Integrated Urban Drainage Modelling Guide

Appendix H

Hydrology

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H.1 Introduction

Hydrology is an integral part of any integrated urban drainage model. It represents the quantity of water (runoff) generated from a specific area or watershed. The hydrological estimation is very important as it will drive the ultimate objective of the Integrated Urban Drainage (IUD) study. It will guide the size or feasibility of a flood alleviation scheme, or determine the level of flood risk at a site or within a catchment, or it will help assess the capacity of existing structures (e.g. sewers, pumping stations) and where interventions are potentially required. It is fundamental therefore that hydrology and the hydrological inputs are given due consideration in any IUD study, the level of which will vary depending on the complexity and purpose of the study.

Section A2 – Model Concept provides an overview of the likely hydrological analysis required for each of the four model concept types. Some information on the application of hydrological methods is provided in **Section B3 – Modelling**. Additional technical information is provided in this appendix which also contains an extensive reference list of specific documents and guidance related to the hydrological methods likely to be applied in IUD modelling.

There are two key points to note:

1. Hydrological estimation is a complex process with many aspects to consider and it is therefore essential that the people carrying out the assessment and deriving the hydrological inputs have the correct knowledge, skills and experience at an appropriate level for the study.
2. Hydrology should not be considered as a standalone activity within the IUD study. It should be carried out in conjunction with the modelling, with input (to varying degrees depending on the complexity and scale of the study) throughout the duration of the study.

This appendix does not aim to provide all the answers, nor will it go into prescriptive detail on all the available methods as these are well documented elsewhere. It will however provide guidance on how, when and how much hydrological input is required into an IUD study, using signposting and referencing to existing documents and technical reports where applicable. It will recognise when there may be different approaches or methods to consider and will provide information on which methods may be more suitable for certain situations, e.g. permeable, urban and/or small catchments.

H.2 Other guidance documents/reports

There is a wealth of existing documents, guidance and technical reports already readily available in the industry on the different hydrological methods and associated topics. Table H-1 highlights the key documents and reports.

Whilst this table provides a series of key documents, methods and techniques are constantly evolving through improved methods and accompanying software (both hydrological and hydraulic modelling). This illustrates the importance of continued professional development and communication between project members (including clients) to understand the changes and how they may affect the outcomes of a project.

Table H-1 – Key hydrology documents reports and references

Author	Title	Document date	Ref No.*
CIRIA	The SuDS Manual – Part E Supporting guidance, 24 Hydrology and hydraulics: design and calculations	2015	A
Environment Agency	Flood Estimation Guidelines: Technical guidance 197_08	2020	B
SEPA	Flood Modelling Guidance for Responsible Authorities Version 1.1	2016	C
Natural Resources Wales	GN008 Flood estimation: technical guidance	2017	D
UK Centre for Ecology & Hydrology	Flood Estimation Handbook (Volumes 1 to 5)	1999	E
Defra/Environment Agency	Improving the FEH statistical procedures for flood frequency estimation: Science report SC050050	2008	F
Defra/Environment Agency	URBEXT2000 – A new FEH catchment descriptor: R&D Technical Report FD1919/TR	2006	G
UK Centre for Ecology & Hydrology/ Wallingford HydroSolutions	The Revitalised Flood Hydrograph Model ReFH 2.3: Technical guidance https://refhdocs.hydrosolutions.co.uk/The-ReFH2-Model/	2020	H
The Office of Public Works	Flood Studies Update – FSU guidance handbook	2014	I
The Office of Public Works	Flood Studies Update – Physical Catchment Descriptors (Volume IV)	2014	J
Environment Agency	Making better use of local data in flood frequency estimation: Report SC130009/R	2017	K
UK Centre for Ecology & Hydrology	https://fehweb.ceh.ac.uk	-	L
National River Flow Archive	https://nrfa.ceh.ac.uk/	-	M
UKWIR	Rainfall Intensity for Sewer Design – Stage 2 (17/CL/10/17)	2017	N
UKWIR	Rainfall Intensity for Sewer Design – technical guide (17/CL/10/17)	2017	O
CIWEM UDG	Rainfall Modelling Guide 2016	2016	P
Wallingford HydroSolutions	WINFAP 4 QMED Linking equation	2016	Q
Wallingford HydroSolutions	WINFAP 4 Urban Adjustment Procedures	2016	R

