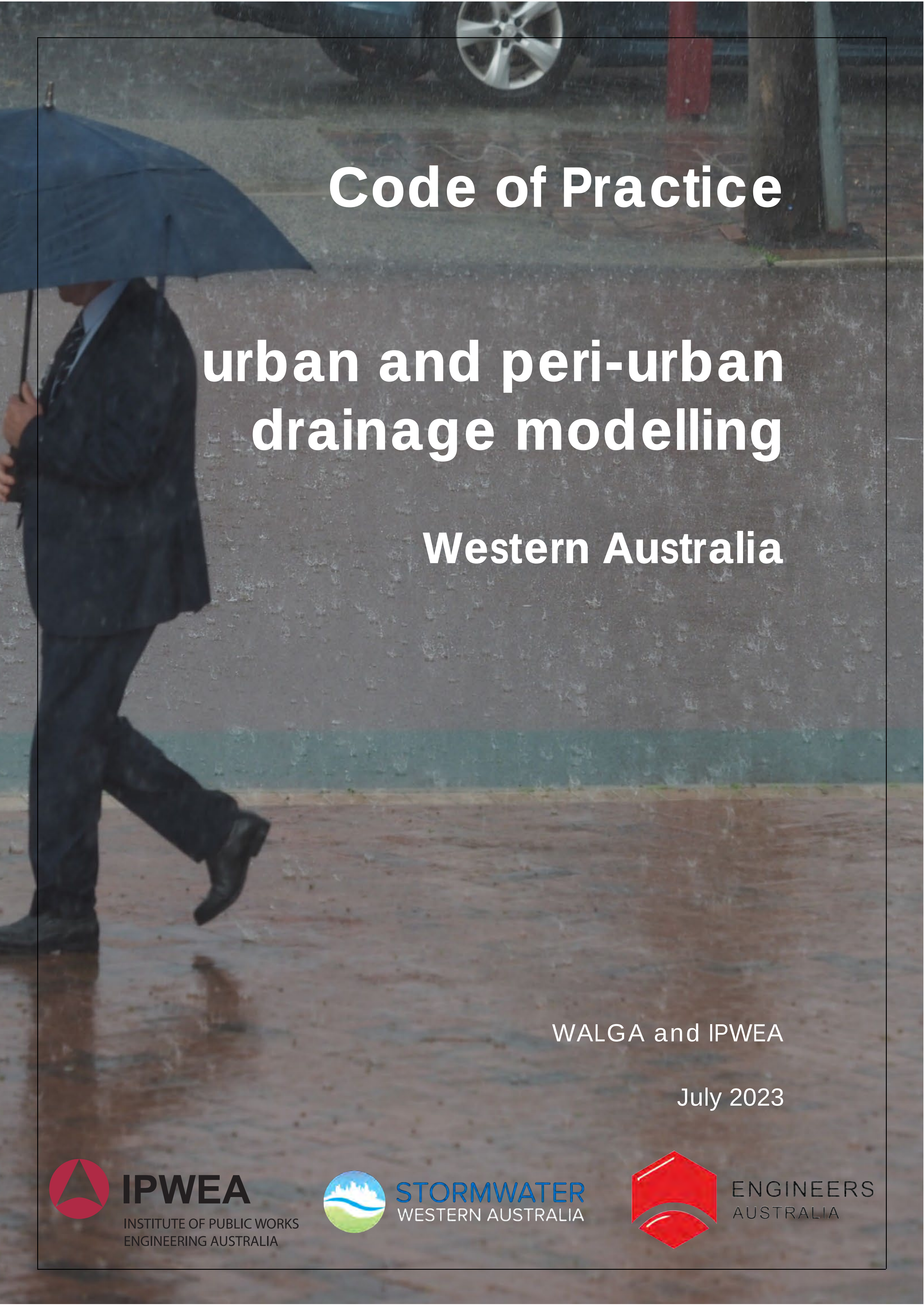

Code of Practice

urban and peri-urban drainage modelling

Western Australia

WALGA and IPWEA

July 2023

IPWEA
INSTITUTE OF PUBLIC WORKS ENGINEERING AUSTRALIA

STORMWATER
WESTERN AUSTRALIA

ENGINEERS AUSTRALIA

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Preface

The Institute of Public Works Engineering Australasia (IPWEA) welcomes the inclusion of this Code of Practice (CoP) as part of the practitioner's toolkit in designing stormwater systems for the frequent, minor and major rainfall events across Western Australia.

This CoP is to be read in conjunction with the latest versions Australian Rainfall and Runoff (ARR) and Stormwater Management Manual for Western Australia (SMM). The ARR being the principal source of guidance for flood estimation and catchment modelling across all of Australia and the SMM is a comprehensive approach to management of stormwater in WA. However, both of these documents would be considered high-level and there was a need to produce a CoP (or guide) that would assist practitioners in determining the most appropriate drainage modelling methods in the urban and peri-urban environment.

Ian Daniels,
Vice President IPWEA Australasia

The Stormwater Industry Association of WA (Stormwater WA) is pleased to support and endorse this modelling code of practice document. Since the concept of Water Sensitive Urban Design was created in WA over thirty years ago there has been significant progress made in urban stormwater management and drainage design practices. This document addresses one of the last remaining impediments in the implementation of current 'best practice' in urban drainage design. It provides guidance to achieve the best possible hydrologic, hydraulic and consequently environmental and urban form outcome. It embeds in practice the principal that designs must address the occurrence of 'Small', 'Minor ' and 'Major' rainfall events to achieve the best possible urban form outcome to achieve both environmental, sustainability and liveability outcomes.

Bill Till
President, Stormwater WA

The latest version of Australian Rainfall and Runoff (ARR) provides updated guidance on the methodology and process of hydrologic and hydraulic modelling within Australia. The revised document represents current industry best practice, and includes greater understanding of climate and hydrology, based on the larger datasets now available (longer datasets as well as improved collection methods). ARR was developed to ensure reliable and robust estimation of flood estimates and risk Australia wide, to provide data and guidance for projects involving critical infrastructure, town planning, mining, flood warnings and flood emergency systems, flood management plans for both urban and rural communities, as well as others.

By necessity, ARR may be reasonably generalistic in application, as it seeks to address the above projects across the wide range of climates, land-uses and settings.

This Code of Practice was written and intended for Western Australian conditions and audiences, providing greater detail about WA and Swan Coastal Plain conditions and hydrology, including WA-centric issues such as infiltration and shallow groundwater, for the urban and peri-urban environments. This document is intended to supplement, rather than replace ARR (referencing ARR where applicable), and provide methodologies suitable for local conditions, as well as addressing WA policy documents and agency direction.

Alex Rogers
Representative of Hydrology and Water Resources Panel, Engineers Australia

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Glossary of terms

These are terms used in documents reviewed that are not always understood or applied consistently.

Term	Definition
AEP	Annual Exceedance Probability. The probability that a given rainfall total accumulated over a given duration will be exceeded in any one year. For example, a flood with a 1% AEP has a one in a hundred year chance of being exceeded in any year.
ARI	Average Recurrence Interval. The average, or expected, value of the periods between exceedances of a given rainfall total accumulated over a given duration.
ARR	Australian Rainfall and Runoff
Baseflow	Baseflow is the water that exists (for example in a river) in the absence of a storm event. It sustains flow and ecosystems between significant precipitation events and helps regulate surface water quality and quantity
Calibration	Process of adjusting model parameters to improve representation of real-life scenarios using observed data.
Catchment modelling	Set of modelling processes or components that are used together to produce estimates of flood characteristics. These modelling processes can be provided within a single modelling platform (such as a runoff-routing model) or can be the combination of a number of modelling platforms (where a runoff-routing model is used to generate inflows to a separate hydraulic model).
Drop structures, orifices, weirs, bifurcations, GPTs, flap valves, pump stations	Hydraulic control structures that may exist as part of a drainage system that require detailed consideration during modelling.
EIA	Effective Impervious Area. Also referred to as directly connected areas, these are the impervious surfaces that are hydraulically connected to a drainage system. Examples include streets with curb and gutter and paved parking lots that drain onto streets.
EY	Exceedance per year
Flood hydrograph estimation	Provides guidance on the hydrologic models necessary for prediction of design flood hydrographs including the different types of hydrologic models used to represent runoff generation and runoff routing and design data for baseflow and losses for design flood estimation.
Flow path	An overland route taken by accumulated runoff
GIS	Geographic Information System (GIS) technology is a system that creates, manages, analyses and maps all types of data.
Groundwater modelling	A groundwater model provides a quantitative framework for synthesising field information and for conceptualising hydrogeologic processes. Used to simulate and predict a groundwater situation or aquifer conditions.

Term	Definition
Hydraulic conductivity	A property of porous materials, soils, and rocks, that describes the ease with which a fluid (usually water) can move through the pore space, or fractures network. It depends on the intrinsic permeability of the material, the degree of saturation, and on the density and viscosity of the fluid. Saturated hydraulic conductivity, Ksat, describes water movement through saturated media.
Hydraulic model	Is a collection of mathematical equations that give a simple representation of reality. They estimate flow, water level and velocity. It can be used as a tool to plan infrastructure improvements, develop maintenance strategies, guide rehabilitation and be proactive in anticipating problems within the system.
ICA	Indirectly Connected Areas. Impervious areas which are not directly connected, runoff from which flows over pervious surfaces before reaching the drainage system. Examples include; a roof that drains onto a lawn, nature strips, garden areas next to paved patios.
Infiltration	The downward entry of liquid into the soil.
Infiltration rate	The rate, based on measured incremental infiltration velocities, at which liquid can enter the soil under specified conditions. During infiltration, this rate may decrease with time until reaching a quasi-steady value.
LiDAR	Light Detection and Ranging. It is a remote sensing method used to examine the surface of the earth. It is a method for determining ranges by targeting an object or a surface with a laser and measuring the time for the reflected light to return to the receiver.
Losses	Loss is defined as the precipitation that does not appear as direct runoff and is attributed to the following key processes: interception by vegetation, infiltration into the soil, retention on the surface and transmission loss through the stream bed and banks.
Model / Modelling	A simplification of reality that is constructed to gain insights into selected attributes of a physical, biological, economic or social system. A formal representation of the behaviour of the system processes, often in mathematical or statistical terms. The basis can also be physical or conceptual.
Peak flow estimation	The maximum rate of discharge during the period of runoff caused by a storm is called the 'peak flow'.
Permeability	The ability of soils to transmit water through its layers.
Rainfall-runoff modelling	A mathematical model that describes how rainfall is converted into runoff in a drainage basin (catchment area).
Runoff generation model	Runoff generation models simulate the interaction between rainfall and the catchment surfaces to estimate the proportion of rainfall that becomes runoff. This includes consideration of losses such as interception, depression storage, and infiltration, and usually accounts for transmission losses, unless they are expected to be very large in which case they should be explicitly modelled.

Term	Definition
Runoff routing model	Runoff routing models simulate the behaviour of runoff across the catchment to estimate the proportion and timing of runoff that arrives at the end of the catchment and enters the drainage system. Allows the user to sub-divide the catchment into a number of sub catchments to model the runoff generation and flow routing. It determines how quickly the rainfall enters the drainage system for the catchment.
SMM	Stormwater Management Manual
Urban drainage modelling	Type of catchment modelling specifically aimed at assessing the performance of an existing or proposed urban drainage system under a range of conditions. Commonly used as a design tool.
Validation	Process of reviewing model performance against real-life data and information or through comparison with other flood estimation methods (where real-life data isn't available). Parameters may be adjusted in this process when no calibration has been possible.
Water management modelling	Broad grouping of modelling of many different types that is undertaken to assist with water management tasks. Includes • Water balance modelling • Flood modelling • Water supply modelling • Wastewater system modelling • Multi-criteria assessment • Cost-Benefit analysis • Decision support modelling • Catchment water sharing models
Water quality modelling	Water quality models provide evidentiary support of water issues and help identify information gaps.

1 INTRODUCTION AND BACKGROUND

This Code of Practice has been prepared to provide advice on urban and peri-urban drainage modelling in a Western Australian context. It does not replace but provides support for the application of relevant guidance, particularly *Australian Rainfall and Runoff* and the *Stormwater Management Manual for Western Australia,* when undertaking urban drainage modelling in support of land use planning decisions in WA.

1.1 Purpose of this document

Australian Rainfall and Runoff, a guide to flood estimation (Ball, J. et al. 2019) (ARR) is the primary technical resource for modelling practitioners, containing extensive guidance for best practice flood estimation and catchment modelling in Australia.

Other resources, such as the *Stormwater Management Manual for Western Australia* (Department of Water, 2004-2007, updated 2022) (SMM) provide more context-specific guidance for the application of ARR principles and approaches but are relatively high-level in terms of technical detail which limits their value as guidance for modelling practitioners.

There are many points in an urban or peri-urban drainage modelling process where a practitioner must use their experience and knowledge to determine the most appropriate methods, assumptions, and parameters to apply in the specific site and context of a particular modelling project. Whilst it cannot replace the accumulated experience of expert modellers, this Code of Practice aims to provide supporting guidance for these deliberations, aimed at:

- new modellers,
- modellers with limited experience of WA sites and contexts, and
- non-modellers required to review and approve the outcomes of modelling.

In addition, the Code of Practice can and should provide clarity for modellers around the expectations of reviewers in relation to reporting, data management and handover.

The use of this Code of Practice is voluntary, but the document has been endorsed by participating industry bodies as the minimum standard for modelling that is expected.

1.2 Scope of this document

This Code of Practice addresses the modelling of stormwater quantity only, including where this intersects with groundwater, for systems that manage frequent, minor, and major rainfall events in urban and peri-urban areas. It is not recommended for application in rural areas. The document represents collective understanding at the time of authorship which may change in future. Modellers can continue to be compliant with the Code of Practice by using the latest science and modelling approaches provided they are appropriate for the catchment and problem being considered. The document may also be supplemented by guidance for other considerations such as water quality and/or continuous simulation modelling in future.

In defining the scope of this Code of Practice, it is important to note several key areas that this document does not address. Specifically, the Code of Practice does not:

- set policies or assessment criteria for drainage design
- provide fixed numerical values for modelling parameters
- replace or reproduce ARR or the SMM

The key areas of application for this Code of Practice are:

- Modelling of urban and peri-urban drainage systems.
- Predicting flood behaviour in developed and developing areas.
- Planning new drainage systems.
- Designing new drainage systems.
- Designing upgrades/modifications to existing drainage systems.

It is noted that road and drainage design need to be undertaken collaboratively with both requiring key outputs and information from drainage modelling. However, this Code of Practice does not provide guidance for road design. Guidance for road design is provided in Modules 4 and 8 of the IPWEA *Local Government Guidelines for Subdivisional Development (latest edition)*.

