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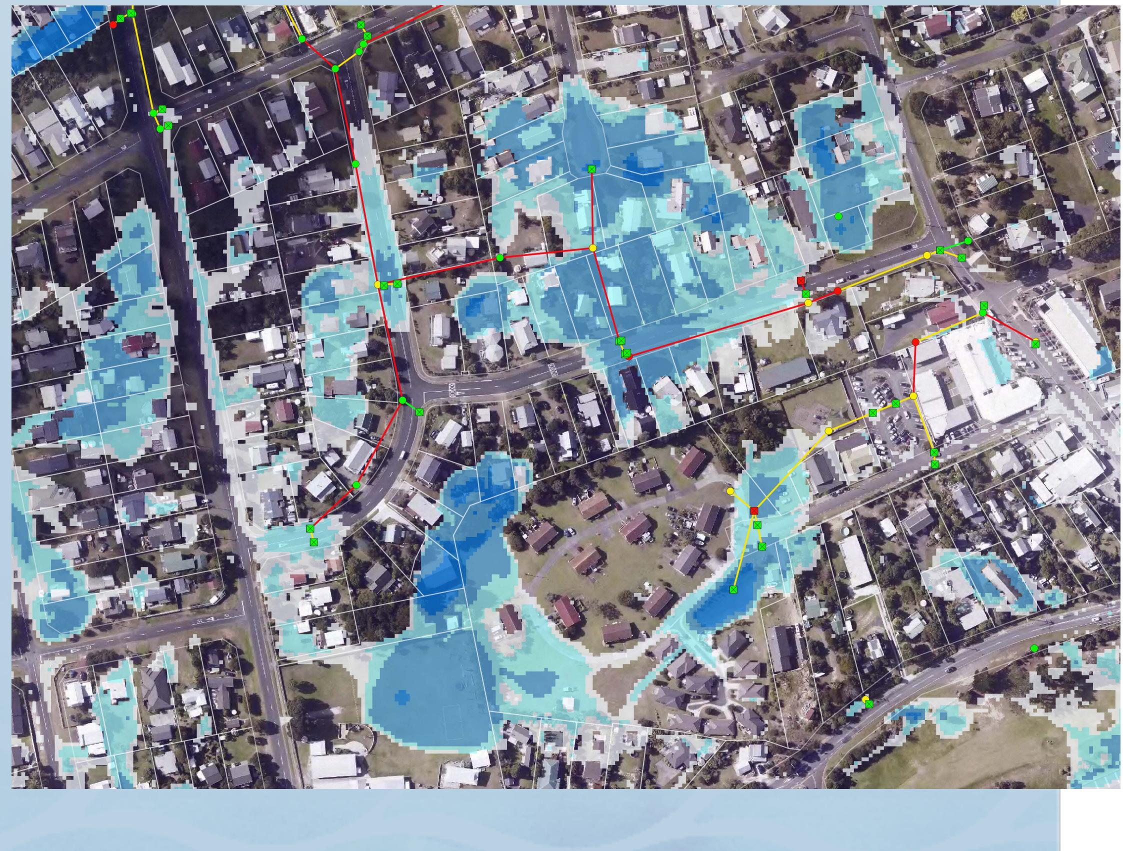
The New Zealand Water & Wastes Association Waiora Aotearoa

National Stormwater Modelling Guide



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This work builds on a volunteer initiative to develop stormwater modelling guidance led by Nadia Nitsche (Wellington Water), Fiona Macdonald (Auckland Council) and other Water New Zealand Modelling Special Interest Group members between 2019 and 2022.

This guide was informed by a number of existing guidelines and specifications on modelling, and principles, concepts, methodologies, and processes have been adapted into this new national modelling approach. In particular:

- Bay of Plenty Regional Council (2021)
- Tauranga City Council (2022)
- CIWEM (2017, 2021)
- Greater Wellington Regional Council (2021)

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- Industry Survey – July / August 2020
- Water New Zealand – National Conference Workshop – November 2020
- Water New Zealand – Modelling Symposium Workshop – June 2021
- Water New Zealand - Modelling Symposium Workshop – March 2023
- Water New Zealand – Online Workshop – April 2023
- Industry Survey – April / May 2023
- Water New Zealand – Stormwater Conference Workshop – May 2023
- Interviews with council staff and consultants in the industry – April to May 2023
- Water New Zealand – Conference and Expo - Workshop – October 2023
- Water New Zealand – Online Workshop – October 2023

Contents

1 INTRODUCTION AND PRINCIPLES

1.1 Purpose

The purpose of this guide is to offer approaches and recommend resources for addressing inconsistencies and gaps in advice relating to computer modelling of urban stormwater systems and flood hazard mapping.

Guidance provided in this document is intended to support and encourage holistic and consistent understanding of flood hazard, which lead to informed decisions about the best ways to manage risk. Councils, land developers and communities may use this guide to understand the simulation of flood risk and the use of model outputs to support a common understanding of urban flood risks and associated impacts.

1.2 Scope

The following items are within the scope of this document.

- Provide a nationally consistent and robust urban stormwater flood hazard modelling process to aid in understanding flood risk and management.
- Provide guidance and define best practice approaches for urban stormwater modelling.

The following topics are outside the scope of this document.

- Water quality, including sediment transport, and erosion and scour assessment. It is recognised that stormwater models may be used in these applications.
- Provide a detailed model-build specification: specification level guidance should be based on local conditions and provided by the organisation leading or procuring modelling work.
- Modelling of large rivers and fluvial flood mapping
- Providing national rainfall-runoff guidance. A summary of common methods used in Aotearoa New Zealand is provided in Section 4.2.

1.3 What is an urban stormwater model?

An urban stormwater model is a numerical hydraulic model that represents the conveyance of stormwater runoff into and through towns or cities. They are commonly associated with flood investigations.

They numerically represent the rain falling within a catchment and the subsequent losses and conveyance of water over land, into stormwater infrastructure, channels, rivers and other waterways. Due to changes in natural drainage patterns, urban models include a representation of engineered flow paths and structures that can cause water to deviate substantially from pathways defined by topography.

Depending on the purpose and detail required in the model, different features and phenomena that impact conveyance are included to support complex decision-making and risk management related to stormwater management in urban areas.

1.4 Modelling principles

This guide cannot provide advice for every possible application of stormwater modelling. Where the guide recommended approaches and methodology do not apply, key modelling principles, outlined in Table 1-1, may be looked to for guidance. These principles underpin the advice that is provided in this document and are widely applicable.

Table 1-1: Hydraulic modelling principles.

Principle	Explanation
Models are simplifications of complex processes	Models are designed to only represent a selection of key processes or phenomena: not all phenomena in a complex system may be included in a model's design. Even for the processes that are explicitly represented, simplifications in the form of assumption are included in input data, formulations of physical laws, and compromises in resolution to achieve practical simulation runtimes.
Use the model for the purpose that it was built for	Assumptions made during the construction of a model can severely limit its applicability to situations it was not designed to cater for. A model requires review, revision, and additional calibration/validation/verification when it is used for a purpose it was not designed for.
Understand the relevant phenomena	Key phenomena must be understood sufficiently in order to effectively resolve the most important characteristics of the real-world counterpart to each modelled component.
Models are best built iteratively	Repeatedly refining a model through iterative build phases helps the modeller build, improve, and develop an intuitive understanding of the model.
Risk tolerance should drive complexity and accuracy	The end use of a model, including the risk to lives, infrastructure, and the environment should be used to determine requirement for model resolution, accuracy and reliability.
A calibrated model will only reliably predict flood behaviour for events similar to those used in calibration	Tuning parameters and geometry within realistic ranges to align model results with measurements ensures that the model reproduces events similar in characteristics to the flood events used in calibration, validation and verification. The model may not be reliable when used to assess events significantly different to the range of events used in the tuning process.
No model is "correct" - results always require interpretation	Experience and understanding of the physical stormwater network and the catchment being modelled is required to interpret results and determine the model's limitations based on the modeller's assumptions.
Uncertainty is inherent in models	There is an inherent uncertainty in model outputs. This should be recognised and quantified where possible.
Modelling is data intensive	The management of different model versions and sources of data and the tracking of changes throughout the modelling process is critical for auditing, legal defence and efficiencies in modelling studies.

References: Adapted from BOPRC (2021)

1.5 How to use this guide

This guide should be used as a reference by those procuring, building and using urban stormwater models as a set of high-level best practice recommendations. This document is structured to align with the main model-build processes of planning, building, using, sharing and maintaining urban stormwater models and so those looking for guidance on all phases may read the document from start to finish. Those with more experience may use elements of the document as a checklist when working through familiar modelling tasks. Most users will only refer to relevant sections based on their needs.

This guide is structured around several key modelling processes. Figure 1 shows these processes, along with conceptual interactions between the processes that might occur. The premises behind these processes are that the project and then the model needs to be planned, a base model established, which is then used for the simulation of scenarios of interest. Once the simulations are complete, the models should be archived, the base model maintained, and model versions and/or metadata shared.

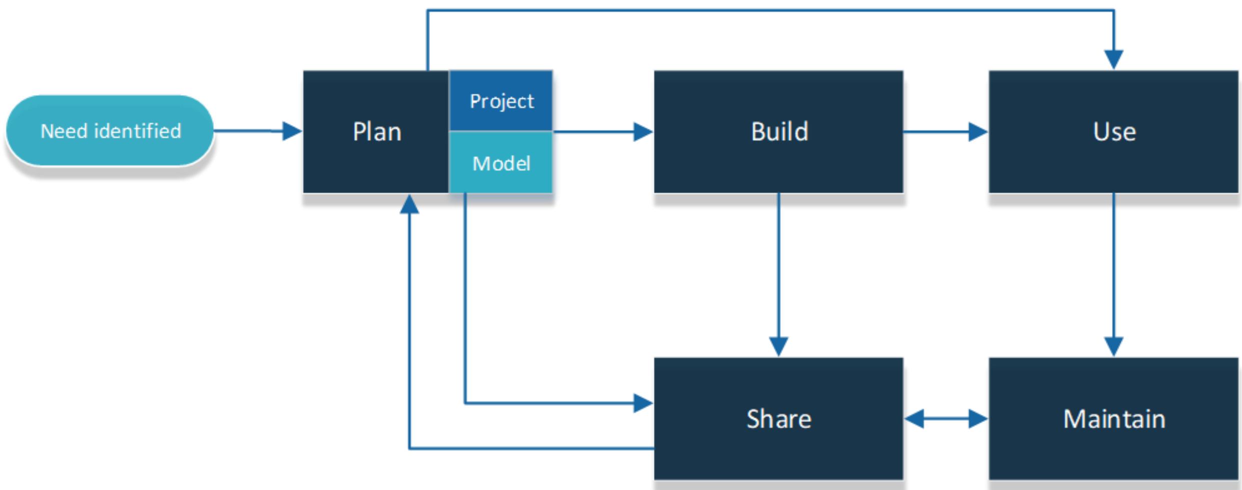


Figure 1: Key Modelling Processes

1.6 Who should use this guide

The structure and content of this document have been designed with the following end users and associated applications in mind.

- Regional and local councils (including future water service managers) when:
  - scoping and procuring stormwater modelling services; or
  - building / using / sharing / maintaining stormwater models and their outputs.
- Iwi, Hapu and other Māori agencies or organisations when:
  - scoping and procuring stormwater modelling services; or
  - understanding, interpreting and applying stormwater model outputs.
- Land developers when:

    - scoping and procuring stormwater modelling services; or
    - understanding, interpreting and applying stormwater model outputs.
- Engineering consultants when:
    - supporting model scoping and procurement;
    - planning, building, using, sharing and maintaining models;
    - understanding, interpreting and applying model outputs; or
    - providing professional services to land developers and councils to deliver the above activities.
- Crown Agencies when:
    - supporting model scoping and procurement;
    - planning, building, using, sharing and maintaining models; and
    - understanding, interpreting and applying model outputs.

Table 1-2 summarises the relevance of sections in this document to the following key roles in the stormwater modelling process.

- Commissioning organisation: sets the overall model purpose (in consultation with relevant stakeholders), plans the modelling project, and funds the overall initiative.
- Modeller(s): the individual (or team) who delivers the detailed model plan, builds the model, and uses it for the defined purpose.
- Reviewer: the individual responsible for internal and or external review of models.
- End user: consumers of model outputs (raw or derived).

Table 1-2: Guide structure and relevance to key roles.

No	Section	Content Summary	Relevant to role			
			Commissioning Organisation	Modeller	Reviewer	End User
1	Introduction	Guide purpose and guiding principles	X	X	X	X
2	Plan - Project	Define model purpose, engage with stakeholders, review background information and plan quality assurance	X		X	X
3	Plan - Model	Define success criteria, identify phenomena, confirm approach and methodology, select software, set model management practices and commence data collections		X	X	
4	Build	Prepare hydrological inputs, build hydraulic model, set boundary conditions,		X	X	

No	Section	Content Summary	Relevant to role			
			Commissioning Organisation	Modeller	Reviewer	End User
		complete quality assurance, define limitations and assumptions, assess model confidence and prepare reporting				
5	Use	Test and compare current and future scenarios by varying model boundary conditions, hydrology and hydraulics (including blockage assessment)	X	X	X	X
6	Maintain	Approaches for archiving and updating model assets	X	X		
7	Share	Managing intellectual property rights, metadata and data formats	X	X		X
8	Glossary	Definitions of technical terms	X	X	X	X
9	References	References used to create this guide and links to good practice examples		X	X	

1.7 Lifecycle of this guide

This guide is published as a PDF document and to a website. It will be reviewed and revised to enhance usability and reflect best practice as it evolves. Versioning will be clearly marked on the website and relevant sections. New methods and approaches will develop in the future and the guide is intentionally non-prescriptive to ensure that it does not interfere with the application of innovative techniques and technologies.

The guide is owned and maintained by Water New Zealand with support from the Stormwater and Modelling Special Interest Groups (SIG's). Feedback, suggestions, and examples of best practice to inform future revisions are always welcome. These can be submitted via enquiries@waternz.org.nz and will be directed to the relevant SIG for consideration and incorporation into future updates.

1.8 Terminology

The following key terms are used throughout this document.

- **Annual Exceedance Probability (AEP)** = The probability of an event of a specific magnitude or greater occurring in any particular year period. This is usually expressed as a percentage and may be applied to marginal and joint probabilities. For example, a 5% AEP rainfall depth event is an event that has a 5% probability of being exceeded in any one year. The greater the magnitude of the event, the smaller the AEP. This document uses AEP to designate event probability[1].

- **Base Model =** Complete and validated model that may be suitable for a range of applications. Copies of base models, termed *reference models*, are used in studies as the basis for project models.
- **Flood Risk** = Includes the hazard (characteristics and severity of flood events), exposure (extent to which people, assets, and the environment are situated in flood-prone areas) and vulnerability (susceptibility of exposed elements to damage or harm when subjected to flood conditions).
- **Hydraulic model** = representation of the piped drainage and open channel system (primary), overland flow paths (secondary) and floodplain of urban areas and associated fluid dynamics (water levels and flows) through these systems.
- **Hydrological model** = representation of the process of transforming rainfall into runoff before it enters the physical drainage system and floodplain.
- **Primary stormwater system** = The components of the urban stormwater system used to manage stormwater runoff (rainfall events of approx. 10% AEP or more frequent). This generally includes the stormwater pipe network, inline flood management devices, streams, watercourses, road kerbs, channel and culverts. Design level of service of these systems is usually governed by local or regional codes of practice, engineering standards or infrastructure standards. These systems are usually modelled in one-dimension (1D) – stormwater flows are sufficiently described in one dimension).
- **Secondary stormwater system** = The overland flow paths and flood plains, that activate during rain events that exceed the design level of service for primary stormwater systems and or when the piped network is overwhelmed. This generally occurs for events with an AEP between 10% and 1%. Design level of service of secondary flow paths systems is governed by land use and building controls in District or Unitary Plans, or codes of practice, engineering standards or infrastructure standards. Events exceeding the design level of service should still be considered and assessed in some circumstances – refer to the residual risk management process outlined in Section 5. These systems are usually modelled in two-dimensions (2D – flows occur within a two-dimensional plane).

[1] Annual Recurrence Interval (ARI) is often used to describe event probability - the average period between events of a certain size. A common form used is "1 in 100yr event", which may be misinterpreted as designating an event that only occurs once every 100 years (instead of the correct interpretation of a 1 in 100 probability of an event of the size of the event of interest or greater occurring in any one year). ARI and AEP are related by this equation: AEP (%) = 100 x (exp(1 / ARI) - 1) / exp(1 / ARI). This results in 1% AEP being equivalent to 99.50-year ARI, a 2% AEP being equivalent to a 49.50-year ARI, and a 10% AEP being equivalent to a 9.49-year ARI. Rounding to two or three significant figures is often applied.

2 PLAN – PROJECT

2.1 Overview

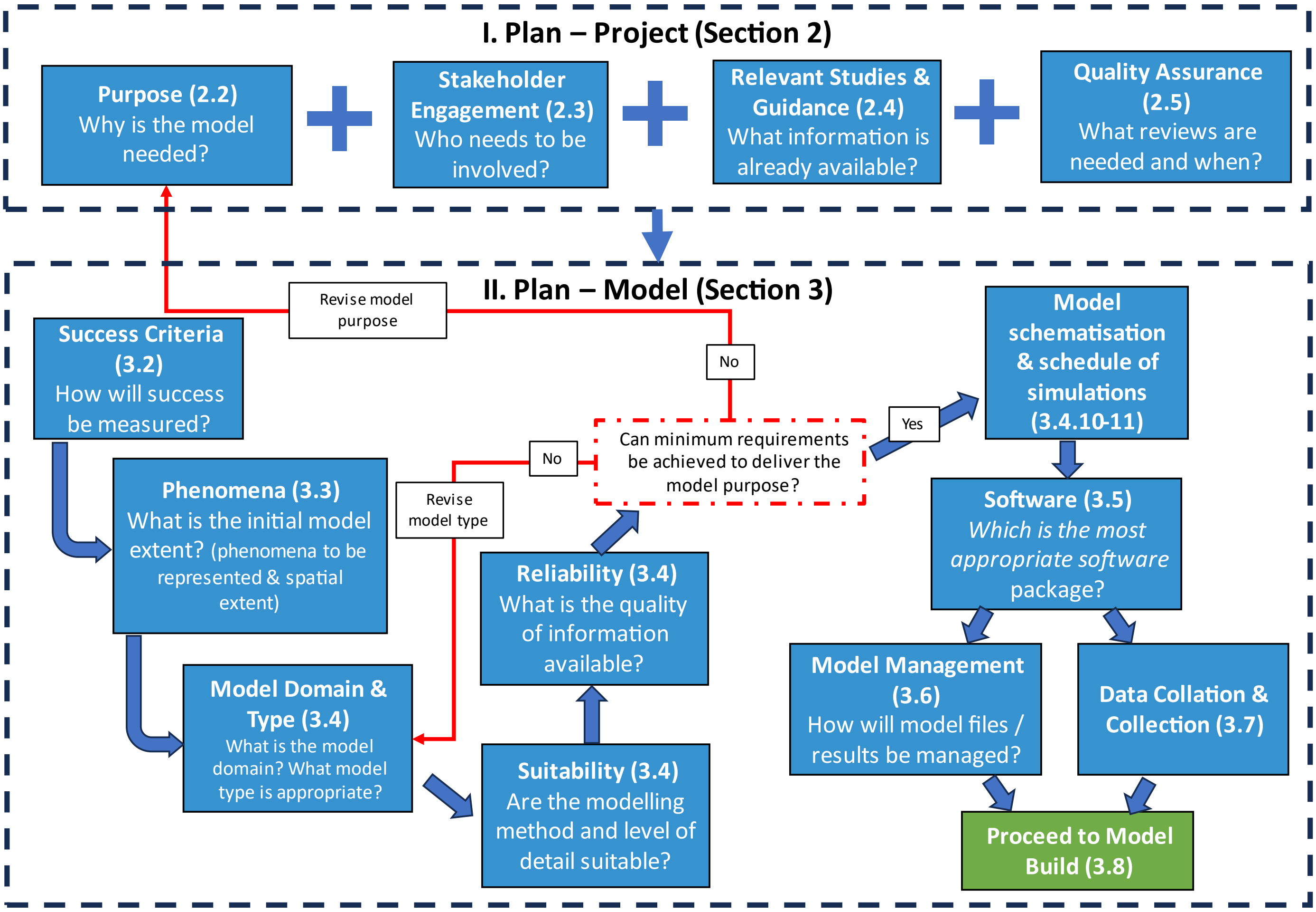
This guide separates two key stages in planning modelling work:

1. Project planning (this section); and
2. Model planning (section 3).

Figure 2-1 provides an overview of the model planning process, which is separated into broader project planning (this section) and model specific planning (Section 3) steps. Project planning is focused on non-modelling activities related to outcomes and stakeholder requirements. Model planning is focused on identification of physical phenomena, defining the model domain and schema as well as software selection and data requirements.

This section specifically provides guidance on defining the purpose of stormwater modelling process within the wider context of a project or other broader process. It is recommended that all key stakeholders are involved in this part of the process, including the commissioning entity, modellers and end users. These parties should confirm that there is a clear need for a model, what it must represent, what outputs are required and the required level of accuracy in the results.

Figure 2-1: Overview of Planning Process.



2.2 Define model purpose

An important first step as part of defining the model purpose is to confirm if a model is actually required. For some stormwater problems or simple scenarios there are a range of non-model-based approaches that may be more appropriate and cost-effective to apply. A model is generally justified under one or more of the following circumstances:

- when seeking to understand interactions between primary and secondary stormwater management systems;
- when investigating hydrological or hydraulic changes to an urban stormwater system from planned in land use modifications, urban intensification or modifications to stormwater networks;
- when identifying, understand and mapping areas at risk of multiple sources of flooding;
- when estimating the damages and or wider impacts of flooding;
- when identifying, evaluating and designing stormwater management solutions across primary and secondary systems;
- when there are significant backwater effects; and
- when climate change is expected to change flood issues and risks.

An urban stormwater model is typically a component within a larger programme where flood risk, system performance and or hydraulic responses to change must be addressed. The model purpose should encompass these objectives and be supported by a range of success criteria (Refer Section 3.2). A model may have multiple purposes, particularly when there are multiple stakeholders. A model may also be initially developed at a low level of complexity to serve one purpose and then made more complex over time to serve additional purposes as new data becomes available. Alternatively, a comprehensive, complex and high-detailed model may be built in an attempt to future proof the model.

The purpose of a model should be articulated as a concise series of statements. From each statement a series of objectives may be derived that support the purpose. These objectives should be narrow in scope and clearly define a specific element of the model purpose. Examples of purpose statements and associated objectives are provided in Table 3-1. The following are example model purpose statements.

- To determine peak flow arriving at a culvert during a 10% AEP, 2030-climate-horizon rainfall event.
- To determine flood hazard within a flood plain.
- To determine the effects of mitigation options on flood hazard within a flood plain.
- To determine the flood impacts of land use changes.
- To determine existing infrastructure's ability to meet design levels of service.
- To inform flood extents for catchment management planning.

References: CIWEM (2021), BOPRC (2021)

2.3 Stakeholder engagement

It is important to map and engage stakeholders as they may hold essential background knowledge of the catchment or be directly affected by the project results. Several example resources on engagement methods and strategies are:

- Department of the Prime Minister and Cabinet: Community Engagement Guidance[2]
- Government Procurement: Stakeholder Management Tool
- Government Procurement: RACI Template
- Te Arawhiti: Guidelines for Engagement with Māori

Several important considerations from these resources are summarised in the following sections.

2.3.1 Identify desired outcomes of engagement

The reasons for the engagement and expected outcomes, influence at which stage in the modelling process stakeholders are involved. Table 2-1 provides some example outcomes and link to the stages of modelling.

Table 2-1: Example stakeholder engagement outcomes and associated modelling stage

Outcome	Details	Modelling stage
Build trust and collaboration	Build a collective understanding and mitigate conflicts or disputes related to the modelling or stormwater management recommendations.	Define model purpose (Section 2.2) and success criteria (Section 3.2)
Legal and regulatory compliance	Ensure compliance with legal and regulatory requirements and mitigate conflicts or disputes related to the modelling process and outcomes.	Quality assurance (Section 2.5)
Social acceptance	Design measures that are not only technically effective but also considerate of local contexts.	Use (Section 5)
Correctly scoped project	Identify local risks, vulnerabilities and critical infrastructure to enhance the accuracy and relevance of models - mitigate conflicts or disputes related to the modelling.	Identify relevant phenomena (Section 3.3)
Obtain local knowledge and expertise	Enhance the accuracy and relevance of models. Ensure that both technical and non-technical perspectives are considered in model schematisation.	Preliminary schematisation (Section 3.3.2)
Data validation	Align model outputs with real-world conditions by cross-referencing with local observations.	Validation (Section 4.7)
Economic and social impact assessment	More accurately estimate the overall consequences of flooding by considering the perspectives of affected individuals and communities, mitigate conflicts or disputes related to the modelling	Model outputs (Section 4.8)

[2] Based on International Association for Public Participation (IAP2) best practice guidance.