Author	Title	Document date	Ref No.*
Institute of Hydrology	Flood estimation for small catchments	1994	**S**
CIWEM UDG	Code of Practice for the Hydraulic Modelling of Urban Drainage Systems	2017	**T**
CIWEM UDG	CIWEM UDG/WaPUG User Notes (https://www.ciwem.org/special-interest-groups/urban-drainage-group)	-	**U**
Defra/DECC	UK Climate Projections science report: Climate change projections	2009	**V**
GOV.UK	www.gov.uk/guidance/flood-risk-assessments-climate-change-allowances	-	**W**
Environment Agency	Adapting to Climate change: advice for flood and coastal erosion risk management authorities	2020	**X**
SEPA	Climate change allowances for flood risk assessment in land use planning	2019	**Y**
Department for Infrastructure	Technical flood risk guidance in relation to allowances for climate change in Northern Ireland	2019	**Z**
Welsh Government	Adapting to climate change: guidance for flood and coastal erosion risk management authorities in Wales	2017	**AA**
Met Eireann & UCD	Ireland in a Warmer World – Scientific predictions of the Irish climate in the twenty-first century	2008	**AB**
Defra/Environment Agency	Joint Probability - dependence mapping and best practice: R&D Technical Report FD2308/TR1	2005	**AC**
Defra/Environment Agency	Use of joint probability methods in flood management – a guide to best practice: R&D Technical Report FD2308/TR2	2005	**AD**
*Used to identify references throughout the hydrology appendix			

In addition to these guidance documents, reference should also be made to internal documents and specifications relevant to each Partner and/or Stakeholder.

H.3 Data

Section B1 - Data collection provides a comprehensive overview of data collection, the importance of using data and the different types of data available. For hydrological analysis, peak flow data is one of the most useful items of data where the main focus of the study is river flows. Where the main focus of the study is concentrated on the sewer network, data from flow monitors are valuable for verification. In both instances, accompanying rainfall data is also very useful. As described in **Section B1** many other types of data are available, which are also valuable to understanding the hydrological regime and associated effects on the wider system.

H.4 Understanding the catchment

Before launching into any hydrological estimations or calculations, those undertaking the hydrological assessment must first understand the catchment and its characteristics. The catchment's characteristics control how the landscape will respond to rainfall and directly influence where, when, how and how much run-off will be generated. The level of input and research required for this will be linked to the purpose and scale of the study.

The nature of an IUD study means it inherently includes a large proportion of urban coverage as well as areas more rural in nature. The first task the hydrologist must undertake is to identify the hydrological boundary, or boundaries, (i.e. the drainage network above ground), as these are likely to differ in places from the sewer catchment (i.e. the drainage network underground) within the urban areas. **Section A2 – Model Concept** provides 4 examples (Types #A, #B, #C and #D) which illustrate how the study, model and hydrological boundaries can differ. **Section B3 - Modelling** provides more information about hydrological catchments and model extents and how these may vary in the four main model concept types.

It is recommended that the initial source for identifying the hydrological catchment, or drainage area of the watercourses, is from the FEH Web Service **(L)**. The GIS layer or model network can be used to identify the extent of a sewer catchment.

The FEH hydrological boundary downloaded from the website as a GIS layer (shapefile) overlaid by the GIS layer of the sewer network can then be used with OS mapping and the best resolution DTM data available to check the catchment boundaries. Amendments to the catchment boundary can then easily be made using a GIS package. It is most important to ensure that the area value/s is correct and also that no area is double-counted, i.e. the catchments covering the rural areas do not overlap with the sewer catchments and vice versa.

