in a drainage system, generally from un-modelled local house connections or elements of the system that have been removed as part of a simplification process.
Time Series Rainfall (TSR)	A series of rainfall data (over a number of years) used with sewer models to analyse the performance of a sewer system. Can be stochastic or historical data.
Topographical Surveys	Manual surveys carried out on surface topography where higher accuracy is required than can be obtained using other digital methods.
Trade Effluent Permit (UK)	A permit given to an industrial user for discharging flow to the public sewer or watercourse. Permits usually have a daily maximum flow and a maximum peak flow.
Trade Flows	Flow to sewer from industrial premises, with or without a permit.

Term	Definition
Unsatisfactory Intermittent Discharge (UID)	Intermittent discharge considered unsatisfactory by the Environmental Regulator requiring upgrade.
Urban Creep	Urban Creep is the progressive loss of permeable surfaces within urban areas creating increased runoff, generally due to small extensions, conservatories and paving over garden areas
Urban Pollution Management (UPM)	Urban Pollution Management (UPM) is defined as the management of wastewater discharges from sewer and sewage treatment systems under wet weather conditions such that the requirements of the receiving water are met in a cost effective way. The3rd edition of the manual is available from the Foundation for Water Research (FWR).
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. Any changes to the model should be made only where this reflects the physical state of the sewer system and not solely to make the model fit the verification data
WaPUG	Previous name for CIWEM Urban Drainage Group, with a long history of promoting best practice in the field of urban drainage.
Water and Sewerage Company (WaSC)	Ten regional water and sewerage companies (WaSCs) are licensed for England and Wales, set up under the Water Industry Act 1991. For the purposes of this Code the term includes any organisation responsible for the management of the sewerage system, including Scottish Water and Northern Ireland Water.
Watercourse	A natural or artificial channel along which water flows
Winter Rain Acceptance Potential (WRAP)	A classification system of soils based on their hydrological response, developed as part of the Flood Studies Report. There are five classes of soil.
WwTW	Wastewater Treatment Work (Sewage Works)

Abbreviations

Term	Definition
1D	One dimensional
2D	Two dimensional
API	Antecedent Precipitation Index
API30	Antecedent Precipitation Index 30 Days
API5	Antecedent Precipitation Index 5 Days
BGS	British Geological Survey
CAS	Contributing Area Survey (See IAS)

Term	Definition
CCTV	Closed Circuit Television
CDA	Critical Duration Assessment
CIRIA	Construction Industry Research and Information Association.
CIWEM	Chartered Institution of Water and Environmental Management
CIWEM UDG	CIWEM Urban Drainage Group
CoP	Code of Practice
CSO	Combined Sewer Overflow
D/S	Downstream
DAP	Drainage Area Plan
DAS	Drainage Area Study
DEFRA	Department for Environment, Food and Rural Affairs
DEM	Digital Elevation Model
DG5	Director General 5 Indicator (Internal Flooding)
DM	Depth Monitor
DTM	Digital Terrain Model
DWF	Dry Weather Flow
EA	Environment Agency
EDM	Event Duration Monitoring
EO	Emergency Overflow
FEH	Flood Estimation Handbook
FFT	Flow to Full Treatment
FM	Flow Monitor
FSR	Flood Studies Report
FTW	Flow to Works
GIS	Geographical Information System
GPS	Global Positioning System
HOST	The Hydrology of Soil Types Classification
IA	Impermeable Area
IAS	Impermeable Area Survey (See CAS)
ICG	Internal Condition Grade
ID	Intermittent Discharge
IDF	intensity-duration-frequency
l/h/d	Litres per head per day
LAMP	Local Asset Management Plan

Term	Definition
LEAP	Local Environment Agency Plan
LiDAR	Light Detection and Ranging.
LOS	Level of Service
MBV	Model Build & Verification
MCERTS	Environment Agency Monitoring Certification Scheme for equipment, personnel and organisations. In this case flow monitoring at WwTW.
MH	Manhole
NGR	National Grid Reference
NIEA	Northern Ireland Environment Agency
NRW	Natural Resources Wales
NSEC	Nash-Sutcliffe Efficiency Coefficient
NRV	Non Return Valve
NTS	Not To Scale
OFWAT	The economic regulator of the water sector in England and Wales
O/S	Outside
ONS	Office of National Statistics
OS	Ordnance Survey
PCC	Per Capita Consumption (G)
PE	Population Equivalent
PS	Pumping Station
QA	Quality Assurance
ReFH2	Revitalised Flood Hydrograph Model.
RG	Rain Gauge
RPA	Return Period Analysis
RQO	River Quality Objective
RTC	Real Time Control
SAAR	Standard Average Annual Rainfall
SASR	Standard Average Summer Rainfall
SEPA	Scottish Environment Protection Agency
SIRS	Sewerage Incident Reporting System
SMD	Soil Moisture Deficit
SPG	Structural Performance Grade
SPS	Sewage Pumping Station
SRM	Sewerage Risk Manual

Term	**Definition**
SS	Suspended Solids
TE	Trade Effluent
TPS	Terminal Pumping Station
TSR	Time Series Rainfall
U/S	Upstream
UCWI	Urban Catchment Wetness Index
UID	Unsatisfactory Intermittent Discharge
UKWIR	UK Water Industry Research
UPM	Urban Pollution Management
WaPUG	Wastewater Planning Users Group
WIC	The Water Industry Commission for Scotland.
WQ	Water Quality
WRAP	Winter Rainfall Acceptance Potential
WRc	Water Research Council
WwTW	Waste Water Treatment Works

CIWEM Chartered Institution of Water and Environmental Management

Urban Drainage Group