Flood Hazard Modelling Standard

May 2025

Prepared for Greater Wellington Regional Council

Greater Wellington
Te Pane Matua Taiao

GW/FP-T-21/15

Foreword

Rivers are an important part of New Zealand’s landscape and culture. Not only providing environmental and social value to all New Zealanders, but holding a special place in Māori culture. To enjoy these benefits many of our communities are on floodplains. As a result river flooding is a significant hazard across New Zealand.

The Wellington Region is no exception with many of our major towns at risk from large floods. Being able to understand the potential scale and extent of floods is a critical tool for engineers, emergency managers and planners.

While no model can be 100% accurate they provide the basis for most risk management options. Such as guiding the siting of defences, providing the basis for flood forecasting and warning systems and informing planners where areas of appropriate development should be.

We have developed this standard to provide a robust flood hazard modelling process which will provide confidence to the community, planners, and engineers. Through the development of this process we have sought to imbed community engagement, and peer review at each stage to ensure the best possible outcome.

Flood Protection would like to acknowledge Cardno NZ for their hard work in developing this standard. It is intended that this standard will inform the flood hazard modelling carried out by Greater Wellington Regional Council, the communities we serve, our partners, and the consultants we work with to deliver these projects and aid all in delivering robust flood hazard modelling to aid in our understanding of risk and our management of it.

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Revision	Reason for Issue	Date	Developed by	Approved by
1	Final for issue.	May 2021	Cardno NZ	Andy Brown – TL Investigations, Strategy, and Planning Greater Wellington
2	Update	May 2025	Stantec	Andy Brown – Risk Management and Resilience Lead

PROCEDURE 00

PROCESS

This procedure outlines the flood hazard modelling process, and provides an overview of the protocols to be followed during planning of flood hazard modelling projects.

Greater Wellington
Te Pane Matua Taiao

Procedure 00

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1 Introduction

Flooding is a significant hazard in the Wellington Region that poses a risk to life, property and infrastructure. A number of communities within the region are considered to be at risk – including urban areas within the Hutt Valley, townships on the Kāpiti Coast, Masterton and Greytown in the Wairarapa and rural areas throughout the region. The 2004 flood in the Waiwhetū Stream that caused major flooding to residential properties along Riverside Drive, the Hutt Park raceway and the industrial area in Gracefield is a recent reminder of the damage that flooding can cause.

Flood hazard modelling is considered a crucial activity in understanding flood risk as it provides the basis for investment and emergency management decisions by Greater Wellington Regional Council (Greater Wellington). Flood hazard modelling involves the use of hydrological and hydraulic models to estimate the range of possible floods that could occur in a catchment and the hazard associated with these events. The output produced from flood hazard models is a series of flood hazard maps and tabulated data for each scenario modelled.

Having a good understanding of the flood hazard in an area enables informed decisions to be made about the best ways to manage risk. This may be through managing or reducing the risk to existing development, and future planning decisions such as excluding sensitive land uses (i.e. residential development, hospitals and schools) from higher hazard areas.

1.1 What is the Flood Hazard Modelling Standard?

Greater Wellington have developed this **Flood Hazard Modelling Standard** (FHMS) to outline the protocols to be followed by any person working on Greater Wellington's flood hazard modelling projects. The FHMS process should be followed on all new flood hazard modelling projects. The process for legacy models is outlined in Section 1.4.1.

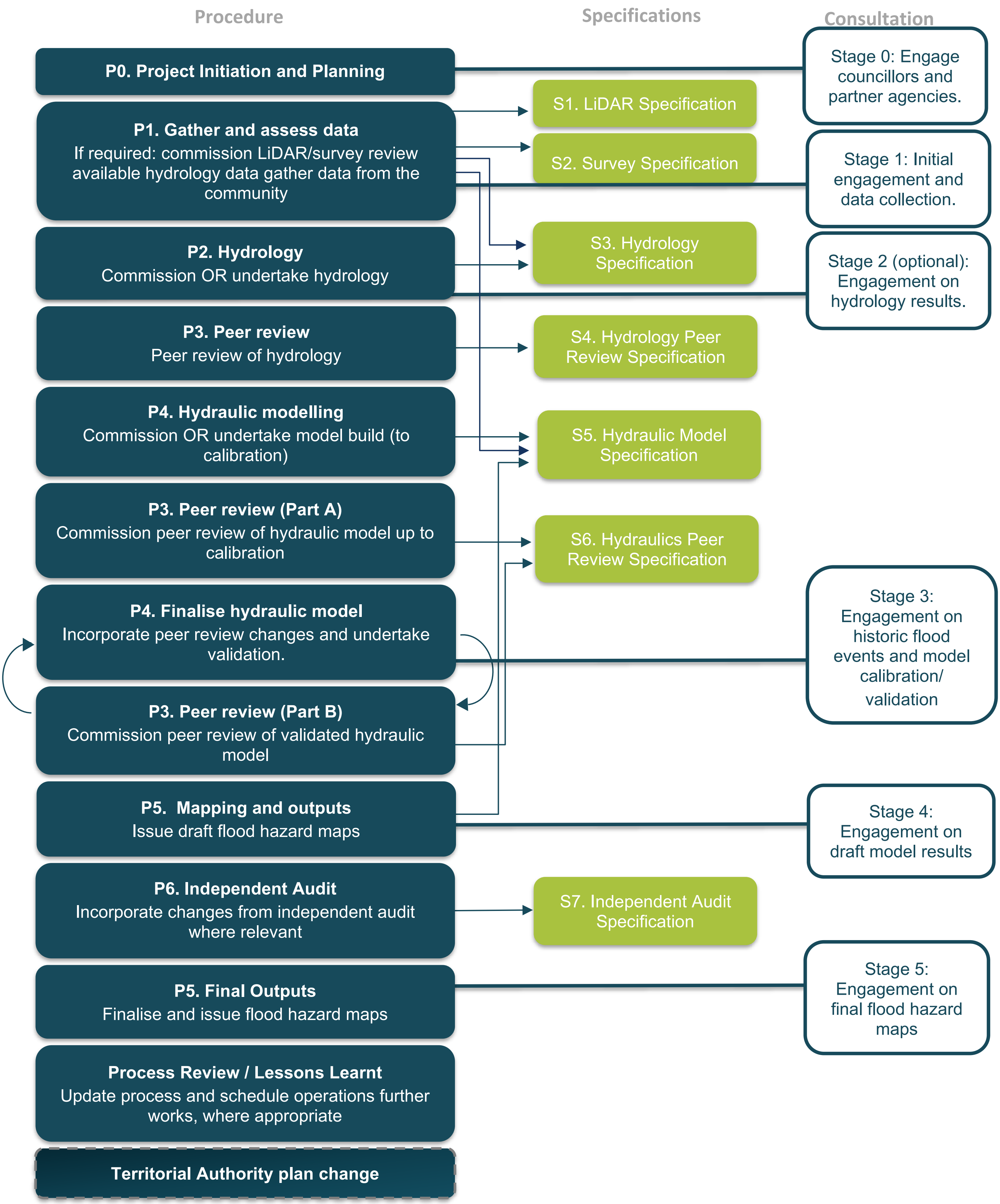
The protocols in the FHMS have been developed to ensure that flood hazard modelling projects are undertaken in a robust and consistent way that is in line with accepted industry practice, while still allowing for flexibility in approach in recognition that the optimal approach may be dependent on catchment or project specific factors. The protocols require that every stage of the process is well documented in reports or spreadsheet logs and registers.

The FHMS is made up of 7 Procedures and 5 Specifications, and a number of templates and supporting documents. The Procedures, Specifications and Templates have the following functions:

- **Procedure:** a Procedure outlines the tasks required to be undertaken within each step of the FHMS process, and describes any technical detail or methodology to be prescribed. The procedure also outlines how the work undertaken at that step of the FHMS process should be documented.
- **Specification:** a Specification is tied to a Procedure or Procedures and forms part of a request for proposal (RFP) for works to be undertaken by a consultant or contractor. Specifications are typically a brief schedule of requirements with the majority of the technical detail located within the relevant procedure to prevent duplication.
- **Template:** a number of templates are provided as part of the FHMS process. Each template is tied to a Procedure that outlines how these templates should be used. Templates are provided where a consistent format is required to document a process or finding. Templates outline the minimum documentation requirements for these elements. Additional detail should be provided where needed.

The FHMS process is summarised in Figure P0-1 below.

Figure P0-1 **FHMS process**



Each of the elements of the FHMS process are described below:

- **Procedure 0: Process** – this document. This procedure outlines the flood hazard modelling process, and provides an overview of the protocols to be followed during planning of flood hazard modelling projects.
- **Procedure 1: Gather and Assess Data**. Outlines the process for the collection of all available data to inform model build, calibration and validation. This includes the collection of hydrometric data, topographic and bathymetric data, and information about historical floods. All collected information is to be reviewed to determine its quality, its suitability for inclusion in flood hazard models, and any limitations that the quality of the data may place on the outputs of the FHMS process. The review should also identify whether any further data collection is required.
  - **Data Register**. A spreadsheet template for the data register is provided in Appendix P1-A. The data register is to be used to record the source and quality of all information gathered and used in the flood hazard model project. The data register will provide an audit trail for the peer reviewer, and assist in ensuring all aspects of the project are documented.
- **Procedure 2: Hydrology**. Outlines the protocols to be followed when undertaking hydrological modelling for flood hazard modelling projects. This includes hydrological model build, calibration, validation, sensitivity analysis and preparation of outputs from the hydrological model for input to the hydraulic model.
  - **Model log template**. A spreadsheet template for recording final model runs including model naming convention, details of all inputs, and calibration and validation runs.
  - **Feedback form**. A form to provide feedback on Greater Wellington's hydrometric stations. On completion of both the hydrometric data review undertaken as part of Procedure 1 and the hydrological model (Procedure 2) the modeller is likely to have a good understanding of the quality of the hydrometric data available for the study catchment, the suitability of the distribution of hydrometric stations, and how the quality of the data has impacted on confidence in the hydrological modelling results. The feedback form is used to capture this information and to provide recommendations to Greater Wellington for improvements to the hydrometric network within the study area.
- **Procedure 3: Peer Review**. Peer review is undertaken at three stages in the FHMS process: on completion of the hydrological model, following build and calibration of the hydraulic model, and following validation, completion of the design runs and sensitivity analysis of the hydraulic model. Procedure 3 outlines the protocols to be followed when undertaking peer review at each of these stages.
  - **Peer review spreadsheet template**. A template is provided to assist the peer reviewer to undertake the peer reviews and to provide an audit trail and clear record of changes to the model during the peer review process. The peer review spreadsheet should be updated by both the peer reviewer and the modeller at each iteration of comments and changes to the model. All peer review comments are to be closed off by the peer reviewer and modeller.
- **Procedure 4: Hydraulics**. This procedure outlines the protocols to be followed when undertaking hydraulic modelling on flood hazard modelling projects. This includes model build, calibration, validation, design runs and sensitivity analysis.
  - **Model log template**. A spreadsheet template for recording final model runs including model naming convention, details of all inputs, and calibration and validation runs.
  - **Example hydraulic modelling report table of contents**. An example table of contents is provided to assist the hydraulic modeller to understand the level of detail to be provided in the hydraulic modelling report.
- **Procedure 5: Outputs**. Outlines the outputs to be prepared and delivered to Greater Wellington including raster grids of flood level, depth, velocity and hazard for all events run, geospatial files, tabulated results and .pdf maps.
- **Procedure 6: Independent Audit**. An independent audit is undertaken following close out of the final peer review of the hydraulic modelling. The independent audit reviews the entire FHMS process to confirm whether the process has been followed appropriately.
  - **Audit spreadsheet template**. A spreadsheet template is provided to assist the independent auditor to undertake the audit and to provide a record of recommendations made by the auditor and subsequent changes made. The spreadsheet should be filled in by the independent auditor and the modeller(s). All independent audit comments are to be closed off by the auditor and modeller(s).

A number of specifications have been prepared to assist with the tendering of works associated with Procedures 1 – 6 of the FHMS. These specifications include:

- Specification 1: LiDAR
- Specification 2: Survey
- Specification 3: Hydrology
- Specification 4: Hydrology Peer Review
- Specification 5: Hydraulic Model
- Specification 6: Hydraulics Peer Review
- Specification 7: Independent Audit

1.1.1 Community engagement

Greater Wellington recognise the importance and value of the community's knowledge and experiences of flooding in their area. Engagement, and in some cases collaboration, will be undertaken in an effort to develop the most accurate flood information. Community engagement may be open to the entire community or may be undertaken with representatives of the community at some stages.

