WASTEWATER PLANNING USERS GROUP

CODE OF PRACTICE FOR THE HYDRAULIC MODELLING OF SEWER SYSTEMS

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TECHNICAL ENQUIRIES

All technical enquiries and suggestions relating to this publication should be addressed to:

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This publication has been checked by the editor members of the WaPUG Committee for major errors, however this publication does not necessarily represent the views of the WaPUG Committee. It is issued for guidance in good faith but without accepting responsibility for its contents.

FOREWORD

In 1974 the Department of the Environment (DoE), in conjunction with the National Water Council Standing Technical Committee, commissioned Hydraulics Research to develop an improved computer based procedure for the analysis of the performance of existing sewer networks.

The Wallingford Procedure[(1)] and the accompanying Wallingford Storm Sewer Package (WASSP) suite of programs resulted and provided a standard tool which was utilised widely by the water industry in the UK. Sewer network models produced using WASSP became the basis for the subsequent design of sewer network rehabilitation projects and required the traditional Engineer to become accomplished in sewer hydraulic modelling.

In 1984 the National Water Council Sewers and Water Mains Committee authorised the creation of the Wallingford Procedure Users Group, now the Wastewater Planning Users Group (WaPUG).

Since that time the capabilities of computers and sewer hydraulic modelling software has advanced significantly with several software vendors now producing software with more functionality.

Sewer hydraulic modelling has now become an indispensable tool in the planning and design of sewer systems. It is therefore important that all network models constructed for use in hydraulic modelling should be built to an agreed standard and adequately documented.

In response, WaPUG promoted the production of this Code of Practice which has incorporated the views of recognised “expert” users from within the water industry. The Code is divided into 10 sections covering all aspects of model building for hydraulic analysis and testing, flow surveys and verification, and documentation, all of which can be incorporated into a quality system.

The first edition was published in November 1993 and minor amendments were incorporated in a second edition in November 1998. This third edition is a comprehensive revision following an extensive consultation with users.

AMMENDMENTS

Reference	Details	Date
3.001	Hyperlinks added to usernotes & minor typographical errors corrected	16/12/02

GLOSSARY

Backwater	Build up of flow in a pipe due to a restriction downstream.
Surcharge	Condition in which the hydraulic gradient is higher than the soffit of a pipe. The flow is pressurised.
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.
Depression Storage	Rainfall retained in surface hollows which does not contribute to runoff.

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1. INTRODUCTION

1.1 EXPERIENCE AND TRAINING OF STAFF

Sewer hydraulic modelling is a complex subject and it is essential that all staff involved in the work should have received training appropriate to the tasks they are carrying out. This Code of Practice is not intended to be 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 of validated training should be kept.

Work should be carried out by, or under the day to day direction of an experienced hydraulic modeller who should have a detailed understanding of the following:

- operational performance requirements for urban drainage systems;
- hydraulics of flow in sewers and sewer ancillary structures;
- urban hydrology;
- the assumptions implicit in the way the software carries out the calculations;
- methods of measurement of flow in sewers and their accuracy;
- engineering solutions.

1.2 DOCUMENTATION

Adequate documentation should be provided to ensure that the maximum value can be obtained from the models and to give confidence in the results. All modelling work should be documented to ensure that the reasons for any decisions can be reviewed at any time during or after the completion of the work. This is to ensure that the implications of any changes in source data, or any cahnges in any of the assumptions, can be easily identified. This information will also be necessary if the model is to be updated at a later date.

Details of assumptions will also be required by subsequent users to establish the applicability of the model for later use.

Further information on documentation is given in section 8.

1.3 QUALITY SYSTEMS

The work of building a sewer hydraulic model involves use of large amounts of data. It is recommended that a quality systems provide a good framework for controlling this flow of data.

Quality systems may comprise only a series of procedural guidance documents covering general areas of policy such as filing, document control, document approval and issue etc.

There are clear advantages to all parties in having detailed working procedures for modelling work to maximise the use of skilled personnel while maintaining high standards of work. This Code of Practice provides a minimum level of guidance that may be used with a quality system to control sewer hydraulic modelling work.

1.4 PLANNING AND PROGRAMMING OF MODELLING WORK

A typical sequence of work in producing a sewer hydraulic model is shown in Figure 1.1. Although it is desirable that the model is built before planning the flow survey, this is not always practicable. Where a study involves updating an earlier model it is sometimes possible to use the original model to plan the flow survey before updating is completed.

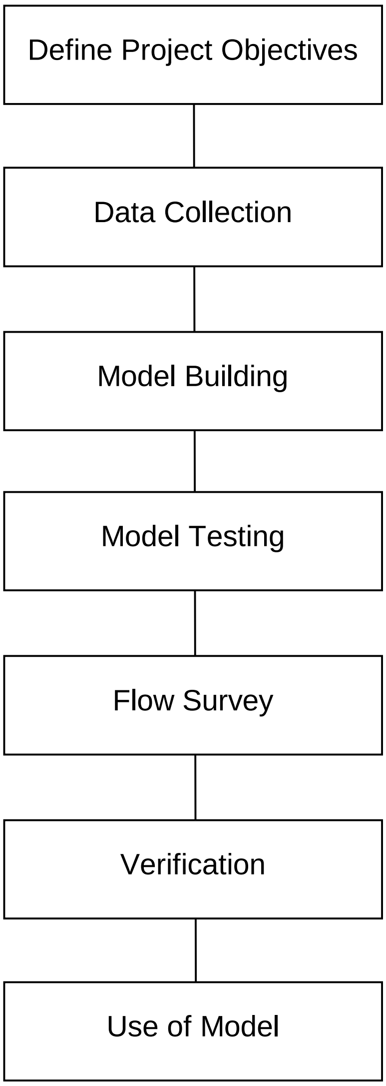


Figure 1.1 Flow diagram for hydraulic modelling work

2. PROJECT DEFINITION

2.1 DEFINING THE PURPOSE OF THE MODEL

Before embarking on producing a model it is essential that the objectives of the model are clearly defined. In particular it is necessary to define the information required from the model and the points at which that information is required.

Where the model is to be used as the basis of a sewer quality model this should also be clearly stated at this stage.

Examples of model objectives could include:

> *To predict the volumes and frequencies of discharge from all the combined sewage overflows in the catchment and to provide the basis for designing upgrading solutions to improve the river water quality. Depending on the findings of the investigation the model may later be used as the basis for a sewer quality model.*
>
> *To identify the locations and causes of all flooding in the catchment as well as the volumes and frequencies of discharge from combined sewer overflows to develop a drainage study incorporating schemes to resolve the hydraulic, receiving water quality and structural problems in the catchment.*
>
> *To identify the causes of the sewer flooding problems at [a specific location] and to provide the basis for designing flood alleviation scheme options.*
>
> *To predict the volume and frequency of discharges at the outfall from the catchment and to provide the basis for designing a new tank and pumping station to improve the bathing water quality.*

Differing standards, techniques, verification standards etc. are applicable depending upon the intended purpose of the model and the information required from it.

Once the objectives are defined the appropriate type of model is selected. A list of different types of model is included in section 2.2.

In addition the commissioning organisation should also determine the emphasis that is to be placed on data collection (see section 3), and what level of verification is appropriate (see section 5 and 6).

2.2 TYPES OF MODELS

It is likely that most models that are built will generally fall within one of the following types:

Type I - Skeletal Planning Model

Type II - Drainage Area Planning Model

Type III - Detailed Design Model

Where none of these types is appropriate, a model may be built to another specified standard which should be defined before work commences.

These definitions are included for guidance and it is intended that modellers should give careful consideration to the objectives of the models and formally set these down at the outset even if they vary slightly from the definitions given below.

It should be appreciated that in some instances a combination of a Skeletal Planning Model, a Drainage Area Planning Model and a Detailed Design Model should give the most cost efficient results. This allows detail to be added only in those areas with problems or where hydraulic upgrading is required. This is illustrated in the flow diagram below.

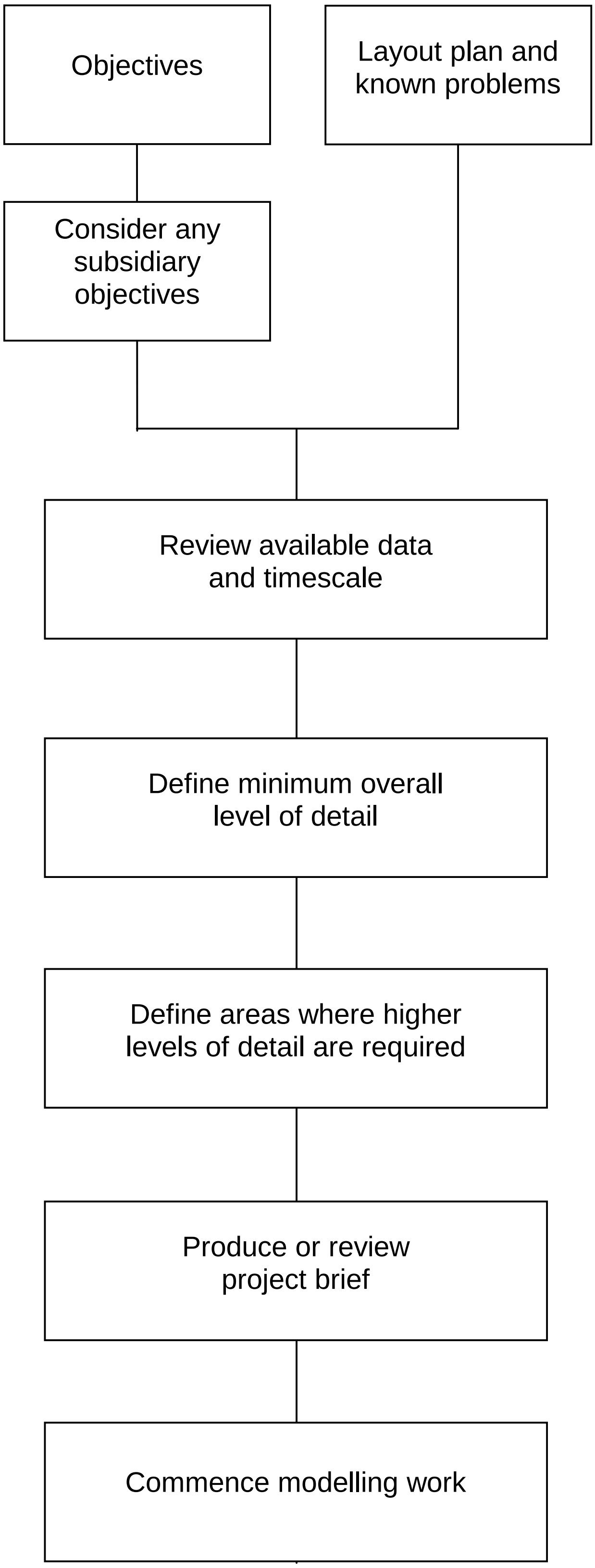
2.2.1 Type I - Skeletal Planning Model

This is otherwise known as a Coarse Macro or Planning Model. This type of model has specific objectives which could be catchment wide or could apply to only a small part of a large catchment. The specific objectives could include providing:

- a simulation of the flows and conditions at one or more specific locations e.g. sea outfall, pumping installation;
- a simulation of the boundary conditions in trunk or interceptor sewers so that more detailed models of connecting sewer systems 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.
- an overall assessment of a whole catchment, either to consider what effects a major new development might have on the trunk sewers in the catchment, or as the initial stage in considering options for major changes to the sewer network;
- a quick means of gaining an understanding of the operation of specific sections of a sewer or ancillaries, at the downstream end of a large sewer system, where there may be reverse flows or other phenomenon that cannot be understood without modelling;
- a reasonably accurate representation of a trunk sewer system or interceptor sewer system without needing to model exactly the layout of the sewer systems that connect into them.

These types of models may be subject to considerable simplification. The number of nodes may be as low as 2 to 6 nodes per 1000 population.

These types of models are not adequate for detailed modelling of flooding within a catchment or for Drainage Area Studies, all of which require more detailed models.



Assess in a logical manner the objectives of the model, the area to be studied and identify or collate the known problems. Consideration should also be given to whether there are any other subsidiary objectives (for example a minimum level of detail to allow models to be used to assess proposed developments).

The availability of data and the timescale available may affect the level of detail which is practicable in the timescale.

Determine the balance between the cost and the level of detail required in order to establish the minimum level of detail over the whole catchment, having regard to the availability of data.

Determine the level of detail required to understand the extent and cause of each problem.