1.3 Aim of the document

This Code of Practice for urban and peri urban drainage modelling aims to:

- Help modellers to:
  - navigate ARR and other guidance materials for modelling
  - develop models to address WA policies and assessment criteria
  - define site investigations/information relevant to modelling including topographical, geotechnical, groundwater, vegetation condition & extent
  - interpret site conditions for use in modelling (including topographical, geotechnical, groundwater, vegetation condition & extent)
  - select model parameters (eg: losses) including consideration of site specific (WA context) issues such as soil types, groundwater conditions, land uses, drainage system types
  - apply modelling methods, assumptions, and parameters specific to greenfield vs infill situations
  - apply modelling methods, assumptions, and parameters specific to common types of WA drainage systems and structures
  - apply different modelling methods, assumptions, and parameters that are specific to different types of commonly used modelling software
  - undertake model validation and quality assurance based on consideration of risks, costs, and benefits, including consideration of acceptable error margins and sensitivity analysis
  - produce reporting to properly address WA policy and assessment processes.

- Help non-modellers required to review and approve the outcomes of modelling to:
  - navigate ARR and other guidance materials for modelling
  - interpret site conditions for use in modelling (including topographical, geotechnical, groundwater, vegetation condition & extent)
  - determine the suitability of selected model types
  - determine the suitability of selected parameters
  - determine when a technical peer review should be considered, based on consideration of risks, costs, and benefits

- Help drainage system managers to:
  - understand the likely accuracy of modelling and the risks associated with both over-design and under-design of systems and structures
  - understand the benefits and requirements associated with handover and ongoing use of models.

1.4 Structure of the document

This Code of Practice contains the following sections:

2. Project planning and definition
3. Model conceptualisation
4. Data collection
5. Model development
6. Model confidence
7. Application of models
8. Documentation
9. Resources and references

These sections provide guidance for the key steps in the modelling and design process documented in ARR Book 9, Chapter 5 and depicted in Figure 1.

Table 1 provides a summary of each stage in the process and where to find relevant information in this Code of Practice.

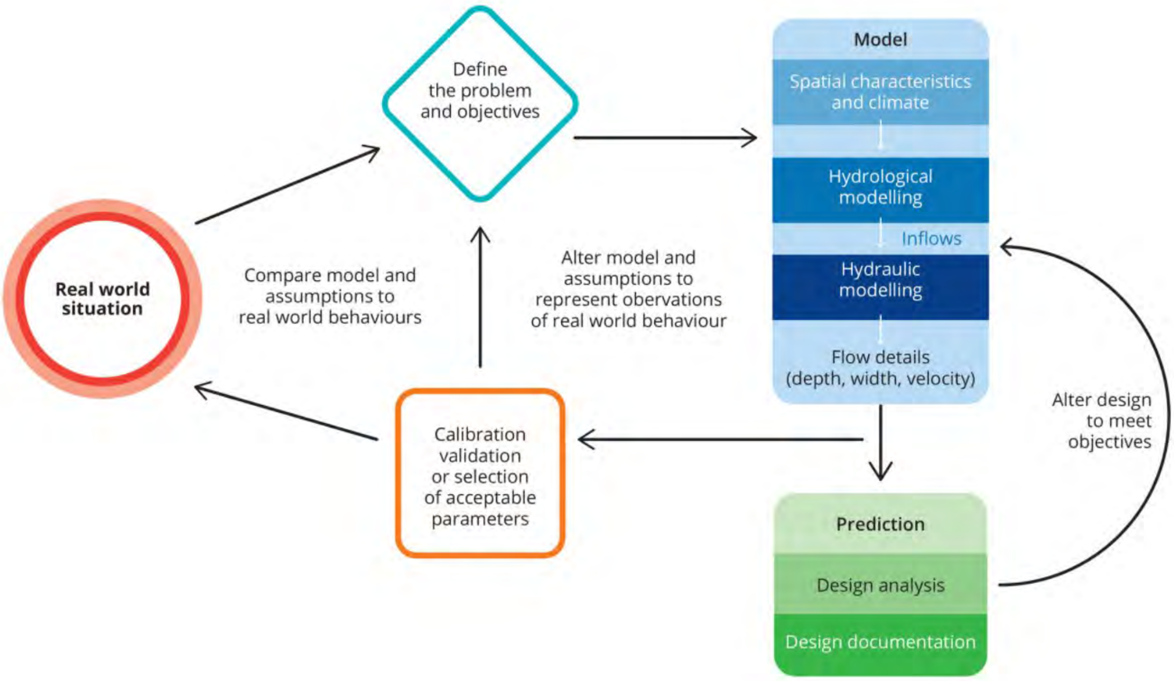

Figure 1: The Stormwater Design Process (Source: ARR, 2019)

Table 1: Urban and Peri-Urban Drainage Modelling Process

Process	Section	Details
Define project objectives	1/2/3/4	• Define project purpose and drivers • Determine interaction with other projects and catchment issues • Identify stakeholders • Develop stakeholder plan • Obtain and review relevant data
Define type and scope of modelling	3/4	• Define data needed to meet project objectives • Model conceptualisation. (i.e. how will system be represented by the model? • Review potential interaction of above and below ground systems • Define catchment boundaries
Collate and review existing information	3/4/5	• Obtain and review existing model information • Obtain and review asset and other relevant data • Assess initial model and data confidence
Gap analysis	3/4/5	• Plan model update requirements • Plan new model build requirements • Plan asset data collection requirements
Model build or update	4/5/6	• Collect asset data • Undertake model build including parameter choice • Review and set data confidence requirements
Model validation	7	• Definition of one or more validation metrics • Validation against site monitoring hydrographs • Historic validation (records of flooding occurrences and/or peak water levels)
Assess model confidence	7	• Review model confidence • Sign off
Adapt model for use	8	• Update model for design horizons • Remove transient operational effects (where required) • Restore permitted/design performance (where required)
Application of models	8	• System performance runs (hydrologic, hydraulic and environmental) • Develop interventions • Check performance against standard including level of service • Reporting and sign off
Documentation and model maintenance	9	• Prepare documentation and QA • Undertake periodic model maintenance

1.5 Relationship to other documents

1.5.1 Australian Rainfall and Runoff

First published in 1958, *Australian Rainfall and Runoff* (ARR) is the principal source of guidance for flood estimation and catchment modelling that is used by engineers in Australia and internationally.

A major revision of ARR commenced in 2008 with the definition of 21 projects aimed at filling specific knowledge gaps, followed by the compiling, and writing of chapters in the revised ARR which is now provided as the web-based publication: *Australian Rainfall and Runoff, a guide to flood estimation* (Ball, J. et al. 2019).

Structure of documentation

ARR includes nine separate books:

1. **SCOPE AND PHILOSOPHY –** A general introduction to Australian Rainfall and Runoff including a brief introduction to terminology, fundamental issues and basic approaches to flood estimation, data related aspects inclusive of its management and data uncertainty, risk-based design and dealing with climate change.
2. **RAINFALL ESTIMATION –** Discusses the importance of design rainfall for flood estimation and differences between historical and design rainfalls, issues associated with development of rainfall models for design flood estimation in ARR.
3. **PEAK FLOW ESTIMATION –** Provides a general introduction to peak flow estimation based on flood frequency analysis, as well as covering specific technical aspects.
4. **CATCHMENT SIMULATION FOR DESIGN FLOOD ESTIMATION –** Deals with general concepts and issues in catchment modelling for design flood estimation including discussion of the types of catchment modelling systems (event and continuous) and the need for integrating hydrologic, and hydraulic components of the system.
5. **FLOOD HYDROGRAPH ESTIMATION –** Provides guidance on the hydrologic models necessary for prediction of design flood hydrographs including the different types of hydrologic models used to represent runoff generation and runoff routing and design data for baseflow and losses for design flood estimation.
6. **FLOOD HYDRAULICS –** Presents information relevant to the hydraulic modelling of river reaches, floodplains and structures for design flood estimation, the application of software for numerical modelling of flood hydrographs, blockage of hydraulic structures and interaction of coastal and catchment flooding. Also included in this book is guidance on designing for the safety of people and vehicles.
7. **APPLICATION OF CATCHMENT MODELLING SYSTEMS –** Provides discussion of major issues in the practical application of catchment modelling systems to different flood estimation problems, including establishment of catchment modelling systems, calibration and validation of model parameters and dealing with uncertainty in model outputs.
8. **VERY RARE TO EXTREME FLOOD ESTIMATION** – Provides information and guidelines for the special design applications where floods of low Annual Exceedance Probabilities need to be estimated, such as for sizing of spillways for large dams, design of major structures located in the floodplain and flood risk management in situations where very large flood damages or significant risk to life from flooding could be expected.
9. **RUNOFF IN URBAN AREAS –** Provides urban drainage guidance including changes to the natural hydrologic cycle resulting from urbanisation, how these changes impact on design flood estimation in urban environments and use of storage facilities from on-site storage to detention (retention) basins to large flood mitigation dams. Also discusses limitations of the Rational method and the changes in approach necessary for consideration of volume-based problems rather than peak flow-based problems.

Scope of documentation relevant to urban and peri-urban drainage modelling

The principal books dealing with topics of relevance to urban drainage modelling are:

- Book 5 – Flood hydrograph estimation
- Book 6 – Flood hydraulics
- Book 7 – Application of catchment modelling systems
- Book 9 – Runoff in urban areas

Books 5, 6 and 7 provide information about modelling tasks and assumptions that are common across all catchment types (i.e. urban, semi-rural, rural, and natural) while Book 9 is more directly dealing with the specific requirements for modelling and drainage design in urban drainage catchments.

1.5.2 Stormwater management manual for WA

The *Stormwater Management Manual for Western Australia* (Department of Water, 2004-2007, updated 2022) was developed to present a comprehensive approach to management of stormwater in WA, based on the principle that stormwater is a resource – with social, environmental, and economic opportunities.

Structure of documentation

The document is presented as a series of eleven stand-alone chapters:

1. **INTRODUCTION** – Describes what stormwater is and outlines the purpose of the manual, the intended audience of the manual and how the manual can help.
2. **UNDERSTANDING THE CONTEXT** – Describes the reasons for improving stormwater management and provides the principles, objectives, key roles and responsibilities for stormwater management in WA.
3. **This chapter is superseded by** *Draft State Planning Policy 2.9 Planning for Water* **(WAPC 2021).**
4. **This chapter is superseded by the** *Decision process for stormwater management in Western Australia* **(DWER 2017).**
5. **STORMWATER MANAGEMENT PLANS** – Provides guidelines on the preparation, implementation and review of stormwater management plans for catchment areas and local government areas. The plans address urban stormwater quantity and quality from a management perspective, rather than a development perspective, to ensure that ecological, social/cultural and economic values are protected and enhanced and that management issues are addressed in a coordinated manner.
6. **RETROFITTING** – Explains issues to be addressed and presents tools for improving stormwater management in existing urban developments through modification of existing stormwater systems, or installation of additional/alternative stormwater management devices and approaches. Includes case studies and examples that demonstrate how to undertake retrofitting projects.
7. **NON-STRUCTURAL CONTROLS** – Describes the initiatives available to manage the quantity and reduce pollution of stormwater by optimising practices of local government operations, state government asset managers, industrial/commercial businesses and householders, through mechanisms such as maintenance practices, regulation, strategic planning and education. Describes non-structural controls, their benefits, use, effectiveness and evaluation. Provides advice on how to select and implement non-structural controls. Provides technical guidelines on the most relevant non-structural controls.
8. **EDUCATION AND AWARENESS FOR STORMWATER MANAGEMENT** – Presents ways to prepare and deliver education programs to reduce the amount of pollution that enters the stormwater system.

9. **STRUCTURAL CONTROLS** – Describes structural measures that can be designed and located in a catchment undergoing new development or retrofitted within an existing development to manage the quantity of stormwater runoff and prevent or treat stormwater pollution. Provides an overview of the benefits, use, effectiveness and evaluation of each type of structural control. Provides information on the selection of structural controls. Provides technical guidelines on the most relevant structural controls. Includes case studies and examples.
10. **PERFORMANCE MANAGEMENT AND EVALUATION** – Provides information on establishing a monitoring and evaluation program that tracks the trends and performance of structural and non-structural stormwater management practices. Examples are included to demonstrate the methodologies promoted in the chapter.
11. **FURTHER INFORMATION** – Provides a glossary of terms used in the manual and some useful contacts, websites and references for obtaining further information about stormwater management. Note: This chapter has been updated to include a new definition for Average Recurrence Interval.

Scope of documentation relevant to urban and peri-urban drainage modelling

Chapter 9 of the manual; *Structural Controls*, describes and provides design guidance for engineered devices implemented to manage runoff quality and quantity, to control, treat or prevent stormwater pollution and/or reduce the volume of stormwater requiring management.

Principally, the design guidance presented is focussed on the design of specific elements of the structures to provide capacity for known or estimated design flows. For more detailed modelling guidance, the reader is referred to Australian Rainfall and Runoff.

1.6 Experience and training of staff

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

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

- input of data and its implications
- operational performance requirements for urban drainage systems
- urban hydrology
- hydraulics of flow in piped and open drainage systems, watercourses and ancillary structures
- the assumptions implicit in the way the software carries out the calculations
- methods of flow measurement and their accuracy
- engineering solutions

2 PROJECT PLANNING AND DEFINITION

Before commencing development of a model, the purpose and required use of the model should be clearly defined including the questions that have led to the commissioning of a modelling study and the considerations that need to be included to address the questions and concerns of relevant stakeholders.

2.1 Problem definition – what is your question?

This step is critical. The purpose of the model and the question it is trying to answer will influence the rest of the process and impact on the acceptability of the outcome. Be clear about what your objective is and who you are demonstrating the outcomes for.

There are many reasons that a drainage modelling study may be commissioned. These include:

- understanding and managing local flood behaviour
- understanding and managing drainage system performance
- developing design solutions for existing drainage systems
- planning and designing new drainage systems

In each case there may be different requirements to address which may require different modelling approaches, standards of data inputs, levels of detail and validation quality resulting in different levels of confidence. Some example questions that are commonly addressed through modelling studies are provided in Table 2. The type of modelling study undertaken will depend on the question being answered (model purpose) and the type of model will depend on the data required from the model.

Table 2: Problem definition – what is your question?

Model purpose	Example questions to be answered
Understanding and managing local flood behaviour	• Where are the critical points in the drainage system where flooding occurs? • Where are the local overland flowpaths? • Do overland flowpaths satisfy relevant safety criteria (depth and velocity)? • Where are floodwaters stored? • Do flood storage areas satisfy relevant safety criteria (depth and accessibility)?
Understanding and managing drainage system performance	• What is the achieved level of service for different parts of the system and what are the social (e.g., safety) or financial consequences of flooding in larger events? • Where are the critical points in the drainage system where failure/blockage would have catastrophic consequences? • Where are the critical points in the drainage system where risk of failure/blockage is high and what are the social (e.g., safety) or financial consequences? • Are relevant system freeboard requirements satisfied? • Are minimum velocities for self-cleaning of pipes satisfied? • Are maximum velocities within tolerances?