Community engagement is recommended to be undertaken at five or six stages in the FHMS process as shown in Figure P0-1. These stages include:

- **Stage 0: Engage councillors and partner agencies**. This stage occurs during project planning, as outlined in this procedure (**Procedure 0: Process**). The purpose of this stage is to inform Greater Wellington's councillors and partner agencies (such as the relevant territorial authority, iwi partners or Wellington Water Limited) of the community engagement that will be undertaken as part of the flood hazard modelling project and to ensure engagement programmes for similar projects are aligned.
- **Stage 1: Initial engagement and data collection**. This stage of engagement occurs when data gathering is undertaken in line with **Procedure 1: Gather and Assess Data**. At this stage mana whenua and the community are notified that flood hazard modelling is being undertaken in their community. Information about historic flood events should be sought from mana whenua and the community to inform calibration and validation of the hydraulic model. The protocols for gathering this information from the public are outlined in **Procedure 1: Gather and Assess Data**.
- **Stage 2: Engagement on hydrology**. This stage is optional. If undertaken, this stage occurs on completion of the hydrological model under **Procedure 2: Hydrology**. The purpose of this stage is to inform the community stakeholders of the hydrological modelling results.
- **Stage 3: Engagement on modelled historic flood events and hydraulic model development.** This stage is undertaken during the calibration / validation phase of hydraulic model development (Part B of **Procedure 4: Hydraulics**). The purpose of this engagement is to show the community (or community representatives) the initial model results, and to seek their feedback on how the initial results compare to their recollections of the calibration / validation flood events. Further amendments to the model may be undertaken following this engagement.
- **Stage 4: Engagement on draft hydraulic model results.** This stage occurs when the draft outputs are available, under **Procedure 5: Outputs,** and following the Part B hydraulic model peer review under **Procedure 3: Peer Review**. This engagement gives the community the opportunity to see how their feedback from the Stage 3 engagement has been incorporated into the model.
- **Stage 5: Engagement on final flood hazard maps.** This stage occurs when the final outputs are available, following **Procedure 5: Outputs** and after the independent audit (**Procedure 6: Independent Audit**). The purpose of this engagement is to inform the community about the new flood maps and raise awareness within the community about flood hazard.

Greater Wellington's Flood Hazard Modelling Engagement Guidance document (September, 2021) should be referred to for detailed methodology on how community engagement should be undertaken.

1.1.2 Mātauranga Māori

Greater Wellington recognises the importance of Mātauranga Māori and the value it can bring to understanding flood risk. It is recognised that each catchment will require a different approach. Greater Wellington is committed to working with our iwi partners to weave Mātauranga Māori into the Flood Hazard Modelling process whilst delivering robust and defendable outputs for land use planning.

The **key** engagement points between Greater Wellington and mana whenua (aligning with the engagement stages in Section 1.1 above) include:

- **Stage 1: Initial engagement and data collection**. This stage of engagement occurs when data gathering is undertaken in line with **Procedure 1: Gather and Assess Data**.
- **Stage 3: Engagement on modelled historic flood events and hydraulic model development.** This stage is undertaken during the calibration / validation phase of hydraulic model development (Part B of **Procedure 4: Hydraulics**). The purpose of this engagement is to show mana whenua the initial model results, and to seek their feedback on how the initial results compare to their recollections of the calibration / validation flood events. Further amendments to the model may be undertaken following this engagement.
- **Stage 4: Engagement on draft hydraulic model results.** This stage occurs when the draft outputs are available, under **Procedure 5: Outputs,** and following the Part B hydraulic model peer review under **Procedure 3: Peer Review**. This engagement gives mana whenua the opportunity to see how their feedback from the Stage 3 engagement has been incorporated into the model.

However, the engagement points should be agreed between mana whenua and Greater Wellington for each flood hazard modelling project prior to engagement stage 1.

1.2 What other documents support the FHMS process?

Flood hazard modelling is typically undertaken to provide an approximation of flood risk to inform district planning, asset management and/or emergency management planning. This standard has been developed to outline the technical flood hazard modelling requirements to support these projects.

Greater Wellington have developed additional guidance to inform other components of the flood hazard management process, outlined below:

- **Flood Hazard Modelling Engagement Guidance (September, 2021):** provides detailed methodology for undertaking community engagement during flood hazard modelling projects.
- **Flood Hazard Planning Guidance (March 2023)**: focuses on non-structural methods for land use planning for flood risk management. This document has been developed to assist Territorial Authorities during district plan level planning.

  Flood hazard categories for land use planning (river corridor, overland flow paths, erosion hazard areas, inundation (ponding) areas and residual hazard areas) are outlined in this document.

1.3 What if a flood occurs while the FHMS process is underway?

Every time a large flood occurs there is a unique opportunity to collect additional data that can be used to improve confidence in the results of both new and existing flood hazard models. Immediate data collection should be undertaken for all floods with a magnitude greater than a 20% AEP event. Guidance relating to post-event data collection is provided in Section 7 of **Procedure 1: Gather and Assess Data**. Greater Wellington may also undertake data collection in smaller magnitude flood events (<20% AEP event) at their discretion.

The quality of post-event data should be reviewed as soon as possible after collection. If the FHMS process is underway in the flooded catchment at the time of an event, the hydrological and hydraulic modellers should review the newly collected data to determine the value of this data in the context of the flood information available for calibration and validation of the hydrological and hydraulic models.

Greater Wellington, supported by the hydrological and hydraulic modellers, should determine whether the flood event is to be included in the hydrological and hydraulic models, given that this is likely to result in delays to project timeframes.

It should be noted that large flood events may cause significant changes in the channel or catchment, such as significant aggradation or degradation of the channel. Following a large event, it should be determined whether these changes require existing modelling to be updated to reflect the new catchment conditions.

The following should be considered:

- Where the hydrological model build is underway, the collected post-event data should be used for calibration or validation, where the data quality is suitable and there are insufficient superior flood events available.
- Where the hydrological modelling is complete, additional validation using the new data should be considered.
- Where the hydraulic model build is underway, the collected post-event data should be used for calibration or validation, where the data quality is suitable and there are insufficient superior flood events available.
- Where the hydraulic model is complete, a high-level validation of flood extent and behaviour using the new data should be considered.
- Where the event occurs at the end of the FHMS process (eg, following or during the independent audit) a high-level validation should be considered. Calibration using the new data is not required unless the quality of the data used for the model calibration was poor.

Where the new flood data is used for calibration or validation and the peer review of the hydrological and/or hydraulic models has already been undertaken, the peer reviewer should also review the revised calibration/validation to confirm that their assessment of the model suitability stands.

1.4 When is flood hazard modelling undertaken?

Greater Wellington undertake on-going flood management and hazard planning in catchments across the greater Wellington Region. Flood management plans and flood hazard models have been prepared for a number of catchments where there is a history of flooding in urban areas, or where significant flooding has occurred in rural areas or across key transport routes.

Where a flood hazard model has been prepared, it may be revised within 5-10 years of the initial model development. Models are revised over time due to:

- Increased data availability – over time longer rainfall and river flow records become available. These records allow for better estimates of the frequency of large floods and storms, and whether this is changing over time (eg, due to climate change).
- Improved data quality – river flow gauging is undertaken to confirm the relationship between flow and levels measured by automatic river level sensors. Over time, more gauging (particularly high flow gauging) can improve the understanding of this relationship.
- More floods – data from actual floods is used to calibrate and validate flood hazard models. When a new flood occurs, this data can be used to test or improve a current model, or may be a trigger for the creation of a new model.
- Catchment changes – over time catchments experience changes to land use, natural and human processes cause changes to river geomorphology (eg, bed aggradation or degradation), and structures are constructed in rivers and floodplains. These changes may affect the validity of previous models.
- Technological changes – technology is continually developing. When new methods of data collection become available or the technology in hydrological and hydraulic models improves existing models may become out of date.
- Changes to industry accepted practice – like all scientific methods, the methods used to estimate rainfall and floods are continually improving. When industry accepted practice changes, existing models should be reviewed to determine whether revision is needed.

1.4.1 Legacy models

At the beginning of the FHMS process any existing flood hazard models within the catchment of interest should be identified. The existing models should be assessed to determine whether update of the existing model can be undertaken, or whether a new model is required.

The following criteria should be considered when determining whether a legacy model should be updated, or a new model is required:

- Age of the legacy model or assessment:
  - Are longer rainfall and/or flow records available? Have any major floods occurred since the previous assessment? Has new data been collected that could be incorporated into the assessment?
  - Are the methods used to undertake the previous assessment still accepted industry practice?
  - Have there been significant changes in the catchment or along the river channel since the previous assessment?
- Robustness of previous assessment:
  - Was relative confidence assessed at the time of the previous assessment? Was there high confidence in the assessment?
  - Was the previous assessment peer reviewed?
  - Was the assessment based on high quality data?
- Technology used to develop previous assessment:
  - Is the software used to develop the model still available? Do Greater Wellington hold licences for the software? Can the models be re-run?
  - Would using newer or alternative versions of software provide more robust results?
  - Would using newer or alternative versions of software support other uses of the model such as optioneering?

The FHMS process should be followed during the revision of existing models to the maximum extent possible, and as outlined in Table P0-1 below.

Table P0-1 Minimum extent of incorporation of FHMS process

Extent of revision	FHMS process incorporation
New model developed	▪ The complete FHMS process must be followed
Extensive hydrological model revision undertaken	▪ The complete FHMS process must be followed
Extensive hydraulic model revision undertaken	▪ The complete FHMS process must be followed from **Procedure 4: Hydraulics** onwards, including peer review of the hydraulic model under **Procedure 3: Peer Review**.
Minor updates undertaken to hydrological or hydraulic model	▪ The updates should be reviewed by a peer reviewer. The updates should be made in accordance with the requirements of **Procedure 2: Hydrology** / **Procedure 4: Hydraulics** as applicable.

1.5 Other Models

Greater Wellington have a number of other flood models that have been developed outside of the FHMS process. These models are described below.

1.5.1 Regional Flood Exposure Model

In 2022 Greater Wellington developed a Regional Flood Exposure Model. This model provides high-level flood risk information for areas not currently included within a catchment specific Flood Hazard Model.

The regional model was not developed in accordance with this standard as it is intended to provide high level, indicative information only. The model will be used for areas without detailed flood modelling and for regional strategic studies and prioritisation.

1.5.2 Flood Forecasting Models

Greater Wellington operates a number of flood forecasting models in various catchments throughout the region. As the FHMS does not specifically address the requirements of flood forecasting models, these models have been developed outside of the FHMS process.

New flood forecasting models should be developed in accordance with the general principles of the FHMS process where possible and applicable, including under-going peer review.

1.6 Event frequency descriptor

The FHMS uses the percentage Annual Exceedance Probability (% AEP) terminology as the descriptor for the frequency of flood events. This terminology is preferred over the Average Recurrence Interval (ARI) terminology which can be misinterpreted by the community as an event that will only occur every given number of years, rather than the probability of occurrence in any given year. The AEP terminology and how this equates to ARI is outlined in Table P0-2 below. Modellers and reviewers undertaking work under the FHMS should maintain consistency and reference event frequency using the AEP terminology.

Table P0-2 Event frequency terminology

Frequency	AEP	ARI
Very frequent	39% AEP	1 in 2-year ARI
Frequent	20% AEP	1 in 5-year ARI
	10% AEP	1 in 10-year ARI
Rare	5% AEP	1 in 20-year ARI
	2% AEP	1 in 50-year ARI
	1% AEP	1 in 100-year ARI
Very rare	0.1% AEP	1 in 1000-year ARI

2 Project Planning

Each flood hazard modelling project will be managed by a Greater Wellington staff member as project manager. The project manager will develop a project plan during the project initiation to outline the objectives of the project, project background, key tasks and programme. The project plan should include the following elements:

- Outline of the objectives of the study. Flood hazard modelling projects should generally aim to understand the flood extent, hazard and behaviour that may affect the study area for a range of current, future climate and residual hazard scenarios. The outputs will generally need to be prepared to a sufficient level of detail and quality in order to inform district planning and emergency management.
- Project team structure including project manager, internal team members and identification of which tasks will be undertaken by third parties (i.e. consultants).
- Definition of the extent of the study area, including approximate extents for the hydrological and hydraulic models.
- Background to the project including a summary of any previous work undertaken within the study area including previous modelling. The summary should include any discussions Greater Wellington has had with the community or territorial authority related to flood hazard in the study area.
- Identification of linkages or dependencies with other Greater Wellington or external projects (i.e. Wellington Water or territory authority projects).