2.3.2 Identify relevant groups

Stakeholders may include the following technical and non-technical groups. The model planning process should identify which of these groups should be engaged and at what stages. This will feed into development of an engagement strategy.

- Regional and local councils
- Mana whenua - Iwi groups
- Land owners
- Infrastructure asset owners
- Communities
- Businesses
- Professional services consultants

2.4 Review relevant studies and guidance

Pre-existing studies of the catchment or related catchments should be reviewed. This can include catchment and asset management plans, environmental studies, engineering options assessments, local engineering codes or specifications, district and regional plans, and flood incident reporting. These related studies can inform the model plan stage, particularly with regards to identification of relevant phenomena, schematisation, identification of historical flood events, and data gap analysis.

References: BOPRC (2021)

2.5 Quality Assurance

Quality assurance confirms that planned outcomes are achieved and ultimately increases the accuracy and reliability of models and confidence in them to represent real-world conditions. The level of quality assurance should correspond to the level of risk associated with the modelling study. In the context of urban stormwater models, there are several common types of review:

- internal review;
- compliance review;
- peer review; and
- audit.

The approach and schedule for quality assurance reviews should be planned and the need for external model review decided and, if required, scheduled for relevant build milestones. The types of model review and frequency required depend on budgets, timeframes, reviewer availability, compliance requirements, and risk associated with the modelled outcomes. If an external peer review is required, it is important to distinguish between compliance reviews and peer reviews (refer to Sections 2.5.1 and 2.5.2). In some cases, an independent audit may also be required.

2.5.1 Internal review

Internal review should involve a senior or principal level technical expert who is allocated sufficient time to engage with the model and modeller at different stages of the planning and build process. It is recommended that the reviewer revisit the model at multiple stages throughout the modelling task to minimise risk to the project. Milestone reviews for significant parts of the project are required, especially before providing material to the external peer reviewer.

External review does not diminish the requirement for a comprehensive internal review.

2.5.2 Compliance review

A compliance review is a detailed comparison of the model to an agreed modelling standard or specification to ensure consistency, traceability and reproducibility. The final outputs are not assessed directly. A compliance review may cover the following broad aspects of a modelling project or task.

- Outcomes meet the project purpose and objectives and are fit for purpose.
- The model and analyses are:
    - consistent with documentation; and
    - comprehensive and complete.

A compliance review will demonstrate that a model and analyses have been completed according to the appropriate specification or standard. Compliance reviews and peer reviews should not overlap in scope. A compliance review requires that the reviewer can interrogate the model and results, then compare these with predetermined standards. This requirement is not as onerous as that of a peer review.

2.5.3 Peer review

"A peer review is a professional opinion based on sound engineering analysis and assumptions, good practice, appropriate regulations and unbiased judgement" [3]. Additional criteria of note, in relation to urban flood modelling, are outlined below.

- A peer review is carried out by a party that is suitably qualified to assess technical aspects of the work (expertise in hydrological and hydraulic modelling, modelling software and the use of models in a range of applications).
- Ideally, the reviewer is from an independent organisation and has not been involved in the modelling work or have any dependent relationship with the commissioning organisation or organisation undertaking the modelling work. However, practically, independence is often compromised due to a lack of suitably qualified personnel or prohibitive expense.
- Peer review should not take the place of internal technical supervision and review. The peer reviewer's independence and value are eroded if required to engage with minor technical issues that should be dealt with by senior technical leads as part of internal reviews. A lack of internal

[3] Engineering NZ (2018) *Practice Note 2: Peer Review, Version 2*. Engineering New Zealand, 24th April 2018

review overburdens the external review process and inevitably increases costs and delays project completion.

- Peer reviews may incorporate a broad scope, but usually will focus on determining whether the model:
  - functions in a consistent manner;
  - appropriately aligns to the model purpose; and/or
  - outputs are of suitable and reliable accuracy for achieving the model purpose.
- Engaging a peer reviewer at the commencement of a modelling project will improve final outcomes by catching issues early and so preventing rework and related impacts to budget and programme.
- A peer reviewer enhances the modelling project by providing an alternative perspective.
- Depending on the complexity of the modelling project, budgets, timeframes and consequences of having an inadequate model, reviews can be scheduled either at staged milestones or at the end of the project.

2.5.4 Audit

To provide an additional level of confidence, an audit may be carried out by an independent party of the entire flood modelling project to ensure that the modelling and peer review processes followed are sound. Audits are a type of assurance most relevant to larger programmes of work.

Independent auditors need to have sufficient experience in large modelling projects, ideally be completely independent from the stakeholders of the project including modellers and peer reviewers or declare and manage any conflicts of interest.

2.5.5 Quality assurance plan

There are several considerations for the development of a quality assurance plan. Below are some examples.

- Prioritise effort by ensuring the level of quality assurance corresponds to the level of risk from the outcomes of the work. Involving multiple parties may increase the cost and duration of a model build project. Larger or more complex projects generally attract greater risk – examples include:
  - new catchment model build and validation; and
  - flood mapping for plan change applications.
- The approach for review should be agreed before modelling work commences because typically modelling work is completed to a contracted scope and review comments can impact this scope and consequently budgets and timeframes. In cases where external peer review is necessary, the commissioning organisation should ideally select the peer reviewer.
- It is important to allow enough time to procure a suitable reviewer and incorporate them into the modelling project plan as appropriate.
- The intention of review is not to transfer responsibility for the project to the reviewer but to provide assurance that the modelling work meets quality requirements and the purpose of the project.

However, depending on the contractual arrangement, some degree of liability may be transferred to the reviewer and this should be clarified contractually.

- Reviews of modelling work and associated documentation should be staged for large projects. Reviews may be required at the completion of:
    - model planning;
    - the hydrological component of the model;
    - the hydraulic component of the model;
    - model validation;
    - scenario simulation;
    - design event flood estimation; and/or
    - optioneering.
- The end client is given an opportunity to participate in meetings between modeller and peer reviewer and to provide feedback on deliverables prior to final revisions and delivery.

References: TCC (2022), HCC (2017), NRC (2022), GWRC (2021), WWL (2022)

3 PLAN – MODEL

3.1 Overview

This section suggests approaches to planning the successful build of an urban stormwater model. Modelling studies should be planned, scoped and commissioned with a clear end goal. Poorly planned modelling projects can create on-going issues stemming from a poorly understood scope including negative quality, budget and programme outcomes. It is essential that that the work *begins with the end in mind.* Figure 2-1 provides an overview of the key steps in the model planning process.

3.2 Define Success Criteria

Success criteria link directly to the model purpose (and associated objectives), which should be defined at the project planning stage. The criteria should define the purpose using measurable, transparent and easily understood metrics. The criteria may be evaluated and reported on during and at the end of the modelling process to document success - or not. It is preferable for the criteria to be quantifiable. Examples of success criteria are shown in Table 3-1. It is useful to use model outputs and specific deliverables that will demonstrate achieving the success criteria. Refer to Section 5.4 for guidance on specification of model outputs.

Table 3-1: Example modelling purpose statements with associated objectives and success criteria.

Model Purpose Statement	Objective	Success criteria
To determine peak flood levels for a 1% AEP, 2130-climate-horizon rainfall event for all buildings within commercial zone.	Demonstrate that the predicted water levels are robust.	95% of simulated water levels for a single historic event are within 150mm of recorded debris level and maximum recorded water level.
		Predicted extents, depths and mechanisms from simulating two historic events match anecdotal evidence provided by the public.
	Simulate a 1% AEP, 2130-climate-horizon rainfall event in a dynamic simulation.	Simulate a nested design hyetograph rainfall event for a 12-hour period.
	Generate a maximum water level for every building within the commercial zone.	All building footprints are associated with a maximum water level
	Determine sensitivity of the maximum water level estimates at each building to stormwater inlet blockage	Simulations incorporating full and partial blockage are simulated and water level differences are calculated across entire commercial zone.
To determine the flood impacts of changing the zoning from rural to urban for the 10% AEP design rainfall event for existing and 2130 climates.	Determine the extent of significant increases in peak water level due to rezoning	Plot extent of increases of greater than or equal to 5 mm in maximum water level between pre- and post-rezoning scenarios.
		Resolution of model is sufficient to resolve differences in flooding around buildings between pre- and post-rezoning scenarios.
	Quantify the impact on peak flow directly downstream of the proposed rezoning area	An explanation of the variation in discharge is plausible and understood by end users.
		No instability in outlet discharge hydrograph.
	Resolve flood hazard sufficiently to determine the extent of significant increases in maximum hazard due to rezoning.	Maximum depth x velocity magnitude hazard can be calculated at a 2m resolution across the zone.
		Plot extent of change in hazard between pre- and post-rezoning scenarios.

References: BOPRC (2021)

3.3 Identify relevant phenomena

3.3.1 Definition

Relevant phenomena are aspects of the physical systems being modelled that will have a significant impact on the behaviour and results of the model. Relevance of a particular phenomenon will be determined by the model purpose. Relevant phenomena may be identified from desktop review, site walkovers, pre-existing studies or models of the specific site or similar sites, anecdotal or physical evidence, or modeller experience. They will shape the selection of model approach, methodologies, software selection and field data collection. Common examples include:

- tidal influence;
- storm surge;
- rainfall distribution (both spatially and temporally);
- flood plain obstacles;
- flap gate behaviour;
- runoff generation;
- coincidence of catchment inflows, rainfall and tidal storm surge;
- groundwater interaction; and
- structure operation (such as pumps and gates).

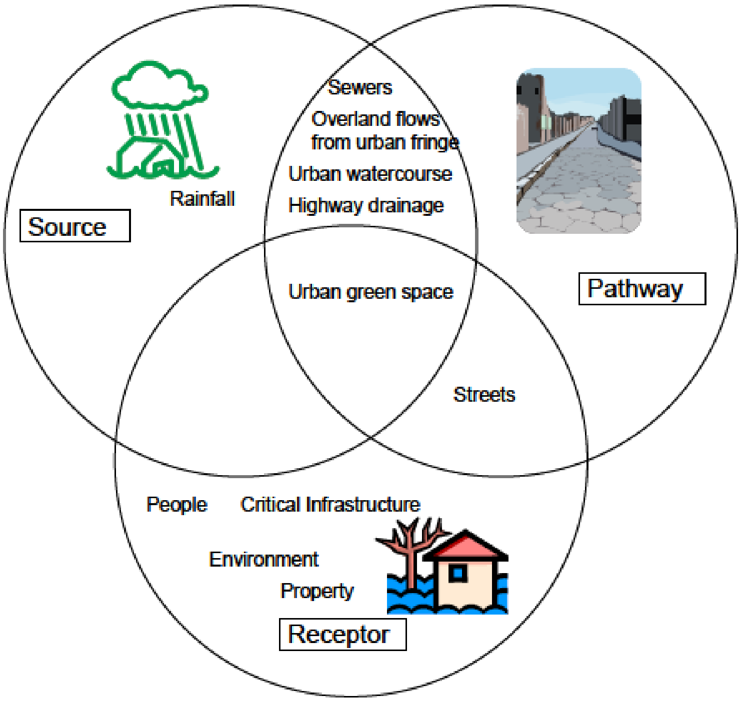
3.3.2 Preliminary schematisation

Previous studies provide context for any modelling task. Consider documents that have been included in the project plan stage (Section 2.4).

The Source-Pathway-Receptor (SPR) approach (Figure 3-2) can help identify the relevant phenomena in a catchment as well as their spatial influence. Identifying the sources, pathways, and receptors will highlight key features that must be included in the model. These can inform the detailed schematisation in Section 3.4.10.

In an urban stormwater context, example sources may be rainfall, upstream catchments or rivers. The pathway is the flooding mechanism through which the source water travels to the receptors. Pathways may include piped networks, overland flow, drainage channels and pumps. Receptors are the entities impacted by stormwater flooding and may include communities, property, or infrastructure.

Figure 3-2: Source-Pathway-Receptor (SPR) Model (Source – Defra, 2010)



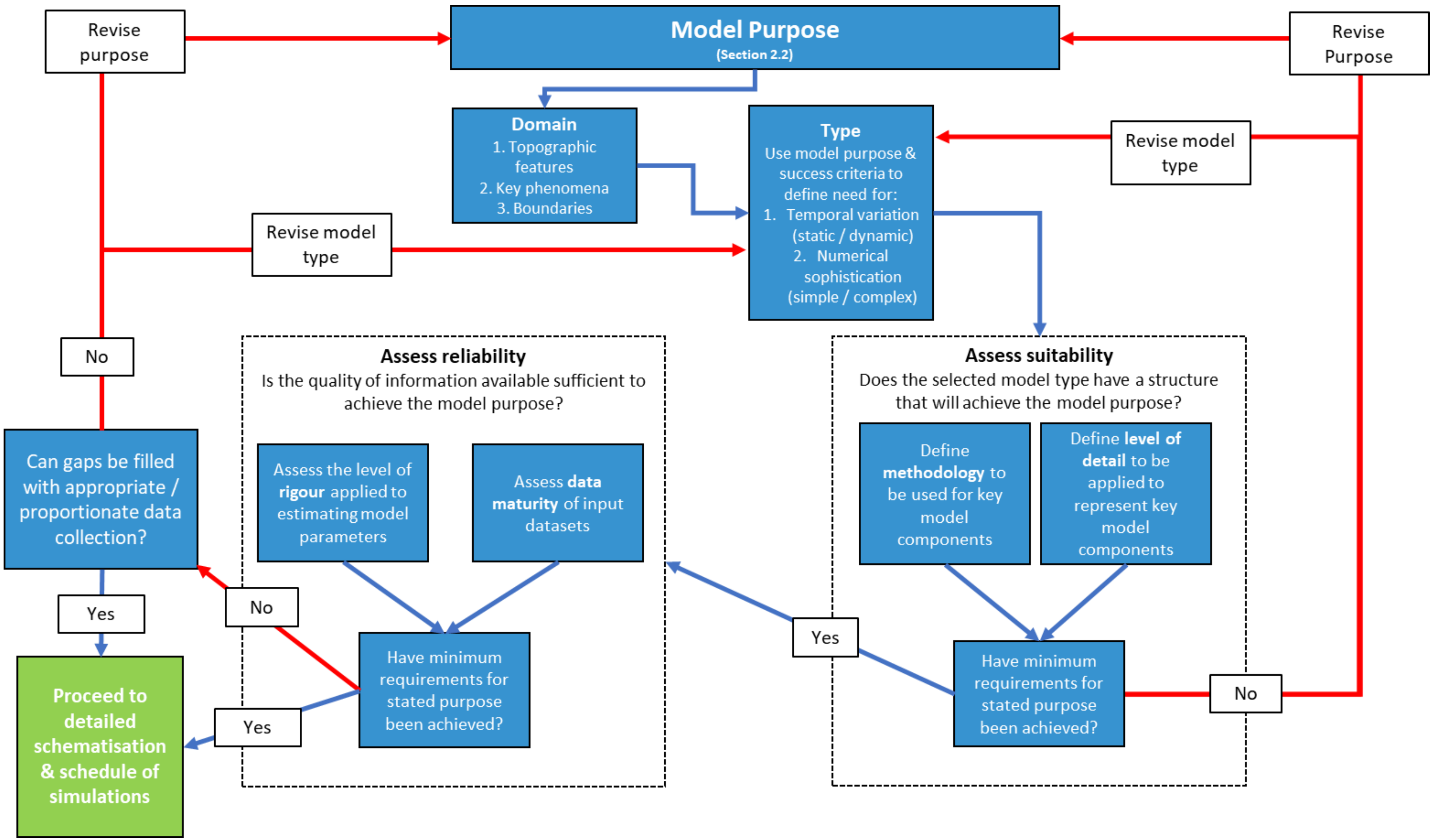
The SPR approach is not perfect. It may be complex to apply in some urban stormwater contexts as sources of flooding may also be pathways depending on the level of detail considered. For example, drainage systems may be a source of flooding (e.g. surcharging manholes) but also pathways (e.g. stormwater pipe network). A park or playing field may be the source of runoff, a pathway and a receptor. It is important not to get caught up in the details of separating out sources from pathways from receptors at the planning stage. Instead, a preliminary SPR approach can be used to identify important modelling features / phenomena and focus effort.

References: Defra SWMP Guidance – Annex D, CIWEM Integrated Urban Drainage Modelling Guideline, Version 2.01, May 2021, BOPRC (2021)

3.4 Model approach and methodology

The modelling approach and supporting methodology development are where model design decisions are made. This ensures a modelling approach is selected that clearly links to the overall purpose and is supported by a suitable & reliable methodology. Figure 3-3 provides a summary of the process detailed in this section.

Figure 3-3: Model approach selection – process diagram.



3.4.1 Model domain

The preliminary model domain (or spatial extent) should be based on and consider the following three different types of boundaries:

i. **Hydrological boundary.** Determined by real-world hydrological boundaries such as catchments, ridgelines, rivers or coasts. This is usually the most expansive of the three boundaries. Where relevant, also consider groundwater flows and aquifers.
ii. **Model boundary.** Determined by the envelope of all the model component domain extents, including hydrological, 1D, 2D, and 3D components. This may correspond to the hydrological boundary if upstream catchments are included directly in the model. It also may only extend upstream to the location where stream/river inflows, generated by some other means, are introduced as boundary conditions. The model boundary should be sufficiently large to prevent the boundary itself from degrading results within the study area boundary.
iii. **Study area boundary.** Determined by the model domain extent where robust model results are required. In most urban stormwater models, the study area generally corresponds to the model boundary or spatial extent of effects being assessed (e.g. hydraulic phenomena such as the drainage network) land use or development impact changes).

The hydrological boundary should generally be equal to or greater than the model boundary, and the model boundary should be equal to or greater than the study boundary. Allowance should be made for model extent to evolve through the model-build phase.

References: (CIWEM, 2021)

3.4.2 Model suitability and reliability

The terms *suitability* and *reliability* have been selected to guide and direct the model component type or modelling approach. These relate to the overall purpose as shown in Figure 3-1. The definition and interaction of these concepts is provided in the following points.

- A *suitable* approach can achieve the objectives defined by the model purpose.
- All model types or approaches can be *reliable* depending on the quality of the implementation and the data used. Some approaches require less comprehensive or sophisticated datasets to achieve acceptable reliability, but if data quality is poor then reliability will be low.
- No matter how *reliable* an approach may be, if it is not *suitable*, then it will not achieve the model objectives or project purpose.
- Quality of implementation is crucial for *reliability* and must be confirmed through quality assurance.
- A decrease in *reliability* is not the same as increased uncertainty. The latter is a result of selecting a lower or higher complexity modelling approach. Broader ranges of uncertainty should be accounted for when using a simpler approach through sensitivity analysis.

Table 3-2 provides recommended minimum standards for model components to achieve suitability for different applications. Details on each model type can be found in Table 3-12. Appendix C provides an alternative to Table 3-12 with the information separated into smaller tables.

Table 3-2: Minimum recommended standard of model type for specific purposes (detailed in the following sub-sections)

Purpose	Application	Outcomes	Model type (refer Table 3-4 or Appendix C)	
			Rural setting	Urban setting
Structure planning	Spatial and growth plan development	Flood extent identification	Static/complex	Dynamic/simple
	Regional or district plan changes	Flood extent identification	Dynamic/simple	Dynamic/complex
Infrastructure planning and design	Long term plan development / funding and finance plans /asset management planning	Infrastructure design (optioneering)	Dynamic/complex	Dynamic/complex
	Stormwater catchment master/ asset management planning	Environmental effects	Dynamic/complex	Dynamic/complex
	Capital works/infrastructure design and upgrades	Infrastructure design (optioneering)	Detailed	Detailed
	Operation and maintenance planning	Infrastructure design (optioneering)	Dynamic/complex	Dynamic/complex
Resource Consent	Low-risk stormwater design for individual site or multi lot development		Static/simple	Static/simple
	Multiple lot stormwater design with known existing risk (to site or downstream)		Dynamic/simple	Dynamic/simple
	Assessment of significant risk from natural hazards (Resource Management Act 1991 Section 106)		Integrated (Dynamic/complex)	Integrated (Dynamic/complex)
	Compliance associated with/requiring:	-	-	-
	Flood plains	Flood extent identification	Integrated (Dynamic/complex)	Integrated (Dynamic/complex)
	Overland flow paths	Flood hazard identification	Integrated (Dynamic/complex)	Integrated (Dynamic/complex)
	Drainage	Infrastructure design (optioneering)	Integrated (Dynamic/complex)	Integrated (Dynamic/complex)
	Effects assessment according to relevant plans	Environmental effects (change in flood hazard)	Integrated (Dynamic/complex)	Integrated (Dynamic/complex)
Engineering approval (greater detail than for resource consent / earlier stages)	Low-risk individual site stormwater design	Infrastructure design (optioneering)	Static/simple	Static/simple
	Network/drainage infrastructure sizing and design	Infrastructure design (optioneering)	Detailed (Dynamic/complex)	Detailed (Dynamic/complex)
	Designing infrastructure that will be vested with council/authority	Infrastructure design (optioneering)	Detailed (Dynamic/complex)	Detailed (Dynamic/complex)
	Complex, high-risk stormwater design	Infrastructure design (optioneering)	Highly detailed (Dynamic/complex)	Highly detailed (Dynamic/complex)
Building consent	Low-risk individual site stormwater design	Infrastructure design (optioneering)	Static/simple	Static/simple
	Natural hazard identification (Building Act 2004 Sections 71-74)	Infrastructure design (optioneering)	Detailed (Dynamic/complex)	Detailed (Dynamic/complex)
	Network/drainage infrastructure sizing and design	Infrastructure design (optioneering)	Detailed (Dynamic/complex)	Detailed (Dynamic/complex)
	Designing infrastructure to be owned privately	Infrastructure design (optioneering)	Detailed (Dynamic/complex)	Detailed (Dynamic/complex)
	Development/individual lot scale	Infrastructure design (optioneering)	Detailed (Dynamic/complex)	Detailed (Dynamic/complex)
	Complex, high-risk stormwater design	Infrastructure design (optioneering)	Highly detailed (Dynamic/complex)	Highly detailed (Dynamic/complex)
Emergency management	Evacuation planning	Flood hazard identification	Integrated (Dynamic/complex)	Integrated (Dynamic/complex)
	Lifeline planning (including CDEM water sector response planning and council business continuity planning)	Flood hazard identification	Integrated (Dynamic/complex)	Integrated (Dynamic/complex)

3.4.3 Model type classification

Stormwater model types can broadly be classified based on two parameters - temporal variation and numerical sophistication. These are explained in Table 3-3.

Table 3-3: Model type classification

Parameter	Options	Explanation
Temporal variation	Static	Fixed point in time or representation of the system in equilibrium
	Dynamic	Flows varying over time
Numerical sophistication	Simple	High-level calculations involving broad assumptions. Often done using hand calculations or basic spreadsheet tools.
	Complex	Detailed calculations that are computationally intensive. Often require specialised software for engineering design or hydraulic modelling.

Four types of model can be derived from combinations of the two parameters:

i. Static/simple
ii. Static/complex
iii. Dynamic/simple
iv. Dynamic/complex

Note that this classification is not comprehensive. There may be models that fit somewhere in between the listed types, include components of two or more types, or fall outside the classification system altogether. The four types are intended as a broad framework only. The modeller will need to apply their judgement and expertise in making decisions specific to their model situation.

The four model types are described in Table 3-4 along with their key components in Table 3.5. Terms used in defining the model types are defined in Section 3.4.4.

As models used for engineering applications are large, complex and multi-faceted, it is recommended that parts of such model domains or specific components are considered separately where large differences in model configuration exist. The intention of these component descriptions is to clearly describe models at a summary level, while using simple terms.

When developing a methodology, it is always possible to justify a reduction in detail or resolution through revisiting the model purpose. Similarly, where features are not required explicitly to fulfil the model purpose, then they may be left out of the model (where it is not detrimental to the quality of the model results).