Figure 2.1 Flow diagram for incremental addition of detail to a Skeletal model

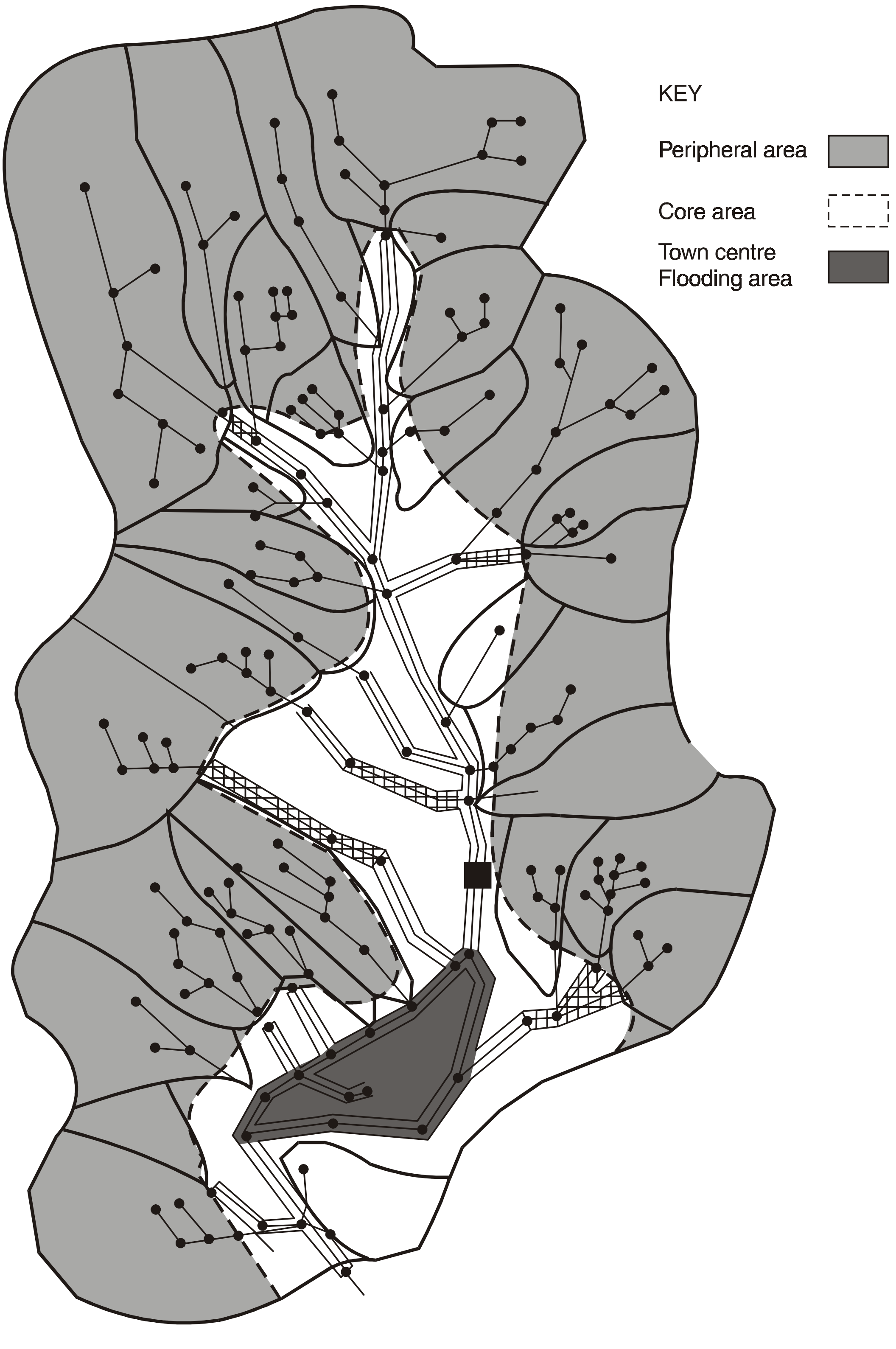


Figure 2.2 Example of different levels of detail in a single model

2.2.2 Type II - Drainage Area Planning Model

This type of model is used to give an overview of a specific drainage area, which may be a discrete catchment in its own right or may be part of a larger catchment. The purpose of such a model is primarily as a planning tool to:

- identify hydraulic problems within a drainage area, including identification of flooding areas, surcharged pipes, throttles, reverse flows and the performance of combined sewer overflows and other ancillaries;

- identify the need for possible hydraulic upgrading schemes and to carry out initial scheme appraisals;

- establish the hydraulic operation of stormwater overflows so that a broad assessment of water quality problems can be undertaken;

- assess the impact of proposed developments.

A type II model would include all ancillaries and should include all known problem areas, particularly those of known flooding and surcharge. The simplification of sewer networks for a Drainage Area Planning Model should be carried out carefully with particular attention being given to low lying manholes or gullies and the heads of branches. There would typically be between 6 and 20 nodes per 1000 population.

2.2.3 Type III - Detailed Design Model

This type of model is used for detailed investigations, scheme appraisals and for the detailed design of schemes. The standards suitable for this type of model are notnecessarily applied across a whole drainage area or catchment, but to a more specific area within a Drainage Area Planning Model. The areas of greater detail would correspond to the specific problem areas, the locations of hydraulic upgrading schemes being considered and any downstream elements of the sewer network (e.g. pumping installations) that may be affected by such schemes.

A Detailed Design Model may therefore be derived from a Drainage Area Planning Model just as the detailed design work itself may follow on from the drainage area study.

It is not appropriate to give guideline figures for the density of nodes in a Detailed Design Model as the correct density can only be determined on the basis of the areas affected by problems, the extent of proposed schemes etc. However, in the area of detailed design most of the manholes are likely to be represented.

2.2.4 Sewer Quality Modelling

Where a sewer quality model is to be produced, a verified hydraulic model is the first stage in this process. Such a model could be a combination of a type I, II or III model with the additions described below, but is unlikely to be type I alone.

The principal features of the model are that it should:

- accurately simulate storm and dry weather flows;
- represent the sediment depths in the sewers;
- simulate the hydraulic conditions correctly, both in pipelines and in ancillaries, so that the sewer quality model can simulate sediment deposition rates and sediment movement;
- ensure that the dry weather flow inputs are in a form which allows different water quality parameters to be applied to different inflows - for example, major trade effluent flows.

2.2.5 A Model To Another Specified Standard

There may be cases where the model types listed above do not adequately cover a particular application. In these instances the commissioning organisation will need to take particular care at the start of the project to clearly define and document the precise purpose of the model and the level of detail required to achieve these objectives.

2.3 REUSE OF A PREVIOUSLY CONSTRUCTED MODEL USED FOR A DIFFERENT PURPOSE

Where an existing model is to be reused the modeller should fully establish:

- the purpose for which the model was originally built;
- the date it was built;
- the methodology of data collection;
- the software used to run the model;
- the implications of any simplifications, omissions or shortcomings in the model
- the implications of any updates or new releases of the software;
- any changes that have been made to the sewer network since the model was built.

This procedure should start with a review of the documentation of the previous model to ensure that any limitations are fully understood. It is particularly important, at this stage, to confirm that the model has been properly built and adequately verified, especially in the absence of obvious supporting documentation. The nature of the work to provide the necessary level of accuracy for the new application should then be established in detail.

The work involved in adapting existing models should not be underestimated and occasionally it could be more cost effective to start again.

3. DATA REQUIREMENTS

3.1 INTRODUCTION

Input data can be collected at a number of different levels of accuracy. The level used will depend on the purpose of the model and the required accuracy of the results of the final model. In some cases inaccuracies in the data will have little impact on the accuracy of the final model while in other cases these will be highly significant. Where the accuracy of data is suspect, it is often possible to increase the effort of verification so that the problem areas are highlighted, rather than spend large amounts of effort checking the input data. Too much emphasis on data checking or, at the other extreme, verification, will not usually be cost effective. The most cost-effective balance between these two philosophies will depend on the purpose of the model and should be considered carefully. Whatever approach is taken it is important that any concerns about the data are included in the documentation.

In some cases, the client will have specific policies which may govern or restrict the choice of techniques.

3.2 SEWER RECORD DATA

3.2.1 Introduction

Sewer record data is now generally held on Geographical Information Systems (GIS). Where there is a programme of re-survey or transfer of records onto a GIS, this should be co-ordinated with modelling programmes so that the data is available prior to the commencement of modelling work. Use should be made of data checking routines whenever possible.

In addition to the sewer records, large scale (e.g. 1:1250 or 1:2500) Ordnance Survey or other similar background data is required. Smaller scale background data suitable for displaying the whole network, or parts of it, are often useful.

3.2.2 Pipe data

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

- Details of the sewer network and connectivity;
- Pipe sizes;
- Ground levels;
- Pipe levels;
- Pipe roughness;

In general most of this data will be available from existing records.

The minimum amount of information required includes the site plans, the system layout and the pipe sizes. When using paper plans care should be taken to check the continuity of the records across the boundaries of the individual sheets.

The items which are most important are the connectivity and, the sizes of the pipes followed by the ground levels and invert levels. Other data, such as the pipe roughness, has less effect on the predictions.

Where data is missing, surveys will usually be required. However it is not always necessary to have details of all manholes. In less detailed models, survey may sometimes be avoided by making best use of other level data such as OS spot heights, or by calculating invert levels from known depths, or by interpolation from levels at adjacent manholes. This data may sometimes be used in Type I, or in limited cases, Type II models directly, or it may be used to assist in the simplification process (see section 4.6), allowing surveys to be limited to those manholes to be included in the model.

Surveys should be carried out to the specification given in the `Model Contract Document for Manhole Location Surveys and Production of Sewer Record Maps[2].

3.2.3 Ancillary data

Data on ancillary structures, such as combined sewer overflows, bifurcations, tanks, control structures and pumping stations, can profoundly affect the results of a sewer model. It is recommended that all ancillary structures that may have a significant effect on the flow conditions are fully surveyed.

3.3 RAINFALL DATA

3.3.1 Choice of rainfall data

There are three principle types of rainfall data used in modelling applications:

- Synthetic design storms – normally used to predict the volume and frequency of flooding or surcharge in a sewer system (see Section 3.3.2);
- Long rainfall time series – normally used for Urban Pollution Management applications (see Section 3.3.3);
- Rainfall data from short term sewer flow surveys – normally used in combination with flow data for verification of models (see Chapter 5)

3.3.2 Synthetic Design Storms

The Wallingford Procedure Design Storms are stylised profiles applied to rainfall volumes derived from intensity-duration-frequency relationships.

Information on using the Wallingford Procedure synthetic design storms is given in the Wallingford Procedure[1].

The original summer profiles are normally used to predict the volume and frequency of flooding or surcharge in a sewer system. Winter profiles are also sometimes used in place of the summer profiles for the design of detention tanks.

3.3.3 Long rainfall time series

Historic series for use in sewer hydraulic models need to be at a resolution of 5 minutes or less. A limited amount of 5-minute interval data is available from the Meteorological Office, however, hourly historic series are available for a larger number of sites. This hourly data can be disaggregated to 5-minute intervals using suitable software [(3)].

For Urban Pollution Management applications a record of at least 10 to 15 years is recommended. Where a series is to be used to predict flooding the record will normally need to be longer. As a guide the record should be at least twice the frequency of the flooding.

Where historic data is not available, or the duration of the record is too short, stochastic generation of suitable series is possible[(3)].

Rainfall time series should be checked for missing data. If the site is remote from the study catchment, the series should be compared with more locally available daily rainfall data.

The series may be used as a continuous series or it may be split into separate 'events'. If the series is split into 'events' then care should be taken to ensure that the event separation period is long enough to allow the system to fully drain down.

A number of annual rainfall time series were developed in the 1980's covering various regions of the country. These are based on storms extracted from rainfall records from one or more sites in the region and were intended to represent a typical year's rainfall. The use of these series is now largely superseded and they are no longer recommended for use in Urban Pollution Management Studies.

3.4 CONTRIBUTING AREA DATA

3.4.1 Impermeable Area Data

The collection of impermeable area data is carried out in three stages:

a) Identification of the methods of drainage (e.g. foul, partially separate, combined etc.) and those areas within each subcatchment which are impermeable and contribute runoff to each part of the system.

b) Determination of the boundaries of the areas contributing runoff to each modelled pipe and marking them on a GIS or plan. (Rules for definition of subcatchment boundaries for the Wallingford Runoff model are given in WaPUG Usernote number 21[(4)]). Other runoff models may have different guidelines for use and these guidelines should be followed.

c) Calculation of the total contributing areas and impermeable areas for each subcatchment from the GIS or by measurement from the plan.