- Any proposed departures from the FHMS and justification for this.
- Any project specific tasks or runs to be undertaken, additional to the FHMS requirements.
- Identification of key stakeholders including the relevant territorial authority.
- Outline of the community engagement approach, noting minimum requirements of the FHMS. The media/communications approach should also be outlined for potentially controversial projects.
- Plan for procurement of FHMS tasks (i.e. direct appoint, closed contest or open tender).
- Budget allocated to the FHMS project and breakdown of budget for each key task.
- Programme addressing all steps in the FHMS project, and allowing time for reiterations of the modelling following peer review and independent audit. Key milestones should be identified.
- Method for reporting (i.e. monthly progress reports). Detail of how consultants will report to the Greater Wellington project manager.
- The location where all project information including communication (emails) will be stored.
- A register of potential risks and how these are proposed to be managed. An example risk register is provided in Table P0-3.

Table P0-3 Example risk table

Risk Category	What can go wrong?	Likelihood (H/M/L)	Mitigation
Quality	Quality of deliverables is poor	Low	Selection of experienced consultant, with track record of producing high quality work. Provide sufficient time to undertake work.
Time	Project delivered late	Medium	On-going communication with consultants to identify and address issues early. Ensure timeframes at start of project are realistic.
Community dis-satisfaction	Community unhappy with results	Medium	Early and on-going community engagement. Ensure transparency of process and decision making. Independent audit.

The project plan should be updated as the project evolves, with all key decisions recorded.

2.1 Procurement approach

As outlined in Section 1.1 the flood hazard modelling process requires a multi-disciplinary approach incorporating surveying and data capture, hydrological and hydraulic modelling, independent peer review and audit, and mapping of final outputs. It is envisaged that a team of internal and external specialists will be required to complete these works.

The following specialists are likely to be procured for FHMS projects, however it is noted that some works may be undertaken in house on some FHMS projects:

- Procedure 1: Gather and Assess Data – surveyor, hydrological modeller, hydraulic modeller.
- Procedure 2: Hydrology – hydrological modeller.
- Procedure 3: Peer review – peer reviewer (expertise in hydrological and/or hydraulic modelling as applicable).
- Procedure 4: Hydraulics – hydraulic modeller.
- Procedure 5: Outputs – hydraulic modeller.
- Procedure 6: Independent Audit – auditor (expertise in hydrological modelling, hydraulic modelling and/or auditing).

2.2 Process review/lessons learnt

The FHMS is intended to be a living document. As such, the final step in the FHMS process is to undertake a review of both the flood hazard modelling project and the FHMS process to determine whether any improvements can be made to the process. This process is likely to be undertaken internally within Greater Wellington but may include a workshop with the consultants involved in the flood hazard modelling project to gather their feedback.

The review should address:

- Whether the FHMS addresses all steps in the flood hazard modelling process?
- Whether the FHMS was flexible enough to cover catchment/watercourse specific factors?
- Whether the requirements in the FHMS were clear enough?
- Whether there were any items that are listed in the FHMS for discussion or workshopping with Greater Wellington that could be formalised in a procedure for implementation in future FHMS projects?
- Whether the specifications were clear enough to the bidders (i.e. were the proposals received consistent enough for comparison? Did tenderers ask questions seeking clarification of the process?)
- Whether enough community engagement is included in the FHMS?
- Whether any issues with the FHMS process were raised by the peer reviewer or independent auditor?
- Whether the order of tasks in the FHMS flow chart is appropriate?
- Any issues that arose during the project, and whether they could they be addressed by the FHMS?
- Any changes to accepted industry practice since the FHMS was prepared, and whether the FHMS needs to be updated.
- Any changes to Greater Wellington's policy or preferences eg, use of new modelling software or new modelling approach that should be included in the FHMS.
- Whether the territorial authority or community provided any feedback that should be incorporated into the FHMS.

Proposed changes to the FHMS should be discussed and agreed with Greater Wellington prior to updating the FHMS.

3 Documentation

All steps in the FHMS must be fully documented. This will ensure an audit trail for the peer reviewer and independent auditor. It will also ensure that the process is transparent, and that the modelling can be replicated if needed.

The required documentation is summarised in Table P0-4, and provided in more detail in each of the procedures. Documentation must be provided in report and spreadsheet format.

Table P0-4 Required documentation

FHMS step	Required documentation
Procedure 1: Gather and Assess Data	▪ Data register ▪ Summary of data review in hydrological modelling report and hydraulic modelling report as relevant to each.
Procedure 2: Hydrology	▪ Hydrological modelling report ▪ Model log ▪ Hydrometric feedback form
Procedure 3: Peer review	▪ Peer review spreadsheet – hydrology, Part A hydraulic model and Part B hydraulic model ▪ Peer review report - hydrology, Part A hydraulic model and Part B hydraulic model

Procedure 4: Hydraulics	▪ Hydraulic modelling report ▪ Model log
Procedure 5: Outputs	▪ Methodologies used described in hydraulic modelling report
Procedure 6: Independent audit	▪ Independent audit spreadsheet ▪ Independent audit report

All model files and the required outputs listed in **Procedure 5: Outputs** must also be provided.

4 Procedure review

This procedure is intended to be a living document that can be revised as technology advances and best-practice evolves.

The need for review of the procedures within the FHMS, including this one, will be determined at the end of each modelling project at the ‘process review / lessons learnt’ checkpoint on the FHMS flow chart.

PROCEDURE 01

GATHER & ASSESS DATA

This procedure has been prepared to outline the protocols to be followed by any person gathering and assessing data for Greater Wellington's flood hazard modelling projects.

Greater Wellington
Te Pane Matua Taiao

Procedure 01

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1 Introduction

This document forms **Procedure 1** of Greater Wellington Regional Council's (Greater Wellington) **Flood Hazard Modelling Standard** (FHMS). This procedure has been prepared to outline the protocols to be followed by any person gathering and assessing data for Greater Wellington flood hazard modelling projects.

This document should be read in the context of the wider FHMS. It has a particular relationship to **Specification 1: LiDAR** and **Specification 2: Survey**.

1.1 Data collection and assessment in the FHMS Process

Confidence in flood hazard model results is significantly improved where high quality input and calibration data is available. A comprehensive process of data collection, and the assessment of the quality of collected data, are important for ensuring that all flood hazard models are built and calibrated using all available reliable information.

Data collection should be undertaken prior to commencing modelling to prevent delays and re-work associated with discovering new information after modelling has commenced. The assessment of the quality of the data should also be undertaken at this stage to ensure that any limitations of the gathered data are understood prior to undertaking the modelling.

As such, the collection and assessment of all available data is the first step in the Flood Hazard Modelling process. The stages of the FHMS process that are related to the gathering and assessment of data for flood hazard modelling projects are outlined in red in Figure P1-1 below.

1.2 What types of information should be collected?

Data collection efforts should focus on the collection of:

- **Hydrometric data.** For example, flow and rainfall data in the study area, including details about the recording station (i.e. type and purpose of site) and details of conditions that may have affected hydrometric records and quality of the data collection (eg, stream bed aggradation, date of most recent gauging, recorded rainfall aligning with check gauge). The rating curves for flow sites, data from the gaugings used to develop the rating curve, and information on confidence in the rating curve (if available) should also be collected.
- **Catchment data.** For example, land use data, current and historical aerial photography, records of changes in the catchment that may invalidate historical evidence in a current scenario model validation (eg, new bridges, construction of flood protection structures, long term aggradation or degradation).
- **Historical flooding information.** For example, community recollections, photographs, flood marks on structures, flood records, newspaper or social media articles, details of conditions that may have affected flood extent and behaviour (eg, presence and height of storm surge, lake flooding, tidal conditions etc) and flood incident reports.
- **Topographic and Bathymetric data**. For example, survey of river cross sections, and LiDAR of the catchment including metadata.
- **Details of structures**. For example, survey of structures within the river channel or floodplain that may affect flood levels and behaviour, dates the survey were undertaken, details of any major maintenance works.

The types of data to be collected are described in more detail in the following sections. Following collection, the quality of the data must be assessed to determine:

- Whether the collected data is suitable for inclusion in the flood hazard modelling.
- What level of confidence can be applied to the collected data.
- Whether the quality of the data, or lack of data, is likely to result in limitations being placed on the use of the final model results.
- Whether additional data should be collected prior to commencing the modelling. For example, additional survey.

1.3 Why is it important to gather information from the community?

Local communities, particularly residents who have lived in the study area for a long time, may hold historic flood information that is unknown to Greater Wellington. This information may be in the form of photographs, recollections, flood marks on buildings or other private structures, or records of damage or disruption. Access to this information could assist with calibration and/or validation of flood hazard models.

Collection of historic flood information from communities may also assist with community engagement in the flood hazard modelling process, and may increase community confidence in the final model results.

1.4 Who undertakes data gathering and assessment?

Initial data gathering and review should be undertaken by the hydrological and hydraulic modellers undertaking the flood hazard modelling, where the modellers collect and assess the information relevant to their component of the modelling.

For example, the project hydrologist would gather and assess rainfall and flow data prior to commencing the hydrological model, while the hydraulic modeller would be required to gather and review data relating to structures in the river channel, and any existing survey cross-sections.

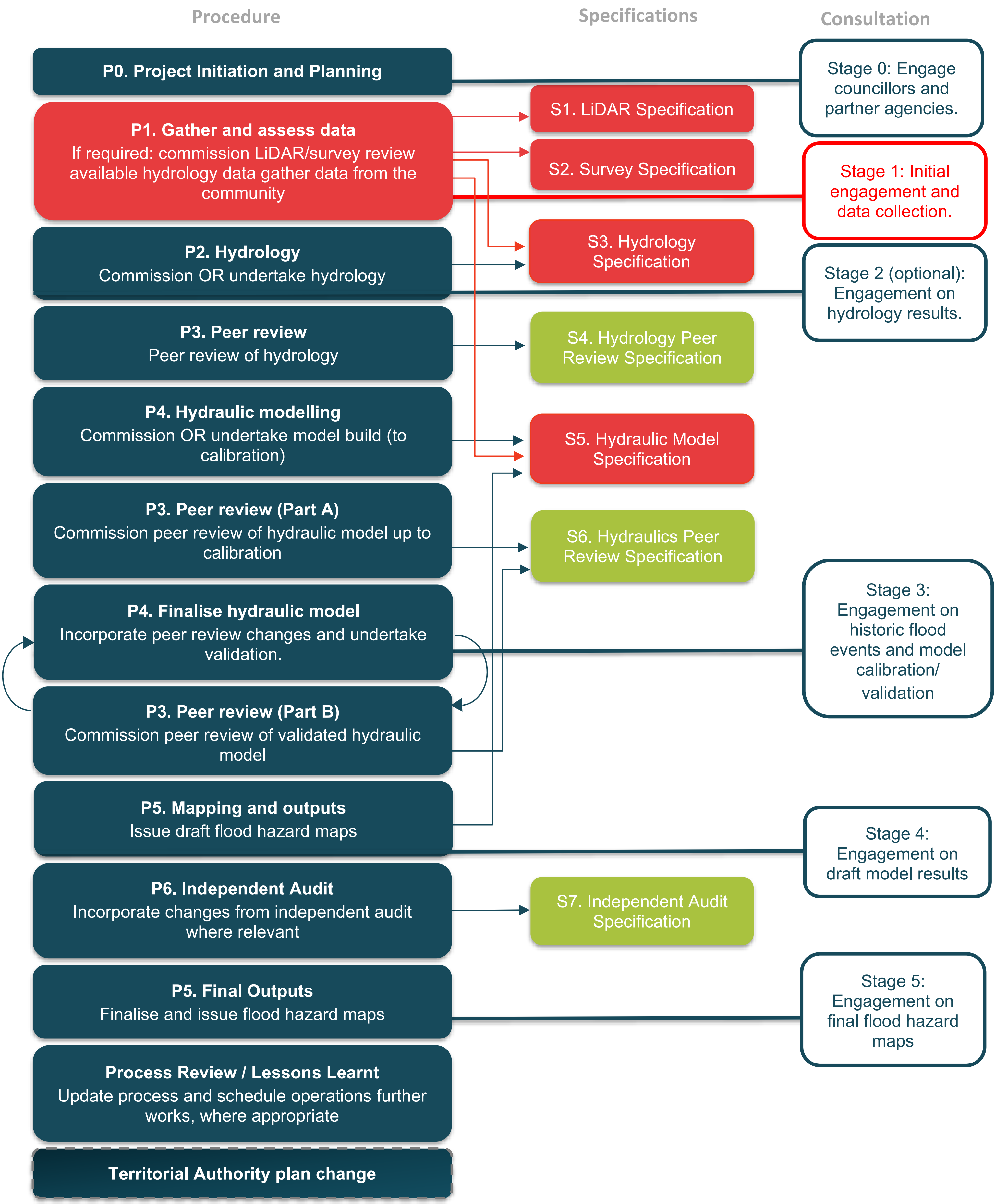
However, where flood hazard modelling projects are expected to run over a long timeframe, the hydraulic modeller may not have been engaged at the time that the initial data gathering and review is undertaken. In this case, the review may be undertaken by another party with expertise in hydraulic modelling, or internally by Greater Wellington.