Model components provided in the following sub-sections are composed of the following four important aspects of typical stormwater models. Tables 3-5 to 3-9 provide detailed descriptions of terms used to define these aspects.

i. **Methodology (Table 3-6)**: Modelling approach used in the representation of component. This is associated with *suitability.*

ii. **Level of detail (Table 3-7)**: How finely resolved modelled features are and what is represented explicitly; how parameters are generated and how they are applied in the final model. Note that this does not necessarily reflect the accuracy of the model but does reflect the suitability of the results for certain applications. This is associated with *suitability*.

iii. **Rigour (Table 3-8)**: How accurately model features and parameters are represented. This may indicate of expected confidence in a particular set of parameters or geometric configuration. It is still possible for model results to be inaccurate even with a high degree of rigour. This is associated with *reliability*.

iv. **Data maturity (Table 3-9)**: The degree to which model geometry and parameters are informed by measured data and the reliability of that data for the intended purpose. This is associated with *reliability*.

Table 3-4: Summary of model types

Model type	Details	Examples	Specific application	Model Component (Table 3-5)	Methodology (Table 3-6)	Level of detail (Table 3-7)	Rigour (Table 3-8)	Data maturity (Table 3-9)
Static/simple	Direct calculations based on standard engineering approaches.	Hand/spreadsheet calculations	Rational method peak runoff estimate for single, small property.	Small-scale hydrology	Simple	Averaged, low-resolution	Literature	Conceptual
	Small scale infrastructure design where backwater effects are absent. Requires experience to ensure that calculations are appropriate and the system can be described sufficiently with minimum effort.	Hand/spreadsheet calculations	Rational method peak runoff estimate for multiple lot development.	Medium-scale hydrology	Simple	Grouped, low-resolution	Literature	Conceptual
Static/complex	Statistical or GIS-based models that do not incorporate explicit descriptions of physics.	Regression of timeseries data.	Flood flow frequency analysis for gauged stream.	All-scale hydrology	Data-driven	Averaged, high-resolution	Calibrated	Mature
	Computerised calculations based on complicated engineering approaches.	Steady-state gutter and inlet design software.	Isolated drainage systems with short times of concentration.	Small-scale hydrology Small open channels Pipe network	Simple 1D hydraulics 1D hydraulics	Averaged, low-resolution Grouped, low-resolution Grouped, low-resolution	Literature Literature Literature	Conceptual Conceptual Conceptual
		Steady-state culvert design software.	Individual culvert design.	Small-scale hydrology Medium-scale hydrology Pipe network	Simple Simple 1D hydraulics	Averaged, low-resolution Grouped, low-resolution Grouped, low-resolution	Literature Literature Literature	Conceptual Conceptual Conceptual
	Methodology based on topography to identify flow paths, catchment sizes, potential ponding areas, naturally vulnerable areas that flood first, deepest or most frequently. Not associated with rainfall event probability.	Rolling ball with depression analysis	Overland flow path and depression area mapping.	Flood plain Large open channels Small open channels	Simple Simple Excluded	Discrete, medium-resolution Discrete, medium-resolution Discrete, low-resolution	Theoretical Theoretical Theoretical	Mature Detailed / mature Unconsidered

Model type	Details	Examples	Specific application	Model Component (Table 3-5)	Methodology (Table 3-6)	Level of detail (Table 3-7)	Rigour (Table 3-8)	Data maturity (Table 3-9)
Dynamic/simple	Models built using comprehensive datasets, such as LiDAR, with coarse assumptions used in the representation of hydrologic or hydraulic phenomena. To be used for developing approximate flood extents with some distinction between shallow and deep flooding for used in broadly identifying flood risks and impacts.	2D domain model with direct rainfall, excluding hydrological losses or pipe network. No editing of DEM to represent channel conveyance.	Evacuation planning. Lifeline planning.	Flood plain	2D hydraulics	Discrete, low-resolution	Theoretical	Mature
				Large open channels	2D hydraulics	Averaged, low-resolution	Literature	Unconsidered
				Small open channels	2D hydraulics	Averaged, low-resolution	Theoretical	Unconsidered
				Upstream catchments	Hydrological	Grouped, low-resolution	Verified	Mature
				Flood plain hydrology	Excluded	NA	NA	NA
		2D domain model with direct rainfall and hydrological losses, but no pipe network. DEM modified at significant structures on large open channels (culverts, bridges, etc.) to ensure flow continuity, if not accurate afflux.	Strategic planning. Programme prioritisation.	Flood plain	2D hydraulics	Discrete, low-resolution	Theoretical	Mature
				Large open channels	2D hydraulics	Averaged, low-resolution	Literature	Simple
				Small open channels	2D hydraulics	Averaged, low-resolution	Theoretical	Unconsidered
				Upstream catchments	Hydrological	Averaged, low-resolution	Verified	Mature
				Flood plain hydrology	Hydrological	Averaged, low-resolution	Literature	Unconsidered
		2D domain model with direct rainfall and hydrological losses, but no pipe network. Detail is added at significant structures on large open channels to determine accurate afflux. Soakage losses are incorporated into infiltration loss.	Spatial planning. District Plan development. Regional or District Plan changes. Long Term Plan development. Multiple lot stormwater design with known existing risk (to site or downstream).	Flood plain	2D hydraulics	Discrete, medium-resolution	Literature	Mature
				Large open channels	1D hydraulics	Grouped, high-resolution	Literature	Mature
				Small open channels	2D hydraulics	Grouped, low-resolution	Theoretical	Conceptual
				Pipe network	1D hydraulics	Discrete, low-resolution	Theoretical	Detailed
				Upstream catchments	Hydrological	Grouped, low-resolution	Validated	Mature
				Flood plain hydrology	Hydrological	Discrete, low-resolution	Literature	Detailed / mature
Dynamic/complex	**1D models**: Comprehensive 1D representation of a drainage system, possibly incorporating open channels, pipes and even overland flow paths. Detailed lumped subcatchment hydrology.	Models of large waterways and smaller contributing channels where flow remains in-channel or where optimisation, testing of operational control, or		Well-defined overland flow paths	1D hydraulics	Grouped, high-resolution	Literature	Detailed / mature
				Large open channels	1D hydraulics	Grouped, high-resolution	Verified	Mature
				Small open channels	1D hydraulics	Grouped, low-resolution	Literature	Detailed
				Pipe network	1D hydraulics	Grouped, low-resolution	Literature	Detailed / mature
				Upstream catchments	Hydrological	Grouped, high-resolution	Validated	Mature

Model type	Details	Examples	Specific application	Model Component (Table 3-5)	Methodology (Table 3-6)	Level of detail (Table 3-7)	Rigour (Table 3-8)	Data maturity (Table 3-9)
		many simulations are required.		Flood plain hydrology	Hydrological	Grouped, high-resolution	Literature	Detailed / mature
	Integrated models: Comprehensive representation of overland flow with representation of significant flood plain obstacles and major primary pipe networks. Significant topographic and primary stormwater features that influence flows outside the study area are explicitly represented (such as significant culverts and open channels). Direct rainfall or detailed lumped hydrology with allowances for infiltration and drainage systems.	Models commonly built by councils.	Stormwater Catchment Management planning. Capital Works / Infrastructure design and upgrades. Level of service assessment. Renewal and maintenance. Infrastructure Planning. Large lot land development planning.	Flood plain Large open channels Small open channels Pipe network Upstream catchments Flood plain hydrology	2D hydraulics 1D hydraulics 1D hydraulics 1D hydraulics Hydrological Hydrological	Discrete, medium-resolution Grouped -high-resolution Grouped, low-resolution Discrete, medium-resolution Grouped, low-resolution Grouped, high-resolution	Verified Literature Theoretical Theoretical Validated Validated	Mature Mature Conceptual Mature Mature Detailed / mature
Detailed (Dynamic/complex)	Urban catchment scale models with detailed representation of the stormwater pipe network as well as key surface flow features. These models are suitable to use for most catchment management activities and assessment of impacts from smaller developments. Major and minor primary drainage and secondary stormwater systems including public and private soakage devices.	Models commonly built by councils for flood hazard mapping.	Identify flooding risks. Pipe and key structure performance. Assess impact of large developments. Assess medium to large-scale flood mitigation options. Identifying flood extents, depths and approximate velocities / hazard ratings. Significant risk from natural hazards (Resource Management Act 1991 Section 106). Flood Plains. Overland Flow Paths. Drainage. Assess effects according to relevant plans.	Flood plain Large open channels Small open channels Pipe network Upstream catchments Flood plain hydrology	2D hydraulics 2D hydraulics 2D hydraulics 1D hydraulics Hydrological Hydrological	Discrete, medium-resolution Grouped, medium-resolution Grouped, low-resolution Discrete, medium-resolution Grouped, low-resolution Grouped, high-resolution	Validated Literature Theoretical Theoretical Validated Validated	Mature Conceptual Unconsidered Mature Mature Detailed / mature

Model type	Details	Examples	Specific application	Model Component (Table 3-5)	Methodology (Table 3-6)	Level of detail (Table 3-7)	Rigour (Table 3-8)	Data maturity (Table 3-9)
			Network/drainage infrastructure sizing and design. Designing infrastructure that will be vested with Council/authority. Natural hazard identification (Building Act 2004 Sections 71-74). Resource Consents. Assessments of effects for land development. Engineering approval. Detailed design. Buildings Consent.					
Highly detailed (Dynamic/complex)	All public / private primary drainage systems including all pipe networks, catchpits with leads, open channels, culverts, and soakage and storage devices; and secondary drainage systems including significant topographic features represented in the model DEM and detailed representation of roads, buildings, driveway crossings, retaining walls and fences.	Detailed 1D / 2D public and private drainage systems and urban features.	Complex network / drainage infrastructure sizing, design, and performance testing. Designing significant private stormwater infrastructure. Development / individual lot scale in high risk areas. Detailed design of complex stormwater interventions.	Flood plain Large open channels Small open channels Pipe network Upstream catchments Flood plain hydrology	2D hydraulics 2D hydraulics 1D hydraulics 1D hydraulics Hydrological Hydrological	Discrete, high-resolution Grouped, high-resolution Grouped, low-resolution Discrete, high-resolution Grouped, high-resolution Grouped, high-resolution	Validated Verified Literature Literature Calibrated Validated	Mature Mature Simple Mature Mature Detailed / mature

3.4.4 Definition of terms in the model type tables

Table 3-5: Model components

Component	Explanation
Pipe network	Stormwater drainage network. May include combined stormwater/wastewater pipes.
2D surface	Ground surface (may also be called the flood plain).
Open channels	Small and large surface drainage channels - including, ditches, streams, rivers, and engineered overland flow paths in the urban environment
Hydrological parameters	Rainfall, antecedent moisture conditions and ground conditions (evaporation, infiltration, etc.).
Upstream catchments	Areas upstream of the study area boundary that contribute runoff flows into the domain.

Table 3-6. Methodology terms with descriptions and examples.

Term	Description	Examples
Excluded	Features are not represented explicitly.	N/A
Simple	Simple calculations or static analysis.	Hand calculations or GIS analysis.
Data driven	Non-physics-based models.	Statistical approaches.
Hydrological	Lumped hydrological model.	Traditional hydrological models incorporating hydrological loss and routing.
1D hydraulics	Free surface, St Venant hydrodynamic model.	Traditional 1D channel and pipe models.
2D hydraulics	Shallow-water-wave hydrodynamic model.	Traditional 2D overland flow models.
3D hydraulics	Navier-Stokes hydrodynamic model.	Computational Fluid Dynamics (CFD)

Table 3-7. Level-of-detail terms with descriptions and suitability of model results.

Term	Resolution	Description	Example	Suitability
Averaged	**Low**	Parameters estimated for entire domain.	Single surface roughness applied to upstream catchment	Results are only valid at an entire-domain level.
	High	Parameters estimated at detailed level and averaged.	Single rainfall hyetograph created as a composite of multiple rain gauges within domain	
Grouped	**Low**	Parameters estimated for subdomains.	Pipe roughness assigned by material (concrete, PVC, etc.)	Results are only valid at subdomain and entire domain level.
	High	Parameters estimated at detailed level and averaged for each subdomain.	2D model roughness determined by landuse type and average over subdomain	
Discrete	**Low**	Coarse resolution with respect to physical features.	2D representation of small open channels	Comprehensive coverage of useful results.
	Medium	Resolution sufficient to resolve effects of features.	Levels of hydraulic structures (e.g. bridges and weirs) obtained from DEM	
	High	At the resolution of the real-world features of interest.	Surveyed depths to invert for all manholes in domain	

Table 3-8. Rigour terms with descriptions and examples.

Term	Description	Examples
Theoretical	Based solely on intuition of modeller.	Discharge-depth inletting relations for scruffy domes.
Literature	Published methods or parameters.	Head loss parameters in pipe networks.
Verified	Indirect corroborating evidence or data.	Comparison of results with a storm event of a similar magnitude.
Validated	Sparse direct evidence based on historic event.	Comparison of measured peak water level results from an event with levels from a simulation of that same event.
Calibrated	Comprehensive direct evidence based on historic events.	Reproduction of gauged discharge from an open channel.

Table 3-9. Data maturity terms with descriptions and examples.[4]

Term	Description	Examples
Unconsidered	No effort is expended in representing features. Interpolated or default values are used.	Open channels or ponds are represented with unmodified LiDAR survey.
Conceptual	No information is available so estimates are used, design requirements may be known.	Storage volume is implemented as loss / sink.
Simple	Basic representation of features of interest, requirements are well-defined.	Pond stage-area and depth-discharge curves are included in the model.
Detailed	Finely resolved data for design is available but does not capture full detail of an as-built survey.	Pond geometry and outfall structure modelled explicitly.
Detailed / mature	Mixture of as-built survey and designed geometry used in estimating parameters/geometry/behaviour.	Topographic survey of pond is available, but outfall structure representation is based on design drawings.
Mature	Model parameters / geometry / behaviour is based on field survey (topographical, LiDAR, remote sensing/aerial photos, etc.).	Topographic survey of pond, including the bed, and the outfall structure is available.

References: Table 1 from HCC (2016) / From H. Lee (personal communication, 21st April 2023) by email / Auckland Council's Model Review Template_v1.0.xlsm spreadsheet / KCDC technical specifications by BMT

3.4.5 Detailed schematisation

A model schema is a high-level plan that outlines the features of the proposed model and should be developed in the model planning stage. The schema is expected to evolve during the plan and build phases. Key catchment features and relevant phenomena are crucial inputs to the design of the schema. Features may include the following items.

- Landforms, vegetation, and land use.
- Catchment areas generating runoff.
- Flow conveyance, for example rivers, streams, floodplains, constructed overflows, overland flow paths, and piped reticulation.
- Natural and man-made flow constraints, for example, stopbanks, flood walls, or flow diversions.
- Natural and man-made flood storage including soakage devices.
- Embankments, for example, roads and railway lines.

[4] The same dataset may be mature for one application, but unconsidered in another. For example, LiDAR is very reliable (a mature dataset) when describing open flat surfaces, but where there is dense bush or narrow features, such as walls or incised channels, it is unreliable (an unconsidered dataset).

- Flow control structures, for example, weirs and gates.
- Transport structures, for example, bridges and culverts.
- Inlet structures, for example, pond outtakes and catchpits.

Key elements of a schema include the following.

- **Model overview.** A summary of the model, events to be simulated and miscellaneous details.
- **Data sources.** Data that will be used, version and where can be sourced.
- **Description of the model domain.** All real-world spatial features and geometries represented by the model.
- **Key structures and assets.** Brief description of how various catchment features will be represented.
- **Computational approaches.** The modelling approaches to be applied to the various components and hydraulic and hydrological parameters.
- **Boundary condition derivation.** Description of different boundary conditions for the model, and their sources.
- **Known limitations.** List of foreseeable issues that should be considered when using the model or interpreting any outputs.
- **Assumptions.** List of any draft assumptions.

3.4.6 Schedule of simulations

The model purpose and or success criteria will usually define the scenarios to be simulated. These will correspond to various reporting requirements, such as the following.

- Regional, district or city plan mapping exercises have statutory requirements for flood plain mapping.
- Resource consent flood mapping requirements will be dictated by the relevant council.
- Design projects must comply with relevant codes of practices, standards, and plans, which will define the required scenarios informed by design life and level-of-service expectations.

Creating a full list of all required simulations, with associated boundary condition descriptions, is useful for setting expectations of workload. It can also identify gaps in the input data and methodology as part of an iterative model build approach. For example, coincident rainfall and river flow return events may be required, but time-varying river flow timeseries for many scenarios do not exist or an entire boundary may have been overlooked. It is useful to seek approval of this schedule from all stakeholders.

The range of boundary conditions may have an impact on the model schematisation, particularly where water levels in extreme events may not be adequately allowed for by the model extent. Consider the following aspects of the catchment when creating a schedule of simulations.

- Existing or historical hydraulic conditions.
- Changes in land use (such as assessing the maximum development potential to inform a district plan).
- Infrastructure changes.

- Structural flood mitigation measures, for example, dams and stopbanks.
- Future development scenarios.
- Change in structure operations.
- Changed catchment conditions assessment.
- Climate change - including sea level rise and predicted increase of storm surge.
- Sensitivity testing.
- Tide and storm surge interaction.

References: BOPRC (2021), CIWEM (2017), CIWEM (2021)

3.5 Modelling Software

The selection of stormwater modelling software is usually limited to the software available within the modeller's organisation. It can also be specified by the commissioning organisation on a similar basis. Table 3-10 summarises software commonly used in Aotearoa-New Zealand for hydraulic modelling. Where a choice is available some of the key factors to be considered include the following.

- **Scale of the model.** All software, whether deliberately or inadvertently, has been designed or tested using models of a particular range of scales. To achieve the model purpose, the software must be able to support domain sizes that fully encompass the area of interest and, at the same time, represent relevant phenomena at an appropriate scale.
- **Skill, experience and personal preferences of the modeller / modelling team.** Consider the skill level, experience, and preferences of the individuals delivering the modelling exercise. Expertise and track record with a piece of software is a valuable asset.
- **Representation of relevant phenomena.** Software packages represent particular phenomena to a greater or lesser degree of approximation. Care must be taken to not rely on software that may be familiar to the modeller but does not explicitly represent key relevant phenomena well (or at all) when another simulation engine does. This can lead to approximations and workarounds being incorporated into the model or the input datasets, which result in a model that may be inscrutable to others or even the modeller themselves after a hiatus. This severely impacts reproducibility and increases the risk of the model being abandoned.
- **Representation of hydraulic structures.** The capability of a simulation engine to reproduce accepted standard solutions for bridges, culverts, weirs, orifices, grates, and stormwater inlets is crucial for most urban stormwater models. In the absence of explicit features to model particular structures, generic structures that allow the user to define the structure behaviour precisely may facilitate the use of tables, developed by other means, to define stage-discharge (H-Q) relations.
- **Numerical schemes.** The design of the computational schemes used to solve the underlying hydraulic equations are crucial to the success of a particular simulation engine. Advances in hardware and software over the last decade have fostered the development of particular numerical schemes, particularly those that can be parallelised and distributed across the thousands of cores in modern Graphics Processing Units (GPU's). These schemes are considered *explicit* as the solution

of each algebraic equation in the system may be solved explicitly to yield each element's variable values for the next timestep independently of the solution in neighbouring elements. In contrast, *implicit* schemes require the complete set of algebraic equations across all elements to be formulated for simultaneous solution using linear algebra techniques for each timestep (techniques were developed to allow for faster, approximate solutions). Implicit-type schemes were popular in the past as they allow for larger timesteps and hence reduced runtimes as the schemes are much more resilient to instabilities. The price for this resilience is damping of the solution at each timestep, which manifests in the results as excessive smoothing of momentum, termed *numerical diffusion*, which reduces variability in transverse velocity profiles and hence will underpredict measures of hazard that rely on velocity magnitude. Modern schemes introduce much less numerical diffusion and so the choice of eddy viscosity has become a more important concern to produce realistic flow patterns.

- **Open vs. closed software design.** The hydraulic simulation engine and the files it interacts with, both input and output, lie on a spectrum of open to closed in terms of their transparency. Proprietary simulation engines, or even free-ware simulation engines, have closed software designs that are not visible to the public. Open-source simulation engines provide the code along with a license for its use. Simulation engines may use data that is either in closed formats or in open or widely available formats. Proprietary software usually comes with a range of tools for generating, importing, or exporting other, non-proprietary file formats. Consider how the end users will interact with the model and its outputs and whether the benefits of adopting a particular closed platform outweigh the disbenefits.
- **Simulation run times.** Advances in hardware and software over the last decade have resulted in significant reductions in run time for stormwater simulations, often relying on dedicated GPU's. Run times will scale with model size and complexity and can do so at an exponential rate, for example doubling the resolution of a 2D model may result in an eight-fold increase in run time. Consider whether the simulation engine provides a means for focusing computational effort on the study area, and so reducing run times, without compromising the model outputs. Some limitations on the speed of the simulation engine are due to theoretical features of the numerical schemes used, and some are due to software design.

Table 3-10: Hydraulic modelling software commonly used in Aotearoa-NZ.

Name	Link	Key Capabilities			Applications
		Key Phenomena Represented	1D (pipes and open channels)	2D (overland flow and open channels)	
HEC-RAS 2D	www.hec.usace.army.mil/software/hec-ras/	1D open channel, and 2D overland flow hydraulics.	Open channels with a range of hydraulic structures.	Unstructured mesh with sub-element topographic description.	River flow and riverine flooding simulation.
HEC-HMS	www.hec.usace.army.mil/software/hec-hms/	Hydrological processes.	Basic routing representation.	None	Hydrological assessments.
InfoWorks ICM	www.autodesk.co.nz/products/infoworks-icm/overview	1D closed conduit and open channel, and 2D overland flow hydraulics.	Open channels and pipes with a range of hydraulic structures.	Unstructured mesh.	Pipe and river flow, and urban and riverine flooding simulation.
MIKE FLOOD / MIKE+ (MIKE URBAN / MIKE 11 coupling was decommissioned as of May 2020 but remains in common use)	www.mikepoweredbydhi.com/products/mikeplus	1D closed conduit and open channel, and 2D overland flow hydraulics.	Open channels and pipes with a range of hydraulic structures.	Unstructured mesh.	Pipe and river flow, and urban and riverine flooding simulation.
TUFLOW	www.tuflow.com/	1D closed conduit and open channel, and 2D overland flow hydraulics.	Open channels and pipes with a range of hydraulic structures.	Unstructured mesh with sub-element topographic description.	Pipe and river flow, and urban and riverine flooding simulation.
XP STORM	https://innovyze.com/products/stormwater-sewer-flood-modeling/xpstorm/	1D closed conduit and open channel, and 2D overland flow hydraulics.	Open channels and pipes with a range of hydraulic structures.	Structured mesh	Pipe, open channel flow and flood modelling in urban contexts.

Note: 'Design' software (for example CAD based drainage design software components) have been excluded from this guide as urban stormwater modelling is not frequently used for detailed design. It is recognised that there is the potential to integrate models, to some extent, in some of these design programs.

3.6 Model Management

Hydraulic models are often multi-purpose technical support tools for broader work programmes. Model management protects the investment in models and facilitates their use. Good model management planning enables:

- transparent storage and retrieval of models;
- reproducible model outputs that support policy and legislation;
- stable outputs that do not change in significant ways with updates to hardware or software versions;
- a single source of truth;
- an overview of past investigations;
- simple to use scenario testing, so that this can be understood by non-expert staff;
- short project turn-around;
- ease of maintenance;
- facilitation of third-party use and streamlined quality assurance; and
- simple tracking and comparison of versions (with the ability to retrieve previous versions).

There are many challenges that good model management practices seek to overcome or eliminate:

- confusion caused by multiple versions of the same model;
- lost or inaccessible models and supporting data;
- lack of transparent and streamlined sharing, use and quality assurance of models; and
- rework and project delays.

The following subsections provide key considerations for setting up an effective model management system.

3.6.1 Folder and File Management

File management recommendations are summarised in Table 3-11. Section 7 includes further guidance and examples of base model and project model archiving structures.

Table 3-11. Core functions of good file management in hydraulic modelling studies.

Function	Requirements
Retrieval	• All data relating to a model should be accessible and stored together or as a single unit so that a third party can quickly and easily interrogate the model or run a simulation.
Understanding	• A consistent and well-named folder structure adds meaning to file names and may vary between different modelling platforms. • Metadata and documentation including scenario definitions, input data sources, and usage instructions should be stored alongside model files. This may include reports, spreadsheets and other model-build tools.

Function	Requirements
	• Naming conventions should be consistent and descriptive enough to allow clear identification, yet no longer than is required. Long file names may cause issues with some software and hamper readability.
Convenience	• Only files of direct relevance should be stored: only log files or results for the latest simulation of the stored model should be retained. If outputs from other models are required as inputs to the model of interest, these other models should be retained. • Very large result files may be discarded where they can be easily regenerated with minimal effort or where all relevant results have been extracted. • Extracted results, perhaps generated for reporting, are to be stored alongside results files.
Version control	• Versioning information should be incorporated into folder/compressed archive names rather than within model file names or with the model structure. • The top-level folder name should include the project/model title, a delivery or reference date and a unique identifier, if relevant. • Where a version number is required, a numbered versioning convention is recommended. E.g. "1.1.0" or "0001".