A number of methods of data collection are available. The method selected will depend on the data collection level and the type of 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 connectivity. For partially separate systems connectivity surveys will almost always be required unless records of connectivity already exist. For foul systems where there may be a small number of "illegal" connections, the cost of large amount of survey work that may be required to determine which areas are connected, may not always be justifiable. In these cases the use of experience together with flow survey data may sometimes be appropriate.

The following methods are available:

a) Impermeable area surveys

This involves the survey of an area to determine:

i) the boundaries of the areas draining to each pipe;

ii) which areas are connected to the sewer;

iii) which areas are impermeable;

iv) which areas are permeable and could contribute to the flow in the sewer.

Surveys may be detailed, or samples of properties may be inspected to determine patterns of connection and the results extrapolated to the whole catchment.

The boundaries may be recorded on a GIS or CAD system, or marked up on paper plans and measured using a planimeter, or estimated from grid squares.

b) Direct measurement from records

This involves using large-scale sewer records together with experience, local knowledge or aerial photographs to determine the boundaries. The areas are generally marked up and calculated as above.

c) Using sewer flow surveys

Where flow surveys are used to calculate the amount of impermeable area connected to largely foul systems, monitors should be placed to cover discrete catchments, taking into account the boundaries between areas of similar types of development. Contributions from permeable areas should also be considered.

Different monitor sites or different storms should be used to those used for verification.

Calculation should be done using at least 3 different storm events and should take account of antecedent conditions and depression storage. Distribution of the total area calculated within the catchment should take account of the different types of developments.

3.4.2 Subcatchment ground level data

It is not sufficient to consider only the ground levels at manholes. Although these are often representative of the ground levels in the catchment, in some cases there may be gullies or other connections at lower levels than the manhole (e.g. basements, or low-lying properties). Ground level information and other local knowledge should be used to identify the lowest connection in the catchment of each modelled pipe. Where necessary this should be used in place of the cover level at the manhole or an additional short branch should be added with the lower upstream ground level. If the ground levels used in the model are different to the cover level or where additional branches are added this should be recorded clearly in the model documentation.

3.5 SOIL DATA

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

The Wallingford Procedure runoff models require the winter rainfall acceptance potential value. This can be obtained from the Wallingford Procedure[(1)]. However in some cases, due to local variations, the small-scale maps in the Wallingford Procedure contain insufficient detail. It is therefore recommended that the information should be checked using large-scale geological survey information or local knowledge.

3.6 BASE FLOWS

3.6.1 Dry Weather Flow

Data from a number of sources may be used to estimate dry weather flows. Information is available from:

- global population figures;
- house counts;
- water usage statistics;
- flow surveys;
- trade effluent licences and measurements (of water usage or discharge);
- design parameters.
- baseflow infiltration 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. It is necessary to have more accurate data where the dry weather is likely to be a high proportion of the total flow. Accurate dry weather flow data will always be required for sewer quality models. Diurnal, weekly or seasonal variations in dry weather may be significant. Where diurnal variation of dry weather flow is being measured, this should be taken at points near the head of the system. See WaPUG user note 33[(5)].

3.6.2 Infiltration data

Where levels of infiltration into the system are significant seasonal variations should be investigated. Long-term flow data can be used to investigate the seasonal and rainfall induced variations in infiltration.

3.7 OPERATIONAL DATA

3.7.1 Liaison with operations staff

Operational records are an important source of information for the modeller. Contact should be maintained with operations staff throughout the model building and verification process in order to ensure that relevant information is available to the modeller.

3.7.2 Changes to the system

Operational issues can have a significant impact on sewer system performance. Staff may undertake temporary changes to the system such as adjustment of dam-boards, penstocks or valves; adjustment of pump switch levels; replacement of pumps etc. It is important that the modeller is aware when such changes occur, particularly where these are during a short-term sewer flow survey or where they might affect an infiltration investigation.

3.7.3 Flooding, surcharge and spill frequency data

Any sewer flooding report data (excluding those known to be caused by temporary blockages) should be analysed to determine the location and frequency of reported flooding in the catchment. Questionnaires can also be used to get more information on sewer flooding, however the results should be treated with caution.

Surcharge records are sometimes also available from manhole inspections. Alternatively, surcharge surveys may be carried out using surcharge recorders in manholes that can be inspected following storms.

Spill frequency data from overflows, pumping stations, storm tanks and inlet works may be available and is a useful data source.

3.7.4 Other incidents

Other operational incidents, for example blockage of combined sewer overflows, sewer collapses, or pumping station failures, can significantly affect flows in the system. Information on such incidents should be obtained for the period of any flow survey or where they are associated with flooding or surcharge.

3.8 BOUNDARY CONDITIONS

Boundary conditions often affect the operation of sewer systems. Examples include:

- River or tide levels – which may restrict outfalls or contribute to infiltration;
- Water levels at inlet to sewage treatment works;
- Water levels at points of connection to trunk sewers.

Boundary condition data will be required for the period of any short term flow survey and the period of any long term infiltration. Sufficient data will also be required to allow the modeller to set appropriate boundary conditions for use in conjunction with design storms.

3.9 PIPE CONDITION DATA

The condition of the pipe can have a significant impact on the roughness of the sewer. Pipe condition data (e.g. CCTV surveys) may be used to determine the roughness of pipes. Methods of determining pipe roughness are given in the Sewerage Rehabilitation Manual[(6)]. Where no data is available values may be estimated based on the pipe material.

3.10 SEDIMENT LEVEL DATA

Sediments may reduce the cross-sectional area of the pipes and also increase roughness. Sediment depth data may initially be obtained from CCTV surveys, sewer flow survey reports, 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. Where a sewer quality model is to be produced more detailed sediment data may be required.

3.11 DATA COLLECTION LEVELS

For the purposes of this section four levels of data collection confidence have been specified. Where lower levels of accuracy are used it should be expected that more data checking will be carried out under the model verification stage. The levels specified here are:

A Maximum accuracy
B
C
D Minimum accuracy

Suggested data collection and checking methods are described in Table 4.1 below for each class of data and for each level of accuracy.

Table 3.1 Data collection levels

Data	Level A	Level B	Level C	Level D
Pipe data				
Prime source	A complete survey or resurvey of the sewers should be carried out.	Ground and pipe levels should be taken from existing records as far as possible.	Existing records should be used for the majority of ground levels, invert levels, and pipe sizes.	Existing records should be used.
Missing data		Surveys should be carried out to provide the missing data	Occasional missing items of data levels are estimated or interpolated from the data at neighbouring manholes or pipes, subject to a maximum of two consecutive manholes and a maximum of 5% of the total data.	Where data is missing: Ground levels may be estimated or interpolated from other levels (which could only be OS spot heights); Invert levels may be estimated from known levels or depths, or if no other information is available the depths can be assumed; Missing pipe sizes may be estimated from the upstream and downstream sizes.
Checks on sewer record data	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 sewer record 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 before modelling work commences.	A representative sample of the data used in the model should be checked for internal consistency, either visually or using suitable software and any obvious discrepancies should be checked on site.	No routine checks on the supplied data need to be carried out unless problems are highlighted by the model software.
Ancillary (CSO and Pumping Station data)	Surveys should be carried out at all major ancillaries.	Plans of the ancillaries should be obtained to provide detailed information to the modeller. Site surveys should be organised where there is any uncertainty as to how the structure will operate.	Data for the ancillary structures should be obtained from sketch plans or from record sheets or surveys should be organised.	Data for major ancillary structures should be obtained from sketch plans or record sheets or surveys should be organised. Other ancillary data may be estimated.

Table 3.1 (continued)

Data	Level A	Level B	Level C	Level D
Contributing area data survey				
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 sewer record plans and a sample survey.	The determination of which areas are impermeable should be based on experience and examination of record plans.	Impermeable areas may be estimated using flow survey data.
Determining contributing area boundaries	Detailed surveys should be carried out to determine connectivity.	For foul and combined systems connectivity should be determined from a sample survey. For partially separate systems detailed surveys should be carried out to determine connectivity.	For foul and combined systems connectivity should be determined from plans by judgement. For partially separate systems sample surveys should be carried out to determine connectivity.	Connectivity should be determined from plans by judgement.
Calculation of contributing area data	Contributing areas calculated from the GIS or taken from paper plans using a planimeter.	Contributing areas calculated from the GIS or taken from paper plans using a planimeter	Contributing areas calculated from the GIS or taken from paper plans using a planimeter or by counting grid squares.	Contributing areas calculated from the GIS or taken from paper plans by counting grid squares.
Calculation of impermeable area data	The percentages of paved and roofed areas are calculated from measurements of the areas.	The percentages of paved and roofed areas are calculated from measurements of the areas.	The percentage paved and roofed determined from measurements of sample areas.	
Operational data				
Temporary changes to the system	Obtain from operations staff	Obtain from operations staff	Obtain from operations staff	Obtain from operations staff
Flooding and surcharge data	Detailed data on flooding and surcharge should be obtained from records and surcharge surveys should be carried out.	Detailed data on flooding and surcharge should be obtained from records.	Detailed data on flooding and surcharge should be obtained from records.	A basic knowledge of major flooding points should be established from records.
Other incident data	Obtain from operations staff	Obtain from operations staff	Obtain from operations staff	Obtain from operations staff

Table 3.1 (continued)

Data	Level A	Level B	Level C	Level D
Baseflow data				
Dry weather flow data				
Daily per capita values	Estimated from flow measurements within the catchment.	Use standard values of water usage.	Used standard values of water usage.	Use standard values of water usage.
Geographic distribution	Distribute according to detailed population estimates based on house counts, and using metered water supply and trade effluent figures.	Distribute according to population estimates based on house counts and using information from major trade effluent increases.	Distribute global population according to length of pipe or connected areas.	Distribute global population according to length of pipe or connected areas.
Diurnal variation	Estimate from detailed flow measurements.	Estimate from detailed flow measurements.	Use standard values.	Assume no variation.
Infiltration data				
Fixed element	Data from detailed infiltration survey and from long term records at outfall	Data from detailed analysis of long term records at outfall	Standard values	Use standard values of infiltration.
Seasonal variation	Data from detailed infiltration survey and from long term records at outfall	Data from detailed analysis of long term records at outfall	Estimated from long term records at outfall	Not included
Rainfall induced variation	Data from detailed infiltration survey and from long term records at outfall	Data from detailed analysis of long term records at outfall	Not included	Not included
Geographic distribution	Detailed infiltration survey across the system	Estimated from available CCTV data and from short-term sewer flow survey used for verification.	Estimated from available CCTV data and from short-term sewer flow survey used for verification.	Distributed uniformly

Table 3.1 (continued)

Data	Level A	Level B	Level C	Level D
Boundary Conditions				
River levels	Use continuous level monitor	Use continuous level monitor	Periodic (e.g. daily) level measurements	Exceptional levels recorded otherwise normal levels assumed.
Tide levels	Use continuous level monitor	Values inferred from tide tables – adjusted from peak level measurements	Values inferred from tide tables – adjusted from level measurement elsewhere.	Values inferred from tide tables
STW inlet water levels	Use continuous level monitor	Use continuous level monitor	Peak levels recorded.	
Pipe Roughness Data				
	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				
	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

Typical Levels for use with each type of model are given below:

Table 3.2 Typical data levels

Model type	Type I (Skeletal Planning Model)	Type II (Drainage Area Planning Model)	Type III (Detailed Design Model)
Pipe data	D	C	B
Checks on sewer record data	D	B	A
Ancillary data	A	A	A
Contributing area data	C/D	C	B
Contributing area data	C/D	C	B
Operational data	C	A	A
Dry weather flow	Depends on significance of dry weather flow in total flow		
Infiltration data	Depends on significance of infiltration in total flow		
Boundary condition data	Depends on significance		
Pipe roughness data	D	B	B
Sediment level data (higher level if model to be used as basis of sewer quality model)	D	B	B

4. MODEL BUILDING AND TESTING

4.1 INTRODUCTION

Before commencement of model building the modeller should acquire a general understanding of the structure and layout of the sewer system in the catchment. A network plan at an appropriate scale, showing the routes of the principal sewers, is often necessary to gain a proper understanding of a large sewer system.

The model should extend far enough downstream to take account of any hydraulic conditions which may effect the performance of the system, including any restrictions inside the sewage treatment works, or outfalls restricted by trunk sewer, river or sea levels.

4.2 SOFTWARE SELECTION

In many cases the client will specify the software to be used. In other cases this will be left to the discretion of the modeller. Before selecting a software package the modeller should review the project objective and the software capabilities in order to ensure that the software is capable of producing a model which can meet the objectives.

In the design of new systems a simple method such as the Modified Rational Method will usually be sufficient for an initial design unless the proposed system includes complex ancillaries. However, a more sophisticated model will normally be required to design storage ponds, and to study flooding frequencies and flood routes in the initial design. A more sophisticated model is also normally required if it is necessary to investigate interactions with existing systems.