When a hydraulic modeller is engaged to build the flood hazard model, if different from the party that conducted the data gathering and review, they must:

- Undertake a review of the data gathering and suitability documentation.
- Identify any limitations that the available data/data quality may place on the model results.
- Confirm whether they agree with the data gathering and suitability assessment, and raise any concerns.
- Identify whether any additional data needs to be collected before modelling should commence.
- Confirm their acceptance of the suitability of the available data into be used the hydraulic model.

Greater Wellington may assist with data collection through the provision of data, records and technical reports and will lead any community consultation and data gathering required.

Figure P1-1 FHMS process showing where gathering and assessment of data is undertaken (red)



2 Hydrometric Data

Greater Wellington holds a significant volume of hydrometric data across a number of locations in the Wellington Region. This data includes rainfall, water level in rivers, streams, lakes, and known floodways, and flow in some rivers and streams. This hydrometric data is publicly available through Greater Wellington's Hilltop database.

Hydrometric data may also be available from sources external to GWRC such as NIWA (i.e. via the Cliflo database), MetService, forestry or Fire Service gauges, or private gauges.

At the majority of Greater Wellington's hydrometric monitoring sites, hydrometric data is supported by comment files and in some cases, technical reports. These documents provide additional information relating to the history of the site. This information may include details of known issues or constraints to the collection of accurate data at the site, details of site conditions that may affect the validity of the rating curve for specific events (such as large volumes of scour of the riverbed during a flood event), and details of the types of recording equipment installed at the site over its history.

Greater Wellington's hydrometric data and the associated site information can be provided by Greater Wellington and is critical to understanding the limitations of the data (if any).

2.1 Data collection

Greater Wellington maintains a geospatial database of the locations of all existing and closed hydrometric stations it operates, or has operated within the Wellington Region. This database should be reviewed to identify existing and closed hydrometric sites located within or near to the study catchment. The availability of hydrometric data from other sources should also be investigated.

Stations outside the catchment should be included in the analysis based on the professional judgement of the modeller, based on factors such as presence or absence of data within the study catchment, distance of the sites from the study catchment, catchment similarities and geographic orientation to weather systems.

Greater Wellington's data can be collected by requesting data for the identified sites from Greater Wellington. The Greater Wellington data team should be provided with the project background to ensure that all relevant data can be collected.

The minimum requirements for the collection of hydrometric data (where available) is listed in Table P1-1 below.

Table P1-1 Minimum requirements for hydrometric data gathering

Data type	Data to be collected (where available)	Who to contact for data request
River level and flow	Locations of all existing and historical gauges within Greater Wellington and external networks, complete record of gauge data for current and historical gauges within the catchment, history of the gauges, comments files, confidence limits, rating curve and gaugings. Flood flows from historical events (pre-gauge) should also be collected.	Greater Wellington data team External data sources (eg, NIWA, MetService)
Rainfall	Locations of all existing and historical Greater Wellington and external gauges within the network, complete record of the rainfall data for current and historical gauges within and near to the study catchment, history of the gauges, comments files, and confidence limits.	Greater Wellington data team External data sources (eg, NIWA, MetService including rain radar)
Known watercourse information	Information on the watercourse conditions that may affect hydrometric data i.e. bed degrading.	Greater Wellington

Technical reports	Greater Wellington technical reports relating to hydrometric data in the region, eg, • Flow gauge network review (Cardno, 2020) • Hydrological statistics for surface water monitoring sites in the Wellington Region (Greater Wellington, 2016) • Ratings and gauging priority assessment (Greater Wellington, 2015) • Hydrology network review (Greater Wellington, 2015) External technical reports (eg, NIWA, Ministry of Works and Development)	Greater Wellington External data sources (eg, NIWA, Ministry of Works and Development)

2.2 Assessment of hydrometric data

Collected hydrometric data should be reviewed and analysed in order to determine the suitability of the data for inclusion in flood hazard modelling. This assessment should include a determination of whether the quality of the data is likely to limit confidence in the model results and should consider whether the level of confidence will vary across reaches and/or events.

Where appropriate, the assessment of hydrometric data should include, but is not limited to:

- Rainfall sites:
  - Assessment of the appropriateness of the gauge sites in relation to the catchment including assessment of rainfall variance for individual events and in general.
  - Review of the completeness of the hydrometric record, including length of record, and number and length of gaps.
  - Consideration of whether there is sufficient data to determine a temporal pattern of rainfall.
  - Consideration of whether there is more than one dominant synoptic pattern that generates flooding in the catchment, for example frontal systems vs. tropical lows.
  - Review of rain gauge comment files and notes on data quality, and assessment of the level of confidence in the rainfall data.
  - Comparison of rainfall frequency data to HIRDS, where rainfall record lengths are less than half the maximum recurrence interval to be modelled.
  - Patching of rainfall records where needed. Patched data should be supplied to Greater Wellington for their records. Refer to Section 2.2.1 of **Procedure 2 Hydrology** for further guidance on patching rainfall records.
  - Consideration of whether the recorded rainfall data is likely to have been impacted by snow.
- Water level and flow sites:
  - Review of rating curve and gaugings, particularly during high-flow events and assessment of the confidence in the high flow portion of the rating curve.
  - Review of gauge control conditions, eg, is the control stable, and how does this affect confidence in the data.
  - Identification of any limitations or issues associated with the use of the flow data for calibration and validation.
  - Review of the suitability of the data for frequency analysis, including the length of the record relative to the largest recurrence interval to be modelled.
  - Confirm whether the gauge is likely affected by tides or backwater.
  - Confirm the bankfull level at the gauge, and whether flows above the bankfull level are realistic?
  - Confirm whether the data quality is similar throughout the record, or whether there are events that affect this eg, change of recording equipment, installation or wash-out of a weir.

An assessment should be made of:

- Whether the collected data is suitable for inclusion in the flood hazard modelling.
- What level of confidence can be applied to the collected data.
- Whether the quality of the data, or lack of data, is likely to result in limitations being placed on the use of the final model results.
- Whether additional data should be collected prior to commencing the modelling.

It is noted that flow data recorded before the 1970s should be treated with caution due to the limitations of the data collection methods at the time. Greater Wellington's statistics for flow sites are calculated from the mid-70s onwards.

3 Catchment Information

Catchment information is an important input to both hydrological and hydraulic modelling. Catchment information may include:

- Details of current land use and historical land use changes. Details of future (planned) land use changes may also be of interest, such as where large-scale urban development is planned for the catchment, or land use changes permitted under district plan zones. This information may be obtained from a range of sources such as current and historical aerial photography, catchment reports, and GIS datasets.
- Details of structures located on the watercourse being modelled such as bridges, culverts and flood protection structures (i.e. stopbanks), the design standards for these structures, and when they were built relative to historic floods.
- Historic river channel information and details of modifications to stream banks, i.e. erosion protection works.
- Geological information, to assist with understanding of infiltration and runoff rates.
- Previous modelling and associated technical reports.

It is noted that the collection and review of survey and LiDAR data is discussed in Section 5. The minimum requirements for the collection of catchment data (where available) is listed in Table P1-2 below.

Table P1-2 Minimum requirements for gathering catchment data

Data type	Data to be collected (where available)
Aerial photography	Current and historical aerial photography showing catchment land use
Technical reports	Catchment studies or watercourse studies
Land use	Geospatial datasets of land use, records of land use change
Buildings	Geospatial dataset of buildings within the catchment that may affect flow paths
River structures	Records of bridges, stopbanks or other flood control structures etc. Data verifying losses across structures, where available.

It is noted that Greater Wellington's Guide to Flood Protection Advisory Responses may assist with locating catchment specific flood information.

The quality of all gathered catchment information, and the applicability of the data to the required model scenarios should be assessed.

4 Historic Flood Data

Historic flood information is required for calibration and validation of flood hazard models. Historic flood information can be gathered from both Greater Wellington and public records, and the private records of the community.

The minimum requirements for the collection of historic flood information from Greater Wellington and public records is listed in Table P1-3.

Table P1-3 Minimum requirements for collection of historic flood data from GWRC and public records

Data type	Data to be collected (where available)
Photography	Photographs of previous flooding. It is noted historical flood photography and levels can be found on Greater Wellington's Flood Protection WebApp on the Greater Wellington website.
Technical reports	Previous flood studies and modelling reports.
Flood records	Recorded levels, incident reports, flood marks, damage reports, newspaper articles, CCTV footage, TV news footage.

The quality of the collected data should be assessed, including:

- Whether photographs have been time and date stamped, and if not, whether the timing can be verified.
- Whether the location and direction that the photos were taken from is clear, and correct.
- The source of historic level data and how this was measured i.e. was the level surveyed?
- Whether the recorded flood extents and levels may have been affected by other factors, such as blockage, wave action etc.

4.1 Community data

The community, in particular residents who have lived in an area for a long time, may have information about historical floods that is unknown to Greater Wellington, and could be useful for model validation.

In accordance with the FHMS flow chart in Figure P1-1, community consultation should be undertaken at a number of stages within the FHMS process. The first consultation session should be commenced early in the process to enable the collection of community flood information to inform flood hazard model validation.

4.1.1 Role of the Territorial Authority

The local Territorial Authority (TA) should be consulted prior to undertaking community consultation. The role of the TA in the on-going community consultation associated with the flood hazard modelling project should be agreed during this consultation, noting that different levels of involvement are preferred at different TAs.

The TA may also have information on consultation methods that have been found to be effective or ineffective within their local government area.

4.1.2 Notifying the community of upcoming consultation and data collection

Effective communication of upcoming consultation and data collection is required to ensure that:

- The community is aware that consultation relating to flood hazard modelling that may affect their community is being undertaken.
- The community is aware of when and where this consultation will happen.
- The community has sufficient notice of the consultation to enable them to make arrangements to attend.

- The community is aware that the consultation involves the gathering of historic flood information from the community, why this type of information is being gathered, and types of information they should bring to the session.

Notification of the consultation and data collection should be undertaken by methods that are targeted to the demographics of the community. Methods could include:

- Letter drop in mailboxes. Previous Greater Wellington experience indicates that personal letters can be more effective than flyers which could be mistaken for advertising.
- Notices in public areas, such as the local library.
- Notices in the local newspaper.
- Posts on social media. It is noted that sponsored posts may reach a larger audience.

Methods that are correctly targeted to the demographics of the community are likely to be more effective. For example, a notice in the local newspaper or letter drops may be most effective in communities with a high proportion of older people, whereas social media may be more effective in younger communities. A range of methods could be applied to capture the entire demographic.

4.1.3 Gathering data

Data may be gathered from the community via a number of avenues including:

- In person drop-in sessions – these sessions can be used to tell the community about the flood hazard modelling project and seek community flood knowledge.
- Community walk-arounds – a walkover of a property previously affected by flooding with the landowner.
- Website – a form or hub could be set up on the Greater Wellington website for people to upload photos and flood information.
- Email address – an email address could be provided for community members to send their flood information to.