Model purpose	Example questions to be answered
Developing design solutions for existing drainage systems	• What has caused the system issue that requires a solution? • What system change is required to resolve the issue? • Are there multiple options to resolve the issue? • Which solution option is the most effective? • Can multiple issues be addressed by a single solution? • What are the detailed design considerations that will need to be addressed? • What are the risks and consequences of an event larger than the design event? • What risks and management requirements are associated with the proposed solution?
Planning new drainage systems	• What are the critical extent and sizing requirements of the drainage system to satisfy level of service requirements? • How will the system perform under a range of conditions? • Where are flood storage areas likely to be required? • How large do flood storage areas need to be and how long will they take to empty? • Where are the critical locations that require fail-safes such as overland flowpaths, to be built into the system? • What are the risks associated with system failure?
Designing new drainage systems	• Pipe, channel, and culvert sizing and material choices • Inlet and outlet types, sizing, and arrangements • Hydraulic structure types, sizing, and arrangements • Scour locations and design requirements to address • Sag and gutter flow locations, extent, and design requirements

2.2 Common design rainfall events

It is noted that the information required from the model and the level of confidence required is generally established by the commissioning person or organisation following consideration of the requirements of key stakeholders. However, in WA, the planning and design of new urban drainage systems is often commissioned by a developer. In this case, the information and level of confidence requirements should be aligned to the *Decision process for stormwater management in WA* (DWER, 2017) and agreed with the eventual drainage system owner/manager which is usually the local government.

The *Decision process for stormwater management in WA* (DWER, 2017) presents a stormwater management design approach for application in developed and developing urban and peri-urban areas. A core principle for this approach is:

> *"Design for the small, then minor, then major rainfall events and aim to replicate how water moves in the natural landscape."*

This approach, therefore, requires consideration of rainfall events described as small, minor and major events. These descriptions are typically aligned with the range of rainfall event descriptors that have been adopted in ARR and are presented in Figure 2.

Frequency Descriptor	EY	AEP (%)	AEP (1 in x)	ARI
	12			
	6	99.75	1.002	0.17
	4	98.17	1.02	0.25
Very Frequent	3	95.02	1.05	0.33
	2	86.47	1.16	0.5
	1	63.21	1.58	1
	0.69	50	2	1.44
Frequent	0.5	39.35	2.54	2
	0.22	20	5	4.48
	0.2	18.13	5.52	5
	0.11	10	10	9.49
Rare	0.05	5	20	19.5
	0.02	2	50	49.5
	0.01	1	100	99.5
	0.005	0.5	200	199.5
Very Rare	0.002	0.2	500	499.5
	0.001	0.1	1000	999.5
	0.0005	0.05	2000	1999.5
	0.0002	0.02	5000	4999.5
Extreme				
			PMP/ PMP Flood	

Figure 2: Australian Rainfall and Runoff Preferred Terminology (Source: ARR, 2019)

The alignment of the ARR descriptors from Figure 2, with the ranges of events that are generally considered small, minor, and major events for urban and peri-urban drainage design purposes in WA is shown in Figure 3.

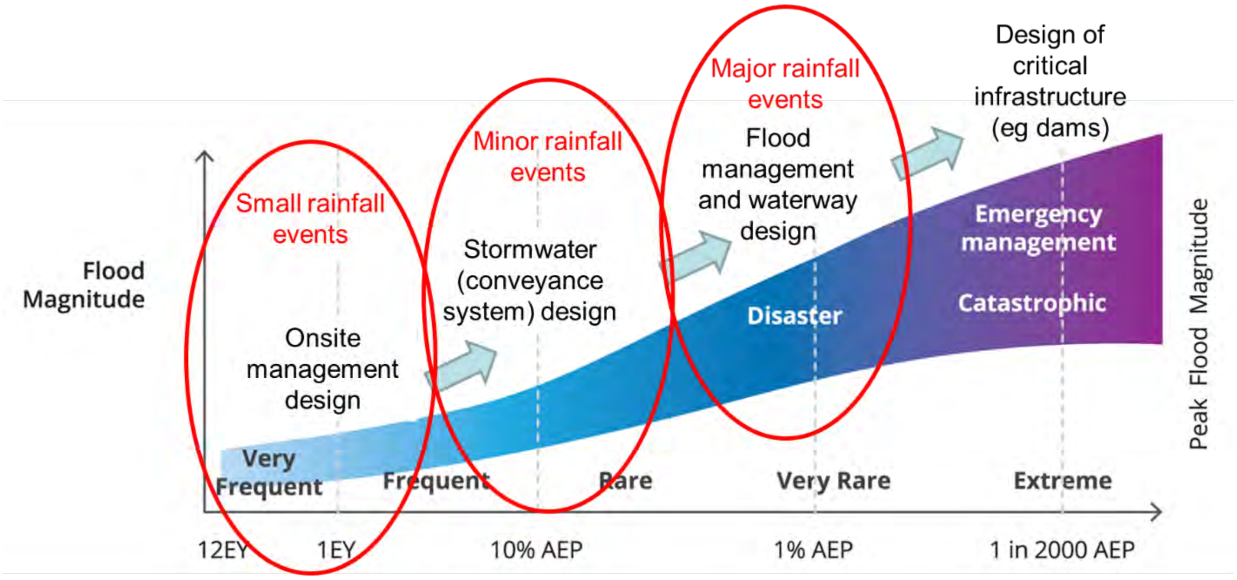

Figure 3: The Stormwater Design Continuum in WA (Source: New WAter Ways, adapted from ARR, 2019)

2.3 Stakeholder definition – who are you talking to?

A drainage modelling study is likely to have multiple interested stakeholders with differing requirements and areas of interest. This will include agencies responsible for approval of the model outputs as well as those affected by its outcomes and those providing information or data as inputs to the study.

The key stakeholders that need to be considered in drainage modelling studies in WA and their key considerations are represented in Table 3. It is important to note that stakeholders will often have an interest in a broader range of considerations than those presented in Table 3 which includes only the key focus areas for each stakeholder.

Table 3: Stakeholder definition

Stakeholder	Environmental protection	Planning criteria	Amenity and community outcome	Performance standards	Asset protection	Maintenance
Community groups and individuals	✓		✓			
Planning						
DPLH/WAPC		✓	✓			
DBCA (Swan-Canning Development Control Area)	✓	✓	✓			
Environmental						
EPA	✓					
DWER	✓	✓		✓		
DBCA	✓					
Engineering Design						
Local government	✓	✓	✓	✓	✓	✓
Main Roads				✓	✓	✓
Water Corporation				✓	✓	✓

Having determined which stakeholders will be involved, it is critical to consider if they are likely to have different questions to those chosen to underpin the model purpose and ensure that these are considered as part of project delivery. This will require effective engagement with each stakeholder so that their questions and requirements can be properly captured and allow them to be explored by the study where appropriate.

2.4 Defining and assessing confidence levels

There is uncertainty in many aspects of drainage modelling and any list of potential uncertainties would be large given the number of data inputs and the complex numerical calculations that are applied to represent multiple physical processes. There are; however, three main categories of uncertainties that need to be considered when defining and assessing confidence levels:

- Input data
    - Asset data
    - Catchment data
    - Rainfall data
    - Land use data
    - Parameter selection
- Model construction
    - Software selection
    - Model coverage and boundaries
    - Representation of flowpaths
    - Representation of structures
- Validation data
    - Flow data
    - Historical records

Each of these categories will have varying levels of confidence. For physical components of the model this will be dependent on the level of detail, accuracy and amount of data used in the model. In general, the more real-life measured data that are used in the model, either from physical surveys or from other reliable sources, the higher the confidence in model structure. However, introducing additional physical detail will increase the uncertainty associated with parameter selections and therefore reduce confidence in the model performance. The best model performance will generally be achieved when parameter uncertainty and model structure uncertainty are balanced.

It is important that the required confidence levels are set in consultation with the commissioning person or organisation. They should be set at levels that are appropriate for the specific purpose of the model and level of risk associated with modelled outcomes. Setting the levels too high will result in an unduly expensive model, whereas levels set too low may result in a model that does not meet expectations. In many cases budget constraints should be considered in defining the data collection and verification requirements.

The level of detail required is considered further in **Section 3** of this Code of Practice, data collection is discussed in **Section 4**, and model validation is considered further in **Section 6. Section 6** also deals with consideration of risk and provides a framework for confidence to be assessed in a qualitative or quantitative approach.

2.5 Where and when to get support and assistance

Assessment of drainage modelling requires the assessor to have a level of model understanding that is appropriate to the complexity of the modelling presented and Appendix A provides a list of considerations for model assessment.

For simple drainage modelling where the risks associated with model inaccuracy are low, such as for greenfield development with limited interaction with existing drainage systems and where the groundwater is not shallow, the model assessment may be completed by the modeller themselves or by a supervising modeller. In these cases, it is expected that model documentation provided to the commissioning person or organisation, approvals agency, and/or the eventual drainage system owner/manager, as described in Section 8, will be sufficient to demonstrate that an appropriate modelling process has been followed.

Section 9 of this *Code of Practice* provides information for reviewers with limited experience to guide their review of modelling documentation provided.

For more complex models or where risks are more significant, such as modelling of extensive or complex existing drainage systems, modelling should be undertaken by a more experienced practitioner and a third-party peer assessment could be considered.

It is recognised that the level of knowledge required to determine when a model requires additional assessment is not always available within organisations required to review and approve modelling reports. In this case, assistance and advice can be requested from the Department of Water and Environmental Regulation.

3 MODEL CONCEPTUALISATION

Every model should be built to represent the site-specific characteristics of the site in a manner which enables the model to answer the questions defined in project planning, as described in section 2. The model should convey the fundamental principles and basic functionality of the system which it represents. This is known as model conceptualisation.

ARR Book 6 Chapter 4 presents a conceptualisation process for development of a site-specific numerical model, shown schematically in Figure 4. The details of this process are not reproduced in this Code of Practice, but the following sections provide additional guidance for applying this process in the context of urban and peri-urban drainage modelling in WA, under the headings of level of detail, model selection and model build.

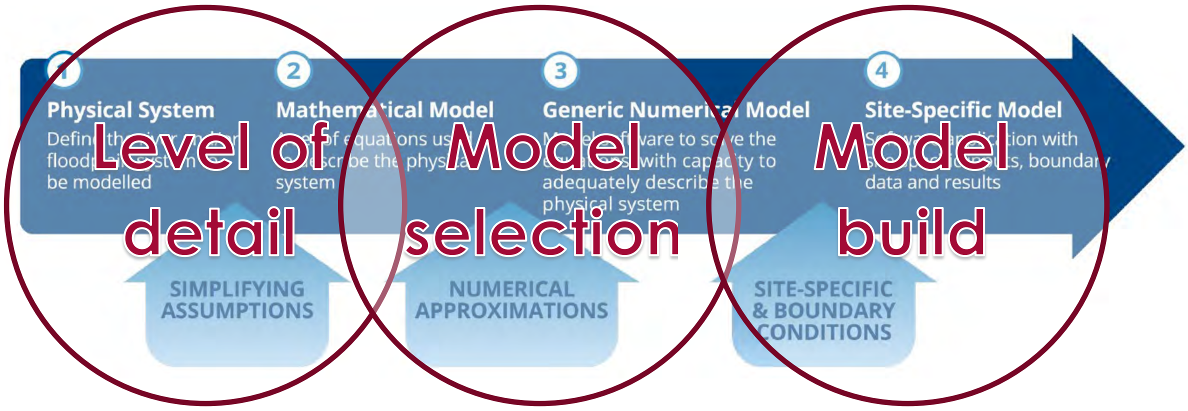

Figure 4: Stages in Numerical Hydraulic Model Conceptualisation and Development (Source: ARR, 2019)

3.1 Level of detail – how detailed does the model need to be?

The levels of detail applied in urban and peri-urban drainage models can be generally described in three categories:

- Type I – simplified model, constructed with limited detail. This category of model is typically used in locations to gain an appreciation of overall performance or to represent the transfer flows to a more detailed part of the model.
- Type II – planning or general-purpose model. This category of model is typically used where the model is being used to understand risk and/or develop conceptual designs.
- Type III – detailed model, constructed with a high level of detail. This type of model is typically used for detailed local investigations and development of detailed designs.

The level of detail selected for an urban drainage model needs to provide a representation of the catchment and drainage system that provides the required output data and satisfies the required confidence levels. The model may combine different model types to feature simplified representations of less critical parts of the system or catchment and a higher level of detail in specific areas or in relation to certain types of assets or features, as detailed in the project scope. This is explained in more detail below.

3.1.1 Type I – Simplified

Simplified models are used to provide a highly conceptualised representation of the modelled catchment or system. They are generally used to provide information at a specific location, as part of a larger catchment model or as an input to another model.

Their primary functions are:

- Replacement of boundary conditions in a more detailed model.
- To understand high level performance of a catchment at a single location such as its outfall or terminal storage area.
- As an input to a water balance model or rapid simulation model

Simplified models are likely to have higher levels of uncertainty than other types due to the ‘lumped’ representation of hydrological and/or hydraulic processes.

3.1.2 Type II – Planning

This type of model is the most frequently used type and is typically the default applied where there are no specific requirements. Their primary functions are:

- Understanding and managing local flood behaviour
- Understanding and managing drainage system performance
- Developing design solutions for existing drainage systems
- Planning new drainage systems (most water management reporting will fit into this category)

Planning type models should include representation of all significant structures and all known problem areas. Some minor simplification of the network in the model is reasonable, such as omitting small diameter pipes. Data inputs to the model will generally be based on available GIS or design information with surveys limited to critical locations and structures or areas of significant uncertainty. Network simplification or interpolation of missing or unreliable data may be accepted provided this is consistent with the required level of confidence.

3.1.3 Type III – Detailed

This type of model is similar to Type II but with increased detail, particularly in relation to hydraulic performance within and around inlets, outlets and other structures. Their primary functions are:

- Detailed investigation of a specific location or structure.
- Detailed design of a system or structure.

For detailed models of existing systems or structures it is usually necessary for detailed surveys of the specific area of interest to be undertaken to obtain information that is not generally held in asset records and to confirm the accuracy of data. Interpolation of data should be avoided for this type of model.

3.2 A bit about shallow groundwater

In many areas of Western Australia, but particularly on the Swan Coastal Plain, groundwater is present close to the ground surface in shallow superficial and surficial aquifers, and this can be an important consideration for runoff and drainage system modelling.

Where groundwater levels are close to the ground surface the capacity of the soil to receive infiltration losses is reduced, impacting upon both the loss model used for catchment runoff generation, and the infiltration achieved from stormwater infiltration systems such as soakwells, basins, and swales. Groundwater can also have a direct impact on flow or storage capacity within drains by providing baseflow from seepage from groundwater.

This Code of Practice addresses the modelling of stormwater quantity only. Groundwater is discussed in relation to its interaction with stormwater systems but specific guidance on modelling of groundwater or design of groundwater drainage systems is not provided.