The principal difficulty of modelling existing systems is that the collection of input data is subject to errors and consequently model verification is required. This will usually dictate the use of software which is capable of accurately predicting the shape of the hydrographs in both surcharged and unsurcharged flow and which can predict surcharge levels and flooding frequencies.

4.3 SELECTION OF RUNOFF MODEL

Some software packages give the modeller the option of a range of different runoff models. In some cases different models could be appropriate for different parts of the catchment. Models available include the following.

- The original Wallingford Procedure runoff model (See WaPUG Usernote 9 [(7)]);
- The revised Wallingford Procedure runoff model (See WaPUG Usernote 28[(8)]);
- Fixed rate runoff parameters;
- The Technical University of Denmark Nedbør-Afstrømnings-Model (NAM) runoff model;
- The US Soil Conservation Service runoff model (for certain types of rural run-off).

In selecting a runoff model for the modeller should take account of the nature of the runoff in the catchment, which could include:

- Runoff from paved areas;
- Surface runoff from saturated pervious areas;
- Subsurface runoff from pervious areas;
- Fixed rate infiltration;
- Rainfall induced infiltration.

The modeller should ensure that the selected model takes account of the nature of the runoff in the catchment to the extent required to achieve the objectives of the model.

4.4 FLOOD ROUTING

To accurately predict flooding the model must take account of the point at which the effluent will leave the sewer system. This may be lower than the cover level of the manhole at the upstream of the sewer length. In some cases, therefore, it may be necessary to adjust the ground levels in the model to accurately predict flooding. For further information see WaPUG Usernote 29[(9)].

When flooding occurs the effluent can pond at that location or it can travel some distance over the surface. Increasingly, the flood route is being considered as a part of the design for dealing with extreme events. Some software can model the flood routing. Further information can be found in WaPUG Usernote 37[(10)].

4.5 INTERACTION WITH OTHER SYSTEMS

Many sewer systems interact with watercourses or surface water systems. Other systems may have restricted outfalls due to the levels in watercourses, or tidal waters.

Where there is interaction with a surface water system this can be modelled by incorporating the surface water system in the model. It is also sometimes possible to incorporate a small watercourse in the model.

Where there is no reverse flow through the outfall into the model, for example where there is an effective non return valve, the restriction can be modelled using a non-return valve and a level hydrograph file. Guidance on selection of level hydrographs for tidal restrictions can be found in WaPUG usernote 22[(11)].

4.6 MODEL SIMPLIFICATION

4.6.1 Introduction

Simplification can sometimes be helpful to reduce data collection work and run times, or to overcome limitations of the model software by modelling complex parts of the network as simpler equivalents. The extent of simplification should be compatible with the type of model detail required and the final purpose of the model as defined by the objectives of the study.

Computerised sewer record data is now widely available and this saves much manual input. There can, however, be errors or gaps in the data. Simplification can help to reduce the effects of these limitations and the costs of further surveys.

Large models can become unwieldy for multiple simulations, particularly with large, historic data sets, and run times can be excessive. In these cases it is sometimes difficult to review all the data and so there is a risk that anomalies or instabilities will go undetected. Some large models are also prone to instabilities. If a model, produced directly from good sewer record data, has less than about 3000 nodes, then there is probably little point in simplifying it. However, if it is to be used for water quality purposes, then it could be worthwhile as a means of reducing run times. This is likely to change as hardware and software improves.

With increasing capability of computer hardware and software, the need for simplification is less that it has been in the past. It should, however, be appreciated that even when all the sewers are included some level of simplification is inherent in omitting the drains from the system. In these cases it is normally only necessary to consider the following aspects:

- Ensuring that the flood exit points are adequately modelled (see paragraph 4.4);
- Compensating for the volume of storage in the drains that are not included in the model. Much of this storage is mobilised in severe storms before flooding occurs and unless an allowance is made the model can over predict flooding. Further information can be found in WaPUG usernote 15[(12)].

4.6.2 Methods of simplifcation

There are various methods of simplification including the following:

- excluding small diameter pipes from the periphery of the system and inputting the flows to the next pipe downstream (pruning);
- grouping a number of similar consecutive pipes together to a single pipe (merging);
- replacing a complex layout with a simpler arrangement which behaves in a largely similar fashion (equivalence).

In carrying out simplification it is necessary to apply judgement to ensure that the model will still accurately simulate the flows under different conditions.

a) Correct simulation of hydrographs in low flows

The changes in the model, particularly when peripheral pipes are not included, will have an effect on the time of flow and the distribution of area throughout the catchment. This, in turn, will affect the shape of the predicted hydrographs. The changes should be limited to ensure that the effects do not significantly affect the results of the model. Obviously a greater degree of simplification will be possible in skeletal planning models than in detailed design models before the function of the model is significantly affected. Where contributing areas are very large, checks should be made to ensure that the time of flow is correct.

b) Correct simulation of flooding in high flows

Even if the model is correctly predicting the shape of the hydrographs, this will not necessarily ensure that it correctly predicts flooding. Flooding occurs when the line of the hydraulic gradient rises above the ground level. Flooding is only predicted when this occurs at a modelled node. The simplification process will therefore have to take account of:

- the lowest ground level connected to the sewer in the catchment of each modelled pipe;
- the changes in ground surface gradient which lead to points where the flooding will occur earlier than other adjacent points.

An allowance should also be made for the volume of storage which is available in those pipes, including house connections etc. which are not included in the model.

In areas where there are only dry weather (foul) flows a much greater degree of simplification is often possible. In these areas it is necessary to ensure that at the point of connection of the foul flow to the remainder of the system:

- the correct dry weather flow rate is input into the system;
- any storage in the foul system which may be mobilised due to surcharge at the point of inflow is correctly modelled;
- any low points which may flood due to flows in the remainder of the system are included.

Where the diurnal variation in dry weather flows is being modelled and the area is very large, it may be necessary to include a larger number of pipes to ensure that the dry weather flow hydrograph is simulated correctly. However in many cases it will be sufficient to include the dry weather flow on a single pipe branch or on the pipe where system flow connects into the system.

A procedure for simplification can be found in Appendix A.

Details of any simplification carried out should be recorded in the documentation.

4.7 MODELLING ANCILLARIES

4.7.1 Introduction

In addition to the pipework and manholes of a sewer network there may be a number of ancillary structures including combined sewer overflows, sewage pumping installations, bifurcations, flow control devices and inlet works at sewage treatment works. The correct representation of these ancillaries is usually crucial to the accuracy of the resulting model.

The equations used in the software to represent such structures are generally simplifications of what occurs in real structures. Special care should be taken to understand:

a) how the structure behaves over the range of conditions that occur;

b) how the software handles the ancillary and how data should be interpreted to represent that ancillary.

c) how closely the performance of the model compares with the real performance over this same range of conditions.

In order to determine how the structure performs, an up-to-date set of drawings is essential. Where the structure is at all out of the ordinary, a site inspection to observe the hydraulic performance, preferably in a range of flow conditions, is also advisable.

It may be possible to omit some ancillaries from the model where their operation does not affect the performance of the network. For example small pumping installations serving totally separate foul catchments can be modelled by assuming that the flows drain directly into the pipe downstream of the pumping station. However this assumption cannot be used where the station provides significant attenuation to flows or where, in sewer quality models, it is likely to affect build up of sediments.

4.7.2 Conceptualising the ancillary

Most software packages allow the modeller to conceptualise the ancillary as node or a number of linked nodes, with a number of controlled outlets. Types of control can include:

- Orifice plates or throttle pipes (see WaPUG usernote 2[(13)]);
- Vortex flow control devices (see WaPUG usernote 1[(14)]);
- Pumps;
- Weirs (see WaPUG usernote 14[(15)] & WaPUG usernote 27[(16)]).

Guidance on representing large detention tanks can be found in WaPUG usernote 38[(17)].

4.7.3 Representing flow conditions

In some cases, particularly at bifurcations and where hydraulic jumps occur, it will not always be possible to adequately calculate the hydraulic performance. Additional flow monitoring may be necessary in the vicinity of these structures so that a true understanding of the behaviour can be obtained.

It may not be possible to produce a model within the limitations of the software which matches the performance of the structure over the whole range of conditions which might occur. Test runs may be used to give a better estimate of the likely range of conditions, but it may be necessary to produce a number of different models for differing conditions. In these cases clear and concise documentation is essential both in the data files and in the model documentation. Most software packages allow the use of a stage discharge relationship to represent complex flow patterns.

Since the calculations are important to the results they should be clearly presented, and should be checked by an experienced hydraulic modeller who is familiar with the particular software being used. These calculations, notes explaining the assumptions made and the limitations of the model should be included in the model documentation for the benefit of future users.

Particular care should be taken where unusual or difficult flow conditions are likely to arise such as:

- low weirs;
- side weirs;
- structures where screens, or scumboards restrict the flow;
- structures where pipes or outfall conditions may limit flow over a weir or orifice;
- structures where the direction of the main flow changes through the structure;
- structures where hydraulic jumps are likely to occur;
- bifurcations in free surface flow;
- variable speed pumping installations;
- automated penstock control systems;
- other automated control systems;
- manually controlled pumping installations.

4.8 CONVERSION OF EXISTING MODELS

Where the model is to be converted from one developed on a different piece of software, it is essential to check that the simplifications and assumptions made in constructing the original model remain valid.

Particular points to note include:

- The runoff model used and how it is implemented in the software (see WaPUG usernote 5(18))
- The way the software handles ancillaries – for example how the original modeller took account of the level pool effect in WASSP or WALLRUS.

Further information on converting sewer system data between models can be found in WaPUG usernote 30(19).

4.9 UPDATING MODELS

Models represent a considerable investment. As the system changes, either because of new building or alterations to the sewer system, the model should be kept up-to-date. Care should be taken to ensure that all changes to the model are fully documented and that it is clear which of the updates, if any, have been subject to any verification.

4.10 INITIAL MODEL TESTING

4.10.1 Representation of the layout

Before testing the stability of the model the interpretation of the connectivity of the pipes by the software should be cross-checked with original data. Many software packages can now produce a schematic diagram of the network that can be overlaid on a map background. This can greatly assist in making this check.

4.10.2 Instability testing

In order to gain confidence that the model is performing correctly without any mathematical instabilities a rigorous programme of initial testing should be undertaken. Once this confidence has been established, pre-defined routine checks can be used later to ensure that the model remains stable.

To test the stability of the model, the modeller should run the model with four storms of differing magnitude. The following storms are suggested:

- a dry weather flow event;
- a low intensity multi-peaked storm, such as the first event in the south western annual time series.
- a 1 in 5 year storm of say 60 minutes duration;
- a 1 in 50 year storm of say 60 minutes duration;

Hydrographs should be produced of depth and flow at key points on major branches (e.g. those branches whose diameter is greater than twice the minimum modelled pipe size) and at all ancillaries. Where any instability is found in a branch hydrographs should be produced at intervals of no more than 10 pipes along the branch.

In most models the final mass balance does not take account of the flows still in the system at the end of the simulation time. In order to be sure that the global balance is correct the duration of the simulation should be sufficient to ensure that all the storm flow has drained out of the system. This should be checked by reference to the hydrographs at the outfalls.

The volume summaries for the whole model and at each ancillary should be checked to ensure that the incoming and outgoing flows balance to within 10%. The plotted hydrographs should also be inspected for signs of oscillation.

Where any evidence of instabilities are found these should be resolved and the full tests repeated on the resulting model, before proceeding further.

4.10.3 Ancillary testing

As discussed in paragraph 4.7.3, in some cases the representation of ancillaries in the model will often only be valid over a certain range of conditions. The results of the above runs should be used to establish where any of the assumptions may be invalid. The points considered should include the following:

a) Calculations of side weir coefficients should be rechecked by detailed calculation or by reference to earlier detailed calculations. This should include checks on the types of flow (see WaPUG Usernote no 14)[(15)].

b) Where weirs are very low, checks should be carried out on the applicability of the coefficient selected for the full range of flows.

c) Where overflow pipes have not been included in the model, the capacity of these pipes and any outfall constraints should be checked to ensure that this does not limit the flow over the weir.

d) At pumping installations where the rising main is not modelled the effect on the water level downstream of the rising main should be checked to see whether this has any influence on the pump rates.

e) Detailed calculations for siphon overflows should be rechecked to ensure that they are valid over the range of flows now expected.

f) Where the variation in the characteristics over a large proportion of the range of conditions is significant (likely to affect the predicted flows by more than 10%) then consideration should be given to using alternative representations of the ancillary dependent on the flow conditions in any run.