Where in-person sessions are held, it is important that the hydraulic modeller attends to ensure that details of reported flood events are correctly captured.

4.1.3.1 Drop-in sessions

Drop-in sessions can be used to obtain flood information from the community and to share information about the flood hazard modelling project. This in-person approach may reduce the likelihood of misunderstanding the information provided by the community.

During these sessions, Greater Wellington should provide the following information:

- Description of the flood hazard modelling work being undertaken by Greater Wellington.
- What the process for flood hazard modelling is (i.e. this FHMS process), and how seeking historic flood information from the community fits in.
- What types of flood information are sought from the community.
- When the next consultation session will be.

The format of drop in sessions should be determined on a project by project basis, suited to the demographics of the particular community. Some options include:

- Running a presentation on a regular basis throughout the session (i.e. every 15 minutes).
- Displaying visual aids, such as newspaper articles of flood events to help jog memories, and previous flood maps as a starting point for discussion.
- Printing a large map of the study area to allow members of the community to identify previous flood locations, and tell the story of the event. The contact details of each contributor should be recorded to allow for clarification at a later date, if needed.

Attendees should be encouraged to bring materials such as photos to the drop in sessions to confirm and clarify flood locations and behaviour. Previous Greater Wellington experience indicates that it is more difficult to obtain photos after the session.

4.1.3.2 Community walk-arounds

Where significant flooding has occurred on a property, a walk-over with the landowner can be used to observe and map where flooding occurred during both large and regular flood events. During the walk around the landowner should be asked about flood depth, locations of ponding and flow, and factors that may have affected flooding such as blockage of structures.

4.2 Types of data

The types of data that can be collected from the community are outlined in Table P1-4.

Table P1-4 Data to be collected from the community

Data type	Data to be collected (where available)
Photography	Photographs of recent and historical flooding, including where the river has not broken its bank. Photos that are time and date stamped and where the location and direction the photo is taken is known are preferred where available.
Marks on structures	Locations of marks on buildings or private structures indicating the level that flood waters reached, and the date the flooding occurred.
Recollections	Information on flood depth, information on flood behaviour such as areas of ponding and flow, timing (eg, this area floods first), information on structures that blocked, and events that may have affected flood behaviour eg, sandbagging. Any changes in flood behaviour due to changes in the river morphology. Members of the community may also share information about how they were impacted by flooding (such as which roads became blocked) which may help to tell the story of the flood event and assist with calibration.

4.3 Quality control

The quality of the data gathered from the community should be assessed to confirm its likely accuracy. A number of approaches can be applied, such as:

- Community members can be asked to ‘self-rate’ their level of confidence in the information they have provided.
- Comparison to hard evidence such as photos.
- Comparison to recollections from other members of the community, to identify contradictions.
- Modellers estimate of reliability based on modelling results and hard evidence.

It is noted that inconsistencies in the information provided by community members may be a result of a communication error. Where contact details are provided during the collection of the information, the community member should be contacted to clarify or confirm understanding of the information. Other inconsistencies may be the result of a localised intense rainfall burst, blockage, or flooding caused by other factors such as a surcharged manhole.

Any inconsistencies identified and the quality of the information gathered should be noted in the relevant modelling report. The modeller should justify the use or exclusion of gathered data in the calibration or validation in the modelling report.

5 Topographic and Bathymetric Data

Spatial data, such as catchment topographic data and river bathymetry is a key input to flood hazard models. As these data define the river channel, top of bank elevations and floodplain morphology within the model, inaccuracies can have a significant impact on model results, including inaccuracies in the location, extent and depth of flooding.

As such, it is important that all available topographic and bathymetric data is gathered prior to commencing modelling, and that this data is thoroughly assessed to determine its quality and limitations. Where this assessment determines that additional data collection (i.e. further survey) is required then this should be undertaken prior to the commencement of modelling, where possible.

5.1 Data collection – existing data

A review of existing data availability should be undertaken prior to the commencement of flood hazard modelling. The types of spatial data that should be collected to support flood hazard modelling are summarised in Table P1-5 below.

Table P1-5 Spatial data to be collected

Data type	Data to be collected (where available)
Catchment and floodplain topography	Digital elevation model of the catchment and/or floodplain. The model should exclude surface features such as buildings and vegetation.
Channel topography and bathymetry	Surveyed cross-sections at regular intervals along the river channel and major tributaries.

This information may be available from Greater Wellington and/or territorial authorities. These data types are described in more detail in the sections below.

5.1.1 Digital elevation model

A digital elevation model (DEM) is a 3D model of the elevation of a portion of the earth's surface. It may be created from topographic survey, photogrammetry or LiDAR data. In flood hazard modelling, a DEM may be used to inform inputs to hydrological modelling (i.e. catchment slope), to define the bank and floodplain elevations in a 1D-2D linked model or 2D hydraulic model, or to map the flood extents resulting from channel overtopping in a 1D hydraulic model.

When used for flood hazard modelling, it is important that surface features such as vegetation has been filtered out of the DEM such that the 3D-surface represented is the true ground surface. Insufficient filtering of dense vegetation or other surface features may result in an incorrect representation of flood extents and/or behaviour.

5.1.2 River channel survey

Cross-sectional surveys of river channels are used in hydraulic modelling to provide a representation of the river channel shape and volume at the cross-section location, and an interpolation of channel shape and volume between cross-sections. River cross-section surveys typically include river bank and bed levels, including levels below the water surface.

5.2 Assessment of data quality

The quality of available topographic and bathymetric data should be assessed to determine:

- Whether the data is of sufficient quality for inclusion in flood hazard modelling, given the purpose of the study (i.e. detailed study, or catchment wide model). The required data quality may vary throughout the catchment, for example a higher data quality may be required where a river passes through urban areas or there is a risk of flow breaking out of the channel compared to flow through confined gorges or catchment headwaters. Where data is considered to be of insufficient quality for inclusion in flood hazard modelling commentary should be provided on the reasons the data quality is insufficient, and what actions could be taken to improve the data quality or data from alternative sources.

- Whether there are any gaps in the available data (i.e. is topographic data available for the whole catchment? Have cross-sections been surveyed at key tributaries?)
- The age of the data and whether it is still appropriate for use in modelling i.e. has there been channel aggradation or degradation since the data was collected?
- What limitations the quality of the existing data may place on the model results.
- Whether any additional data capture (survey or LiDAR) is required.

5.2.1 Digital Elevation Model

The quality assessment of the DEM should include (but is not limited to) a review of:

- Whether a DEM is available (or needed) for the entire study area.
- Whether unusual shapes are present in the DEM that may indicate insufficient filtering of structures and vegetation. For example, where a row of houses has not been sufficiently filtered out of a DEM a series of cone shapes may be apparent. This originates from the original data capture detecting true ground elevations around individual houses, while also detecting points on the roof of the house, which is interpolated as a cone or other raised shape.

  Bridges may also be represented in a DEM by higher elevation within the river channel.

  - If the filtering undertaken is insufficient, the original cloud point data should be sourced for re-processing of the DEM, if possible.
  - The DEM may need to be edited to appropriately represent flow paths such as under bridges, tunnels and verandas/walkthroughs.
- Comparison of the DEM to other available topographic data, such as survey. For example, comparison of top of bank elevations between surveyed river cross sections and the DEM.
- Review of the tidal conditions and water levels in watercourses, ponds and lakes at the time the LiDAR was flown to confirm whether the DEM represents typical conditions around these features.
- Assessment of whether the spatial resolution is sufficiently fine for input into the hydraulic model. Note that the acceptable spatial resolution may vary across the catchment.
- Assessment of whether the vertical resolution of the DEM is suitable for the application.
- The age of the dataset, and whether works have been undertaken in the catchment since the data was captured (eg, new development) or whether features in the catchment may have been affected by natural processes such as stopbank subsidence, severe river erosion, or land shifting due to large earthquakes etc.

If the assessment determines that additional data collection is required, the data capture area and the required spatial and vertical resolutions should be determined and reported to Greater Wellington.

5.2.2 River channel cross-sections

It is noted that river cross-sections are available for the majority of the major rivers within the Wellington Region. In gravel bed rivers, surveys are undertaken on a regular schedule as part of gravel extraction works that are undertaken for flood management.

The quality assessment of river channel cross-sections should include (but is not limited to) a review of:

- Whether the spacing between cross-sections is sufficient, or whether more cross-sections need to be captured.
- Whether cross-sections for any tributaries are available or needed.
- Whether the length of the cross-sections is sufficient (i.e. do the cross-sections extend to the top of bank? Is information needed beyond top of bank?).
- Whether the spacing of collection points across the section are sufficiently dense.

- Whether the surveyed vertical accuracies are acceptable.
- The age of the cross-sections, and whether there have been any floods, severe bank erosion, channel aggradation or degradation since the cross-sections were captured.

If the assessment determines that additional data collection is required, the number, location and extent of cross-sections required should be determined and reported to Greater Wellington.

5.3 Data capture

Where the findings of the data review indicate that additional data capture of topographic and bathymetric data is required, the protocols in Sections 5.3.1 and 5.3.2 should be applied.

5.3.1 LiDAR

LiDAR (light detection and ranging) is a technique used to capture topographic data through a device mounted to an aircraft or large drone that emits pulses of laser light and measures the time it takes for the reflected light to return to the sensor after bouncing off the ground, or other object (i.e. water, a building or vegetation) on the surface.

Where data collection by LiDAR is required, this work should be commissioned using **Specification 1: LiDAR**. This specification outlines how this work should be undertaken. A summary of key points is included here:

- Data should be captured in NZTM2000, vertical elevations should be in Wellington Vertical Datum 1953. Where the survey is undertaken in the Wairarapa, the vertical datum should be confirmed with Greater Wellington prior to commencement.
- The LiDAR should capture sufficient ground points to ensure that the ground elevation is captured. Additional points may be required in areas of dense vegetation. Ground verification should also occur.
- In areas with dense riverbank vegetation, LiDAR should be flown in winter when deciduous trees are not in leaf, to improve capture of ground points. LiDAR collection should not be undertaken when there is snow cover or when the ground is flooded, as this will prevent the capture of true ground levels. Near the coast, LiDAR should be flown at low tide.
- The spatial and vertical resolution should be agreed with Greater Wellington prior to commencement and may vary across the survey (i.e. with increasing detail near to the river channel).

5.3.2 Survey

Ground based survey may be undertaken to capture specific features such as stopbank elevations, or in areas where capture of accurate LiDAR is not possible (eg, under water or under dense vegetation). Survey may also be used to capture topographic features that are too fine to be picked up in LiDAR accurately, for example, narrow tributaries.

Ground survey may also be undertaken to capture additional or more up to date cross-sections of the river channels.

Additional ground survey work should be undertaken in accordance with **Specification 2: Survey** of the FHMS. This specification outlines how this work should be undertaken. A summary of key points is included here:

- Data should be captured in NZTM2000, vertical elevations should be in Wellington Vertical Datum 1953. Where the survey is undertaken in the Wairarapa, the vertical datum should be confirmed with Greater Wellington prior to commencement.
- For cross-section surveys:
  - Where existing cross-section locations exist, the survey is to be undertaken at these locations. Where new cross-section locations are to be surveyed, the locations are to be agreed between Greater Wellington and the hydraulic modeller.
  - Profile spot heights shall be taken at no more than 1 m intervals where the profile is even. Within the river flow, spot heights should be taken at no more than 0.5 m intervals.
  - The water level at the time of survey must be recorded for each cross-section. Where a river is braided a water level is required for each channel.

5.3.3 Other techniques

It is noted that alternative technologies, such as the use of a drone (using photogrammetry or LiDAR) or a drone boat with sounder may be appropriate in some cases.

Where proposed, the use of these technologies should be discussed with Greater Wellington and approved prior to undertaking the survey.

6 Structures

The as-built details of structures within the river channel and floodplain, such as bridges and culverts, are required to inform the hydraulic model. It is important that the details of these structures are accurate in order to allow the model to reliably estimate potential constrictions to flood flows, and to estimate hydraulic losses over the structures.

All available details of structures within the river channel and key structures within the floodplain should be gathered during the initial data collection phase prior to commencement of the hydraulic model build. This information may be obtained from as-built drawings or previous survey and should be requested from Greater Wellington, the territorial authority or the asset owner (eg, NZTA).