Modellers seeking guidance for modelling of groundwater mounding associated with subsurface drainage systems should refer to: *Draft Specification Separation Distances for Groundwater Controlled Urban Development* (IPWEA, 2016).

Modellers seeking guidance for the development of groundwater flow and solute transport models in Australia should refer to: *Australian groundwater modelling guidelines* (Barnett et al, 2012).

The following sections of this CoP provide specific guidance for modelling in shallow groundwater conditions:

- Section 5.1.1 – Field tests to determine infiltration rates
- Section 6.3.1 – Selection of loss parameters
- Section 6.3.2 – Selection of infiltration rates
- Section 7.2 – Risks associated with infiltration systems
- Section 7.3 – Sensitivity testing for changing groundwater conditions

3.3 Model selection – what is the right tool for the job?

Drainage models typically have two components. These are:

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

3.3.1 Hydrology

Chapter 9 of ARR provides guidance for selection of urban stormwater models based on the flow chart shown in Figure 5.

For most urban and peri-urban drainage modelling purposes in WA it will be important for the selected model to include moderate or strong estimation capabilities for runoff generation and surface routing, channel and storage routing, and structure hydraulics.

The history and limitations of the rational method in urban areas is discussed at length in ARR Book 9. The method is noted as having limited (rational) to moderate (extended rational) estimation capability for runoff generation and routing. ARR suggests that the rational method should only be used where there is no storage present and that the extended rational method should only be used for small catchments or individual lots.

In addition, in most cases urban drainage modelling will be completed at the scales defined by ARR as 'neighbourhood' or 'precinct' scale and flood magnitudes under consideration will range from frequent to rare. This means that, in most cases, the type of hydrologic model used for urban drainage modelling will be runoff routing or continuous simulation as shown in Figure 6.

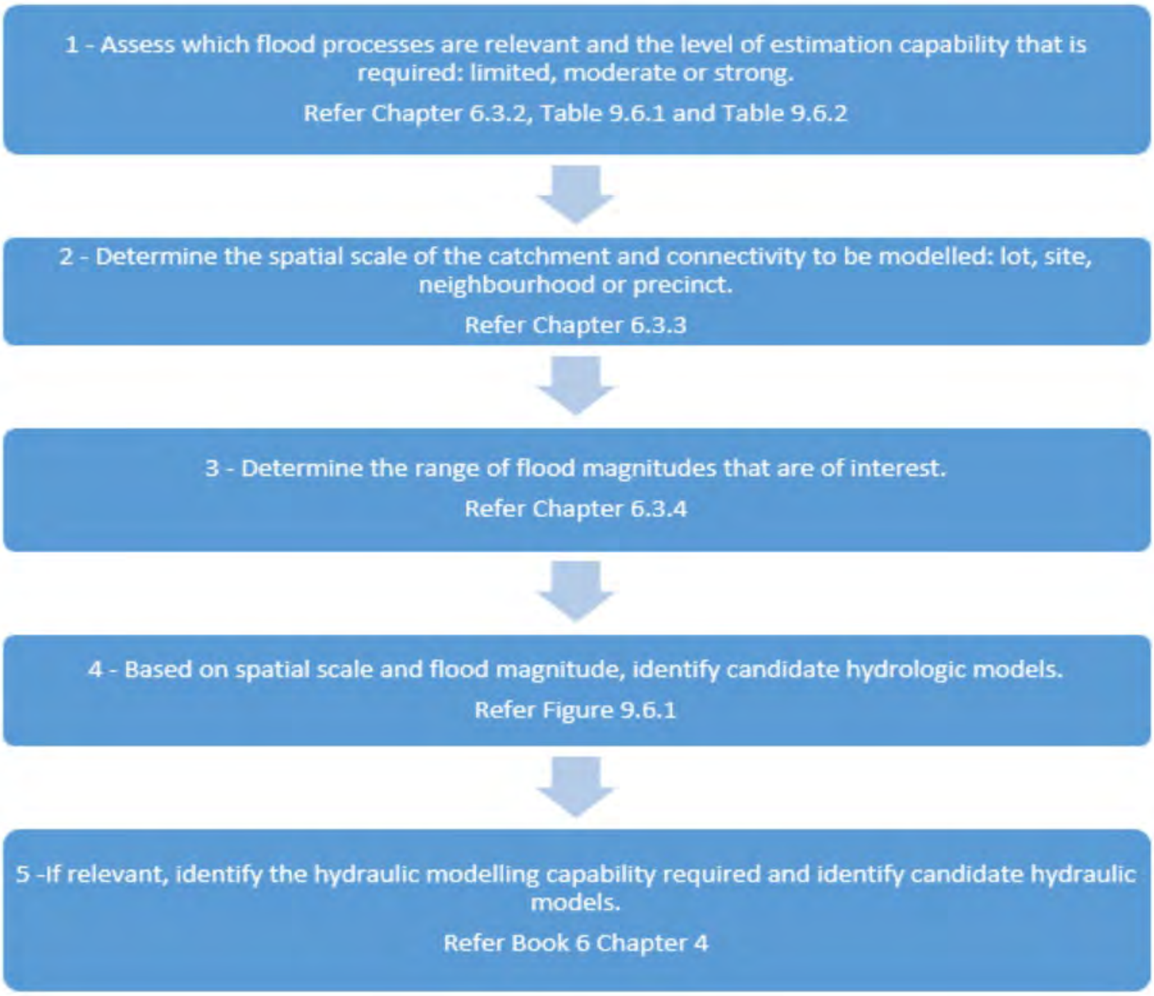

Figure 5: Stepwise flowchart for selecting an urban stormwater model (Source: ARR, 2019)

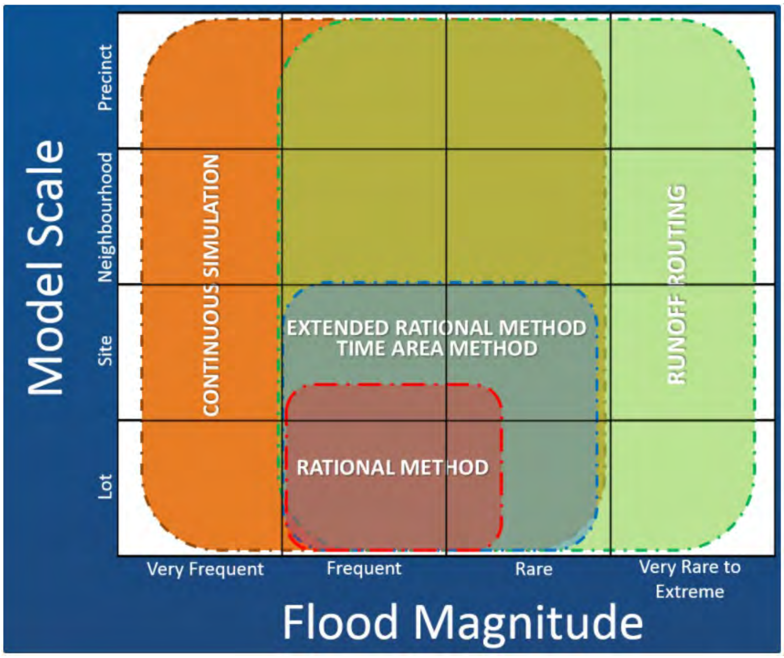

Figure 6: Types of Urban Hydrologic Models and their Likely Application Range (Source: ARR, 2019)

In WA the application of continuous simulation modelling is generally confined to groundwater, water balance, or water quality modelling where frequent events and their influence on water dependent ecosystems are critical. In addition, the levels of service relevant to design and management of urban drainage systems are expressed in terms of design events such that runoff routing models are the most suitable in most cases. Therefore, this Code of Practice discusses this type of model predominantly.

Standalone runoff routing models can be used to prepare hydrographs for input to a separate hydraulic model but combined hydrologic and hydraulic modelling systems have become more common in recent years and tend to be preferred by practitioners. The two components of runoff routing can be considered separately:

- Runoff generation
- Runoff routing

In some cases, a direct rainfall (or ‘rainfall-on-grid’) approach may be applied which attempts to explicitly resolve the accumulation of runoff progressively down the catchment, removing the need to pre-identify flow paths and sub-catchments. This is a useful way to ensure flow paths are not inadvertently omitted from an investigation. However, this approach is evolving and should only be used by experienced practitioners with caution.

Runoff generation

Runoff generation models simulate the interaction between rainfall and the catchment surfaces to estimate the proportion of rainfall that becomes runoff. This includes consideration of losses such as interception, depression storage, and infiltration, and usually accounts for transmission losses, unless they are expected to be very large in which case they should be explicitly modelled.

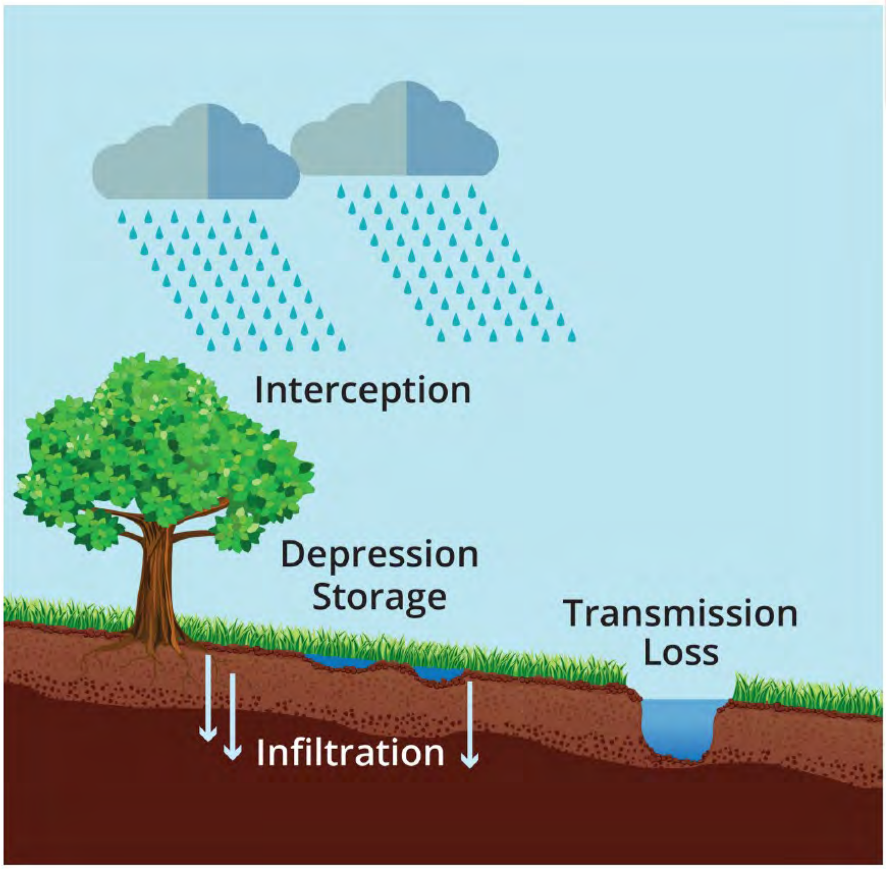

Figure 7: Physical processes which contribute to Rainfall Loss (Source: ARR, 2019)

Runoff routing

Runoff routing models simulate the behaviour of runoff across the subcatchment to estimate the proportion and timing of runoff that arrives at the end of the catchment and enters the drainage system.

3.3.2 Hydraulics – one or two dimensions?

For the hydraulic component of urban and peri-urban drainage modelling, a 1-dimensional model will usually be sufficient for modelling pipe networks or simple channel drains where flood behaviour is not complex. The addition of discrete overland flowpaths can be used to simulate simple flood behaviour over short distances but a more complex representation of flooding should be considered using 2-dimensional modelling where:

- there are significant flood waters that may impact on properties or land adjacent to flowpaths
- flooding has the potential to flow in multiple directions over larger distances
- there are large and/or complex flood storage areas that need to be represented
- flooding has the potential to re-enter the drainage system in multiple locations some distance from the source
- there is flooding from open channel drains

Fully 2-dimensional models where the only underground portions of the drainage system modelled are waterway culverts, are not generally suitable for urban and peri-urban drainage modelling unless the drainage system is entirely formed of open drains, or the intent of modelling is only to consider overland flood behaviour.

Selection of model type for continuous simulation must include further consideration of the timestep and duration to be modelled balanced with the computational complexity and output file size to make a balanced decision that will provide the data needed with the required confidence level.

1-dimensional models

1-dimensional models are computationally simpler than coupled or 2-dimensional models and are therefore generally able to complete simulations more quickly. This means that 1-dimensional models are more suited to an iterative option assessment or design process.

The typical representation of flooding in 1-dimensional models is either for floodwater to be lost from the system or to store floodwater in a notional flood cone at the ground surface and return it to the drainage system when there is sufficient capacity.

Coupled 1-dimensional / 2-dimensional models

For modelling studies considering the performance of a drainage system under flood conditions and where there is a significant component of complex overland flow the addition of a 2-dimensional layer or zone should be considered.

The boundary of the 2-dimensional zone should be large enough to capture all flood flows so that flood water does not run off the edge of the area of interest except to a watercourse or the sea.

Initial simulations with a coarse scale grid across wide areas of the catchment allow overland flow paths to be identified before being refined to include more detail locally in key areas of interest or flood risk.

3.4 Model build

The requirements for development of a site-specific urban drainage model are discussed in **Section 5** of this Code of Practice including:

- Selection of scenarios to be modelled.
- Selection of model boundaries and application of boundary conditions.
- Selection of modelling parameters.
- Catchment definition.
- Network definition.
- Representation of structures.

Several of these elements require consideration of, or direct use of site-specific data including:

- Catchment data, such as topography, soils, land uses, and vegetation cover.
- Hydraulic data, such as drainage system levels, dimensions and materials.
- Rainfall data, including design events and/or time-series rainfall.
- Flow or level data.
- Boundary condition data, potentially from other models.

These data types and guidance for their collection and use are discussed further in **Section 4**.

4 DATA COLLECTION

The amount and accuracy of data required to build an urban drainage model will vary with the scale, level of detail and required confidence level for the model.

4.1 Minimum requirements

The following sections summarise the minimum data requirements for a typical Type II – Planning model with some additional comments provided around data requirements to provide greater confidence and/or for more detailed modelling.

4.1.1 Catchment data

Sufficient catchment data will be required to define and characterise catchments. This will include:

- Topography and slope
- Waterway and drainage alignments
- Land use
- Vegetation cover
- Soil types and hydraulic characteristics

The best available topographic data combined with known waterway and drainage alignments should always be applied to determine catchment and subcatchment boundaries and connectivity. Where there are rural catchments connecting to the urban drainage system some simplification of the model in these areas may be accepted but subcatchment size should be limited to ensure that the major features of the network are represented.