Where any pipe sizes, or levels have been changed during the course of these tests or where values of coefficients have been changed by more than 10% then the stability tests described in paragraph 4.10.2 should be repeated.

4.11 ROUTINE MODEL TESTING

Brief checks on the stability of the model should be carried out each time the model is run. As a minimum this should involve checking the volume summaries for the whole model and at every ancillary to ensure that they balance within 10%. The outfall hydrographs should also be checked to ensure that the storm flows have emptied from the system as this could otherwise mask an instability which generates volumes within the model.

Where there is a history of instabilities in a model further checks on hydrographs in problem areas may be necessary.

5. FLOW SURVEYS

5.1 INTRODUCTION

The Guide to Short Term Flow Surveys in Sewers[20] gives detailed guidance on planning and carrying out flow surveys. A specification for flow surveys is given in the Model Contract Document For Short Term Sewer Flow Surveys[21]

5.2 PLANNING FLOW SURVEYS

The primary source of data for the verification of a sewer hydraulic model is the flow survey. Many of the problems with verification come from poor flow survey data due to inadequate planning. It is essential that adequate pre-survey planning is carried out before commissioning a flow survey. The following sections give practical guidance when planning a survey.

5.3 SELECTING RAINGAUGE SITES

5.3.1 General

Raingauge site selection is important when planning a flow survey. Poor data from a raingauge site will affect the verification of many, if not all, of the flow monitor sites. Many verification problems occur due to the lack of data about the spatial variability of rainfall and problems with raingauges. The marginal costs of extra raingauges are frequently justified by the savings in flow survey extensions and reduced effort in verification.

Choosing raingauge sites is a two stage procedure. Firstly, a raingauge density compatible with the flow survey's overall objectives should be determined and secondly, individual raingauge sites should be selected from practical site considerations.

5.3.2 Raingauge density

Sufficient raingauges should be installed to enable an adequate coverage of the catchment and a realistic estimate of the rainfall to be made. Sufficient monitors should be provided to allow for some redundancy in case of problems with a particular site. The following general guidelines are suggested, though particular consideration should be given to any local topographical features, and local variations in weather.

i) The number of raingauges will be dependent upon the catchment area, complexity and topography. Suggested densities are given in Table 5.1.

ii) A minimum of three raingauges are required; Two will provide an estimate and the third act as a backup.

Table 5.1 Raingauge densities

Type of terrain	Typical number of raingauges
Flat	1 + 1 per 4 km^2
Average	1 + 1 per 2 km^2
Mountainous	1 + 1 per 1 km^2

Notes:
1. A minimum of 3 raingauges is required.
2. It may not be possible to achieve these levels in large type I models. In these cases the modeller will have to use judgement to determine the number used.

5.3.3 Individual raingauge sites

Having determined the density of raingauges, determine their approximate locations using a rough grid pattern, taking account of variability in topography, and the location of the subcatchments. The final selection of their locations is based entirely upon practical site considerations. The fundamental requirements are that:

i) sites are not sheltered from the true rainfall pattern by buildings or trees or overexposed to wind;

ii) sites are secure and safe from vandals and thieves to protect both the equipment and the data.

Options include large flat rooftops, private gardens and roofs of buildings such as police stations and schools. In all these cases the gauge should be reasonably secure from vandals and clear of rain shadows and severe localised turbulence. Where possible, the distance from any tree or tall structure should be more than the height of the obstruction.

5.3.4 Supplementary rainfall information

To assist in the interpretation of rainfall data a diary of weather conditions should be kept during the survey. Particular care should be taken to record frost and lying snow as these conditions can effect the runoff. Other sources of data are autographic rainfall records at reservoirs or sewage treatment works. The Meteorological Office's weather radar information can also be useful.

5.4 SELECTING FLOW MONITOR LOCATIONS

5.4.1 General

The choice of monitoring sites is similarly a two stage process. Initially general locations rather than specific manholes should be selected. The number of monitors used will depend on the purpose and type of the model and the level of confidence that can be placed in the accuracy of the input data. In general a greater number of monitors will be required for data input levels C and D (see section 4.5).

Examples are given in Figure 5.1.

Four levels of flow survey are defined

1. A flow survey is carried out on the major outfall sewers only.

2. A flow survey is carried out at a few key points immediately upstream of the points where the accuracy of the model is important.

3. A flow survey is carried out throughout the whole catchment with additional measurement at locations well upstream of the points where the accuracy of the model is most important.

4. As 3 but more detailed.

5.4.2 Selecting the monitor locations

The general location of monitors will be in accordance with the following guidelines.

a) 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.

b) In large subcatchments free from known major problems, a single monitor should be placed on each main branch sewer near the junction with the trunk sewer. The recorded data will confirm whether the modelled response from the subcatchment is accurate.

c) In subcatchments experiencing known performance problems, where accuracy in modelling is particularly important, monitors should be placed at critical points to enable verification of these areas.

d) Monitors should also be placed at points along the main trunk sewer at or near major junctions where the effects of major subcatchment flows can be assessed. They may also indicate any major connections or features, such as overflows, that have been omitted.

e) Upstream and downstream of major combined sewer overflows, bifurcations, loops or specific problem points, so that their behaviour can be defined, provided that there is adequate rainfall during the survey. When there are large numbers of combined sewer overflows it will not generally be possible to monitor all of them. In these cases groups of combined sewer overflows should be monitored upstream and downstream.

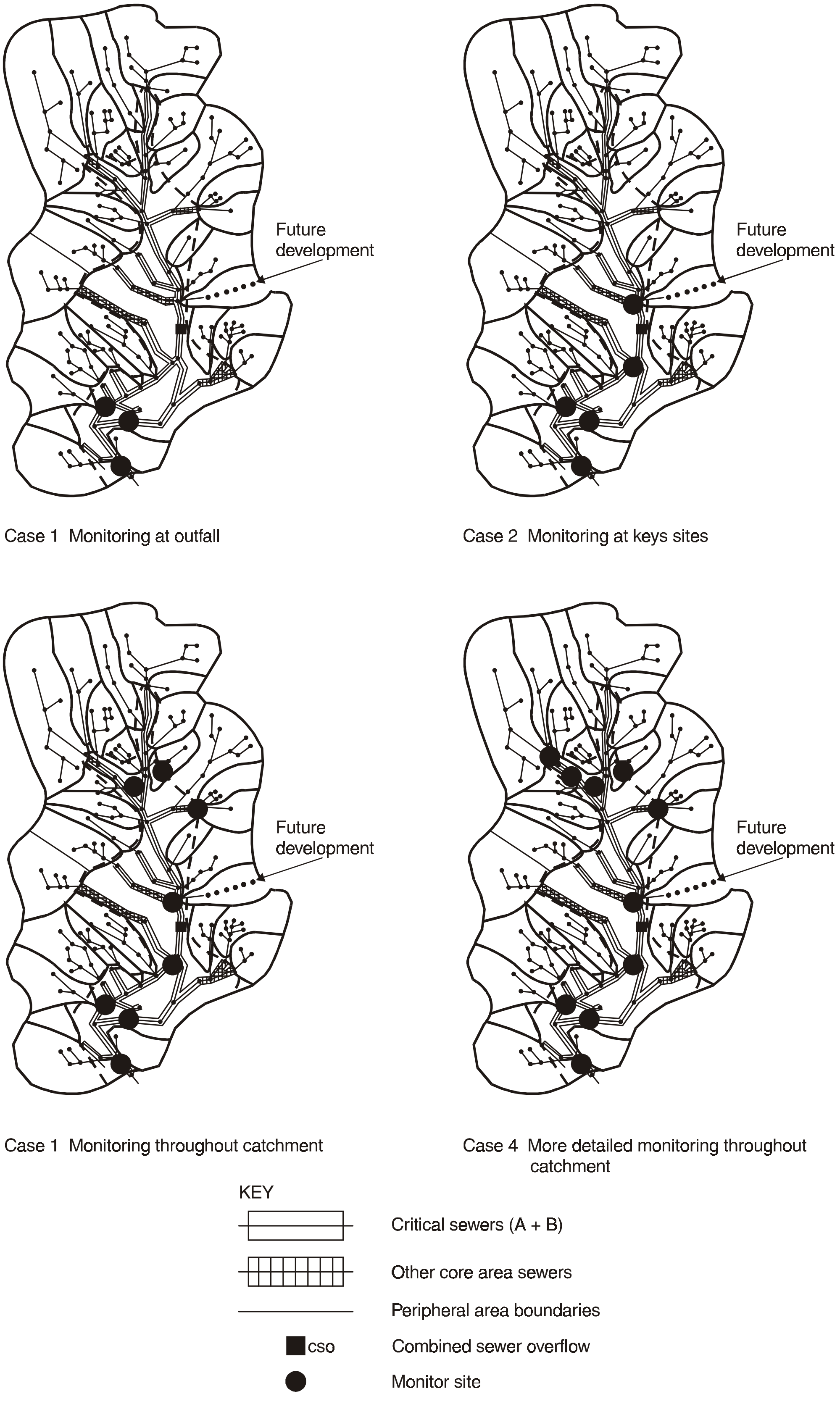


Figure 5.1 Examples of flow survey monitor locations

f) Additional monitors should also be provided, if necessary, to provide redundancy in case of problems with a particular site.

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

Each general location should ideally include between two and three potential monitoring sites.

5.4.3 Selection of specific monitoring sites

Selection of the most suitable monitoring sites ultimately depends upon the local hydraulic conditions. If available, the model should be used to predict the range of flow velocities and depths at possible locations. These should be compared to the capabilities of the equipment being used. Ideally the conditions should be suitable in both dry weather flow and during storms. A summary of the capabilities of typical monitoring equipment can be found in Figure 5.2. However, manufacturers regularly introduce new equipment and in some cases the limitations in Figure 5.2 may not apply. Consideration should be given to the use of such equipment, provided that there is evidence that the instrument meets the specification claimed by the manufacturer.

From this review two or three potential locations should be selected for each flow monitoring location. Contact should also be made with operations staff to obtain their comments before arranging an inspection of the suitable sites. These should then be inspected to ensure that:

a) the cover can be accessed safely and is free to lift;

b) the manhole is safe to enter;

c) the manhole is on the correct sewer;

d) there are no features that would cause unstable flow either during dry weather or in high flows;

    i) turbulence near to the sides of the sewer due to high roughness;

    ii) skewed flow due to a bend in the sewer;

    iii) 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);

    iv) turbulence due to upstream drop shafts and vortex drops or junctions etc.;

    v) turbulence due to overflow weirs - the sensor should be at least 2 times the length of the weir upstream of the weir;

    vi) turbulence due to the continuation orifice or throttle on an overflow - the sensor should be placed at least 10 diameters downstream of the throttle.

    and,

e) the flow conditions (depth and velocity) are as predicted and are within the capabilities of the monitor.

f) site calibration checks are practicable, for example:

   i) sewers should have sufficient dry weather flow depth to register on the depth sensor to allow calibration;

   ii) 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 also be worth observing the conditions during storm flow, provided that adequate safety precautions can be taken. Where more than one site is suitable, the site with the most stable flow pattern should be chosen. If there is any doubt about the flow conditions, and a more suitable location cannot be found, consideration should be given to using more than one of the sites to provide a comparison.

Measurement of flows at combined sewer overflows 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 less than 50% 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 in predicting when a weir is spilling, but care should be taken with side weirs since the depth will vary along the length of the weir.

It can be helpful to mark the manhole cover to assist the Contractor in identifying the site.

The Contractor should be given every opportunity to comment on the hydraulic suitability of individual sites.