The quality assessment of the as-built drawings, and/or previous surveys should include (but is not limited to) a review of:

- The age of the as-built drawings or previous survey, and whether the structure could have been modified since this time.
- The condition of structure (i.e. has the structure washed out, been damaged by floods or is there long-term blockage/capacity reduction due to aggradation).
- Whether the existing data contains all of the details that are required.

Where as-built drawings are unavailable, do not contain all details required or are considered to be unreliable or not representative of current conditions, then new survey may be required. This should be confirmed with Greater Wellington on a case by case basis.

Where survey of structures is required, this work should be undertaken in accordance with **Specification 2: Survey** of the FHMS.

7 Post-event Data Collection

Large flood events represent an opportunity to gather valuable data on the extent, depth and behaviour of flooding, the performance of structures and flood defences, and the impacts of large events on the community. These insights can be used to calibrate and/or validate both existing and new flood hazard models. As such, post-event data will be collected for all flood events greater than a 20% AEP event. Data may be collected following more frequent events at Greater Wellington's discretion.

Flood event data should be collected during an event where it is appropriate and safe to do so, or as soon as possible following an event, and in accordance with this guidance as much as practicable. In some cases, it may be appropriate to deploy equipment to collect flood data prior to a potential event if severe weather is forecasted. The health and safety of Greater Wellington staff, contractors and the community takes priority over any data collection. All health and safety protocols must be followed.

Data collection should be undertaken with sensitivity to those impacted. Members of the community who have suffered loss or disruption to their home, belongings or business or have become isolated during a flood event may be experiencing significant stress and may prefer to share their recollections at a later date.

Post-event data should be collected across all categories of data collection outlined in Sections 2, 3, 4 and 5 of this procedure and should include the following tasks:

- Visit to the impacted area during or after the flood event to take photographs and make observations where it is safe to do so.

- Engage contractors to undertake aerial and/or drone photography to capture flood extent, blockage of significant structures, and impacts including flooded housing, commercial, industrial and rural areas, damage or disruption to infrastructure including roads and bridges, and areas that have become isolated. Flood protection structures such as stopbanks and flood diversion structures should also be photographed for later assessment of performance. Photography should be undertaken as close to the event peak as possible.
- Engage surveyors to undertake survey of flood debris marks and water marks.
- Record flood protection activities that were undertaken prior to or during the event such as opening or closing flood gates, including the timing when these measures were undertaken.
- Desktop data collection – including collection of hydrometric data, and footage from social and traditional media.
- Engagement with community after the event.

A summary of the required data to be collected during a large event is provided in Table P1-6 below. The extent of the data collection for each event will be determined by Greater Wellington on the basis of the magnitude and impact of the event and existing data availability.

Where there is warning of a large weather event that may cause flooding, additional data capture methods may be deployed prior to the event. For example, installation of temporary cameras on bridges or other structures.

Table P1-6 Data to be collected

Data type	Data to be collected (where possible)	Collection methods
Hydrometric data	Event rainfall and catchment antecedent conditions. Water level and velocity in watercourse. Backwater conditions (i.e. tide and water levels in conjoining watercourses). Event river conditions that may impact existing rating curves i.e. bed scour, significant bank erosion.	Confirm whether event was captured via Greater Wellington's rain and river gauge network. Opportunity to deploy additional data collection devices (i.e. cameras) if warning of severe weather. Undertake flow gauging where safe to do so. On-ground, aerial and/or drone photography. Topographical / bathymetric survey of bed and banks (see below).
Catchment Information	Catchment conditions during the event that have potential to impact flood behaviour and structure performance (i.e. forestry slash/recent land clearance, significant earthworks in the catchment, condition of dams such as spilling, overtopping etc).	Discuss catchment conditions with Greater Wellington operations team. Discuss dam conditions during the event with operators and request data if available. Recent aerial photography or drone footage where available.
Community data	Community observations around flood extent, flood depth, timing of peak, flood behaviour. Observations of blockage and debris load. Photographs and videos. Flood protection and civil defence activities undertaken that may have altered the extent, depth or behaviour of flooding e.g. sandbagging, operation of flood gates, cutting river mouth prior to or after the event.	Obtain any photographs or video from media outlets including TV and news media. Obtain photographs and video from social media – consider a sponsored post requesting footage. Interview impacted community members. Obtain CCTV and home security camera footage where available. Request information from civil defence.

Topographic and bathymetric data	Flood marks (flood depth). Floor level survey of flooded homes may also be useful. Flood extent. Changes to channel topography and bathymetry i.e. scour. Damage to flood defences.	Topographical survey of debris marks or water marks. Aerial/drone photography (ideally during the flood peak). Cross-section survey where morphological changes to the river channel have been observed or are suspected could be considered. However, it is noted these changes may be short term. The cost-benefit of this survey should be considered on a case-by-case basis. Survey of damage to flood defences.
Performance of structures	Audit/site visit of structures to see where blockage may have occurred and the type of blockage (e.g. wooded debris raft, urban debris such as shopping trolleys and vehicles, or sediment). Photographs of structure blockage.	Site visit Review community or operations information on performance Photographs and video from media, community, social media.

7.1 Event photography

Photographs can provide critical information for calibration or validation of flood hazard models, particularly when photographs are captured at or near the flood peak. To provide the best information, event photographs should include:

- A timestamp (date and time the photo was taken).
- The location that the photo was taken from, and the direction the camera was pointing. This can be recorded manually or by enabling GPS settings in camera (if available). Photos that include easily identifiable features such as street signage, landmarks or shop fronts are helpful.
- Scenes showing flood extents (aim to include the edges of the floodwater where possible), depths, blockage, surcharging structures, areas where flow is constricted and flow paths. Where possible, photos of structures should be taken from both the upstream and downstream side.
- Scenes showing areas that have been impacted by flooding such as blocked access routes, flooded buildings, and blocked or damaged infrastructure.
- The water level relative to flood defences (i.e. stopbanks). Anything that may be causing localised impacts on flood level i.e. waves should be noted.
- The locations of debris lines and silt (with location context) if the flood peak has passed to help identify the maximum flood extent.

8 Documentation

8.1 Data Register

All data and documents gathered as part of the FHMS process should be recorded in a data register. The data register records the name and type of data, source, date collected, any limitations or licencing associated with the use of the data, and a summary of any assessment of the data quality, or key findings during analysis of the data or review of a document. The data register should also include justification for including or excluding data from the hydrological or hydraulic model. A template for this register is provided in Appendix P1-A

The purpose of the data register is to:

- Provide an audit trail that may be used during peer reviews and/or independent audit.

- Clearly identify all of the data that has been collected and reviewed.
- Clearly outline the quality of the data, any issues identified, and if these can be addressed by the collection of additional data or the use of other datasets.

The completed data register should be provided to Greater Wellington on completion for review by the Greater Wellington hydraulic modeller. The data register should be appended to the hydrology and hydraulic modelling reports.

8.2 Reporting

The data gathering and assessment undertaken under this procedure should be documented in the hydrology report (**Procedure 2**) and hydraulic modelling report (**Procedure 4**), where relevant to each.

8.3 Modeller’s acceptance

As outlined in Section 1.4, where the data gathering and review of the quality of the available data required by this procedure is not undertaken by the hydraulic modeller used to build the hydraulic model, then the hydraulic modeller must:

- Undertake a review of the data gathering and suitability documentation.
- Identify any limitations that the available data/data quality may place on the model results.
- Confirm whether they agree with the data gathering and suitability assessment, and raise any concerns.
- Identify whether any additional data needs to be collected before modelling should commence.
- Confirm their acceptance of the suitability of the available data into be used the hydraulic model.

The modeller’s acceptance should be provided to the Greater Wellington in writing.

9 Procedure Review

This procedure is intended to be a living document that can be revised as technology advances and best-practice evolves.

The need for review of the procedures within the FHMS, including this one, will be determined at the end of each modelling project at the ‘process review / lessons learnt’ checkpoint on the FHMS flow chart.

PROCEDURE 02

HYDROLOGY

This procedure has been prepared to outline the protocols to be followed by any person undertaking hydrological modelling for Greater Wellington's flood hazard modelling projects.

Greater Wellington
Te Pane Matua Taiao

Procedure 02

Table of Contents

1 Introduction

This document forms **Procedure 2** of Greater Wellington Regional Council's (Greater Wellington) **Flood Hazard Modelling Standard** (FHMS). This procedure has been prepared to outline the protocols to be followed by any person undertaking hydrological analysis or modelling for Greater Wellington's flood hazard modelling projects.

The protocols in this procedure have been developed to ensure that hydrological analysis and modelling for flood hazard modelling projects is undertaken in a robust and consistent way, and is in line with accepted industry practice. This procedure has been prepared to allow for flexibility of approach, in recognition that the optimal approach may be dependent on catchment and/or project specific factors, the availability and quality of input data, and the end use of the results.

This document should be read in the context of the wider FHMS, and in conjunction with **Specification 3: Hydrology**.

1.1 Hydrology in the FHMS process

Hydrological analysis and/or models are used to estimate runoff from catchments during storms of differing magnitude and duration. They are a critical component of the flood hazard modelling process, the outputs of which are a key input to the hydraulic model.

In the FHMS process, assessment of hydrology is commenced on completion of the steps outlined in **Procedure 1: Gather and Assess Data**. Procedure 1 outlines the requirements for undertaking a comprehensive process of collection and review of all available data required to complete the FHMS process. The intention of Procedure 1 is to ensure that the hydrological and hydraulic models prepared under the FHMS are based on the best available information, and that the limitations of input data and resulting model results are well understood.

Data collected and reviewed under Procedure 1 may include hydrometric data (eg, flow and rainfall data), details of historic floods including recollections from the community, details that may have affected historical floods or hydrometric records (eg, blockage), changes in the catchment that may invalidate historical evidence in a current scenario model validation (eg, a new bridge, land use change), flood information from technical reports, flood incident reports, previous catchment studies, GIS datasets, and aerial photographs.

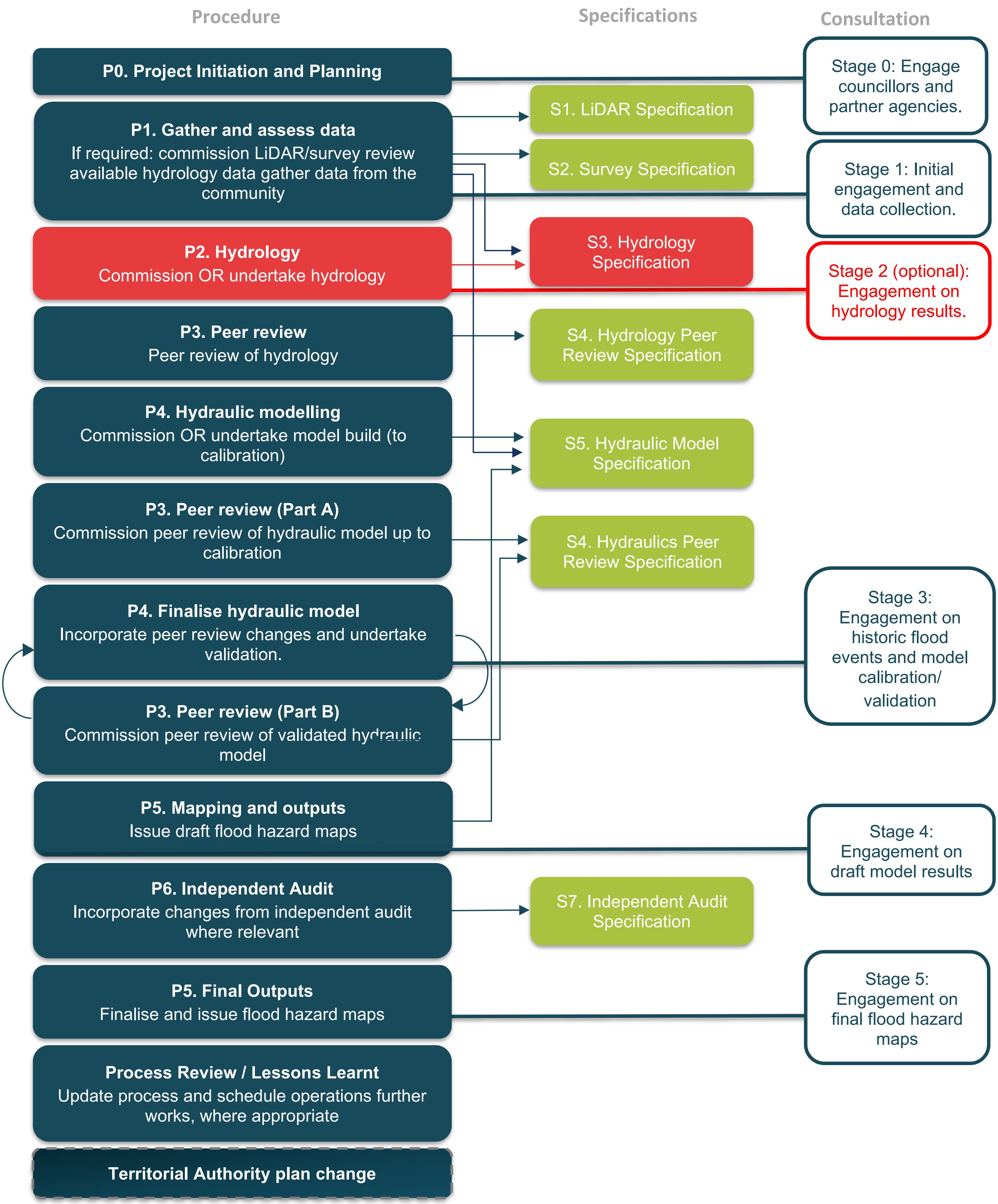
Procedure 2: Hydrology focuses on the development of hydrological inputs for hydraulic modelling including:

- Criteria for determining whether hydrological modelling is required
- At-site frequency analysis using gauge data as inputs to hydraulic modelling
- Protocols for determining rainfall inputs to hydrological models, including event and design rainfall
- Protocols for hydrological method selection
- Design flows required for input to the hydraulic model
- Protocols for model calibration and validation
- Requirements for documentation.