Once the catchment boundaries have been established and the relative coverage of urban and rural areas has been determined, the hydrologist must then understand what may influence the run-off within these catchments. There are a range of factors which should be considered. As a minimum they should include:

- size and shape of the catchment
- land use
- underlying soil types
- geology
- gradient
- attenuation (e.g. lakes and reservoirs)
- previous rainfall (antecedent conditions)

Other potential factors may influence the system, which are not necessarily the norm for every study, but should be considered beyond the minimum listed above where required. These might include, but are not be limited to; infiltration, saline intrusion, groundwater effects, abstractions and tidal influences.

There are various sources this information can be found, including OS mapping, aerial mapping, geology and soil maps and LiDAR. A good place to start would be with the catchment descriptors available from the FEH Web Service **(L)**. The catchment descriptors provide a quantification of the physical and climatological properties of a catchment, available for the whole of the UK, for topographical catchments of 0.5km^2 or more, generated from any point on a drainage network on a 50m grid.

The catchment descriptors provide useful information about the hydrological characteristics including area, slope, climate, soils, attenuation, length of drainage path and urban cover. They are digitally derived and are either directly or indirectly based on the Institute of Hydrology Digital Terrain Model (IHDTM).

Key points to note about the FEH catchment descriptors:

- Only 10 of the descriptors are used in flood estimation procedures.
- The catchment descriptors should not be used without, at least, a simple check of the values against other available data.
- Catchment descriptors do not give a complete picture of the physical characteristics of a catchment but do provide a very good starting point.
- Further details on the catchment descriptors can be found in FEH Volume 5 **(E)** and on the National River Flow Archive website **(M)**.
- If significant changes are made to the catchment boundary (i.e. catchment area value) then it is also important to recalculate the DPLBAR, FARL and URBEXT descriptors. FEH volume 5 **(E)** and 197_08 Flood Estimation Guidelines **(B)** provide appropriate methods for the recalculations.

Digital, or numerical, catchment descriptors describing catchment attributes or characteristics are also available for the Republic of Ireland. These are known as PCDs (physical catchment descriptors). PCDs **(J)** were prepared to support the Flood Studies Update **(I)** and are available on the FSU web-portal for approximately 134,000 catchments, or points on the digital river network in Ireland. For further information on PCDs please refer to reference **(I)**.

H.5 Approach

There are well established methodologies for deriving hydrological estimates for a fluvial study and numerous methods for estimating hydrological inputs for an urban drainage study. However, there are limited similarities between the approaches of the two systems (fluvial and urban), which currently creates a significant challenge in IUD modelling studies.

To add to the complexity, there isn't just one hydrology method under each system (fluvial or urban) to select. Each system has numerous approaches to choose from, where the choice will often depend on a set of conditions and factors. Some techniques will also only be available for certain limited applications or software, whilst others can be more universally applied.

This appendix sets out the most common individual methods and approaches and should be read to support **Section B3** which provides an indication of likely methodologies for each model concept type and explores the suitability and potential combination of the different techniques that can be used within one integrated urban drainage model.

H.5.1 Fluvial

Model concept Type #B is likely to require some kind of hydrological analysis of the upstream rural catchment contributing to the main watercourse(s) in the study area in order to derive design event inflow hydrographs for the model simulations. This analysis would typically follow the same process as a fluvial flood study for any main river or ordinary watercourse, as described below.

For fluvial flood studies in the UK, industry standards and guidance recommend that in most cases a hydrological analysis should be based on methods in the Flood Estimation Handbook (FEH) **(E)** which provides two main approaches to flood frequency estimation:

- Statistical method
- Revitalised Flood Hydrograph (ReFH) rainfall runoff method

It is worth noting that there are small but notable differences in the approaches and guidance on the use of FEH methods in England, Scotland and Wales. Please refer to the relevant guidance and best practice documents for specific details **(B)**, **(C)**, **(D)**.

In the Republic of Ireland, the Flood Studies Update (FSU) methodologies **(I)** are the preferred method for flood flow estimation in fluvial studies.

The Institute of Hydrology Report No. 124 method (IH124) **(S)** is also an industry recognised method used in the UK and the Republic of Ireland for flood estimation on small catchments (less than 25km^2). In the UK it has generally been superseded by the FEH methods, however it is still the current preferred method in the Republic of Ireland for ungauged catchments smaller than 25km^2. An updated Environment Agency R&D project on small catchment methods is expected in 2020.