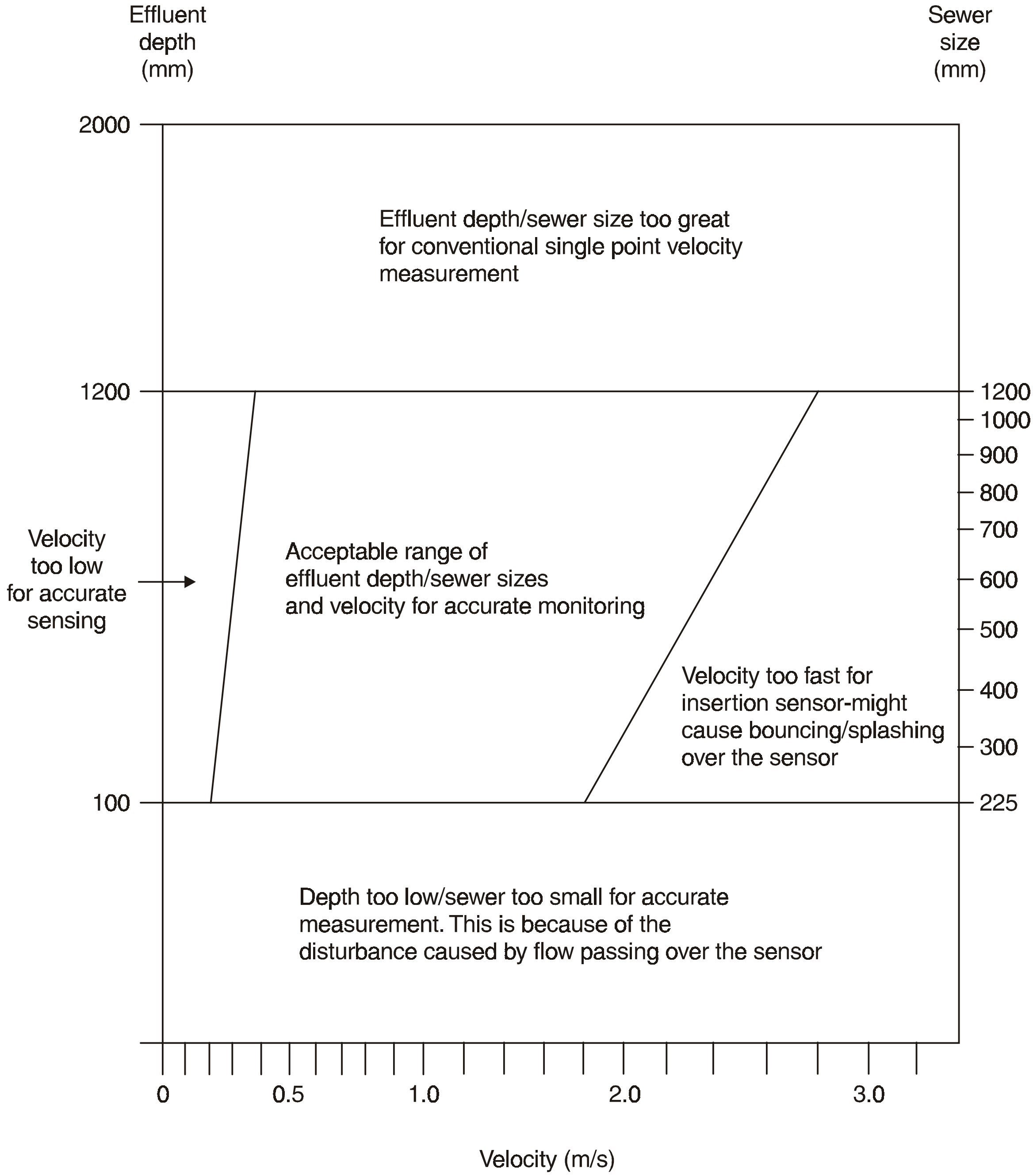


Figure 5.2 Guide to acceptable monitoring sites in terms of effluent depth, sewer size and velocity

5.5 OTHER FLOW DATA

Although the collection of flow data from a sewer network using velocity and depth monitors is the primary aim of any flow survey, it is sometimes necessary for the modeller to obtain other flow measurement data. The most common sources are:

5.5.1 Flow to treatment works

Flow records from the inlet of a sewage treatment works may be used, provided there are no other incoming flows or discharges between the catchment and the point of measurement.

5.5.2 Pumping installations

Pumping installations are an important part of many sewer networks. An indication of their performance is essential when a survey is being carried out for model verification purposes. Where possible drop tests should be carried out for all pumps singly and in combination. These can be supplemented by measurements of the water level in the wet well and event recorders to monitor the operation of the pumps.

Where drop tests are not practical, it may be possible to measure the total flow just downstream of the rising main using conventional equipment.

Flow conditions in the vicinity of a pumping installation can vary considerably depending on which (if any) of the pumps are operating. With this in mind readings should be taken at appropriate intervals.

It should be emphasised that if flume or pumping installation data is to be collected as part of a contract, full details should be given in the Contract Documents. In the case of pumping installations, engineering drawings of the wet well details, pump arrangements, electrical information and pipework details are essential.

5.6 NUMBERS OF EVENTS

In general the flow survey should aim to record three acceptable storm events and two dry days as defined in paragraph 5.9. Consideration should be given to increasing:

- the number of dry weather periods where there are significant variations in the diurnal dry weather flow patterns, for example between weekdays and weekends;
- the number of storm events (perhaps to five events) where confidence in the input data is low;
- the duration of the dry weather flow periods or storm events or use of a single continuous flow record where there is significant rainfall induced variation in infiltration.

5.7 SUPERVISION OF FLOW SURVEYS

The Model Contract Document for Short Term Sewer Flow Surveys requires the contractor to report to the client after each weekly visit, among other things, any unsuitable sites. The modeller should review these reports and liaise with the contractor throughout the survey. Where possible arrangements should be made for alternative sites to replace unsuitable sites.

5.8 LIAISON WITH OPERATIONS STAFF

Contact should be maintained with operations staff throughout the planning and execution of the flow survey to ensure that the equipment is not damaged during operational activities, that the equipment does not interfere with necessary operational activities and to collect other relevant data as follows.

a) Details of any mechanical failures at pumping installations, sewage treatment works etc.

b) Details of any spillages, fires etc. where large volumes of water are used.

c) Changes in trade effluent discharges.

d) Operation of penstocks.

e) Maintenance activities (e.g. sewer cleaning).

f) Collapse or partial collapse of sewers.

5.9 ASSESSING FLOW SURVEY DATA

When assessing the results of a sewer flow survey undertaken for hydraulic and model verification purposes, the following criteria should be considered. For each storm:

- There should have been enough rain to wet the catchment sufficiently so that initial losses are not a significant part of runoff.
- A comparison between the results measured at each of the raingauges should be sufficiently consistent so that the rainfall at any point in the catchment can be determined by interpolation.
- Where there was lying snow during the rainfall event the flow survey results may be affected.
- Flow at each site should be high enough to ensure measurements are accurate.
- The flows should be sufficient for all combined sewer overflows and sewage pumping installations to have operated where it is necessary to verify their operation.
- There should have been a sufficient rise in flows at each site so that measurement errors are not significant.
- There should have been not so many peaks as to make comparison difficult.

The interpretation of these requirements will require considerable experience and judgement, but they may be interpreted broadly as follows:

a) For the rainfall:

   i) The total depth should be greater than 5 mm.

   ii) The range of total durations of the rainfall should vary. Ideally one storm should have a duration equal to ½ of the time of concentration (Tc) of the system, one storm equal to Tc, and the third more than twice the time Tc.

   iii) The rainfall intensity should be greater than 6 mm/hour for more than 4 minutes.

   iv) The period between events should be sufficient for the flow to return to dry weather conditions.

b) In addition, variation between rainfall measured at adjacent raingauges should not be outside the following limits:

   i) The total depth of rainfall should not vary by more than 20%.

   ii) The should be no more than a 15 minute difference in the time of a peak measured at the different sites.

   iii) The time interval between successive peaks in an event should not vary by more than 10% at the different sites.

   iv) There should be no more than a 30% variation in mean intensity of the peaks (when measured over a 6 minute period around the peak).

   Where one raingauge is obviously faulty, the data should be discounted.

c) Also, the response measured at each flow monitor site should be as follows:

   i) The depth of flow should exceed 100 mm and the velocity of flow shouldexceed 0.2 m/s for at least 75% of the storm duration.

   ii) The ratio of the peak depth of flow to the depth of the base flow should exceed guidelines given in Table 5.2 below.

   iii) The ratio of peak velocity to the base flow velocity should exceed two.

   iv) All storm sewage overflows and other ancillary structures, such as pumping installations, should operate where this is necessary to prove the calculations.

   Experience and judgement will have to be exercised in the application of these rules, especially in partially separate systems where the response criteria may not always be achievable.

Table 5.2 Response criteria based on peak to base flow depths and various depths in free flow conditions

Proportional depth of baseflow <u>Base flow depth x 100%</u> Diameter of pipe	Minimum acceptable proportional peak flow <u>Minimum acceptable peak depth x 100%</u> Diameter of pipe
0%	0%
5%	30%
10%	30%
15%	30%
20%	30%
25%	40%
30%	45%
50%	100%

Examples

1. For a 450 mm diameter sewer with a base flow of 50 mm

   Proportional depth of baseflow = 50/450 ≈ 10%

   ∴ minimum acceptable peak depth = 30% × 450 ≈ 150 mm

2. For a 600 mm diameter sewer with a base flow of 150 mm

   Proportional depth of baseflow = 150/600 = 25%

   ∴ minimum acceptable peak depth = 40% × 600 = 240 mm

6. VERIFICATION

6.1 INTRODUCTION

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 sewer system and not solely to make the model fit the verification data.

Calibration is the process of adjusting model parameters to make a model fit with measured conditions (usually measured flows). This process should be followed by verification using a different set of data to that used in the calibration.

Force-fitting is the process of making arbitrary changes to a model to make it fit observed data and should not be undertaken. The dangers of force-fitting are described in WaPUG usernote 13[22].

The result of the verification for all or part of a model can be one of three possible outcomes.

- The model or part of the model is verified.
- The verification procedure identifies that the model is incorrect, but this is not able to be resolved.
- It is not possible to verify whether the model is correct or not.

6.2 VERIFICATION REQUIREMENTS

For very small models, where the cost of any over-design of works typically would not justify the increased cost of a flow survey, models may be verified by reference to historic flooding and surcharge data only. In all other cases verification should also be by comparison of modelled flows with observed flow data from a flow survey.

The order in which the verification with historic data and the verification with flow survey data are carried out is a matter for individual preference. It is important, however, that the final model is verified using both sets of data and that any changes made as a result of the second check do not invalidate the first.

Where networks carry a significant amount of dry weather flow or where the model is to be used as the basis for a water quality model this should be verified prior to verification against storm flows.

6.3 LEVELS OF VERIFICATION

The main differences in the levels of verification will be in the number of points at which the model is verified rather than the exactness of the fit. (see section 5.4).

6.3.1 Verification with historic data

Two levels of verification can be defined

- Verification of all surcharge and flooding throughout the model.
- Verification of all surcharge and flooding within a defined core part of the model. This should include surcharge/flooding at any point less than 500 metres upstream of where the model is required to be accurate. Verification of severe flooding only outside this area.

6.3.2 Verification against flow survey data

The requirement for the positioning of flow survey monitors for different levels of verification are described in paragraph 5.4.1.

6.4 VERIFICATION PROCEDURE

There is no definitive sequence of working through the stages of verification. The following sequence is commonly used.

- Dry weather flow verification with flow survey data.
- Verification with storm events from flow survey.
- Verification with any available major historic events.
- Historic verification with medium return period design events.

Some modellers prefer to carry out the historic verification before the verification with the events from the short term flow survey. This can be useful to give an indication of the accuracy of the model before the flow survey data is available.

A possible procedure is outlined below.

a) Assess the suitability of the verification data.

b) Review the flow survey report and consistency of the flow data (see paragraph 6.5.2).

c) Assess the fit between the model and the flow survey or historic flooding data according to the criteria below.

d) Assess the suitability of the model for the purpose stated in the project definition.

e) Document the findings.

6.5 VERIFICATION WITH FLOW SURVEY DATA

6.5.1 General

For each of the events selected from the flow survey, model runs should pass through the routine stability test requirements given in paragraph 4.11.

In looking at the matches 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 criteria given below are a general guide to verification. However, the modeller should always substantiate any claim that the verification is acceptable and record this in the documentation.

No changes should be made to the model during verification other than where this has been independently shown to reflect the physical condition of the system, and all changes should be reported in the documentation.

6.5.2 Checking flow survey data

Before using any flow survey 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.

The modeller should, by this stage, 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 see whether the changes in volumes are as expected.

The modeller should then assess whether there is sufficient data to verify the model.

6.5.3 Dry weather flow verification

DWF verification should be carried out for two dry weather days and the predicted flows/depths compared to the observed flows/depths. The two flow hydrographs should closely follow each other both in shape and in magnitude.

In additon to the shape, as a general guide, the flow hydrographs should meet the following criteria.

a) The timing of the peaks and troughs should be within 1 hour.

b) The peak flow rate should be in the range ± 10%.

c) The volume of flow should be in the range ±10%. Care should be taken to exclude periods of missing or inaccurate data (see paragraph 5.9 (c) (i)).

6.5.4 Storm flow verification

For the events from the flow survey, the predicted flows/depths should be compared to the observed flows/depths. The two flow hydrographs should closely follow each other both in shape and in magnitude, until the flow has substantially returned to dry weather flow rates.