3.6.2 Naming conventions

The following general principles should be applied to any digital items whether they are files or model component names.

- Short as possible with any intermediate version numbers, dates, modeller / organisation initials or undocumented codes removed.
- Most significant or unique identifiers included.
- Use folder or database structure to provide context to shortened names.
- Use clear delimiters, such as underscores, to separate identifiers
- For delivered outputs - result type (e.g. flood depth, level, velocity, hazard) and a delivery date may be considered useful.

For example, a flood depth (FD) raster output from a flood mapping project for the area "Catchment A", in the Maximum Probable Development land use scenario, simulated for the 1% AEP rainfall event with a 2.1-degree climate change increase, could be named:

CatchmentA_FD_R1pctAEP_2pt1CC_MPD_20240101, or

CatA-MPD-2.1degC_R1%AEP-v2.7.0.

3.6.3 Ownership and intellectual property

Key factors to consider are outlined below. Further guidance on data sharing and licensing is provided in Section 6.

- Ownership of the model, intellectual property, data agreements and other matters should be defined and understood at the signing of the contract.
- Entities that own and maintain models should require a data licensing agreement to be signed that supports their rights as owners when the model is to be used or interrogated by a third party. Licensees may be required to provide a copy of the model derived from the commissioning entity's version.
- In some cases, the deliverables of interest are the outputs from the model and the subsequent analysis and so the model may be owned by the party commissioned to build it.

3.7 Data Collation and Collection

The model domain and schematisation stages, in the planning process, can identify critical data gaps that can change the modelling approach and prompt confirmation that the model can still achieve its original purpose. This gap analysis will not identify all missing data, which may only become obvious during the build phase. The analysis of existing and available datasets should consider the following aspects of the data.

- Accuracy
- Completeness
- Currency
- Consistency
- Credibility / confidence

References: BOPRC (2021), CIWEM (2017), CIWEM (2021)

3.8 Checklist

It is important to take time at this point to ensure that the selected modelling approach can meet the objectives derived from the model purpose (see Section 2.2), minimum requirements and represents good value for the investment being made. The following questions provide prompts.

- Will the model purpose and success criteria be met?
- Have the primary and secondary stormwater management system levels of service been defined? (Do you know what success will be measured against?)
- Have appropriate planning / time horizons been defined with associated climate change scenarios?
- What suite of model runs will be required? Will the model run time allow the planned number of runs to be completed within the programme?
- Does the approach represent the perceived flooding mechanisms?
- Does the approach allow likely mitigation measures to be tested?
- Can the approach be applied at the spatial scale required?

- Does the approach favour analysis of low or high probability events? Which is most important for the modelling assessment?
- Does the approach support the consideration of future risk? (Such as unchecked urban growth, climate change and population growth)?
- Does the approach support representations of key interactions within urban drainage systems?
- Do you have sufficient data and / or appropriate tools to carry out the approach? (If not, can these data or tools be acquired and at what cost?)
- Is the approach compatible with budget and programme constraints for the modelling assessment?

4 BUILD

4.1 Overview

The build phase follows the planning stage and covers the development of the model. The model is:

- manifestation of the schematisation (Section 3.4.10)
- which is designed to satisfy the success criteria (Section 3.2)
- by accounting for relevant phenomena (Section 3.3)
- Which stem from model purpose (Section 2.2)

In this way it should be possible to justify specific implementation details through their connection to the model purpose. Assumptions and limitations (Section 4.6) should be collated as the model build progresses.

4.1.1 Model build process

The general stages of a large model build are shown in Figure 4-1, which is only a coarse approach. This guide does not provide a prescribed workflow for building models because:

- model builds come in a variety of sizes;
- multiple stages may progress concurrently;
- individual stages may be only partially completed to be returned to later stages;
- particular model components may be completed before others are started; and
- complete stages may be repeated.

It is recommended that a model is built in an iterative manner, where a simulation is run when each component is added. This contrasts with the approach of building the entire model with all detail included and only then initialising simulations and debugging the model. The iterative approach is recommended for the following reasons as it:

- allows the modeller to build an intuitive understanding of what the model represents;
- quickly uncovers errors in schematisation (particularly regarding domain extent);
- simplifies the model debugging process;
- provides early indications of model run times;
- provides preliminary results for presentation to clients and stakeholders very early in the build process; and
- provides positive feedback to the modeller for whom the earlier stages of a model build may be tedious and unrewarding.

In addition to the stages in Figure 4-1, an audit of the entire process may be undertaken to ensure that all relevant stages have been carried out. Informal reviews with colleagues are required throughout the build process.

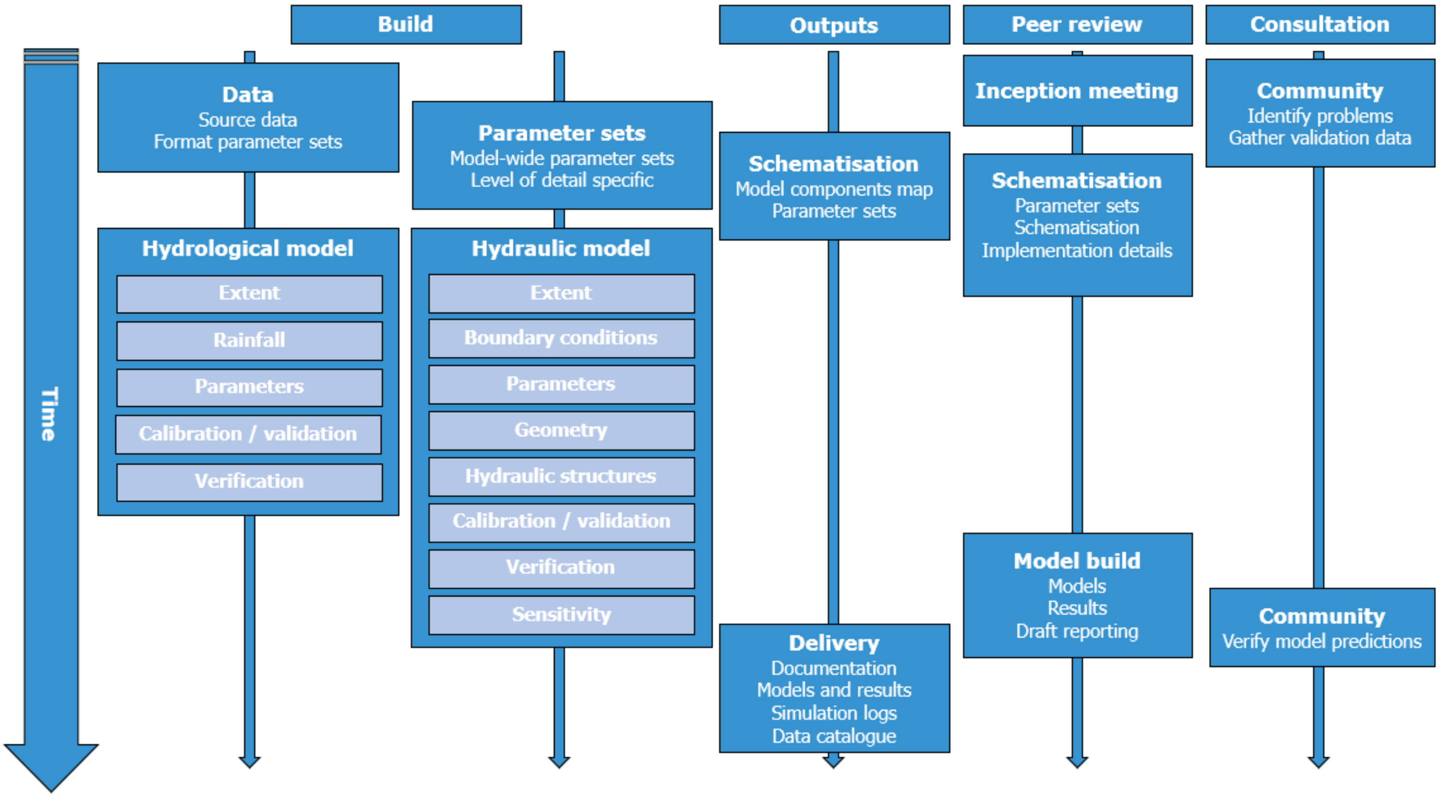


Figure 4-1. Model build process

References: (adapted from Figure 0-1 of NRC (2022), Figure 1 of BOPRC (2023) and Figure P1-1 of GWRC (2021))

4.1.2 Model build practices

Once built, models are commonly used over many years, by many different parties, and for a range of purposes, some of which may go beyond the original model purpose. A model should be maintained in a functional and tidy state so that it may be easily used again. To this end, recommendations include the following.

- Model build processes should be reproducible where possible.
- Where processes are complicated, they should be explained with reproducibility as the aim.
- Consistent techniques or methods should be used across the model to reduce documentation.
- It is better to develop a technique or method, test it on a few example situations, modify the method if necessary, and then apply it across the model, than it is to develop bespoke approaches for individual model features.
- Care in applying naming conventions and spelling throughout the model simplifies the identification of errors and anomalies.
- Ensuring naming conventions align with asset data source - allowing for easier model interrogation and update.

4.1.3 Model build considerations

Common urban stormwater model-build considerations are provided in Table 4-1. It is intended that the relevant parts of this section are used by the modeller and Table 4-1 should be used as an index. Models may not include all the components listed. These considerations are not part of the schematisation – which should be concerned with large-scale components, not the fine detail and numerous entities they comprise.

Table 4-1. Model build considerations (with references to sections containing more detail).

Topic	Components	Section
Model geometry	Domain extent	Section 4.3.2
	Coordinate systems	Section 4.3.1
Hydrology	Losses	Section 4.2.2
	Routing	Section 4.2.3
	Soakage	Section 4.2.2
Subsurface	Pipe network	Section 4.3.3
	Inlets	Section 4.3.15
	Soakage	Section 4.3.4
	Culverts	Section 4.3.5
	Storage	Section 4.3.6
	Outtake structures	Section 4.3.7
	Pumps/control structures	Section 4.3.8
	Groundwater interaction	Section 4.3.9
	Hydraulic losses	Sections 4.3.3, 4.3.5, 4.3.10 and 4.3.11
Open channel	Channels	Section 4.3.10
	Bridges	Section 4.3.11
	Weirs	Section 4.3.12
Overland	Surface topography	Section 4.3.13
	Obstacles	Section 4.3.14
	Fine-scale features	Section 4.3.13
Flow exchange	Stormwater inlets	Section 4.3.15
	Culverts	Section 4.3.5
	Channel bank	Section 4.3.15
Boundaries	Location	Section 4.3.2
	Boundary conditions	Section 4.4
	Interaction with neighbouring catchment	Section 4.4
Results	Type	Section 4.8
	Location	Section 4.8

References: BOPRC (2021), NRC (2022), GWRC (2021), TCC (2022)

4.2 Hydrologic models

Hydrology is the study of water movement, processes, distribution and management and overlaps into hydraulics. In terms of stormwater modelling, hydrology refers to the transformation of rainfall to runoff.

The following sections provide a summary of common hydrologic models used in New Zealand by regional and local councils. These are followed by lists of model-build considerations grouped by topic. The lists may be used as an informal checklist during a model-build process.

4.2.1 Hydrologic methods used in Aotearoa-NZ

Guidance for hydrologic modelling is provided by many councils in Aotearoa New Zealand. Due to jurisdiction, guidance provided by regional councils focuses on river catchments and often does not give specific advice for urban stormwater networks. Regional council advice is typically relevant to urban stormwater models at the urban rural boundary, or when a river scheme and urban stormwater runoff catchments interact. The Building Code (section E1/VM1) provides guidance for how to account for runoff in design.

Hydrologic modelling methodologies comprise rainfall, hydrological loss, and routing: Table 4-2, Table 4-3 and Table 4-4 summarise methodologies used by various guidance documents from throughout Aotearoa New Zealand. The following authority name abbreviations are used:

AC: Auckland Council

BOPRC: Bay of Plenty Regional Council

CCC: Christchurch City Council

GWRC: Greater Wellington Regional Council

HCC: Hamilton City Council

KCDC: Kāpiti Coast District Council

NRC: Northland Regional Council

NZG: Aotearoa-NZ Government

TCC: Tauranga City Council

WDC: Waimakariri District Council

WRC: Waikato Regional Council

WWL: Wellington Water Limited

Table 4-2. Rainfall estimation approaches used in Aotearoa-NZ.

Topic	Approaches	Where approach may be applied
Historic events	Use multiple closest rain gauges in vicinity of catchment.	GWRC, NRC
	Thiessen polygon method or similar used to produce spatially representative distribution.	GWRC, TCC
	Weighted average used to produce rainfall data for catchment.	BOPRC
	Gaps in rain gauge record to be filled using regression techniques.	GWRC
	Gridded rainfall based on rain radar and calibrated with rain gauge data.	CCC
Design rainfall depth / intensity	When determining a design event rainfall depth, the record must be at least half as long as the event return period being estimated.	NRC
	NIWA's HIRDS v4 extreme event design depths to be used.	CCC, NRC, NZG, WDC, WRC, WWL
	NIWA's HIRDS v4 extreme event design depths to be used if records from a representative (similar elevation or orientation) rain gauge are not available.	GWRC
	Comparison of HIRDS v4 estimates with rain gauge records as anomalies can appear near rain gauges.	NRC
	Design event AEPs to be considered: 10% and 1% AEP	NRC, GWRC, TCC, WDC
	Design event AEP to be considered: 5% AEP	NRC, GWRC
	Design event AEPs to be considered: 50%, 20% and 2% AEP	NRC, GWRC, WDC
	0.1% AEP residual hazard or over-design event ARI to be considered.	NRC, GWRC
	24 hour-duration design depth isohyets derived for region.	AC, KCDC
	Sensitivity of HIRDS depth estimates to spatial shifts to be considered.	BOPRC
	Design event depth-duration-frequency (DDF) table developed for region.	TCC
Design temporal pattern	Representative profile taken from rain gauge records.	NRC
	Profile informed by average variability method.	GWRC
	East of South Island average variability method temporal profile developed by NIWA.	WDC
	Triangular profile.	CCC, NRC

Topic	Approaches	Where approach may be applied
	Nested storm profile:	KCDC, GWRC, NRC, WRC
	Peak between 20% and 80% for storms shorter than 6 hours.	CCC
	Peak at 50% of duration.	AC, KCDC, TCC, WRC
	Peak at 67% of duration.	WWL
	Peak at 70% for storms longer than 6 hours.	CCC
	Peak at 75% of duration.	BOPRC
	5-10 durations to be simulated.	NRC
	Up to two temporal patterns can be used.	GWRC
	10-minute duration to be used for urban areas.	NRC
	Test sensitivity of results to temporal pattern.	NRC
Areal reduction factors	Taken from HIRDS v4.	NRC, GWRC, TCC
	Presented in TP108, based on Tomlinson (1980)	AC, GWRC, CCC
	Australian Rainfall and Runoff 2019	GWRC
	Applied only to rural catchments upstream of urban catchments.	TCC
Climate change	Rainfall depth upscaling factor of 16.8% for 2090 horizon. RCP8.5 for 2130 horizon is also applied in practice.	AC
	Climate change projections based on the IPCC Fifth Assessment, 2018.	BOPRC, GWRC, NRC
	RCP8.5 projection for 2100 horizon.	WDC
	Upscaling factors from 8% to 16% based on return period for 2090 horizon.	KCDC
	16% upscaling for 2100 horizon	CCC
	20% upscaling for 2100 horizon.	WWL
	Specific normalised temporal pattern for 2090 horizon (peakier than existing climate for short durations).	AC
	Augmentation factors (percentage rainfall depth increase per degree Celsius warming) provided by NIWA (2018).	BOPRC, GWRC, TCC

Table 4-3. Hydrological loss approaches used in Aotearoa-NZ.

Subject	Approach	Where approach may be applied
Antecedent Moisture Condition	To be included in sensitivity assessment.	NRC
	Accounted for through Curve Number AMC classes.	AC, WWL
	Curve Number AMC II class used for design scenarios.	WWL
	Accounted for by shifting soil class.	WRC
	Initial loss storage is filled or design scenarios.	TCC
	Groundwater and soil moisture estimates used to approximate vadose zone capacity.	CCC
Loss	Hortons	CCC, NRC, WDC
	SCS / NRCS Initial abstraction and Curve Number	AC, HCC, KCDC, NRC, TCC, WRC, WWL
	Pervious and impervious portions of catchments are simulated separately.	AC, WRC
	Pervious and impervious portions are weighted together for each subcatchment.	TCC, WWL
	Initial and constant continuing for urban catchments.	TCC
	Initial and proportional.	TCC
	Private soakage is accounted for.	TCC

Table 4-4. Hydrological routing approaches used in Aotearoa-NZ.

Subject	Approach	Where approach may be applied
Model type	SCS / NRCS non-dimensional unit hydrograph	AC, CCC, NRC, TCC, WRC, WWL
	Clark Unit Hydrograph	KCDC, NRC, TCC
	Time-Area	TCC
	Kinematic wave.	CCC, NRC, TCC, WDC
	Modified Rational method.	BOPRC
	Rain-on-grid	CCC, HCC, TCC, WDC
	Include in sensitivity assessment.	NRC
Delineation	Subcatchment-based.	CCC, KCDC, TCC, WDC, WWL
	Subcatchments delineated at 0.1 to 3 ha size to enter sumps and open channels.	WWL
	Buildings delineated separately	TCC, WWLL
	Rain-on-grid.	CCC, TCC, WDC
Time of concentration / lag time	Equal-area slope with time-of-concentration calculation derived from regression analysis for Auckland catchments.	AC
	Ramser-Kirpich	BOPRC, TCC
	Bransby-Williams	BOPRC, TCC
	US Soil Conservation Service (Appendix B of TM61)	BOPRC
	Nomograph (Appendix B of TM61)	BOPRC
	NZ Building Code	WRC
	Natural Resources Conservation Service lag formula	WRC
	Eagleson lag equation	WRC
	Kerby-Hathaway formula	WRC
	Building time of concentration set to 5 min.	TCC, WWL
	Arithmetic mean of Ramser-Kirpich and Bransby-Williams used for undeveloped catchments.	CCC, WWL
	Geometric mean of Ramser-Kirpich and Bransby-Williams used for catchments smaller than 50 ha.	TCC
	Calculated as sum of overland flow time, shallow, concentrated flow time, open channel flow time, pipe flow time.	CCC, KCDC, NZG, WWL
	Different parameters used for impervious steep and flat and pervious medium.	WDC

In addition to the approaches summarised above, it is common for design hydrographs to be estimated directly without recourse to a hydrological model. Design hydrograph shapes are taken from historic events of a similar return period to the desired design event and are scaled to reproduce expected peak flow and flood volume based on flood flow frequency analyses. Peak flows are estimated using methods summarised in Table 4-5.

Table 4-5. Peak flow estimation approaches used in Aotearoa-NZ

Subject	Approach	Where approach may be applied
Model type	Rational method to estimate peak flow for flat catchments up to 15 ha and hill catchments up to 5 ha.	CCC
	Rational method.	BOPRC, NZG
	$A^{0.8}$ transposition	BOPRC
	TM61	BOPRC
	Flood frequency in Aotearoa-NZ	BOPRC

4.2.2 Losses

Hydrological losses constitute water that is retained by the catchment or lost to evaporation and so does not contribute to runoff. The following considerations relate to losses.

- Often literature values are only source of estimates.
- Calibration/validation/verification for a range of events is of high importance.
- Soil in urban areas, especially in the upper layer, is usually compacted and so low losses are expected.
- Parameterisation methodology should be reproducible and easily modified for various scenarios.
- Conservatively low hydrological loss may be suitable for assessing flood risk. However, conservatively high losses should be considered when assessing development impacts.
- Test sensitivity of net rainfall (rainfall after the losses have been removed) to variation in a range of model parameters as well as simulation period.

Antecedent Moisture Condition (AMC) are significant for losses in highly absorbent catchments. In many cases, AMC may determine whether flooding occurs or not. Urbanisation increases impervious surfaces, significantly increases soil compaction and so reduces the influence of AMC. This becomes important when considering the effects of land use changes from rural / undeveloped land.

While AMC is often considered purely a hydrological concern, components of hydraulic models may reflect the AMC through aspects such as infiltration rates and watercourse base flows.

- Increased soil moisture contributes to elevated groundwater and the resulting base flows. Base flows may be represented as:
    - inflows from hydrological analysis via boundary conditions; or

    - fixed base flows for minor watercourses that are not modelled explicitly as they are peripheral to the area of interest.
- Where AMC is significant, it will affect the Annual Exceedance Probability (AEP) of the simulated flood event. It can invalidate the often-implicit assumption that rainfall AEP matches that of the resulting flood. AMC should be accounted for in joint probability sets of boundary conditions where it is significant. It is preferable to develop a relationship between AMC and flood AEP from historic measurements. Where it is not feasible to extract a relationship from historic events, average AMC should be used for base case events and wetter than average for future-climate, post-development and mitigation-option scenarios to overestimate impacts. For level-of-service analysis, wetter than average AMC should be applied.
- AMC should be accounted for when simulating historic and design scenarios. This can be done through the filling of initial abstraction depths / volumes and other storages at simulation initialisation. This make take a range of forms, depending on the model applied, such as the shifting of Curve Number (CN) in the SCS Curve Number approach.
- Long-term meteorological phenomena can affect long-term trends in soil moisture. Consider the impact of large-scale meteorological phenomena, such as the Interdecadal Pacific Oscillation (IPO) and El Nino Southern Oscillation (ENSO) on soil moisture when simulating historic events or when deciding design storm parameters.

Soakage devices may be represented explicitly as a hydraulic or hydrologic model component, or implicitly as a contribution to averaged parameter sets. The following considerations relate to the representation of soakage devices:

- Storage capacity and soakage rate are the most important characteristics of a soakage device.
- Soakage devices are generally designed for 10% AEP or more frequent design events and drain a specific area. They will become overwhelmed in larger events, especially if flows from outside their designated catchment area are captured.
- Well-drained-soil soakage rates associated with a specific device that are measured in the field are usually highly spatially variable and may be orders of magnitude greater than averaged surface infiltration rates. Very high rates are unlikely to be sustainable, especially when there is a high groundwater table. In addition, soakage tests are usually carried out at a single site at a time, which does not necessarily simulate performance during a storm event when neighbouring soakage devices are operating or when channel levels are elevated.
- Soakage devices, particularly private devices, are likely to not be well maintained and so their efficiency will degrade over time.
- Discounting public or private soakage entirely is also inappropriate. For example, 50% reduction in performance could be used where no better information is available. For large soakage structures, sensitivity testing is recommended.

4.2.3 Routing

The routing component of a hydrologic model affects how rainfall runoff moves through a catchment (shape of the hydrograph) before it enters the drainage system that is represented by the hydraulic model. The following considerations relate to routing:

- For small catchments (that often occur in urban areas) routing is less influential compared to hydrological losses.
- For building roof sub-catchments, gutters may not have the capacity to convey larger rain events and water spills onto the ground around the building.
- In rain-on-grid models, the 2D solution resolves the routing. As the smallest channels (such as kerb & channel) are not generally resolved, care must be taken to account for exaggerated lag times. This is especially the case when simulating small rainfall events.
- In flat catchments lumped subcatchments do not provide accurate estimates of runoff routing as flow direction may change with surface flooding.
- In lumped subcatchment models, the fine-resolution subcatchments are developed from property parcels or surface drainage analysis. Spot checks of lag time are necessary.
- In large catchments the shape of the generated hydrograph may become important for timing the arrival of the peak runoff.
- If laterals lead to subcatchments being connected directly to stormwater networks, then allowance should be made for spilling to the surface if the main surcharges to ground level.

Subcatchments represent hydrological units within the model extent that allow for detailed analysis of how runoff is routed into the drainage system. The granularity of subcatchment boundaries and connectivity with the hydraulic model influences model accuracy and usability. The main considerations when defining subcatchments are listed below:

- Topography using fine scale Digital Elevation Models (DEMs) to identify natural drainage paths.
- Property boundary lines can be followed when defining subcatchment extents if the topography only varies slightly within the property.
- Within a subcatchment, maintain similar land use and land cover characteristics
- Within a subcatchment, maintain homogeneous soil groups
- Individually represent large impermeable areas such as car parks, supermarkets, schools or industrial units to simplify the future representation of surface water removal measures.
- Define pre-development subcatchment boundaries considering known future development extents to simplify future scenario assessments. For example, when assessing plan change impacts.
- Relevant hydraulic model components such as sumps and stormwater management devices that are likely to affect the flows into the area of interest, and how subcatchments load to these components.
- Minimise unrealistically loaded drainage systems where due to subcatchment load points, the network may be "dry" or overloaded.
- Limitations of the hydrologic model applied. For example, models that do not represent routing will need to be small and routing is instead represented hydraulically.