LiDAR data, where it is available, will usually provide sufficient representation of subcatchments and connectivity. Limited frequency (1m or 2m) contour data may be sufficient for catchment delineation in steep landscapes but should not be used for catchments in flatter landscape areas, or to define channel cross sections. For increased accuracy, typically around specific locations of interest, site survey is recommended but would not typically be required for whole catchments. Site inspection is essential to provide more detailed understanding of catchments and connectivity.

In addition to catchment definition, topographic data will be required to identify the slope of subcatchments which is a key input parameter for urban drainage modelling.

Land use and vegetation cover is required to allow for representation of runoff generation and routing in each subcatchment. They are used to define the breakdown of surface types, with different runoff generation capacities, that are found in each subcatchment as well as the subcatchment roughness which affects runoff routing.

For Type II – Planning models, modelled land uses may be defined by planning scheme zones and reserves with reference to vegetation cover and aerial imagery to validate the level of build-out. Site inspection is also recommended to provide more detailed understanding of land use characteristics. Model scenarios may be required to consider alternative land use states (e.g., current zoning and build-out, current zoning at ultimate build-out, or future zoning). For more detailed modelling, it may be necessary to model land uses with increased accuracy to provide a detailed breakdown of surface types such as actual roof, hardstand, turf, vegetation, and other areas and to determine the level of direct connectivity to the drainage system.

Soil types and their hydraulic characteristics are required to determine appropriate parameters for subcatchment modelling and for modelling the performance of open drainage and infiltration systems.

For Type II – Planning models, assumed hydraulic parameters may be acceptable for subcatchment and open drainage system modelling but field measurements for in-situ soils are generally required for modelling of existing and proposed infiltration systems. For developments, where infiltration into imported fill is proposed, assumed rates may be applied for planning and conceptual design but should be confirmed with reference to the selected fill source and earth-working methodology prior to final detailed design.

Field tests to determine infiltration rates

Infiltration rate is the rate at which water enters the ground, which varies over time, typically commencing at a high rate and decreasing until the underlying soils are saturated, at which point the rate stabilises. The infiltration decay period is similar in duration to many urban catchment response times. Figure 8 shows the typical change in infiltration rate that may be observed during infiltration testing.

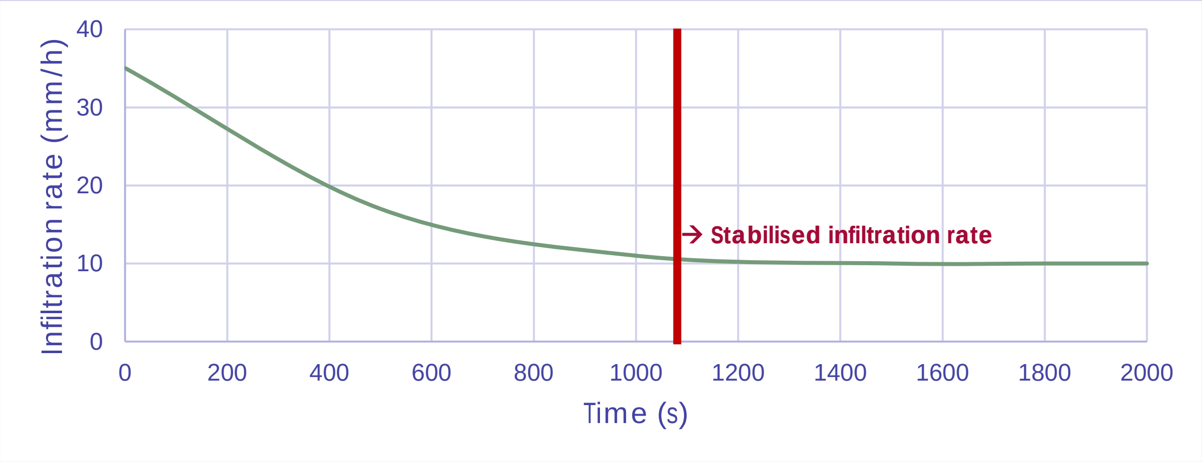

Figure 8: Variation in infiltration rate over time

However, it should also be noted that the infiltration rate is dependent upon the water level within the stormwater system, with higher water levels generally resulting in higher infiltration rates. This means that the infiltration rate from a stormwater system as it fills and empties is more likely to start slow, increase at a rapid rate as the water level in the structure rises and then fall until saturation of the underlying soils is reached.

Infiltration testing is often undertaken as part of a geotechnical investigation and the stabilised rate towards the end of the test is usually converted to saturated hydraulic conductivity. This calculation of saturated hydraulic conductivity from the measured infiltration rate is generally reasonable. However, it must be noted that infiltration rate is not the same as hydraulic conductivity (with the latter being an aquifer property and the former being a flow rate resulting from that aquifer property).

It should also be noted that a point scale, short duration infiltration rate from testing is not necessarily a good indication of an infiltration rate that could be achieved by a stormwater infiltration system where a number of issues, including the natural heterogeneity of soils, depth to groundwater, and maintenance of the system. These issues are discussed further in **Section 5.3.2**.

Field measurements of saturated hydraulic conductivity (infiltration tests) should be undertaken by a suitably qualified person to determine the hydraulic properties of soil at locations where infiltration losses will be modelled.

Testing methods should be applied in accordance with recognised standards, for example:

- ASTM D3385-09 Standard test method for infiltration rate of soils in the field using the Double Ring Infiltrometer.
- AS/NZS 1547:2012 appendix G soil permeability measurement constant head test.

Testing should be undertaken in-situ at the location of each existing or proposed infiltration system and measurements taken at the depth corresponding to the base elevation of the system. Soil samples may be taken for testing in a laboratory where the required depth is too deep for field testing.

The final infiltration rate selected for use in modelling will need to include adjustments from field tested rate(s) and the determination of the modelled rate (as discussed in **Section 5.3.2**) should include the following considerations:

- Weather conditions and soil saturation before and during testing.
- Depth to groundwater during testing compared with seasonal maxima.
- Number, depth, and spatial distribution of tests undertaken.
- Intended earthworks strategy (e.g., in-situ soils only, imported clean fill, or blended soils).
- Biological influences (worms, rabbits, wombats, etc) on soil structures and the inherent high spatial heterogeneity in infiltration rates.

4.1.2 Hydraulic data

Sufficient catchment data will be required to define the drainage system being modelled. This will include:

- piped drainage systems
- open drainage systems
- storage tanks and basins
- structures and ancillary items

Most of the data used to construct the hydraulic network for Type II – Planning models are the physical dimensions of the system, and this will usually be provided from GIS databases or design information. Standardised hydraulic parameters for the drainage network can then generally be assigned based on material types (see **Section 5.3.2** for details) with some consideration of condition where it is known.

Piped drainage systems

Minimum data requirements for modelling of piped drainage systems are:

- pipe layout, dimensions, and invert levels
- pipe material (for roughness estimation)
- manhole types (e.g., inlets, outlets, sealed junctions)
- inlet and outlet details where required (e.g., grates, headwall arrangements etc)

Open drainage systems

Minimum data requirements for modelling of open drainage systems are:

- cross sections, invert levels and top of bank levels

- channel material (e.g., concrete, earth, grass, vegetation)
- presence and dimensions of structures (e.g., weirs, drop structures, riffles, culverts, headwalls, bridges)

Limited GIS data is usually available for open drainage systems, and these usually require some survey to be undertaken to define cross sections and culverts. Cross sections should be surveyed at a frequency that is sufficient to reflect changing geomorphology and associated with structures. For Type II – Planning models, LiDAR data, where it is available, may provide sufficient detail to derive simple cross sections, minimising the need for augmentation with survey. For more detailed modelling, or where the system has more complex cross sections, survey is likely to be required.

Storage tanks and basins

Minimum data requirements for modelling of storage tanks and basins include:

- storage type and dimensions (typically: stage/area/volume)
- inlet and outlet arrangements and dimensions including overflows
- surface treatment and soil type (including infiltration rates where relevant)

Infiltration rates used in modelling of infiltration systems such as soakwells, raingardens, swales, sumps, and underground infiltration systems should be determined based on site-specific investigations (see Section 4.1.1).

Structures and ancillary items:

Structures and ancillary items that may require modelling include:

- drop structures
- orifices
- weirs
- bifurcations
- gross pollutant traps
- flap valves
- pump stations

Where structures and/or ancillary items such as pump stations are required to be modelled, detailed physical dimensions and site-specific hydraulic parameters may be required. These items should be considered individually to determine survey requirements and suitable model representation including derivation of discharge coefficients.

4.1.3 Rainfall data

Rainfall data inputs to urban drainage models should be selected in response to the objective of the modelling study, availability of data, and the level of confidence required. This may include:

- design ensembles of rainfall from the ARR data hub
- time series data obtained from established rain gauges
- time series data collected at locally installed rain gauges

Further guidance for the selection of rainfall for urban drainage modelling is provided in ARR Book 9 Chapter 6.

As mentioned in **Section 2.1**, drainage modelling undertaken for design purposes in WA will typically need to include modelling scenarios with a range of small, minor, and major design rainfall events with a range of durations for each AEP event, to enable determination of the critical duration.

4.1.4 Flow and level data

Prior to undertaking urban drainage modelling, a review of available system flow or level data for use in the model should be undertaken. Where there is available data, it should be used as a minimum, to provide some validation of modelling results. Where a sufficient length of record is available, it is preferable to undertake calibration and validation processes as discussed in **Section 6**. The types of data that may be available for this purpose include:

- gauged continuous flow data
- discrete flow readings
- continuous depth logger data
- discrete depth readings
- historic flood height records
- other records of historic flood extent (e.g., photographs, tidemarks etc)

Groundwater levels should also be a consideration when developing an urban drainage model. Where the drainage system is known or anticipated to intersect groundwater it may be necessary to include allowance for groundwater inflows within the system and/or at model boundaries. In some circumstances, it may be necessary to include explicit modelling of the interactions between surface water and groundwater.

4.1.5 Boundary condition data

The boundaries of an urban drainage model should be set with consideration of the study objectives and level of confidence required. In most cases, the downstream boundary of an urban drainage system will require a simulated hydraulic (outlet control) boundary condition to be applied. In addition, in some cases, a simulated upstream hydrological (inflow) boundary condition may also be applied.

The types of data that may be used to simulate boundaries include:

- Upstream (inflow) data
    - Gauged hydrographs.
    - Modelled hydrographs from a separate model or study.
- Downstream (tailwater condition) data
    - Gauged continuous level data.
    - Modelled hydrographs from a separate model or study.
    - Specified flood levels at the outlet.
    - Tidal levels at the outlet.
    - Groundwater or baseflow levels at the outlet (may also be applied within the network).

4.2 Data availability

The key data types used for urban drainage modelling and their custodians in WA are represented in Table 4. In addition to publicly available datasets, data can also be commissioned or purchased from commercial providers.

Table 4: Data sources

Data types	DPLH/WAPC	DWER	DBCA	DPIRD	DMIRS	Local Government	Water Corporation	Main Roads	BoM	Landgate	ICSM	Commercial providers
Catchment data – often accessed via Landgate (attributed to data owners)												
Land use	✓					✓						
Cadastre										✓	✓	✓
Topography		✓		✓			✓			✓	✓	✓
Vegetation cover			✓	✓								
Soils/geology					✓							
Catchment boundaries		✓				✓	✓					
Aerial imagery						✓				✓		✓
Hydraulic data												
Drainage asset data						✓	✓	✓				
Watercourse information		✓										
Wetland information		✓	✓			✓						
Rainfall, flow, and level data												
Rainfall data		✓		✓		✓	✓		✓			✓
Flow data		✓				✓	✓					
Groundwater levels		✓										
Boundary and condition data												
Flood levels and extents		✓										
Modelled hydrographs		✓				✓	✓	✓				

5 MODEL DEVELOPMENT

5.1 Scenario selection

As mentioned in **Section 2.1** and **Section 4.1.3**, modelling for drainage system design purposes in WA typically requires all model scenarios to include a range of rainfall events to represent system performance in small, minor, and major event conditions.

The number and scope of model scenarios should be agreed with the commissioning person or organisation following consideration of the requirements of key stakeholders.

For the planning and design of new urban drainage systems commissioned by a developer, modelled scenarios will typically include consideration of alternative or staged land use change and/or system design options. However, it is also important to consider the requirements of the eventual drainage system owner/manager, which is usually the local government, and investigate the influence of other factors such as climate change or infrastructure delivery.

Typical model scenarios for urban drainage modelling to understand and manage local flood behaviour, drainage system performance, develop design solutions or investigate the impact and risks associated with land use change would include:

- Current system with current land use to identify current capacity constraints and issues.
- Current system with future land use to identify future capacity constraints and issues.
- Proposed system with future land use (including system upgrade options as required).

Additional scenarios may be required to consider alternative or staged land use change and/or system upgrade options, or to investigate the influence of other factors such as climate change or infrastructure delivery.

5.2 Model boundaries

Model boundaries and boundary conditions are discussed in some detail in ARR Book 7, Chapter 4.

The boundaries of an urban drainage model should be set with consideration of the study objectives and level of confidence required.

The upstream extent of the hydraulic model may not be the same as the upstream extent of the hydrological model. That is, the catchments upstream of the area of interest may be simplified or replaced by a hydrograph from a separate model. In these cases, the upstream boundary must be sufficiently removed from the area of interest to avoid hydraulic boundary effects at the model inflow location from having significant influence on model performance within the area of interest.

The downstream extent (or outlet) of the model should be established at a location where there is a known, or assumable, tailwater condition that can be modelled with consideration of the downstream receiving environment to identify any control points that may impact on tailwater conditions in the model. The location must also be sufficiently removed from the area of interest to avoid hydraulic boundary effects at the model inflow location from having significant influence on model performance within the area of interest.

Where modelling includes a 2-dimensional layer or zone, it should be large enough to capture all flood flows within the area of interest, so that flood water does not run off the edge of the area of interest except at the downstream boundary into a watercourse or the ocean.

Initial simulations with a coarse scale grid across wide areas of the catchment is recommended to allow identification of overland flow paths before being refined to include more detail locally in key areas of interest or flood risk.

5.3 Model parameters

Model parameters are selected to represent key environmental conditions and processes within the model and their definition must be based on a thorough understanding of the site and modelled system. Parameters should also lie within accepted ranges with supporting evidence provided for any deviation. It should also be noted when testing or adjusting parameters that different combinations may achieve similar model predictions.

The following sections provide additional advice for parameters that are considered particularly important and/or are highly variable.

As noted in **Section 3.2**, shallow groundwater conditions can significantly influence catchment runoff generation and the hydraulic performance of drainage systems.

5.3.1 Catchment losses – runoff generation

The parameters discussed in this section are applicable to most runoff routing models used for urban and peri-urban drainage modelling in WA. For additional guidance on loss parameters refer to ARR Book 5, for catchment roughness refer to ARR Book 6 and for application of parameters to urban drainage modelling refer to ARR Book 9.