In addition to the shape, as a general guide, the observed and modelled hydrographs should meet the following criteria in at least two of the three events.

a) The timing of the peaks and troughs should be similar having regard to the duration of the event.

b) The peak flow rates at each significant peak should be in the range + 25% to - 15% and should be generally similar throughout the event.

c) The volume of flow should be in the range +20% to -10%. Care should be taken to exclude periods of missing or inaccurate data (see paragraph 5.9 (c) (i)).

d) The depth of surcharge should be should be in the range +0.5m to - 0.1m.

e) The unsurcharged depth at any key points, where this is important having regard to the objectives of the model (e.g. at combined sewer overflows), should be within the range ±100mm.

Where rainfall induced infiltration is modelled the use of a single verification period incorporating a number of rainfall events should be considered instead of a number of discrete events.

During the events selected from the flow survey, the flooding locations predicted to have significant volumes of flooding (see paragraph 6.6) should be substantiated by some evidence of real flooding or a clear explanation for there being none. All flooding known to have occurred during these storms should be reproduced by the model.

6.6 VERIFICATION WITH HISTORIC DATA

Where long term records of historic rainfall information are available they should be used for this purpose, otherwise design storms with a return periods of one in one and one in five years should be tested with the model.

The predictions of flooding by the model should be compared with reports of flooding. All reported flooding should be generally reproduced by the model both in terms of location, severity and, insofar as records permit, frequency. Similarly, all predicted flooding should be assessed to establish what effect such a volume of flooding would have if it were to occur, and this should then be compared to reported flooding. (see WaPUG Usernote 29 [9]). In general any predicted flooding will need to be substantiated by some evidence of real flooding or by a clear explanation for there being none. However, small volumes of flooding may sometimes be considered insignificant, since they are not perceived as such. During heavy rainfall on roads, for example, volumes of as much as 25m³ can sometimes be viewed as acceptable standing water. However, inside a building, the smallest volumes are likely to be unacceptable.

Where there are discrepancies these should be investigated so that if there are any errors in the input data, these can be amended, or the flooding database updated, if further reports of flooding are received.

Low return period storms can also be used to indicate the hydraulic performance of each ancillary and thus enable them to be ranked in order of significance.

Where there are records from permanent flow or depth recorders and raingauges, these should be used to increase confidence in the accuracy.

If further flooding data becomes available after the verification has been completed, the model should be reviewed and, if necessary, further verification work undertaken.

6.7 NON-COMPLIANCE

Where any of the above criteria cannot be met and further investigation has failed to identify a cause the situation should be reviewed. If the model has not been shown to be wrong, but cannot be shown to be correct, then the use of any further storm data from the flow survey should be considered or a further flow survey commissioned. The project definition should also be carefully reviewed. It may still be possible to consider the model sufficiently verified, in some circumstances provided that:

a) The reasons for the non-compliance have been determined but cannot be modelled and have been assessed as not being important to the subsequent use of the model. For example, a transient feature such as the 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 purpose of the model. 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 accuracy of the model.

c) Infiltration is the cause of the discrepancy and this will be taken into account in other ways in subsequent use of the model. In these circumstances consideration should be given to the use of an alternative runoff model with improved infiltration modelling capabilities.

7. USE OF MODELS

7.1 ROUTINE MODEL TESTING

Routine model tests described in section 6.2 should be carried out each time the model is run.

7.2 ASSESSMENT OF HYDRAULIC PERFORMANCE AND ENVIRONMENTAL IMPACT

Procedures for using models to assess the hydraulic performance and impact on receiving waters of existing sewer systems are described in the Sewerage Rehabilitation Manual(6).

7.3 PREPARATION OF MODEL FOR DEVELOPING UPGRADING OPTIONS

Before the verified model can be used to design rehabilitation works, the following issues will need to be considered and changes made accordingly. All changes should be fully documented.

7.3.1 Local Repairs

Any matters such as local collapses, blockages, jammed or missing flap valves, badly operating pump, blocked gullies or badly drained areas which are to be corrected by local repairs, should be considered and amendments made to the model to show the changes made.

7.3.2 Committed Schemes

Any schemes which are committed should be included in the model as if they had been built.

7.3.3 Sediment

When there is sediment in the model the modeller should make a judgement as to whether this is a permanent feature (i.e. the hydraulics of the system will ensure that it returns very quickly after cleaning) or whether it is due to some one-off event (e.g. a collapse) in which case it should be removed from the model. If there is any doubt then it should be left in and a more detailed analysis carried out during assessment of the unrehabilitated system.

7.3.4 Future Development

Assessment should be made of future development within the catchment over the period under consideration.

7.3.5 Increased Infiltration

Where infiltration is or is likely to be significant (e.g. in areas of very high groundwater levels) the likely changes in infiltration over the period under consideration should be taken into account.

7.3.6 Increased Inflow

In foul systems, allowance should be made for future "illegal" connections of runoff to the foul system.

In combined and partially separated systems, consideration should be given to increases in runoff due to changes in connections and the construction of extensions or new buildings.

7.3.7 Water Use

Allowance should also be made in dry weather flows for likely changes in water use.

7.4 REPEAT ASSESSMENT

The hydraulic performance and environmental impact of the system should then be reassessed as before to determine the areas where rehabilitation works are required. This should be documented.

7.5 UPGRADING

Changes made while modelling the upgrading of the system should be clearly documented and all the revised models tested in accordance with section 6.2 where all changes in one part of the model are major (e.g. addition of a tank) then the more rigorous tests given in section 6.1 should be applied to this part of the model. Details of all changes to the model should be documented.

8. DOCUMENTATION

8.1 INTRODUCTION

In order that future users can properly assess the appropriateness of a model for a particular purpose and to allow for updating and upgrading, 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 an essential basis for both internal and third party audits of the work. This documentation is not to be confused with the requirement from a client for a final report, which may be significantly less detailed. The following should be considered as a minimum requirement.

The main documentation should comprise four separate reports as follows.

- A model building report.
- A flow survey report – normally produced by the flow survey contractor.
- A verification report.
- An upgrading options report.

8.2 MODEL BUILDING REPORT

8.2.1 Introduction

This report should contain a description of the work involved in:

- project definition;
- data collection;
- model building;
- model testing.

8.2.2 Project definition

a) A summary - outlining the purpose, methodology and the main conclusions.

b) An introduction - giving the background to the study and why it was commissioned.

c) The purpose for which the model is intended and the type of model built and any constraints. This may include a copy of any detailed client's brief.

d) A description of the existing system, area, population, types of catchment, ground, topography, condition of system, silting etc.

8.2.3 Data collection

a) A schedule of data used, including reference to its source including issue numbers or dates (e.g. 'Drawing number 1194/34 Rev 1' or 'Sewer records database as existing on 14-Feb-2002'). 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.

b) Details of any specific surveys carried out which are not to be archived elsewhere should be included as an appendix otherwise the location should be added to the reference to them in the data schedule.

c) Where conflicts were identified between different sources of information a schedule of the conflicts and how these were resolved.

d) Information from impermeable area surveys should be recorded in a standardised way on a GIS or on large scale plans as described in Appendix B. An explanation of how the information from the sample surveys was extrapolated to provide data for the whole catchment should also be included.

e) Details of any checks carried out on the data

8.2.4 Model Building

a) Assumptions about data.

b) Where these are not included in the model data file, details should be recorded of selection of model node references. This should include a means of cross referencing the model pipe references to manhole number on the sewer records.

c) Any changes to the data, for example to represent low points in the system, should also be recorded and justification given.

d) If simplification has been carried out the criteria used and justification for any changes made which will not be obvious from the model data. (For example, the omission of a node may normally be assumed to be obvious since the manhole reference for each node is recorded (see paragraph (b)). The representation of two parallel pipes by a single pipe of a calculated dimension should be recorded and calculations included).

e) Whether any allowance has been made for unmodelled storage and the basis for this.

f) Details of ancillaries included and omitted from the model and any calculations used. .

g) A paper copy of the sewer system data file, together with either a copy of the file on disk, or a description as to how to retrieve it from a formal archive system.

8.2.5 Model testing

Details of the tests carried out should be recorded. Any locations where instabilities were identified should also be recorded, together with details of the changes made to resolve them.

8.3 VERIFICATION REPORT

The verification report should include:

a) A summary - outlining the main conclusions.

b) Details of the flow survey locations and how they were selected. The documentation should list the locations chosen and any alternatives considered. The reasons for the selection of each monitor and raingauge location should be described. For flow/depth monitors this should include their intended role in the verification process.

c) A copy of the sewer flow survey contractor's report.

d) A copy of any supplementary comments from the modeller of the performance of the flow and depth monitors.

e) Comments on the storm events with relation to the criteria set out in paragraph 5.9 and spatial distribution of the rainfall on an event by event basis. The basis for the selection of the event should be included.

f) Plots of the first fits of the model with the flow survey data.

g) A detailed description of any changes made to the model during the course of the verification and the justification for making these changes.

h) The final verification plots together with an indication whether the criteria in paragraphs 6.4 and 6.5 have been met and explanation of any discrepancies.

i) A commentary on the final fits and a description of how well the model is considered to be verified. Any judgements taken or weaknesses should be highlighted and any sensitivity analysis reported.

j) A paper copy of the sewer system data files, together with copies of the files on suitable media.

k) Copies of relevant flow survey and rainfall files on suitable media.

l) Details of reported flooding and surcharge and a comparison with predictions using design storms and/or times series.

m) Conclusions - in addition to the normal conclusions an indication of the accuracy of the verification of the model is essential and the statement of any limitations in its potential use (i.e. design).

8.4 UPGRADING OPTIONS REPORT

This should incorporate the following.

- Details of any changes made to the verified model to take account of committed schemes and future developments etc. (see paragraph 7.3). This should be clearly documented. Precise details of the changes made to the model data should be supported by, any calculations made and references to any source data or assumptions.

- For each option 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.

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.

APPENDIX A SIMPLIFICATION PROCEDURE

Where simplification is to be to be carried out, the following procedure is recommended.

a) Prepare plan

It is helpful to mark the simplification work on a plan of the whole catchment. This may be a compilation of the 1:1250 sewer record plans or a smaller scale plan may be prepared specifically for the purpose. Alternatively, where the simplification is carried out on a computer database, the plan may be in digital form. The plan should be retained as part of the model documentation.

b) Check ground levels

Identify those points where the lowest connected ground level is significantly lower than the manhole cover levels given on the public sewers. This should be done using existing flood information, an inspection of ground profiles, and from local knowledge. These levels should then be used in place of the cover levels of the manholes. Artificial changes to ground levels can cause subsequent difficulties unless they are clearly documented. It may be preferable in certain circumstances (when modelling basements, for example) to include an additional branch with the correct ground/floor level at its head.

c) Remove small peripheral pipes (pruning)

A procedure to determine whether pipes may be omitted and their catchment considered to be part of the downstream catchment is given in the flow diagram in Figure A.1 below.

d) Group pipes together (merging)

Pipes may be grouped together to reduce the number of modelled nodes provided that the following should always be included:

i) all combined sewer overflows, tanks or pumping installations;

ii) the manhole immediately downstream of a tank;

iii) all manholes where there is a significant change in size or shape of pipe;

iv) all known flooding points;

v) manholes where flow monitors are to be sited preferably with the upstream manhole;

vi) junctions of two or more modelled pipes;

vii) drops in invert which increase the depth of the sewer by more than 2 diameters (in these cases the incoming and outgoing invert levels at the node will be different).

viii) Structures or other arrangements with head losses.

Note: It is not normally necessary to consider changes in the gradients of pipes as most changes are associated with changes in ground gradients. Where no verification is being carried out by flow survey which would check the effect of any such changes then differences between the average gradient of the modelled pipe and any real constituent pipe should be limited to the values specified in Table A.1. A more rigorous method of carrying out this test is given in WaPUG Usernote 8[(23)].

The lengths of pipe between the remaining manholes should then be considered and additional nodes included so that any points where the upstream ground slope is greater than that downstream, which may lead to the hydraulic gradient in the downstream system being limited by flooding. (see Figure A.3 below)

Additional manholes should also be included to limit the maximum length of modelled pipe to the value specified (see Table A.1) (or less if recommended by the software supplier).

e) Further simplification

Further simplification should then be carried out to remove any pipes shorter than the minimum length which the model can handle. Complex arrangements may also be simplified by for example replacing twin parallel pipes with a single equivalent pipe.

f) Unmodelled storage

After all contributing area and dry weather flow data has been added an allowance for unmodelled storage should be added (for an example of this see WaPUG user note 15)[(12)].

Table A.1 Recommended simplification parameters

Model type	Type I	Type II	Type III
Minimum diameter of pipe to be included in the model	300 mm	225 mm	225 mm
Maximum length of pipe	1000 m	500 m	200 m
Maximum difference between modelled pipe gradient and real gradient of any part of that pipe – where no flow survey verification is to be carried out	100%	50%	30%
Note: These values should be used unless alternative values are specified by the commissioning organisation.			