Where catchments are flat and lack distinctive ridgelines, delineation of subcatchments may be difficult. In these situations consider a rain-on-grid approach with rainfall applied directly to 2D domain.

4.3 Hydraulic models

Hydraulics is the study of flow and pressure. In the urban stormwater modelling context, this corresponds to flow or discharge, and water level or hydraulic grade line. Together, flow and pressure, may be combined to be represented by energy and the energy grade line. Simulation engines are based on the solution of equations, often termed *governing equations*, that conserve these quantities. It is helpful to conceptualise your model as a **network of storages interconnected by conveyances**. Subsections below cover considerations that may be used as an informal checklist during a model-build process.

4.3.1 Geometric coordinates

- The coordinate system (horizontal) and vertical datum must be consistent across all model components. It is crucial that these are decided early in the model build and are clearly documented.
- It is preferable if the datum is included in the model itself if possible, in a description field or other appropriate location.
- Conversion of levels between datums should be reproducible.
- Conversion of levels for large catchments can be challenging – A single datum (such as NZVD2016) should be used where possible.

4.3.2 Boundaries

- Boundaries should be sufficiently distant from the area of interest to prevent artifacts in the boundary conditions from unduly influencing results. Examples may include a water level boundary too close to locations of flooding, which draws down the surface creating an unrealistically steep water surface, which in turn generates unrealistically high outflows.
- Extent of the domain must be sufficient to prevent flood flows ponding unrealistically against boundaries.
- "Hard boundaries" are those provided by modelling software. They are efficient and straight-forward but can only be applied where the flow regime is well-described by a single variable, either flow or water level. In the special case of a stage-flow relationship, the flow behaviour can still be fully determined by knowing either the flow or water level. Suitable boundary locations include hydraulic breaks, such as at supercritical sections, or where there is standing water with a significant storage area.
- "Soft boundaries" may be required where there are no clearly defined suitable locations for a hard boundary. In this case, model extents overlap. Flat urban catchments provide examples of this where it may be impossible to delineate a clear boundary between adjacent model domains as flow directions may change throughout a storm event. These boundaries are a result of limitations in computational capacity and are difficult to define and manage. They should be avoided wherever possible. Approximate hard boundaries are still necessary at the domain extent of the soft-boundary (invalid) zone.

4.3.3 Pipe network

- Significant public and private drainage may be represented.
- Geometric dimensions and parameters in pipe networks have the following order of priority (from highest to lowest):
  - pipe diameter
  - manhole hydraulic loss parameters (exit contraction loss, entry expansion loss, direction-change loss, etc.)
  - pipe flow resistance (roughness)
  - pipe length
  - pipe inverts
  - manhole diameter
  - manhole invert
- When conflicting dimensions arise, use the higher confidence source of the data to decide the value to be used in the model.
- Flow resistance in pipes is not usually calibrated for stormwater systems and literature values, decided by material type, are generally considered acceptable.
- If applicable, exclude pipe network based on function or location rather than pipe size. Subsoil drains are commonly excluded.
- Minor pipes (such as individual property laterals or catchpit leads) may connect to stormwater main pipes as lateral connections, rather than at manholes. Where this occurs and the lateral is to be included in the model, consider the impacts on numerical stability and hydraulic loss of adding a junction node to the pipeline.
- Most manholes will not generally exchange flows with the surface, but this should be represented for locations where the specific design allows for this or where there is evidence that the manhole lid surcharges during high-flow events (manholes at the bottom of steep grades may demonstrate this behaviour). Alternatively, some manholes may be welded or bolted shut to prevent lifting or may have a grated lid to mitigate surcharge potential and impacts. Explicit representation of these exchanges should be represented.
- Water level or Q-H boundary conditions should be applied to all outlets or outfalls, or they should be connected to the 2D domain. Allowance for flow exiting outlets should be made in the 2D domain. It is often the case that LiDAR does not resolve channels downstream of outlets adequately.
- Hydraulic losses in manholes should be accounted for but may be difficult to verify.
- Dry pipes indicate that there are missing connections upstream.
- Depending on the simulation engine, steep pipes, usually steeper than 10%, may cause instabilities and volume errors and the results, particularly for flow depth and velocity magnitude are likely to be incorrect.

4.3.4 Soakage

- May be represented in the hydrological (refer Section 4.2.3) or hydraulic model.

- Public soakage devices are often large and are best represented explicitly as a hydraulic structure, especially when as-built information is available.
- Private devices may be represented explicitly in the hydraulic model. Allowance for overflow should be accounted for, including where the overflow is located.

4.3.5 Culverts

- A culvert conveys flow through an embankment.
- Overtopping of the embankment should be allowed for with the crest defined.
- Momentum preserving connections between open channel flow and closed-conduit flow is preferred.
- Head losses at culverts are significant for urban flooding. Flow contraction at the upstream end is the most important aspect of culvert flow for flooding applications. Headwall details are important in this calculation.
- Verification with a second, independent method is recommended. If possible, choose a different calculation method rather than a different software implementation.
- Blockage scenarios should be included in sensitivity analysis.

4.3.6 Storage

- Storage may be represented as a stage-area volume relationship when the dynamics of the storage are not of interest or when inlets and outlets or outtakes are well-defined and are limited in number.
- Storage should be represented in 2D when the dynamics of the storage are not simple, when there are multiple inlets and outlets or outtakes, or when overland flow may enter or exit the storage.
- The storage *prism*, or the volume of storage available during an event, is the most important characteristic of storage. The volume stored below this prism is not active. When the bed level of a pond is not known, it is reasonable to set it at least a few hundred millimetres (for example 500mm) below the invert of the lowest outlet. This may be combined with an initial water level in the pond that is level with the outlet invert.

4.3.7 Outtake structures

- Outtake structures commonly include outtake orifices, low-flow orifices, and a high-flow weir (for example a scruffy dome).
- Weir flow through partially submerged orifices should be accounted for.
- A Q-H relationship applied to the outlet pipe based on the structure's design is an efficient method to represent outflow capacity without explicitly modelling the individual components. Confirm that backwater effects do not invalidate the Q-H relationship during simulation.
- If components of the structure are represented explicitly, it is recommended that the overall structure operation is verified and the performance is documented.

4.3.8 Pumps and control structures

- Geometric dimensions and parameters in pump stations have the following order of priority (from highest to lowest):

- pump set point or pump curve and system resistance curve
    - wetwell stage-area/volume relationship
    - start and stop levels for all pumps
    - acceleration and deceleration
    - overflow level and capacity
    - inlet pipe levels
- Realistic pump curves should be used.
- System resistance should be accounted for.
- Verification of the operation should be documented if control rules are implemented.

4.3.9 Groundwater interaction

- May be represented as Antecedent Moisture Conditions (AMC) and accounted for through hydrological losses.
- Groundwater interaction with stormwater is most significant in flat, absorbent catchments, often by the coast.
- Groundwater effects for rain-on-grid models may be represented by limiting the soil capacity using estimates of porosity or specific yield and depth to the groundwater table. AMC for historic and design events may be controlled in this way.
- Where the groundwater table is sufficiently high, groundwater may enter pipes through cracks. Inflow may be represented by discharge sources directly into manholes, similar to the approach used in wastewater modelling, or may be represented by a water level boundary connected via highly constrictive orifice structure that allows for flow both inflow and outflow. In either case this will likely be applied to few manholes, only ones that demonstrate inflow issues in reality.

4.3.10 Open channels

- Storage volume and conveyance capacity are the two most-important characteristics to account for.
- Cross section survey is recommended for large channels.
- Approximate cross sections may be used for minor channels.
- In 1D models, severe contractions or sudden and large changes in bed slope may cause the erroneous generation of energy and should be avoided by the addition of a hydraulic structure.
- Flow resistance in minor open channels is not usually calibrated and Cowan's procedure (Arcement and Schneider, 1989) may be applied. Consider the effects of dense vegetation at higher stages.
- For wide channels with meanders where there is an appreciable flow velocity, superelevation and bend losses should be considered around tight bends. 1D models do not account for these affects.

4.3.11 Bridges

- Contraction and expansion losses generally dominate bridge hydraulics and these are the focus of many bridge head loss calculation approaches.
- A rapid increase in flow is expected when the water level reaches the bridge soffit

- Many bridges may be represented by pier losses and form loss when the bridge soffit is reached, particularly if the channel is represented in 2D.

4.3.12 Weirs

- Account for free- and submerged-flow regimes.
- The weir type, determining the crest shape, is crucial for estimating upstream water levels.
- Very wide weirs, for example along road crests, should be accounted for in the 2D domain, both for the sake of accuracy but also for numerical stability.

4.3.13 Surface topography

- Surface elevation data, whether in a structured or unstructured format, will be interpolated to the computational grid cells or mesh elements and so the relationship between the two should be considered.
- The resolution of the overland flow grid surface will depend on the model purpose.
    - Reasonable representation of channel flow requires five or more cells or elements across the width of the channel.
    - Flow between buildings requires at least one cell or element.
    - Flow concentrations around obstacles such as buildings require fine resolution to capture the highest velocities.
- The approach for discretisation (rectangular or flexible mesh) will depend on the model purpose and whether additional topographic information can be added to cells or elements. Where possible, cell element faces should align with, or be perpendicular to, obstacles and principal flow directions.
- LiDAR survey data provides a good basis for a stormwater model, but generally has the following limitations:
    - vertical accuracy is difficult to interpret
    - point density is highly variable
    - inundated surfaces, such as channel beds, are not represented (water-penetrating LiDAR exists, but is not common)
    - vegetation severely degrades representation of the surface
    - it can be difficult to discern interpolation artifacts in areas with sparse survey points
- Lumps in the topography due to inaccuracies in the surveying can have a much greater impact on flow patterns than flow resistance does.
- Flattening or otherwise removing depressions in a LiDAR-derived surface inside building footprints, prevents the unrealistic storage of water and reduces the need for tidying flood maps up before publication.
- Topographical survey can provide excellent resolution with centimetre accuracy. It is important to tie any surveyed surface into wider underlying data around the survey perimeter to avoid artifacts in the model results where water may pond at the transition.

4.3.14 Overland flow resistance and obstacles

Overland flow is generally considered to be all flow that is not conveyed by pipes or open channels. Open surfaces are those without significant topographical obstructions.

- Flow resistance on open surfaces may be approximated using Cowan's procedure (Arcement and Schneider, 1989).
- Resistance should be distributed according to land cover, rather than averaging over large areas. Distributed resistance produces more realistic flow patterns than averaging does.

Stopbanks are built from soil and rock and provide flood protection from large open channels:

- The footprint of a stopbank is generally larger than the resolution of the 2D grid or mesh and so is best represented in 2D.
- Stopbank crest levels should be reinforced in 2D domains as crest levels can be smoothed and lowered inadvertently through the transfer of level information from fine-resolution LiDAR or topographic survey to coarser-resolution grid cells or mesh elements.

Walls are permanent, continuous, vertical obstructions and in the modelling context:

- Generally impenetrable for water with overtopping flow described as a weir.
- May be described as "thick" where cell element elevations are modified to reflect crest of wall.
- May be described as "thin" where flow between adjacent cells elements is blocked up to crest of wall. This requires specific software features to be available.
- Alignment should be well represented by computational grid element alignment with allowance for flow in the direct vicinity of the wall.

Fences are permanent, continuous, light-weight obstructions that allow the passage of water to a greater or lesser extent:

- Described as a "thin" constriction, regulating flow between adjacent cells elements.
- Includes a crest level, above which weir flow occurs, and an allowance for porous flow through the fence line.
- May include allowance for fence structural failure at a depth threshold.
- Fences require specific software features to be available.

Urban debris is composed of outdoor furniture or toys (trampolines, etc.), landscaping materials, or vehicles and trailers:

- As the debris is not permanent it should not be explicitly represented in the hydraulic model, unless there are specific circumstances requiring it.
- May be represented by increasing flow resistance within the property.

Vegetation may comprise a range of plants and trees of a variety of types, heights and densities:

- From a flood modelling perspective, vegetation is considered a permanent, porous obstruction.
- May be represented by a porous region within the model domain, or heightened flow resistance using guidance provided by Arcement and Schneider (1989). Depth-varying resistance may also be used.

- It may be necessary to smooth the LiDAR-informed surface to remove interpolation artifacts before increasing flow resistance to not exaggerate its obstructive effect.

4.3.15 Flow exchange

Flood flows in various locations throughout a catchment may be categorised into different regimes according to each regime's most suitable analysis technique. These divisions are artificial and are reflected in the structure of simulation engines that are based on these techniques and calculations. *Exchange flow,* in this context, refers to flow passed between regimes, which may be schematised differently to accommodate the limitations of various simulation engines. Exchange at stormwater inlets and outlets, and on the banks of open channels are common examples in urban stormwater catchments. In many simulation engines flow exchange occurs between 1D and 2D components at the transition in regime.

Stormwater inlets are ground-level structures that may incorporate catchpits, grates and kerb-openings that drain paved surfaces, commonly on roads. These structures exchange water between overland flow and pipe flow. They may also act as outlet structures during surcharging. Stormwater systems also discharge from the piped system to overland flow, open channels or tidal environments via outlet structures. Considerations for these structures are similar and include:

- Survey information is generally lacking.
- Depth-discharge relations (Q-H or Q-D) are used for sag locations.
- Approach-capture discharge relations (Q-Q) are used for on-grade locations (sloping gutter). Fine resolution (< 1 m) is required to adequately represent on-grade structures.
- A simple approach applied catchment wide is generally acceptable.
- Inletting capacity is crucial to predict surface flooding and in blockage assessment.
- Sag (discharge-depth relationship) and on-grade capture (approach-capture relationship) require different techniques.
- Ground levels of sumps should tie in with the surface representation and the location of the sumps is of high priority. In addition, where inflow capacity curves are used, the depth at the grate is important in defining capture, unless backwater effect dominate the inlets operation.
- Allowance should be made hydraulic losses as water enters and exits the pipe. It is recommended that longitudinal sections are used to understand the behaviour at exchange locations.
- Water may flow in or out of the pipe at both inlets and outlets, especially when tidal boundary conditions are high.
- Trash grills and other obstructions may be present at inlets or outlets and should be accounted for in terms of hydraulic loss and potential for blockage.

Overbank flow exchange water between open channel flow and overland flow:

- Flow exchange, as a minimum, should be considered. Depending on the simulation engine, this exchange may be described as weir flow.
- The location of flow exchange should be located at a ridge, such as a stopbank or channel bank, between the open channel and flood plain.

- When the flow patterns and water levels in the vicinity of the large open channel banks are of particular interest, a 2D representation is preferred to estimate momentum exchange.
- Where flood flows are expected to exceed the bank levels of minor, meandering channels and the flow is not aligned with the channel direction, a 2D representation of flow is preferred to estimate momentum exchange.

4.3.16 Model errors

The following items should be considered when checking model results for errors.

- Water ponding at boundaries, often termed *glass-walling.* This indicates that the boundary must be extended or another more appropriate boundary implemented.
- Very deep water may indicate that unrealistic downstream constrictions are present. This may arise when channels are obscured by vegetation and LiDAR is used to inform the 2D surface.
- Very high velocities, greater than 5 m/s, in shallow water usually indicate that the underlying assumptions used in the simulation engine's governing equations are not suitable for the situation modelled. Changes to the schematisation or parameters may resolve the issue. In 1D models this will likely be associated with steep slopes.
- Discrepancies in the water volume between connected model components may indicate software implementation errors or incorrect model configuration.
- Water volume continuity imbalance greater than 1% usually suggests instabilities or the generation of water in dry pipes.
- Rapid, large fluctuations in discharge are the clearest signs of model instability.
- Consider warnings reported in simulation log files when investigating issues in the model results.

Simulation engines do include errors in the implementation of the solution algorithms and so if all other possibilities have been excluded, then it will be necessary to seek appropriate software support.

4.4 Boundary conditions

Boundary conditions applied in the model build stage are generally drawn from historic records that represent calibration, validation or verification events. Common types of boundary conditions are listed below.

- Rainfall
- Inflows
- Water levels

4.4.1 Rainfall

The following considerations apply to rainfall boundaries for a historical scenario:

- Rainfall can be represented as rainfall intensity or rainfall depth, applied to hydrologic models, or as direct point sources to a 2D hydraulic model. Rainfall depth time series are typically provided by tipping bucket rain gauges which record fixed-depth tips at irregular intervals. Rainfall intensity is applied as a constant for each interval in the timeseries. Rainfall depth should be distributed evenly across the preceding time interval (step accumulated).

- Areal reduction factors, which are designed for use with lumped catchments, may be applied in the rain-on-grid approach. It should be noted that when factors are applied flooding may be under-predicted in upstream areas of the catchment, and when they are not, flooding may be over-predicted in downstream areas.
- Individual or multiple rainfall time series measured at rain gauges should be used directly as boundary conditions for calibration, verification or validation simulations.
- Identify the closest gauges to the area of interest. The Voronoi grid or Thiessen polygons methods may be used to identify the rain gauges that are relevant for the catchment.
- Some consideration should be made to estimate the possible variability of the rainfall across the catchment of interest. It is known that storm cells (zones of high intensity rainfall) during flood events can travel between gauges and so may not have been recorded.
- Rain radar, if available, provide spatial grids of rainfall intensity that vary with time that can capture localised events.
- Determine the period of interest considering the catchment hydrological characteristics (base flows). Commonly, at least 1 week of rainfall prior to the storm event.

Rainfall data can be sourced from:

- Local authorities who commission the installation, maintenance, calibration, data collection and data quality control of rain gauges. This data will often have a higher resolution and frequency of measurements compared to national databases.
- Local authorities who commission localised, high resolution rainfall radar collection and/or data processing.
- NIWA maintains a database of historical rainfall at 10minute, hourly and daily frequencies (https://cliflo.niwa.co.nz/)
- The MetService can provide rainfall radar data upon request. Raw rainfall radar data should be calibrated against rain gauge data and processed to account for scan frequency and distance before adoption for modelling.
- Where useful or necessary, private rain gauges when the data collection process is regarded as sufficiently robust.

References: BOPRC (2021), TCC (2022)

4.4.2 Inflow

Where upstream catchment or river inflows are a primary discharge boundary condition, flood frequency analysis or other methods can be used to generate flows from historical data. Alternatively, an appropriate hydrological model or simplified hydraulic model with initial and continuing losses can be applied.

For large design events, surface water is not always contained within the modelled stormwater catchment boundaries. It is important to minimise the number of catchment interactions when schematising the model where possible, but sometimes this is not practical. Catchment interaction inflows will need to be extracted from nearby model results if available or appropriate discharge-stage (Q-H) relationships applied.

Two-dimensional numerical software engines often do not automatically store discharges across specific locations. Some planning is required to ensure outflows from one model are stored as discharge extraction outputs to be made available as inflows into nearby catchment models.

4.4.3 Water level

Water level boundary conditions are generally used in cases where backwater effects are likely but inflows are unlikely. Common examples include large ponding areas and discharges to tidal environments.

Where water ponds at the boundary of a nearby catchment during a large event, water levels will need to be extracted from nearby model results if available, or an appropriate static level applied. Stormwater ponds within a catchment will require a static or time series water level boundary condition depending on the information available.

The following considerations apply to tidal boundary conditions for a historical scenario:

- Tidal boundaries are applied as a downstream boundary condition at stormwater outlets, along beaches and mudflats in the vicinity of the Lowest Astronomical Tide.
- Measured tidal levels must be used in simulations of historical events for calibration, verification or validation purposes.
- Identify the most appropriate tide gauge(s). Generally, this is the closest to water, or the gauge on the same body of water between constrictions in a harbour. The amplitude and timing may vary throughout a harbour so depending on the application an interpolation may be required.
- Determine the period of interest, related to the rainfall period.
- The datum of supplied measurements are often not the same as other datum so an offset may need to be applied.
- It may be necessary to smooth the timeseries data if the tidal signal is noisy as this can cause issues at model boundaries such as high velocities or waves.

Tide data can be sourced from:

- Regional or local authorities who commission or collate available information.
- Port Authorities
- NIWA historical and forecast tides (https://niwa.co.nz/our-science/coasts/tools-and-resources/tide-resources)

4.4.4 Initial conditions

Initial conditions are a boundary condition on the models temporal domain. Appropriate initial conditions will allow a smooth transition from a frozen, initial state, into a dynamic state that is influenced by boundary conditions. A poor initialisation will result in the propagation of unrealistic flow through the domain, which may cause the simulation to crash or reduce the timestep size dramatically. It may also result in on-going instabilities or other undesirable artifacts remaining long after the start of the simulation. This is a severe problem if minima or maxima from the entire simulation period are primary outputs and it is not possible to truncate the initial period from the sampled simulation period.

- Initial conditions should match the other boundary conditions at initialisation. For example, the initial water level in the 2D domain along the coast should match the tidal boundary condition level.
- Ponds and other storages that are distant from boundaries should be initialised to a realistic, pre-storm condition, such as being full to the invert of the lowest outtake orifice or outlet pipe, or the crest of the lowest overflow weir.
- Antecedent moisture condition (see Section 5.3.6) is the only initial condition that is applied to most, simple hydrologic models that do not include reservoirs or large routing branches.
- When initial conditions have a significant impact on results, water level or borehole records should be analysed to determine a realistic initial condition.
- In rain-on-grid type models, the groundwater table may be used to account for reduced subsurface storage or soil capacity during wetter periods. This may be used in design scenarios where overprediction of runoff is desired.
- Hydrologic and hydraulic initial conditions should be consistent.

4.5 Quality Assurance - Build

Internal, compliance and peer reviews are scheduled during the Plan Project phase of a modelling project (Refer to Section 2.5 - Quality Assurance) and implemented in the Build phase. For static/simple or dynamic/simple models, internal reviews, and in some cases external peer reviews at the end of the build phase, may be all that is required. Complex models may require internal and external staged compliance reviews and peer reviews through the build phase at significant milestones (e.g. hydraulic model, hydrological model, boundary conditions, calibration/validation/verification) or as frequent check-ins to discuss methodologies and issues.

Model reviews in the Build phase ensure the model is accurate and reliable by:

- Verifying the accuracy of assumptions and validity of the mathematical representations about the physical behaviour of stormwater flow.
- Validating the input data to ensure it accurately reflects the current and relevant conditions of the study area.
- Providing additional experience to incorporate advancements in technology and modelling techniques to enhance the model performance and quality of outputs.
- Assessing calibration, validation, verification processes to improve the models predictive capabilities, reliability and confidence.

A simple checklist is provided in Appendix B as a starting point for internal quality assurance of model builds. Note the example checklist is a simple baseline and end users should adapt their own checklists based on the modelling software being used, the experience of their modellers and the type of models being built. Compliance review checks during this phase ensure alignment with modelling specifications developed for the specific needs of the commissioning organisation for the purposes of providing consistency and reliability of models. These specifications often have software specific implementation details. Other sources of review templates or checklists include:

- Wellington Water – Model Review Template (2022).
- Greater Wellington Regional Council Flood Hazard Modelling Standard (2021) – includes a review template.
- Auckland Council's *Model Review Template_v1.0.xlsm* spreadsheet.
- Review templates provided by software suppliers tailored to their products.

References: TCC (2022), HCC (2017), NRC (2022), GWRC (2021), WWL (2022),

4.6 Limitations and Assumptions

Limitations state the circumstances in which the model will not produce accurate or reliable results. Assumptions include any simplifications or invented information that has not been verified for accuracy or reliability. Those that use the results of the model will be most interested in the model's limitations and those that modify the model will be most interested in the assumptions.

4.7 Model Confidence

Confidence in the predictions made by a model can be quantified through calibration, verification and validation. Where this is not possible or further understanding of the model performance is required, a sensitivity analysis may be performed. Outputs from these analyses may be used to assign appropriate freeboard.

4.7.1 Calibration

Calibration is the process of adjusting model parameters to make a model fit with measured conditions (usually measured flows). It is difficult to calibrate a stormwater model as stormwater systems are not closed and many variables impact flows. For similar reasons, stormwater systems are not generally monitored with flow gauges and measured flow data is often unavailable.

Calibration to measured flows is generally not practical in the context of stormwater models. However, calibration at specific large model inflow locations may be practical depending on the data available and the nature of the hydrological model used to represent the inflow.

Force-fitting or over-training (term used in data science) is the making of arbitrary changes to a model to make it fit observed data and should not be undertaken.