Continuous simulation modelling, for example probability distributed modelling (PDM), offers an alternative rainfall runoff approach to design event methods such as ReFH, but they are less widely used. As a conceptual rainfall-runoff model it is sometimes considered for use on complex catchments where flooding is affected by multiple influences.

Table H-2 provides a brief outline of each of these methods and signposts to further information, which should be reviewed and consulted before the appropriate method/s are selected.

Table H-2 - Overview of fluvial hydrology methods

Method	Overview	Key points to note	References for further details
FEH statistical	Involves the construction of a flood frequency curve based on the estimation of the median annual maximum flood (QMED). This is the flood that is exceeded on average every other year and assumed to be the 2 year return period for a subject site. A growth curve is then used to derive design flows for other magnitude events as a function of QMED.	• Only provides a peak flood flow, not a flood hydrograph. • Can be applied in any gauged or ungauged catchment in the UK. • Preferred FEH method for catchments greater than 1000km^2.	**B, E, F, G, L, Q, R,**
ReFH	Is a conceptual rainfall-runoff model than enables the user to generate peak flood flows and hydrographs for a given rainfall event on a catchment scale.	• Replaced the previous Flood Studies Report method in the UK. • Can be used to model an observed event or to generate a design event input hydrograph. • ReFH1 not suitable for use in Scotland. Versions 2+ are applicable in Scotland. • ReFH2 includes a component for incorporating the influence of runoff from paved surfaces. • Can be applied to river catchments or at a plot scale. • Uses FEH13 rainfall	**B, C, H, L**
Flood Studies Update (FSU)	Allows an estimation of flood flows and hydrographs for thousands of river locations in the Republic of Ireland. Using a combination of physical catchment descriptors and gauge data (if available), the user can use the FSU Web Portal to estimate peak flood flows and flood flow hydrographs.	• First launched in 2005 as an update of the FSR method. • Is freely available via the FSU Web Portal. • Only available for the Republic of Ireland • Not recommended for catchments less than 25km^2.	**I**

Method	Overview	Key points to note	References for further details
IH124	A new equation to estimate time to peak of an instantaneous unit hydrograph for part urban and rural catchment of less than 25km^2 was developed by Marshall and Bayliss in 1994. The report also worked out an equation to estimate mean annual flood (QBAR), for small and urban catchments. The calculated QBAR has an estimated return period of 2⅓ years. The estimated QBAR is then multiplied by regional growth factors to obtain peak flow estimates for other return periods.	• Only provides a peak flood flow, not a flood hydrograph. • No longer the best practice method for small catchments in the UK. • Uses FSR rainfall that has since been superseded by FEH99 and then FEH13. • Still the preferred method for ungauged catchments less than 25km^2 in the Republic of Ireland.	**I, S**
Continuous simulation modelling (CSM)	Is a fairly general conceptual rainfall-runoff model which transforms rainfall and potential evaporation data to flow at the catchment outlet. A long series of rainfall is run through a suitable rainfall-runoff model to produce a long flow series. The peaks can be ranked and analysed to obtain design flows of the required return period.	• Can be useful on complex catchments where flooding is affected by multiple factors e.g. permeable and/or urbanised catchments • Long time series can be analysed (1000 years, 5000 years etc. • Where gauge data exists, it can be used in combination, i.e. use short term record from annual maximum series and extend using CSM for higher return periods.	**B**

H.5.2 Urban

All model concept types require some form of urban hydrology, typically a rainfall runoff model, for application either direct to sub-catchments or direct to the 2D grid or mesh. Particular considerations around direct rainfall application are included in **Section B3**.

For urban drainage studies in the UK and Ireland there are a number of runoff volume models or methodologies which determine how much of the rainfall runs off the catchment into the drainage system after accounting for initial losses. The most commonly used methods are summarised in Table H-3 below.

The urban runoff surfaces are generally divided into three categories; paved areas, roof areas and permeable areas. It is only the runoff from permeable surfaces which varies with different storm durations and also during storm events as the soil's saturation varies.