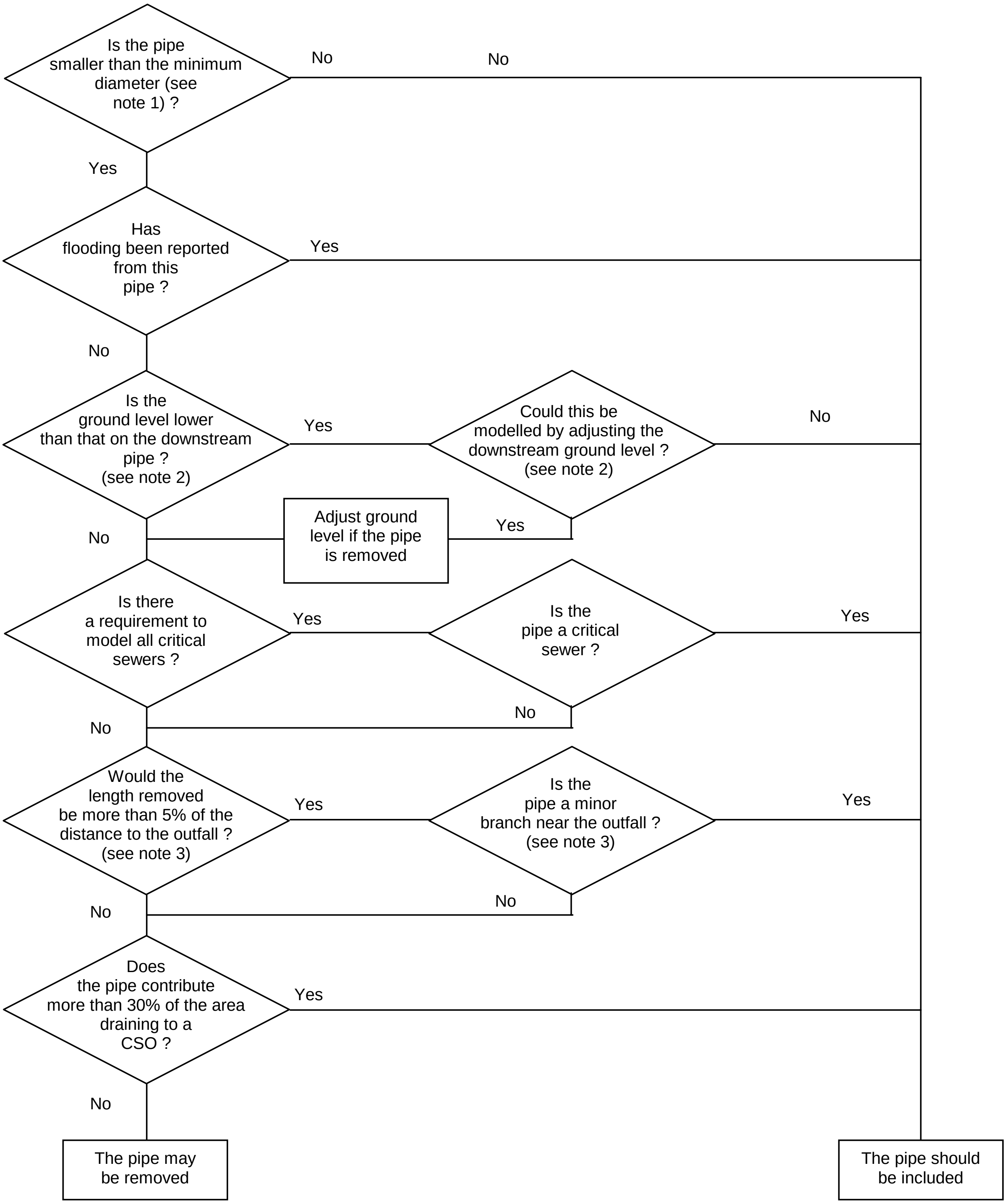


Figure A.1 - Flow diagram to select peripheral pipes that may be omitted

Notes on figure A.1:

1. A maximum diameter of pipes which can be removed may be specified. This will depend on the type of model. Some typical values for various types of models are given in Table A.1.

2. It is important to include any levels which are lower than the adjacent modelled pipes as any surcharge will cause more frequent flooding in these locations. Differences of less than 0.5m generally may be ignored. In some cases it may be possible to remove the pipe and reduce the ground level on the downstream pipe to the lower of the two levels. This should only be done if the downstream pipe is to be retained. Artificial changes to ground levels can cause subsequent difficulties unless they are clearly documented.

3. Except in the case of large foul-only areas it is desirable to include a representative pipe in each area. It is suggested that no more than 5-10% of the total length of the sewer from the head of a branch to the outfall of the system (see Figure A.2 below) is omitted. This rule may be ignored for minor branches near to the outfall (say <1% of the total area) as these are not generally significant.

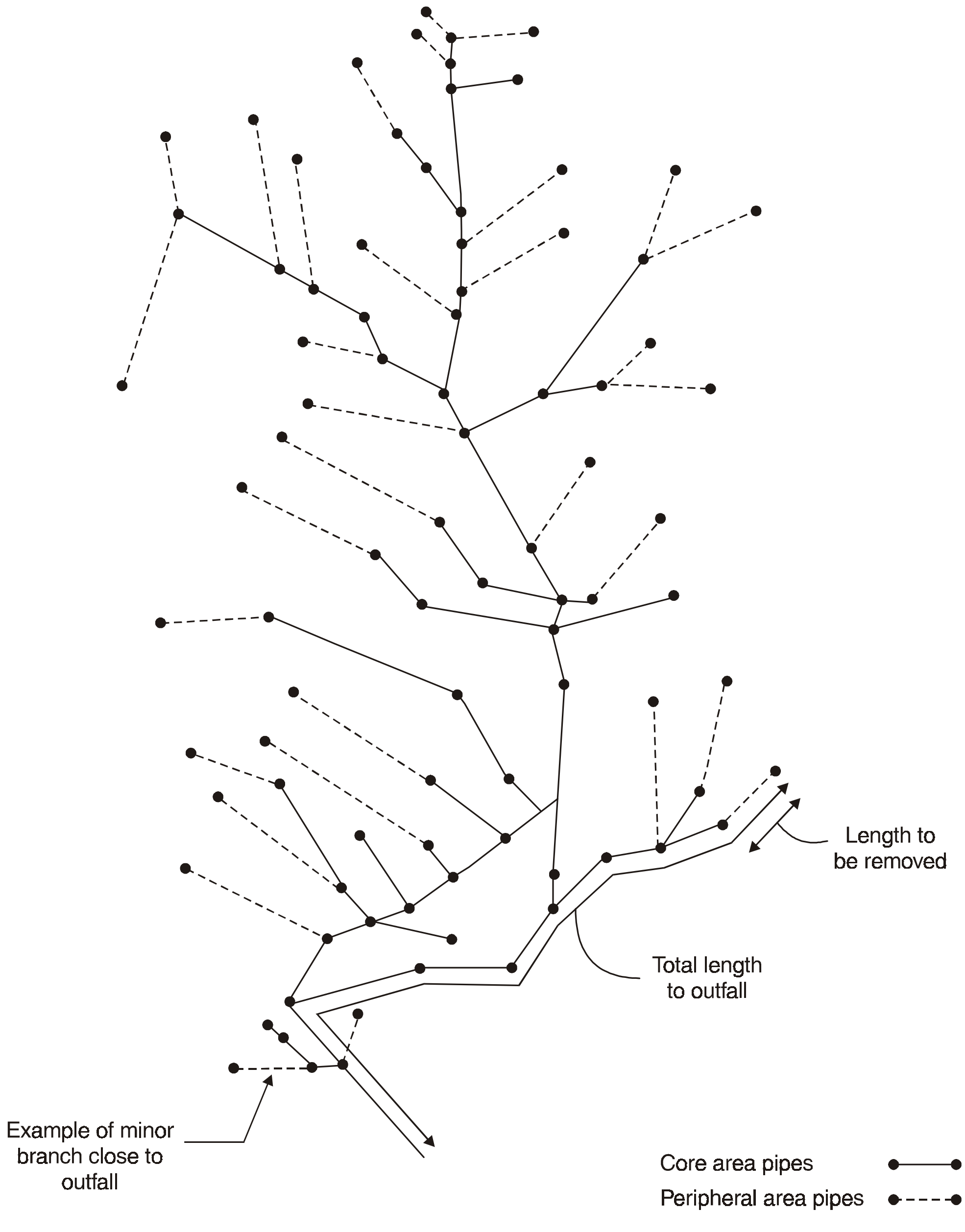


Figure A.2 - Explanation of total length of branch

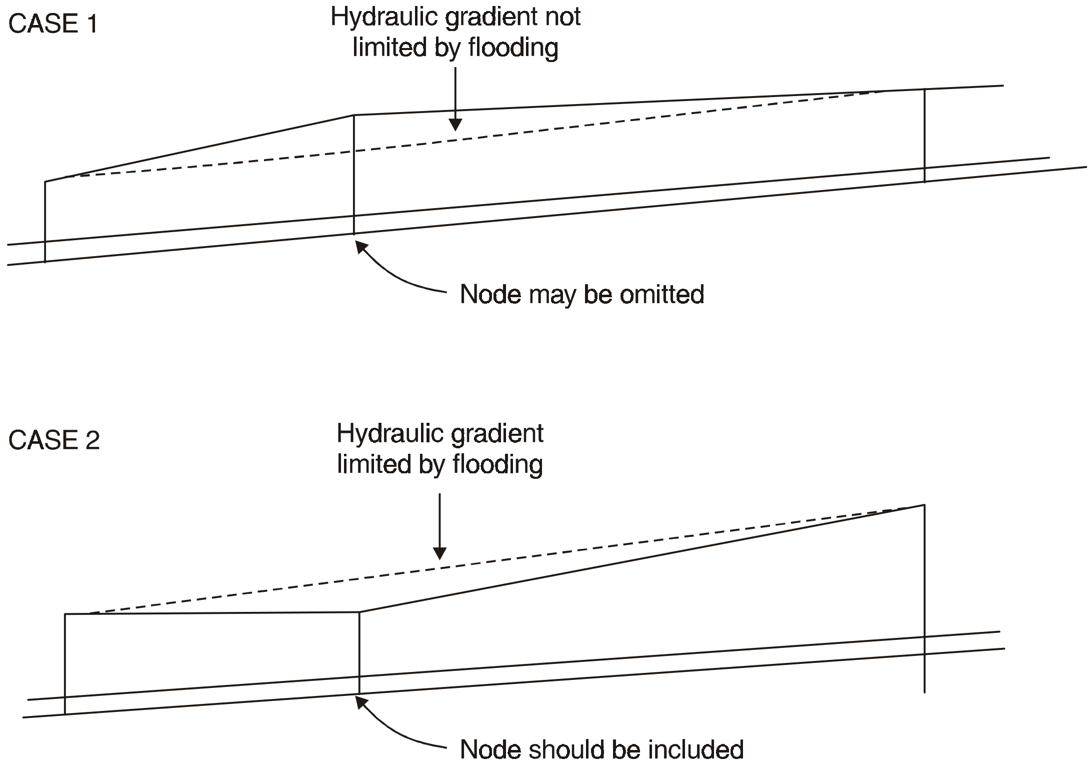


Figure A.3 - Locating point of first flood

APPENDIX B STANDARD CODING OF CONTRIBUTING AREA DATA

B.1 INTRODUCTION

The results of impermeable area surveys should be recorded in accordance with the following convention either on a geographical information system (GIS) or using a permanent marker on small scale (e.g. 1:1250 or 1:2500) plans.

If the area has been surveyed but with inconclusive results it should be clearly marked on the plan and any assumptions stated.

B.2 ROOFS

Details of pitched roofs taken from plans, or where assumptions have been made, are to be crosshatched in the colours listed below. Surveyed properties are to be coloured solid.

Roofs should be coloured as follows depending on where they drain to.

- Soakaway or permeable areas - yellow
- Foul/combined sewers - red
- Surface water sewers - blue
- Direct to road/pavement - mauve

The route for disposal of surface water should be shown whether surveyed or assumed.

B.3 PAVED AREAS

All paved areas should be cross hatched in the appropriate colours, with the tested gullies coloured solid.

Paved areas and flat roofs should be coloured as follows depending on where they drain to

- Soakaway - yellow
- Foul/combined sewers - brown
- Surface water sewers - green

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WaPUG would welcome any comments on this document which should be addressed to:

Technical Queries WaPUG Home Page www.wapug.org.uk