4.7.2 Verification

Verification is the process of checking a model against independent data to determine its accuracy. For stormwater models, the verification process generally consists of comparing model results with:

1. Flow / level surveys or other telemetry data (if available).
2. Known flood event data collected post incident (such as buildings known to have flooded, observed debris lines or anecdotal evidence from observers).

3. Site observations made by the modeller during the build process.
4. Historic observations of the flooding mechanism and or flow routing.
5. Flows / levels predicted by other similar models or simplified representations of the study area.

Changes can then be made to the model schematisation and or parameters to enable improved replication of the independent data sources. Any changes to the model should be made only where this reflects the physical state of the drainage network and not solely to make the model fit the observed data. Any changes made because of checking with a second (or more) set(s) of data should not invalidate the first and so on.

References: BOPRC (2021), GWRC (2022) and CIWEM (2017)

4.7.3 Validation

The validation process confirms that the adjustments made to a calibrated and or verified model are suitable for applying a broader range of design events. Validation typically involves simulating one or more historical flood events of different scales and characteristics to those used for calibration and or verification of the model. This is required as it is assumed that the model will be used over a range of scales for design and predictive purposes. For example, a smaller event, a larger event or an event with different rain patterns (such as a double peaked storm) could be used.

4.7.4 Sensitivity analysis

Sensitivity analysis is undertaken in modelling projects as a method of assessing confidence in the model results. It is particularly important in cases where it has not been possible to undertake calibration or verification or where significant uncertainty remains after calibration, verification, validation exercises. Sensitivity analysis provides a method of being able to quantitatively assess the impact of modelling decisions and assumptions on the output of the model. Model parameters are varied, one at a time, to assess the impact on results that a different assumption would have made. Analysis can be completed on the following parameters:

- Roughness values (Mannings / Colebrook White):
    - To understand how sensitive the model results are to the roughness values that have been assigned within it.
    - Often varied by a percentage, such as +/- 20%.
    - Should be varied in 1D networks (watercourses and pipes) and across 2D models.
- Downstream boundary conditions:
    - To understand how sensitive model results are to the downstream boundary conditions that have been applied and can assess how far upstream the influence of the boundary condition is seen in model results.
    - Change fixed level or the gradient that has been used to automatically generate boundary conditions.
    - Might identify a need to extend the downstream boundary further in the case that it is exerting a significant influence on model results at a key location.
- Inflow hydrographs or input hyetographs:

    - To understand how sensitive the model results are to the magnitude of flow or rainfall applied to it.
    - Often varied by a percentage, such as +/- 20%.
    - Particularly important where there is significant uncertainty in the hydrological analysis used to derive inflow hydrographs.
- Infiltration losses and runoff coefficients:
    - Important when rainfall runoff methods used in either the application of rainfall to sub-catchments or in 2D direct rainfall modelling.
    - If a fixed percentage loss value has been used, this could be varied up and down to assess the impacts on model results.
    - If a variable loss value is applied this could also be varied, or the model tested using an alternative fixed percentage loss.
- Structure representation and coefficients:
    - Specifics of these tests will depend on the software used and the way that structures have been represented in the model.
    - Critical hydraulic structures should be identified for testing.
    - Testing should focus on these structures and may involve adjustment of culvert inlet or outlet losses or adjustment of weir coefficients.
    - If there are pumps in the catchment, testing might include variations in the assumed pump rate, rules governing pump operation / efficiency or failure.

Assessing the results of sensitivity analysis will depend on the setup of the model and overall purpose. Methods to consider include:

- Comparison of stage and flow in 1D long-sections in pipe networks, culverts or open watercourses.
- Tabular comparison of peak stage or depth at model nodes (absolute comparison or a relative comparison of the percentage change in depth).
- Comparison of the number of surcharged manholes (absolute or relative comparison).
- Difference grids or afflux plots created from max stage or depth data across the 2D model extent to show difference in maximum flood depth and extent.
- Tabular comparison of the number of properties affected by flooding (above a certain depth).

The interpretation of the results of sensitivity testing should be presented in a way that considers the original model purpose. Stakeholders must be able to easily understand the implications of the sensitivity analysis on the level of confidence in the model, what this means for the results and any decisions being made that rely on the model results.

References: CIWEM (2021)

4.7.5 Overall Confidence

Model confidence is a critical factor in the management of risk and uncertainty in all modelling processes. Models vary in their ability to replicate real-life performance and therefore in their fitness for intended purpose. Determining model confidence is a complex process that relies on the assessment of the validity of the following factors.

- Asset data: how well the data represents the reality of the asset with regard to physical attributes, including condition.
- Hydrological assumptions.
- Quality and length of record of measured flow data (if available).
- Level of model calibration, verification and / or validation achieved.

Other modelling guidance documents, such as the CIWEM Urban Drainage Group Code of Practice for the Hydraulic Modelling of Urban Drainage Systems (2017) and the supporting Integrated Urban Drainage Modelling Guide (2021) provide a comprehensive framework for assessing and categorising model confidence. This approach can be used when data is available. In lieu of quantitative estimates of confidence, it is recommended that a qualitative approach is used to support the stated limitations of the model.

4.7.6 Freeboard

Freeboard is a standard engineering provision for estimating imprecision and uncertainty of inputs. Even the most sophisticated models are unlikely to exactly predict complex hydraulic behaviours or accommodate all conditions that influence a flooding event. A fixed freeboard is often specified by local guidance or district or regional plans. Where this is not available, the New Zealand Building Code requires the floor level of a residential building to be 'above' a flood level equivalent to a storm event with a 2% AEP. If a model specific freeboard is required, then the following references provide detailed guidance:

- Environment Agency - Accounting for residual uncertainty: an update to the fluvial freeboard guide (2021).
- Would you like freeboard with that? (Conference paper presented at the 2016 Water New Zealand Stormwater Conference).

References: CIWEM (2017), CIWEM (2021) and BOPRC (2021)

4.8 Reporting and Outputs

Reporting is a large component of the model build effort. The following types of output are possible, listed from most significant to least significant. This list does not include outputs required when using the model to support analysis.

1. Final version of model in a tidy and clearly structured format.
2. Report including the following information.
    a. Model purpose, objectives, and success criteria.
    b. Overview of schematisation.
    c. Assumptions and limitations.
    d. Description of software platform.
    e. Geometric coordinate parameters including datums and reference systems.

    f. Data used in model build with associated licenses.
    g. Description of model performance in calibration, validation, and verification.
    h. Description of model performance in sensitivity-analysis scenarios.
3. Simulation results. It is recommended that results are stored in default locations alongside the model files and not in a separate folder. Note that some outputs, such as discharge, are more accurate if they are included as specific outputs from the simulation and so their location must be determined before the simulation is initialised.
4. Model and simulation metadata, including model-build and simulation logs.
5. Catalogue of datasets used.

5 USE

5.1 Overview

The use phase comprises the use of the model to simulate one or more scenarios. These scenarios may incorporate changes in hydraulic or hydrological conditions to represent urban intensification, climate change, or modification of the stormwater system. All model versions created in this phase of modelling work may be termed "project" models to distinguish them from the original "base" model developed in the build phase.

5.2 Configure the model

During the plan-model phase, a schedule of model runs for different scenarios should be created to align with the purpose of the project. Since this schedule was developed, new information or requirements may have arisen. The model run schedule should be reconfirmed and updated and then the configuration of asset and geometry changes and boundary conditions for each scenario may begin.

5.2.1 Using existing models

Where a model was developed specifically for the purpose of a study, the extent was defined in the plan and build phases with no significant modification required to simulate a range of scenarios. However, in some instances, a catchment-wide base model may already exist (that was built for another purpose) and can be used as a starting point for a project model. In these situations, understanding the existing base model limitations and applicability to the new project model purpose is important so that the model may be refined or discounted accordingly.

Where a modeller does not have the knowledge or access to the software used for the base model, a new localised model could be developed for the area of interest in alternative software - or potentially using an extract of reduced extent from the base model. The localised model can use relevant discharge or water level boundary conditions extracted from the catchment-wide base model. For localised investigations, it is more efficient to NOT use existing catchment-wide models due to long simulation times, large results and file workability.

Some considerations when cutting down base model extents to an area of interest are summarised below.

- Use locations where it is easy to implement upstream and downstream boundary conditions, with no or minimal downstream interactions. For example, at hydraulic breaks where the water surface passes through critical depth (Froude number = 1). If this is not possible, ensure that interactions only occur well away from the focus area of the study.
- The primary piped network cut-down model extent may be different to the secondary system cut-down model extent.
- Flooding extents for larger events may require an adjustment to the cut down model extent (largest event considered for the purpose of the model to capture the worst-case secondary flows).
- Minimise boundary interactions for areas most likely impacted by the options under investigation.

- Consider the upstream hydrology represented in catchment-wide model.
- For sub-catchment based hydrological models, re-delineation and parameterisation may be required for sub-catchments near the new boundary.
- Run the clipped model for a significant scenario, compare to the catchment-wide model results and assess differences and importance to the model purpose. There will be some discrepancies between the base and project models. These will only need to be resolved for the network that impacts the specific areas of interest.

It is crucial that the model boundary is sufficiently distant from the specific area of interest to reduce errors introduced by boundary conditions. Without an appropriate boundary condition results may show water ponding against a boundary (a "glass wall") or unrealistically drain the system.

5.2.2 Hydrological Modifications

Modifications to the model's hydrological components (such as initial and continuing loss for rain-on-grid models, or area-weighted loss and routing parameters for subcatchment based hydrology) can be used to assess the effects of changes to land use, buildings, soakage or antecedent moisture conditions (Table 5.1). It is important to follow local guidance specified by councils, where available, for rainfall patterns and / or design depths, hydrological loss, and routing approaches (Refer Section 4.2.)

Table 5-1: Hydrological Modifications for Option or Impact Assessment

Scenario	Common Modification Approach
Landuse change – changes to impervious areas	For rain-on-grid models, modify initial loss or storage and continuing losses to reflect changes to land use. e.g. proportional changes to losses. For subcatchment-based hydrology, modify losses and routing to incorporate effects of changes to impervious areas. For example, modify the Curve Number, initial abstraction depth and time of concentration.
Stormwater network concept design – changes to capture runoff	For rain-on-grid models, hydraulic modifications may be necessary to effectively capture runoff into the stormwater network. For subcatchment-based hydrology, it may be necessary to refine subcatchment boundaries (and therefore loss and routing parameters) and connections to the hydraulic system to better represent inflows into the stormwater network.
Stormwater network concept design – changes to retention and detention	To effectively store and release stormwater, preventing upstream and downstream flooding and minimizing the impact on the surrounding environment, assessing a range of rainfall depths/intensities and temporal patterns are required for a complete assessment. Note, the critical duration storm for one design scenario may not be critical for another design scenario.
Representation of buildings – increased resolution	Higher resolution models for localised investigations may require the effect of runoff from buildings to be represented, particularly larger buildings. For rain-on-grid hydrology, infiltration rates could be modified within building footprints and the connection to the stormwater network or kerb is modelled hydraulically.

Scenario	Common Modification Approach
	For subcatchment-based hydrology, an individual building footprint or a group of building footprints could form its own subcatchment and loss parameters modified. The connection to the stormwater network or kerb is modelled hydraulically. Unconnected private soakage is accounted for through an area-weighted contribution to the subcatchment loss parameters. Note, specific soakage structures could be modelled hydraulically.
Antecedent Moisture Condition (AMC)	Modify initial hydrological model parameters to represent drier or wetter AMCs (Refer Section 4.2.6).

5.2.3 Hydraulic Modifications

Modifications to the model hydraulic components (such as the 1D pipe network, control structures, open channels or 2D components representing the topography / urban environment) can be used to assess the effects of network changes or assess blockage / residual risk in an urban stormwater system. Tables 5-2 and 5-3 show common approaches to representing these in a model. Refer to Section 5.3.10 for more detailed guidance on residual risk and when it should be considered.

Table 5-2: Hydraulic Modifications for Option or Impact Assessment

Scenario	Common Modification Approach
Change to pipe network (configuration and / or pipe sizing)	Modify modelled 1D network to suit changes (where possible, ensure the components that are being modified exist in the base model and project model to allow comparison of results).
Change to topography because of land development	Modify 2D terrain (either using model software tools, direct edits, or apply a differences file).
Change to resolution to represent buildings	Connect subcatchments or relevant 2D cells within building footprints to the public stormwater network / kerb directly or via a hydraulic model component. Consider potential ponding on top of building footprints and the representation of overflows from larger events.
Change to flood storage area control structure	Modify modelled 1D network to suit changes (where possible, ensure the components that are being modified exist in the base model and project model to allow comparison of results).
Performance of proposed stormwater management approach – pipe network	Add proposed 1D network and compare performance to base model results and / or designed level of service.
Performance of proposed stormwater management approach – overland flow and / or flood storage areas with controls	Modify 2D terrain (either using model software tools, direct edits, or apply a differences file) and / or 1D control structures. Compare performance to base model results and / or designed level of service.

Table 5-3: Hydraulic Modifications – Blockage or Residual Risk

Scenario	Common Modification Approach

Full or partial blockage of inlet structure, network component or bridge structure
 	
Failure of control structure for flood storage area
	Modelling approaches vary based on size and nature of inlet structure or network component:
	• Simple approaches:
	  ○ reduce size of inlet pipe while retaining same invert level.
	  ○ add raised weir at inlet to reduce capacity.
	  ○ removal of pipe or control structure from the model.
	• Software specific – some modelling software packages allow blockage to be explicitly represented in model settings.
	• Complex approach – adjust inlet head losses to restrict flows.
	
	Australian Rainfall Runoff – Book 6 (Flood Hydraulics) / Chapter 6 (Blockage of Hydraulic Structures) *– Provides a comprehensive guide to:*
	• *Factors influencing blockage.*
	• *Assessment of design blockage levels.*
	• *Hydraulic analysis of blocked structures.*
	This reference should be used when assessing which structures should be considered for blockage risk within a stormwater network, what degree of blockage is suitable and how a blockage can be represented.

Assessment of how a stormwater system will perform when all network inlets are blocked	• Remove underground components of the primary stormwater system from the model. • Turn off all 1D / 2D model interactions (software specific). • If 1D components are turned off / removed – check hydrological connections remain valid.
Failure of an embankment or retaining wall forming a flood storage area	• Modify 2D terrain (either using model software tools, direct editing, or apply differences file). • Add 1D structures such as weirs or large diameter pipes to represent the failure. • Note that large linear structures may require assessment of failure at multiple individual locations to determine the most critical failure location.

Failure of urban open channel flood defences (such as walls or embankments)	• Modify 2D terrain (either using model software tools, direct editing, or apply differences file).
	• Modify 1D cross sections (where the channels are represented in 1D).
	• Note that long reaches of defences will need additional assessment effort to determine the highest risk locations of failure. This could include:
	  ○ Modelling of failures at equal intervals along the structure.
	  ○ Selection of failure locations based on where they would have the highest impact (such as adjacent to residential properties or critical infrastructure).

5.3 Boundary Conditions

The application of boundary conditions for historic events used to calibrate - validation - verify base models are covered in Section 4.4 of this guide. Typically in the "use" phase, design event scenarios are simulated. A design event is a collection of synthetic boundary conditions that are selected to represent an event of a prescribed frequency, generally expressed as an Annual Exceedance Probability (AEP). A set of boundary conditions defines the characteristics of a scenario, but several sub-scenarios may be required. For example, to understand the 1% AEP flood scenario a series of rainfall dominated versus tide dominated simulations may be required to determine the envelope of flood levels.

When deciding on appropriate boundary conditions, consider the following:

- Regulatory requirements – Regional or district plans, local engineering standards or codes of practice. If no local or regional guidance is available, then the Building Code can be used to set some requirements.
- Project requirements - High-impact projects, such as those involving critical infrastructure or environmental considerations, may require a higher return period to account for increased risk.
- Risk tolerance – Depending on the tolerance of the community to risk, some projects may require a more conservative approach, opting for a higher return period to minimize the risk of flooding and associated damages.
- Engineering judgement - Consider the consequences of underestimating or overestimating the design boundary condition by balancing the conservatism of using a high return period and the practicality of construction and cost implications.
- Sensitivity analysis - Assess how variations in the return period affect the model results and relate to the associated risk.

It is important to note that rainfall recurrence intervals / exceedance probabilities are different to flood recurrence intervals / exceedance probabilities. Rainfall recurrence intervals relate to the frequency of specific rainfall events, influencing stormwater management. Flood recurrence intervals relate to the frequency of specific flood flows, guiding the design of infrastructure to mitigate flood risks.

5.3.1 Design Rainfall

Design rainfall with different depths / intensities and temporal patterns are applied to subcatchment-based or rain-on-grid models across the entire domain of urban flood models. Some larger catchments or specific applications may require spatially varying rainfall (e.g. rain radar or from multiple gauges) and in some cases Areal Reduction Factors (ARF) (Refer Section 4.2).

Design rainfall is a series of synthetic precipitation events for required return periods, often based on statistics, such as timing, distribution and depth of rainfall, from records of historical events. These synthetic events are generated according to the following requirements.

- **Depth-duration-frequency rainfall tables.** Typical sources of these tables to represent "current" climate conditions include:
    - Studies based on local rain gauge data (such as TP108 from Auckland Council).

- NIWA's High Intensity Rainfall Design System (HIRDS) - https://hirds.niwa.co.nz/
- **Rainfall temporal distribution.** Rainfall distribution should align with local rainfall patterns or if unknown, be a conservative representation and be applied consistently. Preferred temporal patterns are often defined by councils. Examples include a triangular-shaped profile simulated for multiple durations, the distribution of a significant historical event, and centred and off-centred nested storm profiles with all durations for a particular return period in one timeseries.
- **Simulated period.** For easier application, it is useful to have all design rainfall time profiles timed so that the peak rainfall occurs at a specific time (such as midday of the simulation time). This allows other boundary conditions such as tide or river flows to be easily set relative to the rainfall peak.

Refer to Section 5.3.9 (Climate Change) for details on applying impacts of climate change to rainfall and Section 5.3.8 (Joint Probability) for relating rainfall probability to other phenomena. Where separate upper catchment hydrological models provide boundary inflows, the boundary conditions for these models must also be suitably updated. The timing of design events applied to upper catchments and the application of Aerial Reduction Factors (ARF) may need to be considered depending on historical event characteristics.

When designing resilient stormwater infrastructure, it is important to understand that design storms and critical durations that are relevant for one application of the model, may not be relevant for another, even when within the same catchment. For example, when designing retention- detention consider that the modified timing of peak flows may exacerbate flooding issues elsewhere.

References: BOPRC, KCDC, TCC, NRC

5.3.2 Design Tide

Tidal boundaries are applied as downstream boundary conditions for urban flood models impinging on coastlines or estuaries. Tidal boundary conditions can be applied as a constant water level or a timeseries with a time and scale offset to a historic or predicted tide cycle. Preferred design tides are often defined by councils, often based on coastal model predictions. If unknown, use a conservative representation and apply it consistently, while considering an appropriate level of service.

Design tides are composed of many elements. Key components are listed below.

- Astronomical tidal cycle (12.5-hour period) - for example, sourced from NIWA Tide Forecaster (https://tides.niwa.co.nz/) – note that the vertical datum used for tides is usually different to the land based vertical datum for LiDAR or pipe level data. Caution is advised and careful checking of datum conversions is recommended.
- Mean Level of the Sea (MLOS) anomaly after detrending of historic records.
- Storm surge (wind setup and atmospheric pressure effects).
- Wave setup (near shore phenomenon).
- Sea Level Rise (SLR) due to climate change.
- Vertical land movement over time (https://www.searise.nz/vertical-land-movement)

Examples of design tide representation include:

- Fixed level - using Mean High Water Springs (MHWS) (https://data.linz.govt.nz/layer/105085-nz-coastline-mean-high-water/).
- Gauged or predicted data – using a representative spring tide cycle or a storm event. Shifted in time to align with runoff flow arriving at the tidal boundary.
- Peak storm tide (with or without the addition of wave setup) - determined from local coastal model studies commissioned by local authorities. These models consider wind setup and tidal variation factors. Applied as an offset to a fixed level or gauged / predicted data. It is uncommon for wave run-up to be included in stormwater model simulations as peak height.

References: BOPRC, KCDC, TCC.

5.3.3 Lakes

Lake level boundaries may be applied as a downstream boundary condition to urban stormwater models. Historical lake level measurements should be analysed to determine a statistical design level (e.g. average, minimum, maximum or 90^{th} percentile). Preferred design lake levels are often defined by local authorities.

5.3.4 Rivers and Streams

As described in Section 4, urban stormwater models which are bounded by rivers and streams will require a water level boundary condition or contain a partial representation of the river model with a discharge boundary condition. For river and stream boundary conditions, consideration should be given to:

- Relevant rainfall and resulting river flow that is applicable to the design rainfall scenario of the urban flood model.
- Design-tide impacts on the rivers and streams.
- Timing of the river peak flows or levels in relation to the urban stormwater model area
- Engineered structures controlling water level and discharges – with an increase to river levels or flows for design events, model schematisation and extents may no longer be appropriate. For example, the base model may have assumed that there was no need to dynamically couple a 1D river model with the 2D model because of a high stop bank. However, for a scenario with increased river flows and levels, overtopping may occur and representation of these dynamics is required.

References: BOPRC, TCC.

5.3.5 Catchment Interactions

For large design events, surface water is not always contained within the modelled stormwater catchment boundaries. It is important to minimise the number of catchment interactions when schematising the model where possible. Some ways to do this include:

- Ensuring the DEM represents reality. Confirmation on site might be required to determine if the DEM needs to be modified or if structures need to be represented.
- Ensuring that the model extent is appropriate. Rather than extracting results from one model to another, it may be simpler to extend the model. Care must be taken to extend the model far enough.

- Ensuring that subsurface structures are represented appropriately (such as culverts under roads or railway embankments).
- Review model results for a rainfall event and check no glass walling of flows along boundaries.

For each catchment interaction, model schematisation needs to consider both sides of the catchment boundary. Discharges across boundaries must be extracted from the upstream model to feed the downstream model's boundary. Where ponding occurs, water levels must be extracted.

It is important to note that the computational methods used by most commercial software packages do not allow the storage of discharge results for an entire 2D model. It is often necessary to define specific extraction locations for results to be saved prior to the model simulation. For open boundaries that discharge to other catchments, it is prudent to define a discharge result output to later be used by the other catchment models. A suitable boundary downstream of the extraction location is crucial.

References: BOPRC, TCC.

5.3.6 Antecedent Moisture Conditions

Antecedent Moisture Conditions (AMC) or model initial conditions define the degree of saturation of hydrologic or hydraulic models at initialisation of the simulated period of interest. (Refer to Section 4.2.6) Where a catchment is sensitive to moisture conditions, AMC will have a significant impact on the Annual Exceedance Probability (AEP) of the simulated flood event and invalidate the often implicit assumption that precipitation AEP matches that of the resulting flood. AMC should be accounted for in joint probability sets of boundary conditions (refer Section 5.3.8).

A relationship between AMC and AEP should be established from historic measurements if AMC is to be effectively included in joint probability event design. Where it is not feasible to create such a relationship, the following approach is recommended:

- Average AMC should be used for base case scenarios and level of service analysis.
- Wetter than average for future climate, post-development and mitigation option scenarios to overpredict the impacts to allow for uncertainty.

Alternatively, sensitivity assessments to understand the effect of AMC on flooding related to the purpose of the model should be considered (Refer to Section 4.7).

References: BOPRC, TCC.

5.3.7 Groundwater

Increased soil moisture contributes to elevated groundwater and resulting base flows. For catchments where groundwater significantly influences urban flooding, observed base flows preceding historic events should be assessed and incorporated into design event boundary conditions. Groundwater can be represented as:

- Changes to AMC - initialising the 2D subsurface storage based on estimated groundwater table levels (min, max or XX^{th} percentile groundwater table level).
- Inflows from gauged or hydrological analysis via boundary conditions.

- Fixed base flows for minor streams that are not modelled explicitly if they are peripheral to the area of interest.

5.3.8 Joint probability

A joint probability approach is applied when developing a suite of sets of correlated boundary conditions and other parameter sets for a particular context. It is used to describe the likelihood of a particular combination of boundary conditions and can take correlation into account. The correlation between phenomena could change with climate. It should be noted that flooding in only some areas of a model domain will be influenced by the interaction of different boundary conditions. Table 5-4 provides a prioritised list of phenomena to consider for joint probability scenario development.