The best source of information for urban hydrology methods is via the CIWEM UDG website. The Code of Practice for the Hydraulic Modelling of Urban Drainage Systems **(T)** provides a good overall summary of the methods. The CIWEM UDG website also contains a number of useful "User Notes" **(U)**, which provide more detailed information about certain topics, including urban hydrology e.g. User Note 28 – A new runoff volume model. Some software providers also provide information via their 'help' and support functions.

Table H-3 - Overview of urban hydrology methods

Method	Overview	Key points to note	References for further details
Fixed	Fixed runoff methodology has fixed percentage runoff from all surfaces including the permeable surfaces.	• The percentage from each surface (road, roofs and permeable) can be set differently. • The percentage runoff remains constant throughout the storm event and is identical for all storm events. • Irish Water specifications state that this method should be used for all impermeable surfaces. • This is generally used as a simplistic method. • It is rarely used for long or continuous storms as the "fixed" percentage does not vary through the simulation.	**T, U**
NewUK	Works on the basis of fixed percentage runoff from paved areas and roofs but with a varying percentage runoff from permeable surfaces.	• Most widely used in the UK. • There are only a small number of variables which can be used to alter the runoff from the permeable surfaces both in terms of magnitude and duration. • The principal drawback with this methodology is that when it is used with synthetic design storms it can sometimes lead to exceptionally large and false flooding volumes. • Irish Water specifications state that this method should be used for all permeable surfaces.	**T, U**

Method	Overview	Key points to note	References for further details
UKWIR	This method was developed to overcome the problems associated with the New UK method when simulating with synthetic design storms. This method used more variables than the New UK method and uses the HOST[1] soil classification rather than the WRAP[2] soil classification.	• This method has not yet gained widespread use in the UK but is gradually becoming more frequently used. • Irish Water are currently stating that this method "shall not be used as part of a model build and verification" until it has been further tested and its suitability confirmed.	**T, U**
Wallingford Procedure (Note: this method is very rarely used now)	The model predicts the total runoff from all surfaces in the sub-catchment, both pervious and impervious. The percentage runoff is given by an equation which has variables for soil type, annual rainfall and percentage impermeable.	• Runoff losses are assumed to be constant throughout a rainfall event. • At very low percentage impermeable values this methodology gave problems which lead to the "10-metre rule" being introduced. • This methodology is no longer recommended, however may still be found in existing models, so readers should be aware of it.	**T, U**

H.5.3 Runoff from pervious surfaces

This section covers runoff modelling for pervious surfaces in the urban area, e.g. gardens, parks and other green spaces. This is sometimes referred to as 'permeable' surfaces but for this appendix the term 'pervious' is used to distinguish from river catchments over permeable geology where more complex hydrological modelling is required. Improving confidence and understanding in pervious runoff modelling is growing in importance due to simulate long time-series rainfall and the increased interest and need to incorporate large pervious areas into integrated urban models.

These runoff methods are generally applied where there is a need to determine how much of the rainfall runs off the catchment and into the drainage system, frequently into the sewer network. As opposed to determining the runoff from a drainage area into a watercourse, which is where the fluvial hydrology approaches would be more appropriate.

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

There is also a lot of cross over with the urban hydrology methods, where several of the approaches can be applied to both urban and rural surfaces. Table H-4 summarises the most commonly used methods.

Table H-4 – Overview of runoff methods for pervious areas

Method	Overview	Key points to note	References for further details
Fixed	Applies a fixed percentage runoff to each area according to the proportion of pervious area.	• The percentage runoff remains constant throughout the storm event and is identical for all storm events. • This is generally used as a simplistic method. • It is not used for long or continuous storms as the "fixed" percentage does not vary through the simulation.	**T, U**
NewUK	Works on the basis of a varying percentage runoff from pervious surfaces. The runoff various with increasing or decreasing wetness. It uses API30 values for catchment wetness which are updated through the storm.	• Preferred option for modelling small (approx. <10 ha) permeable areas. • Most widely used in the UK. • There are only a small number of variables which can be used to alter the runoff from the pervious surfaces both in terms of magnitude and duration. • The principal drawback with this methodology is that when it is used with synthetic design storms it can sometimes lead to exceptionally large and false flooding volumes.	**T, U**