For urban drainage modelling, ARR recommends the definition of three runoff generation surfaces applying initial and continuing losses. The recommended surface types are:

- Effective impervious areas (EIA)
- Indirectly connected areas (ICA)
- Pervious areas

Indirectly connected areas are a combination of indirectly connected impervious and pervious areas. Typically, the indirectly connected area may include residential lots, road verges and small public open spaces. Larger public open spaces or conservation areas, where soil of groundwater conditions have little chance of interaction with the drainage system would be classified as pervious. Guidance for impervious area estimation is provided in **Section 5.4**.

The ARR Data Hub provides regional rural losses for complete storms and pre-burst rainfall. In urban areas, the median values of local losses should be utilised wherever possible. Rural and regional loss assumptions should not be a default assumption for urban areas and a hierarchy for selecting urban losses is highlighted in ARR Book 9, Chapter 6 as follows:

1. **Use local losses based on GIS investigations, local knowledge, and observations.** Losses derived at a regional scale are not local losses- use local losses in small scale models. Note that a well-constructed model with adequate spatial scale should account for effective impervious area and connectivity effects.
2. Regional losses (ARR Book 5, Chapter 3).
3. Rural losses: estimate urban losses by applying some proportion of rural losses.

Estimation of local losses

The estimation of local losses requires consideration of several influencing factors including:

Soil type

- Sandy soils have better infiltration capacity, so this may mean that there are greater infiltration losses into the soil, both initially and over the duration of a storm event.
- Silty or clayey soils have a low infiltration capacity, so losses will be small, with high percentage of runoff generated.
- Bulk density and compaction of engineered soils (fill) may be higher than native soils, resulting in lower hydraulic conductivity.

Vegetation and topography

- Denser vegetation will usually have greater losses, with rainfall interception and increases infiltration through root pathways and longer travel time laterally.
- Steeper catchments will generally have higher runoff than flatter catchments. Steeper catchments also tend to have less depression storage.

Groundwater levels

- When groundwater is close to or above the ground surface, infiltration losses will be reduced, and depression storage may be eliminated.

Connectivity

- At source retention and infiltration systems such as soakwells or rainwater tanks may increase initial and/or continuing losses for connected impervious areas. The influence of these systems will depend on sizing, design, and installation information.
- Note: Adjustment of local losses to account for source retention and infiltration systems should only occur if those systems are not explicitly modelled to avoid double counting their impact.

Local site investigations and monitoring are necessary steps in estimating local losses and should include:

- Local monitoring of rainfall and runoff under a range of conditions
- Detailed mapping of surface types, soil and groundwater conditions runoff pathways and connectivity at monitoring sites and in the broader modelled catchment

The applicability of estimated local losses to different parts of a catchment must be considered carefully. Losses derived based on limited site investigations are unlikely to be directly applicable at a catchment scale due to differences in local soil and groundwater conditions, connectivity, and runoff pathways.

Application of regional losses

Although the use of local data to determine losses is strongly preferred, it is recognised that it is often not available in a form that can be readily or confidently applied. In the absence of local data, ARR Book 5, Chapter 3 provides recommendations for regional initial and continuing losses to be applied in urban areas, which are summarised in Table 5.

ARR Book 5, Chapter 3 notes that the runoff characteristics of much of south-west WA are different from that found in many other parts of Australia. The highly permeable soils and large soil water storages of the south-west landforms means that the regional continuing loss rates tend to be high. Additional guidance for selection of initial and continuing losses for urban ICA in the south-west of WA is therefore provided in Table 5.

Table 5: Regional initial and continuing losses for runoff surface types

Runoff surface	Initial loss	Continuing loss	Additional guidance
EIA	1-2mm	Assume zero	
ICA	60-80% of rural rate	1-4mm/hour	Losses applied should consider local soil and groundwater conditions and the proportion of impervious areas within the ICA, e.g.: • Shallow groundwater/clay soils – select initial and continuing losses at the lower end of recommended ranges. • Deep groundwater/sandy soils – select initial and continuing losses at the upper end of recommended ranges. • Low proportion of impervious area – select initial losses at the upper end of the recommended range (trending towards 100% rural rate when the impervious area is less than 5% of total ICA).
Pervious	Adopt the loss values for rural catchments from ARR Book 5, Chapter 3		Urban pervious areas represent areas that do not interact directly with impervious areas.

5.3.2 Runoff routing parameters

Parameters applied in runoff routing will depend on the runoff routing model selected but may include catchment length or width, catchment slope and catchment roughness.

The runoff routing methods most frequently applied for urban drainage modelling in Western Australia are:

- Laurenson's procedure, also known as the RAFTS model.
- SWMM runoff method.

Laurenson's procedure / RAFTS model

The hydrological data requirements for the RAFTS model are catchment area, slope, degree of urbanisation, loss rates, observed or design rainfall.

These data are used to compute the storage delay coefficient for each of the sub-catchments and hence to develop the non-linear runoff hydrograph. A default exponent is adopted, although the user may override this value with either a different non-linear exponent or a rating table of flow vs an exponent to define different degrees of catchment non-linear response.

Each sub-catchment is divided into 10 sub-areas. Each of the sub-areas is treated as a cascading non-linear storage obeying the relationship:

$$S=Bq^{(n+1)}$$

where:

S = volume of storage (hrs x m3/s)

B = storage delay time coefficient

n = storage non-linearity exponent by default is set to -0.285 (AR&R, 1997)

The rainfall is applied to each sub-area, an excess computed, and the excess converted into an instantaneous inflow. This instantaneous flow is then routed through the sub-area storage to develop an individual sub-catchment outlet hydrograph.

B – can be calculated from:

$$B = 0.285\ A^{0.52}\ (1 + U)^{-1.97}\ Sc^{-0.50}\ \text{PERN RAFTS Adapt Factor}$$

where:

A = catchment area (km^2)

U = fraction of catchment urbanised (from % impervious – see below)

Sc = modified equal area slope (%)

n = storage non-linearity exponent (by default is set to -0.285)

RAFTS Adapt Factor = calibration factor (by default is set to 1)

PERN = roughness adaption factor (from equivalent Manning's n – see below)

Table 6: Laurenson's procedure – parameters applied to calculate storage delay (B)

Equivalent Manning's n	PERN
0.01	0.4
0.015	0.5
0.025	1.0
0.10	3.0

% Impervious	U
0	0
30	0.7
50	1
100	2

SWMM runoff method

SWMM is the Storm Water Management Model developed for the U. S. Environmental Protection Agency. Flow is routed using a single non-linear reservoir and the kinematic wave equation, whose routing coefficient depends on surface roughness (equivalent Manning's n), surface area, average ground slope and catchment width.

For the SWMM method, catchment width should be estimated as drainage area divided by the average maximum overland flow length. The maximum overland flow length is the length of the flow path from the remotest point to where the flow becomes channelised.

5.3.3 Hydraulic parameters

Roughness

ARR provides tables of valid ranges for the Manning's roughness coefficient (n) in open channels (Book 6, chapter 2, Table 6.2.1), in 2D models, suitable for overland flow path representation (Book 6, chapter 2, Table 6.2.2), and in pipes and culverts (Book 6, chapter 2, Table 6.2.3).

In addition to material considerations, the age and condition of a pipe or channel can have significant impact on its roughness and should also be considered when selecting appropriate values.

Energy (head) losses

Significant energy losses (also described as head losses) can be caused by inlet structures and junctions in conveyance networks, especially when pipes are full and surcharging. ARR Book 9, Chapter 5 provides detailed information on the consideration of energy losses in urban drainage systems.

Model representation of energy losses at manholes on piped networks, and culverts or bridges on open drainage networks will depend on the modelling system or software being used. It is important that the modeller takes the time to properly understand the model-specific coefficients required to appropriately model energy losses and applies them with suitable care.

Typically, losses will be higher for poorly constructed drainage systems with large changes of direction. Coefficients applied in modelling should therefore be varied according to the degree of bend and in response to the age and quality of construction.

Infiltration

As mentioned in Section 4.1.1, infiltration rates used in modelling of infiltration systems such as soakwells, raingardens, swales, sumps, and underground infiltration systems should be determined based on site-specific investigations wherever possible.

Where testing of the local infiltration rate has not been possible, or where a proposed infiltration system will be embedded within imported material, it may be necessary to undertake design modelling using published hydraulic conductivities. In this case, it is important to note that hydraulic conductivity is not the same as the infiltration rate and published saturated hydraulic conductivities should only be used to directly approximate the infiltration rate in deep groundwater conditions where the hydraulic gradient is approximately 1(unity).

For a shallow groundwater table, the flow path for infiltration from a basin is quasi 2D, with a strong horizontal component, and so the hydraulic gradient can be much less than 1, resulting in infiltration rates much less than the hydraulic conductivity (e.g., 1 or 2 orders of magnitude, depending on the separation to groundwater).

A groundwater separation of less than 2 to 3 m may be sufficient to impact on the infiltration rate, however for sufficiently large basins (>1 ha), even a groundwater separation of 5 m may reduce the infiltration capacity of the basin.

In these cases, published hydraulic conductivities should only be used with caution by experienced practitioners and modified to reflect the local groundwater conditions.

Where the design of a stormwater infiltration system has been undertaken using modified published rates it is recommended that infiltration testing is carried out after completion of bulk earthworks to confirm the rate used and finalise the design.

It is also important to note that field tested of infiltration rates are also not typically suitable for direct use in modelling due to a number of issues previously mentioned in **Section 4.1.1**. The key factors that must be considered to suitably adjust tested infiltration rates for use in modelling, include:

- soil heterogeneity
- depth to groundwater or underlying impermeable layer
- design, installation, and maintenance

Where depth to groundwater or underlying impermeable layers may be critical for system design, the use of appropriate specific infiltration modelling software should be considered to gain an understanding of infiltration constraints, and to incorporate into the hydraulic model.

Soil heterogeneity

It is important to understand that infiltration rates can vary quite significantly across relatively small spatial areas and therefore the application of soil moderation factors is recommended to represent the inherent heterogeneity of soils. Recommended soil moderation factors from Australian Runoff Quality (Engineers Australia, 2006) are provided in Table 7.

Table 7: Recommended soil moderation factors (EA, 2006)

Soil type	Soil moderation factor
Sand	0.5
Sandy clay	1
Medium and heavy clay	2

Depth to groundwater or underlying impermeable layer

Where drainage systems are likely to intersect seasonal groundwater levels, consideration should be given for application of inflows or more complex modelling of surface water and groundwater interactions.

In addition, infiltration from infiltration systems can be constrained when there is limited separation between the system invert and the groundwater level or an underlying impervious layer. This is caused by the combination of two effects, which are:

- The presence of shallow groundwater may limit the pore space available within the unsaturated soil matrix below the basin.
- The infiltration rate is governed by the hydraulic gradient available once the pore space is saturated.

If field testing of infiltration rates has been undertaken at the location and invert depth of the proposed system, no adjustment for depth to groundwater should be required for small infiltration systems. However, it is important to note that where subsoil drainage is used to control groundwater levels the water level may vary significantly between drains and the location of a small infiltration system will be critical in determining the extent of groundwater influence.

For example, soakwells located to the rear of properties, where subsoil drainage has been installed in the front road reserve, will change the profile of groundwater mounding between drains, as shown in Figure 9. This will result in reduced separation between the soakwell and the controlled groundwater level and may cause performance issues and potential local flooding.

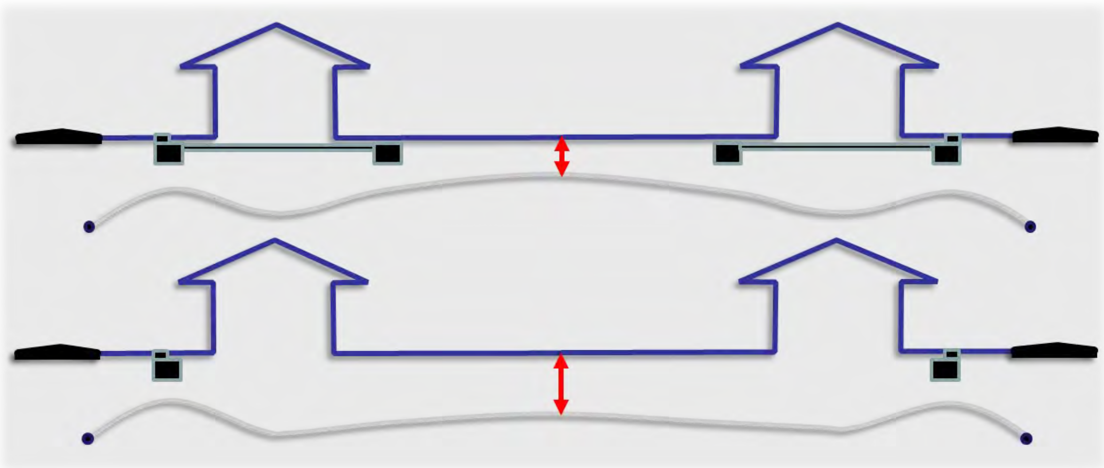

Figure 9: Controlled groundwater level differences associated with soakwell placement (Source: NWW, 2022)

For larger infiltration systems, where larger volumes of water are being infiltrated and the risks associated with extended emptying times and long-term saturation are more significant, more detailed assessment is required s and modification of the infiltration rate should be considered. In addition, for large systems that are potentially impacted by shallow groundwater and/or an underlying impermeable layer, time series modelling to consider the implications of delayed emptying may be required.

As noted previously, where an assumed saturated hydraulic conductivity is used and groundwater is known to be seasonally shallow or an impermeable layer is present, the modelled infiltration rate should be adjusted to consider these effects.

Design, installation, and maintenance

The performance of stormwater infiltration systems can vary significantly in response to design, installation, and maintenance considerations. Design and installation considerations and the ways that they can affect the performance of infiltration systems are presented in Table 8.

Table 8: Design and installation considerations for infiltration systems

Consideration	Associated issues
Soil conditions (e.g., in-situ soils, imported clean fill or blended soils).	Disturbance of in-situ soils and blending of imported fill material with in-situ soils can result in unpredictable fines proportions and reduced infiltration rates. Also, imported fill material may not have the hydraulic parameters that were anticipated.
Amount of compaction.	Compaction of soils for development can change the infiltration rate. Testing should be carried out post-compaction, if possible. Advice should also be provided to the civil engineer/contractor to recommend minimised compaction of basin (particularly infiltration basin) areas during earthworks.
Surface treatments for basins and swales (e.g., turf, vegetation, trees).	The use of vegetation, and in particular trees, in stormwater infiltration systems designed to manage small and minor rainfall events is strongly recommended. The root structure of vegetation and trees promote good soil health, help to prevent clogging and provide improved infiltration rates.
Size, location, type, and number of perforations for underground systems.	Soakwells and underground infiltration cells with side-wall slots provide a greater surface area for infiltration. Angled slots also help to assist infiltration with reduced clogging.
Bedding material, size, and thickness (e.g., crushed rock aggregate).	Bedding material size and thickness should be specified correctly for the surrounding soil type to prevent clogging and maintain the infiltration rate.
Geotextile wrapping	Geotextile wrapping can be susceptible to blockage by sediments; organic residues; plant roots; fungi and algae; viscous petrochemical compounds and slimes. This is particularly problematic where the bedding material has been incorrectly specified and/or where there are high iron levels present in soils and groundwater.