Table 5-4: Considerations for joint probability in order of priority for urban flooding

Priority	Phenomena	Interaction with other phenomena
1	Precipitation, subcatchment runoff and river/stream inflows	Rainfall is the principal predictor of flooding and is treated as the primary boundary condition.
		Runoff from nearby subcatchments that may be produced by the same storm event.
		River base flows may be elevated due to recent precipitation and so are correlated with AMC.
2	Storm surge and wind setup	Generally caused by the same storm as precipitation and so a significant correlation is expected.
3	Antecedent Moisture Conditions (AMC)	Wetter AMC results in greater local runoff and flood volume than would be expected for a given storm event.
4	Discharge peak timing	The worst-case scenario of peak tide coinciding with peak discharge from stormwater outfalls, open channels or floodplains.
		Current variability of coincidence with tidal cycles is generally not accounted for other than the worst case where peaks align. Approximation is best suited to situations in which discharge peaks over many hours.
5	Stopbank / structure breach	Structure failure is a function of ground state, soil strength, and adjacent flood levels. Generally, structure failure probability is not factored into joint probability scenario design and is treated separately.
6	Groundwater	Groundwater levels may be correlated with AMC.
7	Flow resistance	Seasonal variation in land use is relevant for rural land when a distinction between summer and winter storms is made.
		Open channels are affected by seasonal vegetation growth and maintenance.

For practicality purposes, a reduced set of all possible boundary condition types should be considered for the probability of design events, related to the purpose of the modelling study. For remaining phenomena, a judgement will need to be made on its likely occurrence such as worst case or statistically based on recorded information (min, max, average or XX^{th} percentile). The most common considerations in the design of joint-probability scenarios are rainfall, tidal (including storm surge) conditions, nearby subcatchment runoff, river inflow, and groundwater.

In some modelling applications, the worst-case scenario may be required. For example, to represent a 1% AEP flood event, a 1% AEP rainfall event would be paired with a 1% AEP storm surge event and a 1% AEP river flow, along with the highest (wet) antecedent moisture conditions. The AEP of this arrangement is likely to far exceed the AEPs of the individual components. Testing the model's sensitivity to the return periods of different components of the joint probability may be vital where critical thresholds may be exceeded.

Infrastructure design for a worst-case scenario may be beyond level of service requirements and not be cost effective or practical. For cases where the exact configuration of boundary conditions is unknown for a scenario, a suite of configurations with their own sub-scenarios may be required and a joint probability approach used. Table 5-5 provides a set of example boundary condition configurations for testing joint probability impacts.

Table 5-5 - Example of design event boundary condition configurations for a range of flood event AEP's

Scenario	Sub-scenario	Precipitation or flow	Storm surge	Other phenomena
0.2% AEP	Rainfall-dominant	0.2% AEP	1% AEP	~1% (>=0.2%) AEP
0.2% AEP	Tide-dominant	1% AEP	0.2% AEP	~0.2% (>=0.2%) AEP
1% AEP	Rainfall-dominant	1% AEP	5% AEP	~5% (>=1%) AEP
1% AEP	Tide-dominant	5% AEP	1% AEP	~1% (>=1%) AEP
2% AEP	Rainfall-dominant	2% AEP	5% AEP	~5% (>=2%) AEP
2% AEP	Tide-dominant	5% AEP	2% AEP	~2% (>=2%) AEP
5% AEP	Rainfall-dominant	5% AEP	39.4% AEP	~39.4% (>=5%) AEP
5% AEP	Tide-dominant	39.4% AEP	5% AEP	~5% (>=5%) AEP
10% AEP	Rainfall-dominant	10% AEP	39.4% AEP	~39.4% (>=5%) AEP
10% AEP	Tide-dominant	39.4% AEP	10% AEP	~10% (>=10%) AEP

References: BOPRC, KCDC and TCC guidance.

5.3.9 Climate change

The impacts of climate change are already being felt across New Zealand. Stormwater infrastructure and services are under increasing pressure and risk. Ministry for the Environment (2018)[5] predict the following

[5] Based on Ministry for the Environment 2018. Climate Change Projections for New Zealand: Atmosphere Projections Based on Simulations from the IPCC Fifth Assessment, 2nd Edition. Wellington: Ministry for the Environment.

- More extreme rainfall including more intense events, changes to average rainfall, groundwater and soil moisture
- Increased river and surface flooding
- Landslips including soil erosion and instability
- Increased storminess and strong winds
- Progressive increases in mean temperature everywhere, including air and ground temperature and more hot days and fewer frosts
- Increased fog and humidity
- Increase in severity and frequency of drought
- Wildfire
- Mean sea level increases including coastal flooding and storm surge
- Coastal erosion

Surface flooding, from more intense and frequent rain events, and coastal flooding, associated with sea level rise, are the biggest risks identified to urban stormwater assets and services.

Allowances for climate change in stormwater modelling should consider current national, regional and local guidelines / policies.

The Ministry for the Environment (MfE) publishes guidance on climate change projections. This section provides a summary of their current national guidance for ease of reference. This guidance will change over time. As this guide was developed, MfE were in the process of updating guidance in response to climate change. It is advised to check recent MfE publications for the most up to date versions. A summary of current (2023) guidance is provided in Appendix D.

Guidance currently available in Aotearoa-New Zealand is described below:

5.3.9.1 Rainfall

The intensity and frequency of significant rainfall events are expected to be impacted by the effects of climate change. Future climate change scenario rainfall depth estimates are generated by:

- Using the planning horizon to determine the future climate change horizon.
- Determining the temperature increase for the applicable climate change scenario (SSP/RCP) and future climate change horizon.
- Accounting for changes in design rainfall depths/intensities by:
    - Using outcomes from specific regional studies if available.
    - Scaling rainfall by the augmentation factors provided in the report that accompanies HIRDS v4 (NIWA, 2018).
    - Using HIRDS climate change rainfall depths / intensities (https://hirds.niwa.co.nz/) corresponding to temperature increase estimates from the appropriate RCP scenario and climate horizon.

5.3.9.2 Tide

Future climate change scenario tide estimates are generated by shifting baseline tide estimates vertically. Where regional studies have not been undertaken, augmentation factors from the NZSeaRise programme tool (Takiwa) can be used (https://www.searise.nz/). This tool allows users to investigate expectations of sea level rise at locations, with a spacing of less than 2 km, around the entire Aotearoa coastline for a range of SSPs. Local or regional guidance may also be available to inform tide level selection for modelling purposes.

It is recommended that Vertical Land Movement (VLM) is **not** used to shift tidal levels in the same way as SLR is to reduce the potential confusion for comparative modelling applications. VLM should be applied to the model geometry. If it is applied to boundary condition then very clear documentation and naming must be used.

References = MFE guidance (individually referenced), BOPRC and TCC.

5.3.10 Residual Risk

Residual risk is the risk that is still present in areas when the design level of service is being met by the primary and secondary stormwater management system. It should be considered where there are potentially significant consequences because of stormwater management system failure. This risk is present due to the following.

- Events occur that are of a greater magnitude than the design level of service (such as very rare rainfall events).
- Primary systems can fail (such as blockage, pipe collapse or bridge collapse).
- Secondary systems can fail (such as poor land development control or unconsented works obstructing overland flow paths).
- Flood storage areas and defence structures can fail via blockage, structural collapse, or overtopping.

The above failure modes should only be considered if relevant and present with the study area. The model can then be used to test the impacts of various failure modes. Common model scenarios used to test these failure modes include the following.

- **All types of study area.** Very rare events such as 0.5% or 0.1% AEP event with current and future climate effects and / or failure of primary / secondary systems
- **Primary stormwater networks that rely on a combination of piped and open channel systems.** Assess blockage risk for key inlet structures and run appropriate blockage scenarios (Refer Table 5-3)
- **Linear flood defences (such as stopbanks or retaining walls).** Complete defence breach runs to assess the flood extents and hazard of linear defence failure using the 1% AEP rainfall event. The locations of the breaches should be determined based on an assessment of locations likely to be vulnerable to breach and / or those with potentially high impact (Refer Table 5-3).

- **Flood storage areas.** Remove hydraulic controls from the hydraulic model, then run maximum design event (including climate change) and confirm that emergency overflow structures behave as intended.

Source = NRC (Beca, 2022)

5.3.11 Sensitivity Analysis

Sensitivity analysis in hydraulic modelling is an evaluation of how changes in input parameters or assumptions affect the model's outputs or results. Sensitivity analysis is crucial in hydraulic modelling projects for:

- Identifying influential parameters or input variables.
- Assessing model robustness by assessing how changes in parameters affect model outputs.
- Improving model reliability by understanding the sensitivity of a hydraulic model, informed decisions about the model's limitations and accuracy can be made.
- Addressing uncertainty by quantifying the effects of variability in input data and model parameters.
- Enhancing decision-making by providing insights into the potential consequences of variations in key parameters, aiding in risk assessment and management.
- Guiding data collection efforts by focusing on parameters that have the most significant impact on model results.
- Communicating the uncertainties and limitations of the hydraulic model to stakeholders. his transparency fosters trust and facilitates more effective collaboration among project teams, regulatory bodies, and the community.

In an urban flood modelling context, the most common parameters that impact flood predictions include boundary conditions, initial conditions, continuing losses, roughness, and eddy viscosity (for 2D models). Section 4.7.4 provides an overview and examples of parameter sensitivity.

5.4 Outputs

The outputs generated by the model should be clearly linked to the project purpose and success criteria set during the planning stage (Refer Sections 2.2 and 3.2). These will commonly be GIS data, maps, graphs and tables. Further guidance on key output data types is provided in Sections 5.4.1 (depth and level), 5.4.2 (flood extents), 5.4.3 (hazard) and 5.4.5 (levels of service). Section 6.5 provides guidance on open-source GIS data formats to enable data sharing. Section 5.4.4 provides further guidance on flood risk or hazard mapping.

5.4.1 Levels and Depths

It is essential to consider the following when producing level and depth outputs from a model.

- Level datum – Specified in model reporting, mapping and or metadata.

- Depths – Specified as original (unedited model output) or post-processed (such as removing minimum flood depths or small flood areas - similar to the process described for flood extents in Section 5.4.2).

5.4.2 Flood Extent

Flood extent is based on an envelope of selected flood depths across the study area. They can be created from a combination of event durations that lead to the maximum extent of flooding or a single event. Flood extents can also be post-processed to reduce 'noise' in the mapping and make them easier to interpret. Common post-processing methods include some or all the following:

- Extents only show flood depths greater than or equal to a set minimum depth: 50 mm or 100 mm are often used as a cutoff.
- Removal of 'holes' and 'islands' from the extent that are less than a set minimum area: 100 m^2 is often used as a cutoff.
- Review extents and join 'islands' greater than a set area with larger parts of the main flood extent if appropriate.
- Remove extents that are isolated from public land.

5.4.3 Flood Hazard

The definition of 'Flood Hazard' varies locally and internationally. Various definitions include depth (D), extent, velocity (V), Depth (D) x Velocity magnitude (V), and various classification functions of D and V. Councils in New Zealand generally apply the D x V approach to people and vehicle safety. The formulation of flood hazard should be specified by the commissioning organisation or discussed and agreed prior to generation of model outputs. Flood hazard can be defined using locally specified approaches and applications. The formulation used by the selected modelling software package should be checked prior to generating hazard outputs (as the packages often use different default formulations for hazard).

If no local guidance is available, the 2019 Australian Rainfall Runoff (ARR) guidelines recommends a formulation, developed by the Australian Emergency Management Institute (AEMI), that can be applied to people, vehicles and buildings. The AEMI method uses the D and V variables, commonly used in NZ. It then refines the outputs by providing six bands for interpreting potential impacts (ARR Book 6 - Figure 6.7.9, Tables 6.7.3 and 6.7.4) as detailed below and shown in Figure 5-1. Flood hazard can be displayed as the raw D x V values or the hazard classes *H1* - *H6*. Displaying the classes is preferred as they are easier to interpret by non-technical end users.

- **H1**: Generally safe for people, vehicles and buildings
- **H2**: Unsafe for small vehicles
- **H3**: Unsafe for vehicles, children and the elderly
- **H4**: Unsafe for vehicles and people
- **H5**: Unsafe for vehicles and people. All buildings vulnerable to structural damage. Some less robust buildings subject to failure
- **H6**: Unsafe for vehicles and people. All building types considered vulnerable to failure

Figure 5-1: Combined Flood Hazard Curve (Source – ARR, 2019)

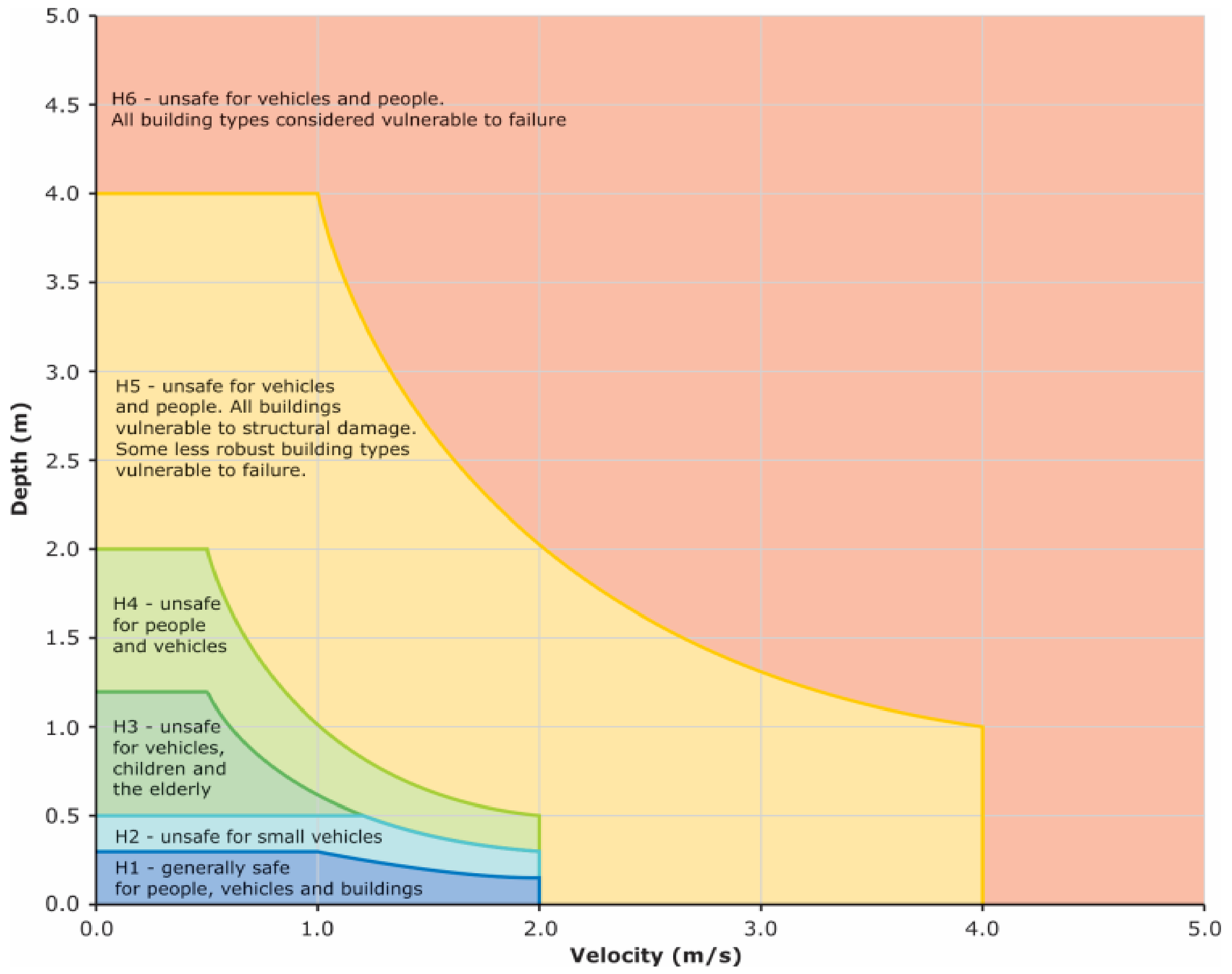


Figure 6.7.9. Combined Flood Hazard Curves (Smith et al., 2014)

5.4.4 Mapping

Mapping of flood model outputs is used to communicate the outcomes of the modelling exercise. This section provides a summary of common approaches to mapping and good practice examples of online GIS Portals. There are numerous approaches to mapping including (but not limited to):

- **Hard copy maps** are generally used for in-person discussions, meetings and / or consultation activities
- **Digital static maps**, such as PDF format or images if included within reporting. PDFs can be enhanced by using GeoPDF or Geospatial PDF functionality that allows the user to turn on and off layers or use PDFs within GIS software. These provide a robust record of work scope and deliverables.
- **Online GIS Portals** – These are generally read only, interactive online GIS tools hosted by local or central government organisations. They can provide easy to use mapping for non-technical end users and advanced functionality for technical users. These portals require ongoing maintenance and can fail over time as technology becomes outdated. Good practice examples for sharing flood risk information include:

- Auckland Council - GeoMaps (generally for technical end users) and Flood Viewer (for non-technical end users)
- Hamilton City Council - Floodviewer
- Greater Wellington Regional Council – Flood hazard extents
- Otago Regional Council – Natural Hazards Portal
- Queenstown Lakes District Council – Wānaka Stormwater Flood Map

All these methods of publication share common good practice map production techniques. These are summarised in Table 5-6. It is recommended that these techniques are applied when producing any type of flood mapping. A key underlying principle is that any map should be created with the end user in mind and show information in way that is easily interpreted by them.

Table 5-6: Good practice map production

Good practice	Applicable to map types		
	Hard copy	Digital Static	Online Portal
North arrow	X	X	X
Legend	X	X	X
Scale (bar or numeric)	X	X	X
Copyright text	X	X	X
Location information (such as street and / or suburb names)	X	X	X
Topographic information (such as names of topographic features and watercourse names)	X	X	X
Disclaimer text and / or links to further information describing limitations, assumptions and intended uses	X	X	X
Background or base mapping – selected to suit scale, type and intended use of displayed flood data (for example, if flood data is not intended to determine flood risk at an individual property scale, then base mapping should not include property addresses or land parcel boundaries)	X	X	X
Flood depth (or depth difference for result comparison) colour palette selected to ensure it is easy to visually discern between different depths	X	X	X
Symbology clearly shows outputs in contrast to selected background mapping	X	X	X
Symbology across multiple layers that are likely used together or for comparison is selected to allow clear contrast between layers	X	X	X
Size and scale of map allows reader to see and interpret relevant details	X	X	
Enable user specified transparency on individual layers			X
Provide layer based links to further information			X
Velocity vectors scaled to be proportionate to magnitude of velocity being displayed	X	X	X
Address search functionality			X
User selectable base maps with a range of options available			X

Good practice	Applicable to map types		
	Hard copy	Digital Static	Online Portal
User selectable layer on / off functionality		X	X
Pre-set zoom level visibility for specific layers (for example, setting certain flood information layers to only be visible at the scale they were intended to be used at)			X

5.4.5 Levels of service

Refer Section 5.5 – System Performance.

5.4.6 Other Outputs

A list of less common outputs is provided below along with a short explanation of when they can be useful:

- **Afflux plots / depth difference maps** are commonly used to show the change in flood depth because of climate change, change in landform or change in network structure or operation. The scale and symbology used to show the change should be carefully considered to allow easy interpretation of results.
- **Flood contours** show spatially varying flood depth in a different way to a raster-based flood depth map. Some end users find this format easier to interpret.
- **Time to inundation** provides a spatial or graphical representation of the time it takes for a pre-set flood depth or a maximum flood depth to be reached. Urban catchments tend to have short times of concentration (less than 2hrs), which makes this output less useful than for larger mixed catchments that have longer times of concentration (more than 2hrs up to several days).
- **Flood affected parcels and / or building footprints** may be used to assess and / or map:
    - flood impacts and / or damages.
    - identify landowners to be notified of potential risks.
- **Animations** can be used to show complex flood mechanisms or engage with non-technical groups to show flood propagation over time.

References: Melbourne Water, ARR 2019

5.5 System Performance

The purpose of a system performance assessment is to identify if the stormwater system meets its expected level of service during target rainfall events now and in the future. Level of service outputs for primary systems can be used to show whether a specific asset class is performing to the target level of service currently or under future climate or development conditions. The asset classes and parameters assessed for urban stormwater quantity management purposes generally include:

- Stormwater pipes (capacity)
    - Percentage of pipe full capacity (based on pipe size, gradient and material).
    - Surcharged / not surcharged (above pipe soffit and / or ground level overflow)

    - Set percentage of pipe full capacity.
    - Constrained by downstream water level / capacity.
    - Range of AEP events able to be conveyed without surcharge.
- Stormwater manholes (surcharge)
- Urban watercourses (overtopping)
- Bridges (overtopping)
- Culverts (overtopping)
- Flood storage areas (overtopping or activation of emergency discharge points)

The desired level of service for these types of primary stormwater system assets is usually set in terms of a specific rainfall event – such as 10% AEP plus climate change allowance for pipe networks in many areas. They can also vary by asset class – critical bridges and culverts may have a higher level of service than the stormwater network. These are generally defined in local or regional codes of practice, engineering or infrastructure standards.

Level of service outputs for secondary system can be used to assess whether targets around flood risk to habitable floors and / or infrastructure are being met currently or under future climate or development conditions. Similar to primary systems, level of service targets for secondary systems are generally defined in local and regional codes of practice, engineering standards or through district or regional plans. They can cover:

- Overland flow paths (no. of buildings / properties / infrastructure locations intersecting).
- Flood plains (no. of buildings / properties / infrastructure locations intersecting without appropriate freeboard allowances).

Common applications of level of service assessments include:

- Stormwater catchment planning – Determining where in the stormwater network has capacity now and which areas are likely to require upgrade under future climate and or development conditions.
- Flood risk assessment and management – To identify property and infrastructure at risk of flooding and the associated impacts (including flood damages and social, cultural, environmental or economic impacts).
- Land development planning – Showing that a proposed stormwater network or modifications to topography can achieve the required design level of service.
- Asset renewal or maintenance prioritisation – Showing which parts of the stormwater network are under capacity and would benefit from investment.

References = CCC.

5.6 Quality Assurance - Use

Internal, compliance and peer reviews are scheduled during the Plan phase of a modelling project (refer to Section 2.5 - Quality Assurance - Plan) and are implemented in the Build phase (refer to Section 4.5 -

Quality Assurance – Build) and Use phase of the modelling project. During the Use phase, a model should be reviewed for the following reasons:

- Ensure that the model outputs are accurate and reliable for the purpose of the model.
- Provide additional experience to incorporate advancements in technology and modelling techniques to enhance the quality and production efficiency of model outputs.
- Ensure that the model aligns with the latest regulatory requirements and standards.
- Identify and mitigate potential risks, to ensure that the model provides accurate information for decision making.
- Build stakeholder trust and confidence in the model's predictions and recommendations.

Compliance review checks during this phase ensure alignment with modelling specifications developed for the specific needs the commissioning organisation for the purposes of providing consistency and reliability of model outputs. Review templates from software platform developers may be referred to for examples of checks to be carried out in reviews. Other examples of compliance review templates include (and are available from):

- Wellington Water – available on request
- Greater Wellington Regional Council (2021) – accompanying their published modelling guidance
- Auckland Council - available on request

References: TCC (2022), HCC (2017), NRC (2022), GWRC (2021), WWL (2022), Auckland Council Model Review Template_v1.0.xlsm

6 SHARE

6.1 Metadata

Metadata is data that describes other data. It is structured reference and attribute data of the information it describes. For stormwater models and their results, metadata provides essential information on the source, context, accuracy, and usability of model and result datasets. High quality metadata that includes data ownership, key assumptions & limitations and confidence levels enables replicability, transparency and easy sharing of stormwater models and results.

A metadata standard for stormwater models and associated result data is provided in Appendix A of this guide. The data structure is provided in MS Excel formats that can be easily converted to other formats to enable wide accessibility and application as good practice in the industry.

The standard was developed in consultation with key industry stakeholders including NIWA, EQC, LINZ, MfE and Kāinga Ora. Background research also included review of approaches already applied by some councils to support online mapping tools (such as Auckland Council GeoMaps and Hamilton City Council FloodViewer).

6.2 Intellectual Property

It is important that the Intellectual Property Rights (IPR) for any data collected explicitly for a model (or generated by a model) are held by the entity commissioning the work, and not retained by entity delivering the model build (if they are a separate legal entity to the commissioning body). This requirement should be included within any contract. This includes:

- Background GIS data (such as pipe network data, LiDAR and other operational data).
- Survey data (CCTV, asset investigations, topographic and site observations).
- Flow or rainfall monitoring data.
- Models and associated outputs.
- Reporting and mapping.

Where data is provided by third parties for use in a model, appropriate licensing agreements should be in place to ensure that use of the data does not affect future use of the model. If this is not possible the costs and benefits of collecting new data, rather than using third-party data, should be assessed.