Method	Overview	Key points to note	References for further details
Standard Percentage Runoff (SPR)	Is generally applied as a rainfall percentage. The percentage is applied as a constant proportional multiplier at each time step where the effective runoff is determined by soil characteristics, rainfall volume and catchment wetness index. SPR is based on empirical equations for percentage runoff and has been derived from UK catchments up to 500km^2, it can be obtained as a catchment descriptor from the FEH Webservice.	• Predominantly used for larger, rural catchment (approximately >10ha). • It doesn't account for infiltration or the infiltration of ponded flood water. • SPR can have a tendency to overestimate the runoff. • Currently SPR, is the most common method used in 2D runoff modelling in the UK.	**E, L, T, U**
ReFH runoff routing model	Is a conceptual rainfall-runoff model than enables the user to generate hydrographs for a rural catchment.	• Can be used to model an observed event or to generate a design event input hydrograph. • Some software allows sub-catchments to generate the runoff within the model. • Can also be used to create inflow hydrographs.	**T, H**
Horton	The Horton Runoff Model was discovered by Robert E. Horton in 1933. The runoff model was interpreted by Horton as a separating surface that divided precipitation into two parts that follows different routes through the hydrological cycle. Simplistically, one part is initially absorbed by the soil and then proceeds through groundwater to the watercourses or is evaporated back to the atmosphere. The other part becomes overland runoff. The infiltration capacity is dependent on soil properties, capacity and the input of water. Once infiltration is exceeded, overland flow occurs.	• Has more flexibility (than the fixed percentage runoff method) in the variables and infiltration parameters. • Parameter selection relies on knowledge of physical soil properties • Intended for modelling runoff from pervious or semi-pervious areas.	Software providers 'help' function

Method	Overview	Key points to note	References for further details
Green Ampt	Named after two American physicists. It is a physically-based model commonly used to model infiltration in rainfall-runoff modelling.	• Intended for modelling runoff from pervious areas • Parameter selection relies on knowledge of physical soil properties • Percentage runoff varies over time through the duration of the storm • Soil drying represented to allow continuous simulation • Does not include evapotranspiration	Software providers 'help' function
Probability Distributed model (PDM)	The PDM is a general purpose, lumped conceptual model for continuous rainfall-runoff simulation.	• Used for real time flood forecast modelling but not commonly used for other applications in the UK	Software providers 'help' function
Soil Conservation Service (SCS) method	Model used for predicting storm flow volumes from rural catchments. Simple runoff model that allows for variation in the runoff coefficient depending on the catchment wetness.	• Derived for catchments with mainly uniform conditions. • Not widely used in the UK. • Only designed for rural catchments.	**T** and software providers 'help' function

H.6 Application of methods

There isn't a one size fits all approach to hydrology. The user/hydrologist must consider all the hydrological characteristics across the catchment and apply the most appropriate method/s for deriving the hydrological inputs in each sub-catchment. This will mean in most IUD studies incorporating both urban and fluvial hydrological approaches. The most appropriate choice will be down to experience of the hydrologist and project team and will influenced by the requirements of the study and the nature of the catchment. In many cases the availability of data will be a large driving factor.

It is also very important to remember that the selection of hydrology method/s is not a standalone activity for the hydrologist. The hydrologist must work with the hydraulic modeller to ensure the hydrology and hydraulic modelling methods are compatible. These discussions between hydrologist and hydraulic modeller should ideally take place as part of the Project Definition stage (**Section A3**) and must also continue throughout the study to make sure the IUD model delivers the desired outcomes of the project.

H.7 Level of competence

The Environment Agency flood estimation guidelines **(B)** state quite clearly that it is essential to ensure that the people carrying out the studies have the correct knowledge, skills and experience. This IUD guide reiterates and emphases this message.

The Environment Agency guidelines **(B)** include a helpful table which provides indicative levels of competence and the level of supervision recommended for different examples of flood estimation study. It should be noted that these are more specific to a fluvial flood study, however the concept can also be applied in an IUD study