In addition to the design and installation considerations identified above, the ongoing management and maintenance of the infiltration system will also influence its performance over the longer term.

Urban drainage modelling for drainage design purposes must consider the risks associated with poor performance or failure of infiltration systems and this is discussed further in Section 6.2.

One of the ways that these issues and risks can be addressed in modelling, is by modifying the modelled infiltration rate by applying a factor that simulates the presence of a clogged layer. Alternatively, sensitivity analysis can be undertaken to consider the impact of reduced infiltration rates and understand the associated risks of declining performance over time. These alternatives are discussed further in Section 6.2 and whichever approach is selected, it is important that reporting includes identification of key design, installation, and maintenance risks and requirements.

5.4 Subcatchment definition

5.4.1 Subcatchment boundary definition

The definition of subcatchment boundaries can be a time-consuming process that influences the accuracy and usability of the final model. Subcatchment definition for urban and peri-urban drainage modelling should generally result in subcatchments no larger than 2 hectares and consider the following general guidelines:

- Subcatchments should be defined to include relatively uniform land use, soil type and drainage system type.
- Subcatchment coverage should include all areas of the catchment that could contribute flow to the modelled drainage system.
- Urban subcatchments should normally be defined along property boundaries.
- Large impermeable areas such as car parks, supermarkets, schools or industrial units should be modelled with individual subcatchments.
- Major developments such as hospitals, retail parks and industrial estates, should be modelled explicitly, preferably using private drainage records to avoid problems of unrealistic localised flooding.
- Large watercourse catchments should be cut down into subcatchments to apply inflows at the appropriate locations.
- To prevent dry pipes, a subcatchment should be included at the head of any pipe run.

5.4.2 Impervious area estimation

Impervious area estimation is a critical step in subcatchment definition. ARR Book 9, Chapter 6 provides guidance for estimation of impervious surfaces and recommends methods for estimation of effective impervious area (EIA) in urban areas.

ARR Book 5 Chapter 3 establishes a method of EIA estimation EIA via linear regression of site stream flow gauge and rainfall data. Where there is insufficient data for this method, estimation of total impervious area (TIA) using GIS methods is recommended to guide estimation of effective impervious area (EIA) based on analysis of a collection of gauged catchments presented in ARR Book 5, Chapter 3.

From ARR Book 5 the recommended ratio of EIA/TIA for the majority of urban catchments sits within the range of 50% and 70%. For example, if the TIA for an urban catchment was measured to be say 55% then the EIA for that same catchment would be somewhere between 27.5% and 38.5% of the total catchment area.

For modelling of urban and peri-urban areas a more detailed consideration or actual assessment of stormwater connectivity is likely to be appropriate to avoid over-estimation of EIA.

Table 9 provides some suggestions for the allocation of runoff surface types to a range of different urban areas. This table is not intended to be exhaustive, and consideration of the site-specific urban form and drainage system will be required to allocate surface types appropriately.

Table 9: Suggested allocation of runoff surface types

Urban area type	Runoff surfaces
Small lots with direct drainage connections	Combination of EIA (most likely roof and front hardstand) and ICA (possibly for rear garden and hardstand).
Small lots with soakwells or other on-lot infiltration system	ICA predominantly with EIA allowance for part of driveway.
Large urban lots with soakwells or other on-lot infiltration system	ICA predominantly. Could consider a small EIA allowance for part of driveway.
Peri-urban lots with soakwells or other on-lot infiltration system	ICA usually.
Road reserves and carparks	EIA for the road surface generally with ICA for pervious verge or garden areas. Consider the connectivity of footpaths and crossovers to the road to determine if they should be EIA or ICA.
Pocket parks, public access ways and gardens	ICA usually.
Larger ovals and conservation areas	Pervious usually. Consider connectivity of any building and hardstand areas to determine if they should be EIA or ICA. Consider ICA for ovals where groundwater is shallow, and drainage is likely to be required.

5.5 Network definition

Some simplification of the modelled drainage network is common but must be consistent with the objective of the modelling study, availability of data, and the level of confidence required. Inclusion of every pipe, every inlet and every structure are likely to provide the most accurate representation of the system. However, this requires a high level of confidence in the data used to construct the model and therefore where there is missing or inaccurate data, a decision must be made to either collect more accurate data or simplify the system in that location.

For example: If the model is required to assess the capacity of individual inlet structures, then they must be accurately modelled, requiring accurate survey of individual structures. If the model is required to assess the capacity of the downstream system, then sufficient detail would be required in subcatchment delineation and connections to the network so that subcatchment inflows are distributed accurately but individual inlet performance could be parameterised.

Inference or interpolation of missing or unreliable data should be kept to a minimum. However, the study objectives and required level of confidence must be balanced with the costs associated with collecting additional data in deciding how much interpolation to accept.

For more detailed modelling, particularly where the impact of system maintenance is being considered as part of the study, the condition of the system should also be assessed. This may include the age and structural condition of the system as well as the tendency for sedimentation, dense vegetation and/or blockages and areas of root intrusion into pipes.

5.6 Structures

Detailed information on the hydraulic characteristics of various structures that may need to be modelled is provided in ARR Book 6, Chapter 3. The level of detail included in modelling of structures will depend on the level of detail required from the modelling study overall as well as the criticality of the structure in controlling flows within the system.

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

All details relating to the modelling of structures, together with relevant calculations of head losses, discharge coefficients etc. should be clearly documented and recorded in the modelling process. Key ancillary data should be obtained by survey as outlined in Section 4.1.

6 MODEL CONFIDENCE

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

Assessing model confidence in a consistent manner helps demonstrate how well models meet their required purpose by providing a system to qualify and/or quantify risk and uncertainty against a range of metrics.

6.1 Confidence level elements

The key elements for consideration in setting and assessing model confidence are:

- subcatchment confidence (definition, connectivity, impervious area estimation, parameter selection)
  - data type
  - data coverage
  - age of data
  - changes to parameters during calibration/validation
- network confidence (dimensions, materials, parameter selection)
  - data type
  - data quality
  - age of data
  - changes to parameters during calibration/validation
- calibration confidence (where possible)
  - quality of data used
  - quality of calibration
  - changes to parameters to improve fit
- validation confidence (where possible)
  - quality of data used
  - quality of match to flooding locations and depths
  - changes to parameters to improve fit

It is important to note that a single model may have different levels of confidence in different areas and therefore it will be critical to consider the desired level of confidence in key areas of interest as well as overall. It may not be practical to significantly improve overall model confidence with improved data collection. However, a relatively small amount of data collected in key locations may significantly improve confidence where it is required.

6.2 Consideration of risk

The level of confidence required for an urban or peri-urban drainage model should be initially set with consideration of the relative risks associated with the system being modelled. For example, a model for determination of environmental flows to a wetland or waterway may require a lower level of confidence than a model being used to assess flood risk for residential properties.

Similarly, the establishment of model parameters, and a preference for over- or under-prediction may vary in response to the relative risks associated with the system being modelled. Where there is uncertainty, the decision to select a more, or less conservative parameter must consider what risks are associated with the resulting model outputs. This is particularly important where a model may be used to address multiple considerations such as performance of a drainage system under frequent, minor, or major rainfall events. Whilst it may be considered desirable to be somewhat conservative in parameter selection for flood modelling purposes, the risks associated with this approach in models used for the design of water quality treatment systems and minor event systems may be significant. Table 10 provides a summary of relevant risks for different drainage system elements.

Table 10: Model risks

Drainage element	Example risks for consideration	
	Model underprediction of flows	**Model overprediction of flows**
Major system	• Unforeseen public health and safety impacts. • Unforeseen infrastructure damage. • Unforeseen public and private property damage.	• Excessive expenditure on flood protection works. • Excessive insurance costs for community. • Excessive land take for storage.
Minor system	• Unforeseen public amenity and wellbeing impacts. • Unforeseen poor infrastructure performance and integrity. • Unforeseen environmental health impacts (erosion and sediment).	• Excessive expenditure on road and drainage works. • Excessive land take for storage • Vegetation fails to thrive, resulting in high maintenance requirements.
WSUD system	• More water to the environment and more frequently than anticipated. • Reduced amount of water treated.	• Less water to the environment and less frequently than anticipated. • Vegetation in WSUD systems fails to thrive and successful treatment is not provided.

In addition to the modelling risks identified above, urban drainage modelling for drainage design purposes must consider the risks associated with poor performance or failure of infiltration systems. This is particularly important in areas of shallow groundwater, as noted in **Section 5.3.2**. Examples are provided in Table 11.

Having identified the risks associated with the modelling study being undertaken, it is then necessary to consider strategies to manage the risks. Broadly, there are three main strategies that can be applied:

1. Modify model parameters to include allowances for major uncertainties and to account for the most significant risks.
2. Undertake sensitivity testing and blockage/ failure scenario testing to quantify the potential impacts of key risks.
3. Include 'fail-safe' provisions within the drainage system design.

It is important that the risk management strategy is selected in consultation with the commissioning person or organisation, and potentially, the ultimate manager of the system. They should be appropriate for the specific purpose of the model and level of risk associated with modelled outcomes.

Table 11: Design and management risks for infiltration systems

System type	Example risks and consequences for consideration	
	Risk	**Consequences**
Infiltration basin, large swale, or underground infiltration system.	Reduced infiltration rate due to: • Landscape design changes such as vegetation type or cover and • Earthworks design changes such as fill source or blending strategy. • Poor design leading to clogging of the system • Poor or infrequent maintenance leading to clogging of the system.	• Premature overflows or flooding. • Extended inundation period and potential mosquito breeding. • Lack of capacity for subsequent events.
Small (roadside) swale, raingarden or biofilter.	Reduced infiltration rate due to: • Landscape design changes such as vegetation type or cover. • Poor or infrequent maintenance. Reduced capacity provided due to: • Streetscape design changes such as a need for larger footpaths or more frequent crossovers. • Clashes with services design.	• More water to the downstream system and more frequently than anticipated. • Reduced amount of water treated.
Lot-scale raingarden or soakwell	Reduced infiltration rate due to: • Poor design or installation of the system. • Poor or infrequent maintenance. Reduced capacity provided due to: • Positioning of soakwells to intersect shallow groundwater.	• More water to the downstream system and more frequently than anticipated. • Reduced amount of water treated. • Poor amenity within the property.

6.3 Model calibration, validation, and sensitivity testing

6.3.1 Calibration

Model calibration is the process of adjusting model parameters to improve representation of real-life scenarios using observed data. ARR Book 7, Chapter 5 provides detailed guidance for model calibration, including discussion of data limitations and requirements for acceptance of calibration.

Calibration of urban and peri-urban drainage modelling with flow or level monitoring data is rare in WA. This is mainly due to a general lack of long-term flow and/or level monitoring within urban and peri-urban drainage systems. In addition, short-term flow surveys, which are typically used for model calibration in other places, are costly and have a high risk of failing to capture sufficiently large rainfall events to be useful.

6.3.2 Validation

Validation is the independent process of reviewing model performance, preferably against real-life data and information. Where possible, validation uses similar quality data to calibration and is undertaken as a final check after calibration has been completed. However, in many cases, calibration is not possible due to data constraints and parameters are adjusted through validation against limited records of flooding or other issues.

In WA, because calibration data is rarely available for urban and peri-urban drainage modelling, the validation of model performance based on historic records of flooding or performance issues and/or anecdotal or photographic evidence wherever possible is critical and drainage system managers should be encouraged to maintain high quality records of flooding, *WSUD System performance* and other issues alongside general asset data records.

ARR Book 7, Chapter 7 provides detailed guidance for model validation.

6.3.3 Sensitivity testing

Sensitivity testing is a process of adjusting model platform parameters within recommended ranges and reviewing uncertainties in input data and the model's schematisation (resolution). Sensitivity testing should be undertaken as part of every modelling study to review the relative importance of model uncertainties and is particularly important for uncalibrated models.

Sensitivity testing of model platform parameters, uncertainties in input data and the model's schematisation (resolution) should be a regular part of a practitioner's activities, especially for inexperienced practitioners, whilst calibrating a model. It also plays a useful role for establishing the uncertainty of uncalibrated models.

Sensitivity testing can also be applied to consider uncertainties such as climate change, changing groundwater levels due to broad-scale land use change or changes in groundwater usage patterns, and maintenance. Sensitivity testing of key elements of the modelled system to parameters affected by these issues should include:

- reduced separation to groundwater
- clogging of infiltration systems
- sedimentation
- blockages

ARR Book 7, Chapter 7 provides detailed guidance for sensitivity testing, including examples of sensitivity testing ranges. The key principle for sensitivity testing is that the parameters modified for sensitivity testing should remain within normal expected ranges.

6.4 Example confidence level matrix

Table 12 provides an example confidence level assessment matrix. Boxes have been shaded to show an example of a completed assessment that returns a mix of medium to high confidence ratings and on-balance, generally provides a medium level of confidence in the model.

Table 12: Example confidence level assessment matrix

	High	Medium	Low
Subcatchment confidence			
Data type	Site survey supported by LiDAR, and geotechnical investigations	LiDAR and 1:10,000 environmental geology	1m contours or greater and 1:25,000 geology or greater
Data coverage	Full coverage of study area	Limited coverage with assumptions required in some areas	Poor coverage with significant assumptions required
Data age	Very recent data and/or no relevant catchment or infrastructure changes	Data predates minor catchment or infrastructure changes	Data predates significant catchment or infrastructure changes
Changes made	No or minor changes, parameters remain well within accepted ranges	Parameters at boundary of accepted ranges	Parameters outside boundary of accepted ranges
Network confidence			
Data type	Survey	GIS database	Assumed layout
Data quality	Detailed information with few gaps	Limited information with more frequent gaps	Extensive inference/ interpolation required
Data age	Within 5 years	5-10 years	>10 years
Changes made	No or minor changes, parameters remain well within accepted ranges	Parameters at boundary of accepted ranges	Parameters outside boundary of accepted ranges

	High	Medium	Low
Calibration confidence (where possible)			
Data quality	Good quality flow records at good site(s) for calibration	Limited or poor quality data at good site(s) for calibration or good quality data at poor site(s)	Limited or poor quality data or data at poor site(s) for calibration
Calibration quality	Good fit	Acceptable fit	Poor fit
Changes made	No or minor changes, parameters remain well within accepted ranges	Parameters at boundary of accepted ranges	Parameters outside boundary of accepted ranges
Validation confidence			
Data quality	Well maintained record of flooding/issues at key locations throughout study area	Limited or poor quality records but some key locations represented reasonably well	Very limited records available with one or two reports during very significant events only
Validation quality	All known locations of flooding/issues matched and no significant flooding or issues in locations where reporting would be expected	Most known locations of reported flooding matched and mismatches between reports and predictions can be explained well	No match to reported locations of flooding and/or significant flooding predicted in locations where reporting would be expected
Changes made	No or minor changes, parameters remain well within accepted ranges	Parameters at boundary of accepted ranges	Parameters outside boundary of accepted ranges

7 APPLICATION OF MODELS

As discussed in Section 2, urban drainage models are developed and used for many purposes. In Western Australia, the principal uses of urban drainage modelling are:

- development control and impact assessment
- subdivision design
- operational modelling

The first two of these are usually funded by development and have well defined objectives that are guided by planning and development controls while the third is undertaken by drainage managers and is relatively infrequently undertaken, except by the Water Corporation.