6.3 Sharing Models

Models should only be shared under license (refer Section 6.4). Shared models should be supported by the following information:

- Model build report and log (refer Section 4)
- Model and result metadata (refer Appendix A1)
- Details of data flagging system adopted (if applicable)
- Details of any modifications or scenario changes since the model build report was written.

6.4 Data Licensing

6.4.1 Model Build

Data licensing agreements should be in place for all datasets used within a modelling study. This should include site surveys, the digital terrain model, hydrometric data and all model outputs.

6.4.2 OpenData

Some output data may be suitable (refer Section 6.4.3 on restricted use data) for sharing on an OpenData platform. Good practice examples of these include:

- Auckland Council - https://data-aucklandcouncil.opendata.arcgis.com/
- Wellington Water - https://data-wellingtonwater.opendata.arcgis.com/
- Northland Regional Council - https://data-nrcgis.opendata.arcgis.com/
- New Zealand Government - https://www.data.govt.nz/

OpenData platforms generally use national or international open data licensing agreements such as:

- Creative Commons Attribution 4.0 International License - https://creativecommons.org/licenses/by/4.0/legalcode
- Aotearoa-NZ Government Open Access and Licensing framework (NZGOAL) - https://www.data.govt.nz/toolkit/policies/nzgoal/

Before publishing OpenData is essential to ensure that the dataset:

- Does not include private information about individuals (it is non-personal, unclassified and non-confidential).
- Has been approved by the commissioning organisation for public release.
- Is not derived from restricted use input dataset that can be reverse engineered from the published data.
- Can be freely used, reused and redistributed by other agencies and the public.
- Is supported by a metadata set that clearly shows the origins, limitations & assumptions and levels of confidence (Refer Section 6.1 and Appendix A1).

Further guidance on OpenData is available from the Open Data Handbook.

6.4.3 Restricted Use

Model commissioning entities can share data for restricted use with other parties under a restricted use agreement. The most common examples of this are where councils:

- Grant use of network planning models for use by land developers or their consultants to assess the impacts of development.
- Share detailed model results to inform land development (where only simplified or lower resolution results are publicly available).
- Share existing models created by a third party with their consultants for strategic or network planning purposes.

This type of sharing is governed by a data license agreement or end user license agreement. These must be created with appropriate legal advice specific to the type of sharing and nature of data being shared. Examples of these agreements include:

- NIWA CliFlo End User License Agreement - https://cliflo.niwa.co.nz/doc/terms.html
- LINZ Data License Agreement for National DVR Data - https://data.linz.govt.nz/license/linz-agreement-national-dvr-data/

6.5 GIS Data Formats

Stormwater modelling software often generates output data in proprietary formats that can only be read by the software itself or other licensed software packages. The model should remain in the software package it was built in to remain usable, but the output data can usually be converted to open source data formats. Table 6-1 provides a summary of common open source data formats that can be used to share model output data. Further information on model output types is provided in Section 5.4.

Table 6-1: Common open source output data formats

Output Type	Vector	Raster	Timeseries
2D - Flood Depth / Level	Point - Geodatabase / shapefile	ASCII / GeoTIFF / TIFF	XMDF (eXtensible Model Data Format) / DFS2
2D - Flood Extent	Polygon - Geodatabase / shapefile	ASCII / GeoTIFF / TIFF	XMDF (eXtensible Model Data Format) / DFS2
2D - Flood Velocity (magnitude & direction)	Points - Geodatabase / shapefile	ASCII / GeoTIFF / TIFF (magnitude only)	XMDF (eXtensible Model Data Format) / DFS2
2D - Flood Hazard (Depth x Velocity)	Point - Geodatabase / shapefile	ASCII / GeoTIFF / TIFF	XMDF (eXtensible Model Data Format) / DFS2
1D - Pipe Flow	Line (pipe) - Geodatabase / shapefile (maxima or single timestamp only)	N/A	Attributed by pipe unique id - Excel / CSV
1D - Pipe Velocity	Line (pipe) - Geodatabase / shapefile (maxima or single timestamp only)	N/A	Attributed by pipe unique id - Excel / CSV
1D – Open channel flow (average)	Line (cross-section) - Geodatabase / shapefile (maxima or single timestamp only)	N/A	Attributed by cross-section unique id - Excel / CSV
1D – Open channel velocity (average)	Line (cross-section) - Geodatabase / shapefile (maxima or single timestamp only)	N/A	Attributed by cross-section unique id - Excel / CSV

7 MAINTAIN

7.1 Model Archiving

It is encouraged to consider how the resulting model and outputs will be stored or archived before modelling work is undertaken and that requirements and allowance for this is incorporated into the scoping stage.

7.1.1 Folder structure

A consistent and disciplined approach to folder structure for base and project models enables efficient model updates, use, sharing and peer review. Table 7-1 provides a recommended structure for archiving a base model. Key files are listed and their folder location specified. Different software packages will require slight modifications to the way model files are stored depending on the way scenarios are represented. All log files generated by the simulation engine should be archived alongside the model files.

Table 7-1: Folder structure example for base model archiving

Folders		Key Files	Notes
Top Level	**Second Level**		
Documentation	Build report	• Original model build report. • Other legacy build reports. • Model build or update report.	The goal is to have new and legacy reporting all included to ensure history can be understood if required.
	Archive Forms	• Legacy base model archive forms. Latest base model archive form.	Based on information from latest reporting
	Change log	• Legacy base model change logs. • Latest base model change log.	Enhancements and fixes contained within this new version. Historical logs for reference purposes.
	Communications	• Related memos, reporting and communications.	
Input Data	Buildings	• Building footprints and levels.	Any new data for this version only, not historical versions.
	Recorded data	• Any gauging information, rain radar, flood incident reports, etc used for calibration/ validation/ verification.	Any new data for this version only, not historical versions.
	Network	• Stormwater network asset information.	Any new data for this version only, not historical versions.
	Survey and as-built	• Raw survey As-built information.	Any new data for this version only, not historical versions.
	Terrain	• New DEM • Specific terrain updates such as around structures.	Any new data for this version only, not historical versions. There is no need to include base layers such as the main LiDAR used as these can be sourced directly from the council.
Models	HE-YYYYMM	• Upper catchment hydrological model.	Historical Event (HE) used for model. calibration/validation/verification. Create multiple folders at this

Folders		Key Files	Notes
Top Level	**Second Level**		
		• Hydrological model (if separate to hydraulic model software). • Hydraulic model control files (.couple, .tcf, .icmt, .prj). • 1D model files. • 2D model files. • Results.	second level when more than one event exists.
	ED-YYYY	• Upper catchment hydrological model. • Hydrological model (if separate to hydraulic model software). • Hydraulic model control file (.couple, .tcf, .icmt, .prj). • 1D model files. • 2D model files. • Results.	Existing Development network and land use.
	DEV-YYYY	• Files required to update the ED scenario, or a new folder with model files as above.	Development model (optional). E.g. consented development.
	MPD	• Files required to update the ED scenario, or a new folder with model files as above.	Maximum probable development layers (files to convert the ED model to MPD).
	Timeseries	• Rainfall. • Water level. • Discharge.	All timeseries files for the base model are to be referenced from the relevant model folder to this folder, rather than being repeated within a model folder. This is to make updating and administration easier. Any inter-model exchange flow timeseries are in the Discharge folder.

Project models have less stringent requirements for data archiving and should be considered on a project-by-project basis. Some principles to support this decision making are:

- The base model used for the project should be referenced in documentation.
- Input data relevant to the project such as survey data, as-builts, new design surfaces, etc should be stored in relevant folders.
- Adapt the requirements of base model archiving outlined in Table 7-1 above for different project simulations.
- Not every simulation must be archived but those important to the scope and outcome of the project will need to be.
- Store all data required to repeat the model simulation (except time series data which is stored centrally) or store only model update files in a unique folder.
- Only results files for critical simulations should be stored.

The approach presented here will result in duplication of some, often large, files. However, the benefits of clarity in model file interconnections and layout, and ease of separation of model simulations outweigh the disbenefit the additional storage required.

7.1.2 Archiving metadata and logs

Key headline information about a modelling study serves to help ensure the right types of data is being stored and provides metadata for searching of records by future users of the model. Refer to Section 6 for considerations related to sharing model information with other parties and requirements for metadata. Key attributes when archiving a base model are as follows.

- Model name
- Previous base model version
- Completion data
- Model purpose
- Model owner and contact information
- Model type
- Records of model review
- Descriptive summary
- Location
- Software
- Coordinate system
- Vertical datum

Further details on recommended metadata items for both models and individual scenarios can be found in Appendix A. Key attributes when archiving a project model and scenarios include those for a base model but may also include the following.

- Version of base model used in the project.
- Summary of project objectives and outcomes.
- Development scenario (ED, CD, MPD, hybrid).
- Summary of boundary conditions applied including joint probability design event configuration, and climate horizon(s) considered.
- Log of recommended changes to the base model based on new information and learnings from the project.
- Summary of:
    - model results included;
    - documentation included;
    - project model simulation log included; and
    - any spatial data included.

7.2 Model Updates

Through effective model archiving including the capture of important information about the model, the model owner can gain an understanding of their model asset and its applicability for future use. A log of issues or enhancements identified during a base model update or when using project models can be collated. Where model limitations were identified and additional data must be collected, this can be scheduled in an organised way to be available for inclusion in future applications of the model.

Base model updates can then be planned when budgets, new data, modeller availability and planning needs align, leading to more efficient and consistent model updates. Reliable base models also help to ensure project models use up-to-date information and can also be developed efficiently. For example, an infrastructure layout from a development impact assessment can more efficiently be included into a base model from a project model once built.

Examples of ways to improve efficiency of model updates and enhance consistency and reliability include the following items.

- Creation of region-wide base layers or boundary conditions. For example, region wide boundary condition timeseries, hydrological parameters, or hydraulic parameters.
- Consistent model management.
- Consistent model archiving with appropriate metadata.
- Capture data from project models.
- Knowledge sharing between consultants and council staff.
- Modelling specifications for locally specific needs.
- Compliance review to ensure adherence to guidelines, specifications and overall model purpose.
- Peer review of modelling methodology.
- Capture issues and potential enhancements identified using project models to inform updates to base models.
- Regular scheduling of data collection depending on budget allocation. For example, LiDAR, aerial photography, impervious surfaces, and primary network survey where missing data exists, gauged data, and flood incident data and flood-level survey following storm events.

References = TCC

8 WORKFLOW EXAMPLE

The following worked example is brief and is intended to demonstrate how different elements of the guide may be applied. It shows how the reader may go about formulating answers and approaches that align with the guide recommendations but does not provide specific details for a particular application. This workflow example is in no way intended to be an exemplar or indicate a minimum standard. The subsections correspond to sections in the guide. In a real-world project, the structure of documentation should suit the application.

8.1 Project planning

The purpose of the project is to assess the effects of developing a ten-lot subdivision within the jurisdiction of a local authority that has well-defined standards. One aspect of this process is to assess the impacts of the development on stormwater runoff entering the receiving environment and the surrounding area for existing and future climate scenarios. The following are considered.

- ***Who are the stakeholders?*** Client requesting the assessment and the consenting authorities.
- ***Is a model required?*** Yes. Numerical modelling of complex stormwater interactions is a suitable and accepted means of assessing the impacts of such a development where there are changes in land use (urban intensification) and assessment of the effects of climate change is necessary. Models can simplify the analysis and presentation of results.
- ***What must the model represent?*** The development site, the immediate surrounding area, inflows to the site (if any), and the downstream catchment of the proposed development, both before (pre) and after (post) the construction of the proposed development. The model must be able to determine changes in flood level.
- ***What outputs are required?*** Timeseries of runoff from the development and maps of peak water depth, peak water level, and peak hazard (depth x velocity magnitude, DxV) for both the existing climate and the climate of the 100 year design horizon. The types of output required are specified by the local authority.
- ***What is the required accuracy of the results?*** The absolute values generated by the model do not have to be very accurate, but the differences in the result outputs between scenarios of interest must be accurate. The level of accuracy for flood depth / water level may be +/- 200 mm, but the model must distinguish differences greater than +/- 5 mm.
- ***Are relevant studies available?*** Local authority flood maps are available and indicate that an existing flow path runs along the western boundary of the subdivision.
- ***What degree of quality assurance is required?*** A low level of quality assurance is required. as the model is small and relatively simple. A single internal review (allowing for checking of revisions) by a senior professional before work is provided to the consenting authorities will be sufficient.

The purpose of the model is: **to generate sound estimates of the impact of the development on the receiving environment in terms of water depth, water level, and flood hazard in both the**

existing and future climates. In order to fulfil this purpose, the following seven objectives have been decided.

1. Realistically represent and accurately resolve the pre-development runoff response of the development site for the 10% AEP and 1% AEP storm events.
2. Realistically represent and accurately resolve the post-development runoff response of the development site for the 10% AEP and 1% AEP storm events.
3. Realistically represent and accurately resolve the pre-development flood hazard (water depth and DxV) in and around the development for the 10% AEP and 1% AEP storm events.
4. Realistically represent and accurately resolve the post-development flood hazard (water depth and DxV) in and around the development for the 10% AEP and 1% AEP storm events.
5. Use consistent modelling techniques for pre- and post-development scenarios so that the effects of model artifacts are minimised, allowing for clear determination of changes in runoff due to the development.
6. Simulate the effects of the development for a 100-year design horizon.

8.2 Model planning

8.2.1 Purpose

The purpose of the model has been defined in the project planning stage. Success criteria corresponding to each of the objectives are presented in Table 10-1.

Table 10-1: Model purpose, objectives and success criteria.

Purpose	Objective	Success criteria
Generate sound estimates of the impact of the development on the receiving environment in terms of water depth, water level, and flood hazard in both the existing and future climates.	Realistically represent and accurately resolve the pre-development runoff response of the development site for the 10% AEP and 1% AEP storm events.	Internal reviewer confirms that the rainfall-runoff model is built to the standard recommended by the local authority.
		Peak flow and volume runoff estimates generated by the model for the pre-development scenario are within 20% of the estimates generated by another model type.
		Simulation results are smooth and stable.
	Realistically represent and accurately resolve the post-development runoff response of the development site for the 10% AEP and 1% AEP storm events.	Updates to the pre-development rainfall-runoff model are consistent with the standard recommended by the local authority.
		Peak flow and volume runoff estimates generated by the model for the post-development scenario are within 20% of the estimates generated by another model type.
		Changes in peak flow and volume runoff estimates align with expectations.
	Realistically represent and accurately resolve the pre-	Internal reviewer confirms that the hydraulic model is built to the

Purpose	Objective	Success criteria
	development flood hazard (water depth and DxV) in and around the development for the 10% AEP and 1% AEP storm events.	standard recommended by the local authority.
		Does halving the computational grid resolution (coarsening) changes peak water depth, water level, and flood hazard by less than 10%.
		All obstacles to flow with horizontal dimensions greater than the computational grid are explicitly represented. Other obstacles are accounted for by roughness.
		Simulation instabilities do not interfere with the estimation of peak quantities.
	Realistically represent and accurately resolve the post-development flood hazard (water depth and DxV) in and around the development for the 10% AEP and 1% AEP storm events.	Updates to the pre-development hydraulic model are consistent with the standard recommended by the local authority.
		Halving the computational grid resolution (coarsening) changes peak water depth, water level, and flood hazard by less than 10%.
		Changes in peak water depth, water level and flood hazard estimates align with expectations.
	Use consistent modelling techniques for pre- and post-development scenarios so that the effects of model artifacts are minimised, allowing for clear determination of changes in runoff due to the development.	The extent of the hydraulic model domain covers all flow paths and ponding areas that are significant for the study area.
		Boundaries and associated conditions are applied identically in all scenarios.
		Runoff from the development site is represented by a lumped hydrological model for both pre- and post-development scenarios.
	Simulate the effects of the development for a 100-year design horizon.	Internal reviewer confirms that the existing and future scenario boundary conditions align with the standard recommended by the local authority for the 100 year horizon.

8.2.2 Relevant phenomena

The relevant phenomena identified for this site include:

1. Flow from upstream catchment area.
2. Runoff generation at the development site and in the surrounding area.
3. Penetrable flow path obstacles including new planting, existing vegetation and fences.
4. Impenetrable flow path obstacles including buildings and walls.
5. Open channel flow in kerb gutters and streams.
6. Overland flow across sealed, grasses and vegetated surfaces.

8.2.3 Preliminary schematisation

Preliminary schematisation of the model includes:

1. An approximate model boundary.
2. The location where the upstream flow path enters the model domain.
3. The location where flow leaves the domain.
4. The route that the majority of flow follows.
5. Identification of obstacles along central flow paths.
6. Locations where ponding may occur.

8.2.4 Model approach and methodology

The "Integrated (Dynamic/complex)" model type has been selected for this application as there is a need to represent flow paths and ponding on the floodplain. The relevant suggested modelling approaches for this category of model include:

1. 2D hydraulics for the floodplain and small open channel using averaged parameters informed by land cover estimates. Roughness parameters will be taken directly from literature or local authority guidance. Estimates of flood plain hydraulics will be verified against other sources even if validation event simulation results are not available.
2. 1D hydraulics for pipe network where geometry will be taken from council asset records and roughness parameters are assigned based on material information.
3. Lumped hydrological models for all rainfall-runoff estimates within the development. Averaged estimates are sufficient for the upstream catchment, but local subcatchments will be parameterised based on area-weighting of land cover estimates digitised from aerial photography.

8.2.5 Detailed schematisation

Formal reporting of the schematisation for this project is limited to a map of the model boundary extent including important features and bullet points explaining the approach used for each of the following components in the model.

1. 2D overland flow surface representation including extent, location of boundaries, land use zones assigned particular parameter sets (infiltration, roughness, etc.), modelled obstacles (buildings, fences, walls, etc.), conveyance channels, and significant locations where the flow regime changes (inlets, weirs and other structures).
2. 1D representation of pipes (and optionally open channels), including hydraulic loss parameter sets, and descriptions of important structures.

8.2.6 Schedule of simulations

The schedule of simulations comprises the following.

1. Simulation 1: Pre-development, existing climate, 10% AEP rainfall event.
2. Simulation 2: Pre-development, existing climate, 1% AEP rainfall event.
3. Simulation 3: Pre-development, 100 year-design-horizon climate, 10% AEP rainfall event.

4. Simulation 4: Pre-development, 100 year-design-horizon climate, 1% AEP rainfall event.
5. Simulation 5: Post-development, existing climate, 10% AEP rainfall event.
6. Simulation 6: Post-development, existing climate, 1% AEP rainfall event.
7. Simulation 7: Post-development, 100 year-design-horizon climate, 10% AEP rainfall event.
8. Simulation 8: Post-development, 100 year-design-horizon climate, 1% AEP rainfall event.

8.2.7 Modelling software

The choice of modelling software is based on the following criteria in order of diminishing priority.

1. The software can represent the resolution of the significant elements in the domain. For example, channel cross-section variation and conveyance, and overland flow obstacles.
2. The software produces stable outputs.
3. The simulation runtime is manageable (a scenario can run overnight < 12 hr).
4. The modeller is familiar with the software.

8.2.8 Model management

As this model will not be used by third parties, besides interrogation by internal and external reviewers, long-term maintenance is not a priority. All model data will be stored in a single folder with all results in default output locations so that someone familiar with the software can find them. Relative file paths within the model structure will be used to link files together. Versioning of the models is implemented at a model folder level (suffix of "_v0", "_v1", etc.) so that files within do not change names between versions. Only final versions of model files will be retained. The model will be owned by the consultant as only the documentation provided to the local authority is specified as a deliverable in the contract.

8.2.9 Data collation and collection

Freely available data collected by the local authority has been reviewed. LiDAR and pipe network assets are available. It was found that survey is required in the local pipe network as inverts and pipe diameters are missing and details of a culvert directly downstream of the development are incomplete. Two channel cross sections must also be surveyed to represent local drainage conveyance.

8.3 Model build

The model is built in line with good practice techniques detailed in Section 4.

8.4 Model use

8.4.1.1 Configure the model

As the model is built for this specific purpose, no modifications will be made to the model, excluding of course, post-development updates.

8.4.1.2 Boundary conditions

The scenarios of interest are precisely prescribed by local authority requirements and so configuration of boundary conditions will simply follow guidance. Internal review of the rainfall and downstream outflow boundary configurations (accounting for joint probability) is necessary. Sensitivity analysis will not be carried out for this project as the risk of underestimating impacts of the development are small.

8.4.1.3 Outputs

The following derived outputs will be generated for use in assessing the impact of development.

1. Maps of peak water depth, water level, and flood hazard (DxV) for each simulation.
2. Maps of water level and flood hazard differences between pre- and post-development scenarios for the existing and future climate scenarios. Locations where the model has been modified in the post-development scenario will be clearly demarcated.
3. Timeseries plots of discharge directly downstream of the development site for all simulations.
4. Timeseries plots of water level directly upstream of the development site for all simulations.

8.5 Model maintenance

Maintenance of this model need not be considered as the life of this model extends only until the end of the resource consent application process. It will be sufficient to archive the model and associated documentation along with an archive form that includes metadata for the model and individual simulations (based on the recommended metadata standard provided in Appendix A).

8.6 Sharing the model

The model or results may be requested as part of a review process. To facilitate this the following approaches have been applied.

1. Naming convention. The model file names reflect the components of the simulation scenarios that they correspond to and include a suffix that captures the version of the model. Each set of results is named with the model that produced them with a suffix that includes the climate scenario, design storm return period, and the results type. All internal references have been removed.
2. A comprehensive archive form for the model and all scenarios is stored with the model.
3. Documentation of the model build is provided with the model.
4. The intellectual property rights of the data used in the model build are included in the archive form.

If a third party requests the use of this model in the future, a clear agreement will be required that limits the use of the model to the explicitly stated purpose.

9 GLOSSARY

Term / Abbreviation	Definition
AC	Auckland Council
Advisory Group / AG	Group of volunteers who supported the development of this report and associated guidance document
AMC	Antecedent Moisture Content
ARI	Average Recurrence Interval
AEP	Annual Exceedance Probability – expressed as a percentage
ARR	Australian Rainfall Runoff Guidelines
Base Model	Fully built and validated model that is ready to be used for a range of applications
BOPRC	Bay of Plenty Regional Council
CCC	Christchurch City Council
CIWEM	Chartered Institution of Water and Environmental Management
CoP	Code of Practice
DAPP	Dynamic Adaptive Policy Pathways
DCC	Dunedin City Council
Defra	Department for Environment, Food and Rural Affairs (United Kingdom)
DiA	Department of Internal Affairs
ES	Engineering Standards
FHM	Flood Hazard Mapping
GWRC	Greater Wellington Regional Council
Hard boundary	A boundary at the edge of the model domain where the boundary conditions directly set flow and/or water level values in the numerical solution.
HEC-RAS	Hydrologic Engineering Center's River Analysis System (modelling package developed by US Army Corps of Engineers)
KCDC	Kapiti Coast District Council
LoS	Level of Service

Term / Abbreviation	Definition
Metadata	Data that describes other data – structured reference data that helps sort and identify attributes of the information it describes. It makes data easier to find, use and re-use.
MfE	Ministry for the Environment
NIWA	National Institute of Water and Atmospheric Research
Primary System	The components of the urban stormwater system used to manage nuisance flooding (rainfall events of approx. 10% AEP or greater). Generally includes the stormwater pipe network, online flood management devices and urban open channels along with associated vehicle / foot bridges and culverts.
Q-H	Flow (Q) – Height (H) relationship
QUDM	Queensland Urban Drainage Manual
RCP	Representative Concentration Pathway
RFHA	Rapid Flood Hazard Assessment
RMA	Resource Management Act (1991)
RoFSW	Risk of Flooding from Surface Water (note that Stormwater = Surface Water in the UK)
SCS	United States Soil Conservation Service (recently re-named as the Natural Resources Conservation Service – NRCS)
Secondary System	These are the stormwater pathways that activate during rainfall events that exceed the design level of service for primary stormwater systems (generally between 10% and 1% AEP rainfall events). Generally includes above ground components including overland flow paths and flood plains.
SEPA	Scottish Environmental Protection Agency
SIG	Special Interest Group
Soft boundary	A location within the model domain, beyond which results are considered invalid, but are required in order to provide a realistic boundary condition for the valid regions of the model domain.
SSP	Shared Socio-economic Pathways
Storage area	The plan-view area of a wet surface, which is used to determine water level increments due to the addition or subtraction of water volume.

Term / Abbreviation	Definition
Surface Water	Stormwater (surface water is the term used for stormwater in the United Kingdom)
TCC	Tauranga City Council
URBS	Unified River Basin Simulator
USDCM	Urban Storm Drainage Criteria Manual
Water NZ	Water New Zealand
WBNM	Watershed Bounded Network Model
WRC	Waikato Regional Council
WWL	Wellington Water Limited

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