On completion of the hydrological analysis and/or modelling, a peer review of the model and results will be undertaken. The peer review must be completed and closed out prior to inclusion of the hydrological model outputs in the hydraulic model. The process for peer review of the hydrological model is detailed in **Procedure 3: Peer Review**.

The stages of the FHMS process that are related to hydrology are outlined in red in Figure P2-1 below. The FHMS process diagram assumes that no large floods occur in the catchment while the process is underway. If a large flood occurs while the process is underway then it may be necessary to return to earlier steps to include data relating to the recent event in the assessment. This is discussed further in Section 1.2 of **Procedure 0: Process**.

Figure P2-1 FHMS process showing where hydrology is undertaken (red)



2 Approach to peak flow estimation

Peak flows can be estimated across different magnitude flood events using a range of methods of varying complexity. Two broad approaches are discussed in this procedure:

- Statistical/probabilistic methods, primarily flood frequency analysis using at-site flow records.
- Development of a rainfall-runoff model.

The relative advantages and disadvantages of each approach are outlined in Table P2-1 below.

Table P2-1 Advantages and disadvantages of approaches to peak flow estimation.

Approach	Advantages	Disadvantages
Statistical/probabilistic methods	• Relatively simple, requiring expertise but low time input. • Relatively cost-effective approach. • Based on actual data collected from the gauged waterbody. In some cases, area-weighted data from a neighbouring gauged catchment may be appropriate. • Results may be less influenced by modellers judgement than rainfall-runoff modelling in some cases. • Can be updated where more flow data is collected over time.	• Limited by length and quality of available flow records. • Provides peak flow only. Hydrograph timing and shape must be generated by other means. • Unable to adjust the data to account for proposed/future changes within the catchment, such as land use change. • Only applies to the catchment upstream of the flow recorder i.e. unable to estimate peak flows lower in the catchment if catchment conditions are significantly different (i.e. upper hill catchment vs plains in the lower catchment). • Assumes stationarity of data. i.e. there are no trends or cycles in the data such as climate oscillations and there are no changes to the catchment over time.
Rainfall-runoff modelling	• Output is a flood hydrograph. Rainfall-runoff modelling can provide estimates of the shape of the hydrograph and timing of peak flows as well as the magnitude of the peak. • Data used to inform selection of catchment input parameters (i.e. geology, land use) is readily available for much of the region. • Where physically based rainfall-runoff models are used, catchment input parameters can be adjusted to model planned or potential future scenarios i.e. land use change. Similarly, catchment input parameters could be adjusted to account for non-stationarity of catchment conditions.	• More time consuming to develop and therefore less cost-effective than at-site frequency analysis. • Requires specialist software that may be subject to licencing. Software can become obsolete over time, limiting the life of a model. • Confidence in results is limited by data available for calibration and validation. • Some scope for modellers judgement in selection of catchment input parameters.

	• Rainfall-runoff modelling can be undertaken in the absence of a long-term flow record at the site, although there is more confidence in model results where there are several recorded flood events for calibration and validation. In the absence of long-term flow records, catchment input parameters or catchment outputs can be compared to a nearby similar catchment. • Where rainfall-runoff modelling is undertaken in consultation with a hydraulic modeller, the model can be developed to provide hydrographs for specific input locations needed for hydraulic modelling. • Can be re-calibrated if a new flood occurs to improve confidence in results.	

Either hydrological analysis or hydrological modelling may be appropriate to provide inputs to hydraulic modelling. The modeller should assess which method is most appropriate in consultation with Greater Wellington. The criteria outlined in Table P2-2 should be considered when determining the approach to be taken.

Table P2-2 Criteria for determining approach to peak flow estimation

Criteria	Attributes to consider	Description
Purpose of study	Are scenarios related to changing catchment conditions required?	A rainfall-runoff model is likely to be necessary where catchment land use change (eg, post-development) scenarios are required.
Availability of at-site flow records	Availability of at-site flow records within the catchment, or at a similar nearby catchment	Hydrological analysis such as frequency analysis of at-site flow records may be appropriate where a reliable flow record is available in the catchment. The use of frequency analysis and scaling of flow data from a nearby similar catchment may also be appropriate in some cases.
	Length of record	Frequency analysis of at-site flow records requires a long record length. Care should be taken when estimating peak flows for return periods that are greater than double the record length. Where only short records (< approximately 15 years) are available, rainfall-runoff modelling is likely to be required. Longer records are also useful to support rainfall-runoff modelling as there are likely to be more flood events for use in calibration and validation.
Quality of at-site flow records	Completeness of record	Frequency analysis is typically undertaken using the annual maximum flow for each year on record and may incorporate large historical events outside of the continuous record. Where records are incomplete or have large gaps, the annual maximum flow may not be known, creating bias in the data. Where a record has a large number of gaps then rainfall-runoff modelling may be more appropriate.

		However, completeness of record is a limitation to all methods that require analysis of major flood peaks. Calibration of rainfall-runoff models may be limited by incomplete records due to fewer flood peaks to use for calibration and validation.
	Quality of rating	Rating curves are used to transform stage information collected at a water level recording site into flow. Fitting of rating curves relies on manual gauging under a variety of river flow conditions. Gauging at high flow can be difficult to achieve and as such, the upper end of rating curves may not be well supported by gauging at some sites. This means that there is less confidence in the magnitude of flows during high flow events at sites with limited high flow gaugings. This issue affects both frequency analysis and rainfall-runoff modelling.
Location of flow recorder	Representativeness of area to be modelled	The location of the flow recorder should be considered to determine whether it is representative of the point in the catchment being assessed for flood hazard. For example, in a catchment where flooding occurs low in the catchment on the coastal plain, data from a flow recorder in the upper hillslopes of the catchment may not adequately represent the flow at the location of the flooding. Similarly, if a river breaches its banks upstream of the flow recorder gauged flows will not represent risk to the community. In this case, a rainfall-runoff model is likely to provide a better representation of flow than frequency analysis.
	Backwater effects	Flood frequency analysis is unlikely to be suitable where there are backwater effects at the gauge, or if the location in the catchment where flooding occurs is limited by significant backwater, and the gauge is not.
Catchment and river channel homogeneity	Catchment land use changes over record	Rainfall-runoff modelling is likely to be more appropriate where significant changes in land use have occurred over the length of the record, for example urbanisation or deforestation. An alternative would be to exclude data from prior to the land use change if the record length is sufficient.
	River channel changes over record length	Similarly to above, significant changes to river channel morphology or the flood defence scheme may affect the representativeness of the flow record compared to current conditions. This can include the construction of major structures or removal of constrictions, depending on where these occurred in the catchment.

3 Hydrological modelling

Hydrological modelling undertaken for flood hazard modelling projects must be undertaken using methods that estimate hydrograph shape, timing and magnitude, as opposed to methods which are limited to estimation of peak flows only.

A wide range of hydrological methods are available that meet this criterion, including:

- Flood frequency analysis of at-site flow records and a representative hydrograph shape.

- A range of conceptual models, such as the storage routing models used in Hydstra, XP-RAFTS, NAM and RORB.
- A number of empirical models, such as kinematic wave equation with Horton's loss model which is frequently used in stormwater modelling in Christchurch City; and the SCS curve number method used widely in stormwater modelling by Auckland Council, Bay of Plenty Regional Council and Wellington Water.
- Some physical models, such as MIKE-SHE.

Hydrological methods for flood hazard modelling projects should be selected on the basis of:

- Availability of method within the software being used. Software is to be selected based on the criteria outlined in Section 3.1.
- Applicability to the Wellington Region (i.e. is the method appropriate for the climate, soils etc.)
- Applicability to the specific catchment (for example, some methods are only applicable to catchments up to a certain size, and some methods are intended to be applied to urban or rural catchments).
- Applicability to the purpose of the modelling.
- Whether the method is industry accepted in New Zealand.
- Whether the method is widely used in New Zealand, with satisfactory results.

The selection of method should be discussed and justified in the hydrological modelling report. The discussions should include any known limitations with the application of the method.

The protocols for undertaking rainfall-runoff modelling are provided in the sections below.

3.1 Software

Hydrological modelling may be undertaken using any widely available, industry accepted software package. The ready availability of the software package is important to allow the model to be re-run or updated at a later date, if needed.

The modeller should confirm that the software package selected produces outputs that are easily converted or imported into the hydraulic modelling package used by Greater Wellington (likely to be DHI or Tuflow software).

3.2 Model extent

The model extent is to be provided by, or confirmed with Greater Wellington prior to commencing modelling. In determining the model extent Greater Wellington will consider the preferred extent of the hydraulic model, and where hydrological inputs may be required to inform hydraulic modelling.

3.3 Naming convention

A logical naming convention should be adopted for all hydrological models and output files. The naming convention should clearly outline the details of the model run and/or scenario.

It is acknowledged that the appropriate naming convention is likely to vary between software packages, due to differing methods of packaging versions and scenarios. The nomenclature used in the model file naming convention should be described in detail in the hydrological model report and model log, and should be broadly based on the naming convention for model outputs detailed below.

Outputs should follow the naming convention listed in Table P2-3, Table P2-4, Table P2-5 and Table P2-6 below. This naming convention has been adopted to ensure consistency between projects, for ease of use for the end user. The output naming convention shall be:

Project ID _RunTypeRunScenario_ Event_Version

For example,

> For the first version of the hydrological model calibration (calibration event on 20 December 1976) for the Hutt River model, the output name would be:
>
> **HUTT_C19761220_001**

For the final (peer reviewed) version of the design run of the 1% AEP event with allowance for climate change for the Hutt River the output name would be:

HUTT_D_1PCAEPCC_F

Table P2-3 Naming convention – run types

Code	Run Type	Run scenario	Description
W	Working	N/A	Outputs of working files during initial model build
C	Calibration	YYYYMMDD	Calibration scenario described by date of event in year month date format.
V	Validation	YYYYMMDD	Validation scenario described by date of event in year month date format.
D	Design Run	N/A	Design runs using the calibrated and validated model
S	Sensitivity Run	LUC-01	Sensitivity runs for Land Use Change. If multiple land use change scenarios are tested, a number (eg, 01, 02...) should be assigned to each scenario. The land use change applied for each scenario should be outlined in the modelling report.
		ANC-01	Sensitivity runs for antecedent conditions. If antecedent condition scenarios are tested, a number (eg, 01, 02...) should be assigned to each scenario. The conditions applied for each scenario should be outlined in the modelling report.
		LOS-01	Sensitivity runs for losses. If a number of loss scenarios are tested, a number (eg, 01, 02...) should be assigned to each scenario. The conditions applied for each scenario should be outlined in the modelling report.