This section outlines recommendations for applying models to each of these three principal uses. Modelling may be undertaken for other purposes but is generally aligned to one of these general purposes and model scenario development can therefore be guided by the recommendations below.

7.1 Development control and impact assessment

Modelling requirements for planning of new urban and peri urban areas are outlined in the draft Planning for Water guidelines (WAPC 2021) aligned to the various levels of planning decision-making as part of preparation of water management reports.

The information required from the model and the level of confidence required for the planning and design of new urban drainage systems should be aligned to the *Decision process for stormwater management in WA* (DWER, 2017) and agreed with the eventual drainage system owner/manager which is usually the local government.

Figure 10 summarises drainage modelling requirements aligned to the water management report and planning instrument hierarchy and provides some additional guidance for selection of the appropriate model type at each stage.

Modelling is required to demonstrate that proposed stormwater management systems comply with the criteria presented in the *Decision process for stormwater management in WA* (DWER, 2017) and any other criteria specified by the drainage manager. This requires pre- and post-development modelling of scenarios in small, minor, and major rainfall events with the general requirements for each outlined below. In each case, the modeller should include a range of rainfall durations for each AEP event to enable determination of the critical duration. It is important to note that the critical duration may be different for pre and post development scenarios and is likely to vary at different locations in the model.

In addition to the model requirements below, the drainage manager may require that modelling provides an assessment of risks to and from the proposed development that are associated with climate change, maintenance issues, sediment build-up and blockages. This can be achieved through sensitivity testing as outlined in Section 6.3.3.

Where modelling is being undertaken to assess the cumulative impact of piecemeal development on an existing drainage system, it may be necessary to model the existing performance of the whole system in some detail to facilitate connections to the system without onerous on-site storage requirements. The extent of modelling required for this purpose must be determined in consultation with the drainage manager.

Planning Instrument	Type of Water Management Report required	Report Intent	Drainage modelling requirement	Model type & additional guidance
Frameworks Region schemes Sub-regional strategies Sub-regional structure plans Local planning schemes Local planning strategies	Regional WMR	Identify and map water resource constraints and opportunities.	Flood modelling and mapping: Modelling of the cumulative impact of any proposed development or fill on upstream and downstream areas	Urban drainage modelling is not generally required. **Type I – simplified model** may be considered for high-level assessment.
Region scheme amendments District structure plans Local planning scheme amendments	District WMR	Determine development capability and feasibility, water services requirements and area requirements for water resource management and protection.	Modelling of surface water and groundwater systems at an appropriate level of detail and/or complexity for the site and planning context.	**Type II – Planning model** Pre- and post-development simulation of small, minor, and major events. How does surface water move within and through the site? What is the impact of the proposed land use change? What infrastructure is required to manage the changes? Level of infrastructure design detail required within the model increases with the level of detail in the planning instrument.
Local structure plans Local master plans Local planning scheme amendments Precinct structure plans Activity centre plans	Local WMR	Location of areas for water resource management and protection and water services identified and delivery plan and conceptual designs for water infrastructure services developed.	Modelling of surface water and groundwater systems at an appropriate level of detail and/or complexity for the site and planning context.	
Subdivision applications Development applications Local development plans (includes strata schemes)	Subdivision and Development WMR	Detailed design.	Stormwater and groundwater management plans supported by relevant stormwater and groundwater modelling for the site, where it has not been provided in enough detail in higher level documents.	**Type III – Detailed model** Simulation of system performance in the relevant design event(s).

Figure 10: Drainage modelling alignment with the water management report and planning hierarchy (Adapted from: WAPC, 2021)

7.1.1 Small rainfall events

Modelling of the cumulative performance of at-source and downstream systems proposed to manage frequent rainfall is required to demonstrate that pre-development peak flow rates and total volume runoff from the outlets of the development area for the critical 1 exceedance per year (EY) event are maintained.

7.1.2 Minor rainfall events

Modelling of the performance of stormwater systems proposed to manage runoff in the development is required to demonstrate that the required levels of serviceability, amenity, and road safety are maintained during minor rainfall events.

The required levels of serviceability will be specified by the local government for the specific development area but will generally include a range of requirements like the examples below that will need to be addressed through modelling.

Residential streets

- Piped or open drainage systems should safely convey the critical 20% AEP rainfall event with appropriate freeboard to the road level.
- Gutter flow in the critical 20% AEP rainfall event should not exceed kerb height or 2m width.

Activity centres and industrial areas

- Piped or open drainage systems should safely convey the critical 10% AEP rainfall event with appropriate freeboard to the road level.
- Gutter flow in the critical 10% AEP rainfall event should not exceed kerb height or 2m width.

Public open spaces

- Stormwater management/storage systems should safely contain the critical 20% AEP rainfall event with appropriate freeboard to the top of bank.
- Stormwater management/storage systems should be designed to empty within 72 hours following the critical 20% AEP rainfall event.

In addition to the examples above, there will generally be a requirement for modelling to demonstrate that peak flows from the development area into any existing drainage system do not exceed pre-development discharges and/or do not exceed the capacity of the system.

For open drainage systems and at outlets from piped drainage systems, modelling should also consider flow velocities during design events to inform the selection of materials and design of scour protection.

7.1.3 Major rainfall events

Modelling of the development area is required to demonstrate that the critical 1% AEP event is safely managed within the development area in accordance with the requirements of any Department of Water and Environmental Regulation catchment plan and/or to maintain the pre-development flood regime (flood level, peak flow rates and storage volumes).

Demonstrating safe management of the critical 1% AEP event requires modelling to include consideration of the depth and velocity of overland flow in roads, paths, and public open spaces.

Modelling should also be used to identify peak water levels in the critical 1% AEP event within the development area so that minimum clearance requirements can be demonstrated for residential, commercial, and industrial building habitable floor levels and critical infrastructure and important community facilities, which require a higher level of flood protection.

7.2 Subdivision design

Modelling to support subdivision design is often undertaken concurrently, using the same model, with modelling for development control and impact assessment purposes. However, there are additional considerations that apply in relation to the detailed design and construction of subdivision drainage systems that may require additional modelling detail to be provided. These include:

- safety in design
- cost and constructability
- management and maintenance requirements
- fail-safe provisions such as overflows or bypass arrangements

7.3 Operational modelling

Less frequently undertaken, well maintained drainage catchment models can provide significant operational benefits to drainage managers and should be undertaken as an integral component of drainage asset management.

Operational modelling is generally undertaken as a Type II planning model although simplification of the system is likely to be very limited because there is a need to represent the system in quite a detailed way. Modelling for operational purposes should be capable of providing the following information:

- Minor event freeboard at individual manholes, structures, storages, and junctions.
- Major event flood levels, flood extents, and overland flowpaths, including in road sags and for gutter flows.
- Flow velocities within the system for assessment of:
    - risk of sediment build-up (slow flow).
    - erosion risk (fast flow in open drains and at inlets/outlets.
    - risk assessment for public safety (fast flow in overland flowpaths).

Aligned with operational drainage modelling, the drainage manager should maintain detailed records of drainage nuisance complaints flooding, maintenance issues, sediment build-up and blockages. This information is a critical input to drainage model development and calibration and should also be used as a trigger for updated modelling where new issues are identified.

Drainage managers should also consider monitoring at key locations where risks associated with system performance are significant, and/or where model uncertainty is high.

In addition to these model requirements, the drainage manager may require that modelling provides an assessment of risks to and from the proposed development that are associated with climate change, maintenance issues, sediment build-up and blockages. This can be achieved through sensitivity testing as outlined in Section 6.3.3.

8 DOCUMENTATION

Water management reporting requirements for planning of new urban and peri urban areas are outlined in the draft Planning for Water guidelines (WAPC 2021) aligned to the various levels of planning instrument as shown in Figure 10.

The requirements for reporting associated with drainage modelling that are provided in the draft Planning for Water guidelines (WAPC 2021) are summarised below.

- Discussion of parameters and assumptions for use in modelling and/or design processes, supported by results and findings of monitoring and site investigations where available, including:
    a) in-situ soils hydraulic conductivity and recommended design infiltration rate
    b) in-situ soils nutrient retention capacity
    c) catchment slope, land use and roughness
    d) runoff rates and catchment losses
    e) rainfall event intensity, frequency, and duration patterns
    f) annual and seasonal rainfall and evaporation rates
- Surface water context plan, and conceptual system layout showing modelling results for small, minor, and major rainfall events
- Surface water management system design details and modelling results including:
    a) presentation and justification of modelling parameters
    b) demonstration of compliance with inflows and outflows specified in WMR for previous planning stages or defined through catchment scale modelling
    c) design of small rainfall event management systems
    d) design of minor rainfall event management systems including conveyance system layout, invert levels, hydraulic grade lines and dimensions
    e) design of major rainfall event management systems including overland flowpath layouts and dimensions including flow depths and velocities
    f) storage system invert levels, high water marks and dimensions; and
    g) integrated street and landscape designs

In addition to the above information that is required as a part of a water management report, it is recommended that a separate, more detailed modelling report is provided as an appendix.

Drainage modelling reports should include sections dealing with the content of this Code of Practice including:

- Model definition
- Model conceptualisation
- Data collection
- Model development
- Model calibration and confidence
- Model application and results

Reporting must include the rationale and justification for selection of parameters, particularly where they lie outside of typical ranges.

Reporting should provide guidance for engineers that will be using the model results for design and construction purposes. This guidance should include:

- Earthworks - soil specifications for fill, including advice on blending and compaction where relevant.
- Drainage – critical invert levels, dimensions, and top water levels.
- Safety in design – locations where the model predicts deep and/or fast flowing water.
- Maintenance – locations where the model predicts erosive flows and/or where sediment is likely to collect.

Reporting should also identify any outstanding questions, key risks, or limitations of results such as areas where there is a lack of confidence in the model.

The following model features and parameters should always be reported, using mapping to aid presentation of the information, and providing supporting evidence and rationale, where necessary:

- Model extent, layout and boundary conditions applied.
- Model type and description of any catchment or system simplification.
- Runoff generation and routing model methodology.
- Loss parameters for runoff surfaces.
- Subcatchment definition including relevant parameters such as area, slope, roughness, width, land use, and surface type breakdown.
- Network definition including dimensions and levels of key structures, and parameters including hydraulic roughness's, head loss representation, infiltration rates.
- Groundwater levels or inflows (where relevant).
- 2-dimensional model definition including grid dimensions, roughness, infiltration, and method of linkage to 1-dimensional elements (where relevant).

9 DOCUMENTATION REVIEW

It is critical that the first consideration in any model documentation review should be to determine if additional support and/or advice for the reviewer is required. Therefore, the reviewer should refer to Section 2.5 of this *Code of Practice* and consider the following question:

Do I understand the information before me and am I sufficiently experienced to decide if the model findings are acceptable and can be used for design purposes?

In many cases, it will not be necessary for the reviewer to be an experienced modeller themselves, but a basic understanding of modelling principles and appreciation of drainage system design requirements is critical.

As noted in Section 2.5, the level of knowledge required to determine when a model requires additional assessment is not always available within organisations required to review and approve modelling reports. In this case, assistance and advice can be requested from the Department of Water and Environmental Regulation.

Once the reviewer has satisfied themselves that they are sufficiently capable to review the modelling documentation provided, Table 13 may be adapted for use as a checklist of questions to guide the review.

Table 13: Model review checklist

Document element	Review questions	Where to look in this document
Project planning and definition	• Is the purpose of modelling described and do you agree with the objectives?	• Section 2.1
	• Have criteria for assessment been set and are they consistent with requirements?	• Section 2.2 and Section 7
Model conceptualisation	• Does the model contain sufficient detail to address the specified assessment criteria at all relevant locations?	• Section 3.1
	• Is the site in an area of shallow groundwater and if so, has the modeller acknowledged this as a key constraint and discussed its representation in the model?	• Section 3.2
	• What model is being used and is justification for its selection provided/accepted?	• Section 3.3
	• Do you agree with the modellers decision to use 1D or 2D modelling for this project?	• Section 3.3.2
Data collection	• Is the model supported by appropriate data and evidence?	• Section 4.1
	• Are data gaps and quality issues acknowledged and has the modeller provided a satisfactory approach for application of assumptions?	• Section 4.2

Document element	Review questions	Where to look in this document
Model development	• Have model scenarios and boundary conditions been described and will they allow for assessment against specified criteria at all relevant locations?	• Section 5.1 and 5.2
	• Are model parameters presented and within expected ranges and/or supported with evidence/data?	• Section 5.3
	• Does the model provide a reasonable spatial representation of the catchment and drainage system?	• Section 5.4
	• Are critical elements of the drainage system, such as major structures and junctions, key inflows and outflows, storages and tailwater levels, modelled?	• Section 5.5 and 5.6
Model confidence	• Has the modeller identified any areas of low model confidence?	• Section 6.1
	• Has the modeller considered risks associated with low confidence in the model findings and appropriately addressed them through sensitivity testing, design modifications, management recommendations or other approaches?	• Section 6.2, 6.3 and 6.4
Model documentation	• Is model documentation set out in a way that is logical and provides sufficient detail?	• Section 8
	• Has the modeller identified any key design guidance/recommendations that need to be considered in future assessments?	• Section 8
General	• Are you satisfied that the modeller has executed the project with suitable rigor?	
	• Are you satisfied that the model is suitable for the purpose it has been used for?	
	• Are you comfortable with the modeller's response to any areas of key risk?	

10 REFERENCES AND RESOURCES

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APPENDIX A - ITEMS TO CONSIDER FOR A MODEL ASSESSMENT

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

- Assessment of sufficient data for review
- Model history and purpose
- Model extents & connectivity and level of detail
- Model stability and volume balance check
- Subcatchment data
- Contributing areas and imperviousness
- SOIL type
- Node data
- Flooding representation
- Representation of head losses
- Storage compensation
- Conduit data
- River cross-sections
- Bank levels
- Backfalls
- Sediment depths and roughness coefficients
- Inclusion and representation of ancillaries including bridges, weirs, inlet and outlet structures, Pumping stations
- Infiltration
- Runoff modelling
- Rainfall
- Changes in catchments since the model was developed
- Inclusion of major systems
- Model detail in vicinity of critical locations
- Interactions with watercourses and other systems
- Sensitivity to local baseflow infiltration and rainfall induced infiltration
- Historical verification
- Overland flow paths

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