Table P2-4 Naming convention - versions

Version codes	Version	Description
00X	Versions of model, eg, 001, 002…	Outputs of working versions of the model are distinguished by numbering.
F	Final	The final (peer reviewed and accepted) version of the model output.

Table P2-5 Naming convention – events

Recurrence Interval Code	Recurrence Interval/Event	Description
1PCAEP	1% AEP	Current scenario design runs
2PCAEP	2% AEP	
5PCAEP	5% AEP	
10PCAEP	10% AEP	

20PCAEP	20% AEP	
39PCAEP	39% AEP	
1PCAEPCC	1% AEP	Design runs with allowance for climate change
2PCAEPCC	2% AEP	
5PCAEPCC	5% AEP	
10PCAEPCC	10% AEP	
20PCAEPCC	20% AEP	
39PCAEPCC	39% AEP	
0pt1PCAEP	0.1% AEP	Residual hazard run
1900CUMEC	1,900 m^3/s flow	1% AEP flow for Hutt River only
2300CUMEC	2,300 m^3/s flow	Design flow for Hutt River only
2800CUMEC	2,800 m^3/s flow	Residual hazard flow for Hutt River only

Table P2-6 Naming convention – output types

Code	Output type	Description
MAXWSL	Water Surface Level	Outputs at maximum level, depth or velocity
MAXIND	Inundation depth	
MAXVEL	Velocity	

3.4 Provision of data

Final model files, input datasets, and outputs are to be provided to Greater Wellington on completion of the modelling.

4 Sub-catchment Delineation

The catchment of interest should be divided into sub-catchments for rainfall-runoff modelling. The size and number of sub-catchments should be determined by the modeller based on the purpose of the model and the level of detail required. Sub-catchments should be delineated on the basis of:

- **Significant tributaries:** in models of large river systems, tributaries may be significant waterways. These should be divided into sub-catchments separate from the main river channel. The tributary sub-catchment may be further divided into sub-catchments if required.
- **Catchment characteristics:** sub-catchments should be delineated based on areas that have similar catchment characteristics (eg, topography, landcover, soil type). The effect of the catchment characteristics on time of concentration should be considered when determining whether catchment characteristics are dissimilar enough to require delineation into further sub-catchments. For example, steep or hilly areas should be separated from plains, land cover types with high rates of interception such as forests should be separated from land cover with low rates of interception such as bare ground, urban areas should be separated from rural areas, and areas with poorly

drained soils should be separated from areas with soils that have high infiltration rates. Modeller judgement must be applied to determine the influence of catchment characteristics on model parameters and balance this against overcomplication which can introduce error and unnecessarily increase model runtime.

- **Rainfall:** sub-catchments may be delineated to allow rainfall to be applied differently across the model. This may be to account for orographic effects, or to capture spatial variation of rainfall across the catchment, particularly where a number of rain gauges are present in the catchment.
- **Links to hydraulic model:** sub-catchments may be delineated to provide outputs at specific locations required for input into the hydraulic model, or other locations of interest to the study.

5 Rainfall

Rainfall is the primary input parameter in almost all forms of hydrological modelling. Total rainfall depth, temporal distribution of rainfall throughout a storm, and spatial distribution of rainfall over a catchment have arguably the largest impact on model results of all input parameters.

Two broad types of rainfall data are required during hydrological modelling:

- Event rainfall from actual storm events. This data is used for calibration and validation of hydrological models where modelled runoff from actual storms is compared to flow data recorded during the event or flood information collected during or post the event.
- Design rainfall derived from probability analysis, used for estimating flows during design events (i.e. the events listed in Table P2-7).

These rainfalls are described further in Section 5.1 and 5.2 below.

5.1 Event rainfall

Event rainfall is actual rainfall data recorded during a real storm event. Event rainfall is primarily used for calibration and validation of hydrological models where rainfall from a real storm is run through the model to test the ability of the model to generate river flows or flooding similar to those observed.

Event rainfall should be selected from gauges within or close to the catchment. Gauges that record rainfall at high frequency (i.e. event or sub-5 minute) are considered to have more value than gauges with daily records only. The quality of available rainfall data should also be considered when selecting gauges. This data should be reviewed as part of **Procedure 1: Gather and Assess Data**.

Where multiple gauges exist, interpolation methods should be applied to obtain a representative estimate of rainfall over the spatial extent of the catchment. This is discussed further in Section 5.3.

5.2 Design rainfall

5.2.1 Frequent, Intermediate and Rare events (39% AEP to 1% AEP)

Design runs of hydrological models are undertaken to estimate catchment runoff during a range of storms of differing likelihoods. Under this procedure, design runs involve running a suite of storms with annual exceedance probabilities (AEP) between 39% and 0.1%. For the frequent, intermediate and rare events, design rainfalls can be derived from two sources:

1. Analysis of historical rainfall data from nearby gauge(s). This source should be used preferentially where it is available. Where multiple gauges are present, interpolation methods should be applied as discussed in Section 5.3. Selection of rain gauges should consider the length of the dataset, resolution of the data and the frequency and length gaps in the data.

   Gaps in the rainfall record should be patched based on data from nearby representative gauge(s). Direct patching of rainfall data from one gauge to another is unlikely to be appropriate given that rainfall is typically highly spatially variable. As such, the use of regression (or other) techniques should be considered to determine the relationship between the donor gauge and patched gauge, and to allow for adjustment of donor data accordingly. The methodology applied should be discussed and justified in the hydrological modelling report.

2. NIWA's High Intensity Rainfall Design System (HIRDS). This source should be used when:
   - There are no rain gauges within, or near to the catchment being modelled. The suitability of gauges outside the catchment should be determined based on distance from the catchment, gauge elevation and orientation to prevailing weather systems as compared to the catchment being modelled.
   - Rain gauges within or near to the site do not have a sufficiently long record relative to the events being modelled. For example, 10 years of rainfall record is considered insufficient for estimation of rainfall depths and intensities during a 1% AEP event.
   - Rain gauge data within or near to the site is not of sufficient quality for use in modelling. For example, the data is recorded at low frequency (eg, daily or hourly in small catchments), the record has been poorly maintained, or there are long and frequent gaps in the record.

5.2.2 Very rare events (0.1% AEP)

An estimate of design rainfall during the 0.1% AEP event is required to enable modelling of residual hazard during hydraulic modelling. As incremental rainfall records at most locations in the Wellington Region generally span significantly less than 100 years, any estimation of very rare rainfall events will require extrapolation beyond the range of observations at a site. In many cases extrapolation to the 0.1% AEP event will be beyond the credible limit of extrapolation and as such any estimate of very rare rainfalls includes a high degree of uncertainty and should be used with caution.

Methods to generate 0.1% AEP rainfalls include:

- Calculation using NIWA's HIRDS v4 polynomial function at each rain gauge location. It is noted that NIWA's HIRDS only provides estimates of rainfall intensities up to the 0.4% AEP event, and rainfall estimates beyond this magnitude event are untested.
- Interpolation between NIWA's HIRDS v4 estimates and the probable maximum precipitation (PMP). The Thompson & Tomlinson (1993) method is widely used in New Zealand for estimating the magnitude of the PMP.
- Regional frequency analysis. This involves extraction of an annual maximum series from long term rain gauges within the catchment and similar catchments and fitting of a statistical distribution to provide a pooled estimate of the 0.1% AEP rainfall.

Book 2 of Australian Rainfall and Runoff (2019) suggests that using a GEV distribution fitted using LH-moments could be explored. LH-moments place more weight on larger rainfalls as opposed to L-moments used for more frequent rainfalls.

The approach selected should be discussed and justified in the hydrological modelling report.

Alternatively, a regional flood frequency analysis can be undertaken to generate a pooled estimate of the 0.1% AEP event flood flows (rather than rainfall). This methodology is described in Probable Maximum Flood: Guidelines for New Zealand (NIWA, 2001) and involves selecting annual maxima flood records for rivers in a homogenous region, converting these data into dimensionless flood frequency data and pooling the data, and then fitting a flood frequency curve.

5.2.3 Temporal patterns

Rainfall temporal patterns describe how the total rainfall depth is distributed across the duration of a storm. A wide range of temporal patterns can occur within a catchment. Temporal patterns may vary with storm duration, or with other factors such as type of weather system. For example, NIWA (2018) cites that frontal systems tend to generate peak rainfalls early in the storm, compared to tropical lows where peak rainfalls tend to occur towards the middle of the storm.

Rainfall temporal patterns can be estimated using a number of techniques. The method outlined in the NIWA High Intensity Rainfall Design System version 4 technical report (Carey-Smith, Henderson and Singh, 2018) is most commonly applied in the Wellington Region.

Alternative methods include the average variability method proposed by Pilgrim *et al.,*(1969), and Pilgrim and Cordery (1975) and modified in Australian Rainfall and Runoff (1987). The average variability method assumes a single rainfall burst (i.e. no pre- or post-burst rainfall) and assumes that temporal patterns are independent of probability (i.e. the same temporal pattern applies for frequent and infrequent events).

Book 2 of Australian Rainfall and Runoff (2019) notes that there are a number of limitations with this method, and that it is most effective where there is a dominant temporal pattern. Alternative methods of temporal pattern generation may be applied where they are industry accepted and justified in the hydrological modelling report.

Where more than one temporal pattern is found to be dominant, hydrological modelling may be undertaken using up to two temporal patterns. However, this should be discussed with Greater Wellington prior to commencement.

It is noted that some international guidance, such as Australian Rainfall and Runoff (2016) recommends the use of an ensemble of temporal patterns. This practice has not been widely applied in New Zealand to date.

5.2.3.1 Nested storm

A nested storm is a type of temporal pattern that is most commonly applied in urbanised catchments where stormwater flooding is a key consideration.

A nested storm contains the peak rainfall intensities for each duration 'nested' within longer duration profiles. The peak intensities are typically nested at the centre of the storm, however this can be shifted where appropriate. For example, Wellington Water's reference guide for design storm hydrology found that nesting peak intensities at 67% of the duration was more suitable for small urban catchments in the Wellington Region (Cardno, 2018).

Caution should be applied where nested storms are used for the estimation of riverine flooding as peak flows in watercourses may be overestimated. Care should be taken to confirm whether modelled flows are comparable to gauged flows.

5.3 Interpolation between gauges

Where more than one rain gauge is located within or near to the catchment, methods of interpolation between these gauges should be undertaken to ensure that applied rainfall is spatially representative.

A common method of interpolation is the Thiessen Polygon method, which can be used to develop an area-weighted rainfall series for the catchment. The method applied should be discussed and justified in the hydrological modelling report.

5.4 Areal reduction factors

5.4.1 Design Rainfall

Design rainfalls are typically derived for a specific point in a catchment. In large catchments, HIRDS rainfall intensities generated for specific locations are unlikely to be representative of the rainfall intensities experienced over the entire catchment during a given storm.

To correct for this, areal reduction factors can be applied to adjust point estimates of rainfall intensities to the average rainfall intensity over the entire catchment. Areal reduction factors should be calculated based on industry accepted methods such as those in the NIWA High Intensity Rainfall Design System version 4 technical report (Carey-Smith, Henderson and Singh, 2018).

5.4.2 Event Rainfall

As event rainfall is the recorded depth at a gauge it does not represent the maximum rainfall at a point. The effective mean rainfall depth across the catchment may be greater than or less than the recorded rainfall, although this is unknown. As such, an areal reduction factor is typically not applied.

5.5 Climate change

A number of design runs with allowance for climate change are required to be undertaken, as outlined in Table P2-7. Climate change is to be applied in line with current advice from the Ministry for the Environment (MfE), and should be in line with Greater Wellington's policy.

MfE climate change predictions (at the time of writing of this procedure) are outlined in *Climate Change Projections for New Zealand: Atmospheric Projections Based on Simulations from the IPCC Fifth Assessment, 2nd Edition* (Ministry for Environment, 2018), and equate to an approximate 20% increase in rainfall depth estimates to 2100 based on an 8% increase in peak rainfall for each degree of climate warming, and a 0.7 – 3.0 degree projected temperature increase.

Predictions of percentage changes to rainfall depths for a range of storm durations and recurrence intervals provided in NIWA (2018) should also be considered.

6 Loss Model

Loss models are used within rainfall-runoff modelling to estimate the proportion of rainfall that is translated into runoff during a storm by removing losses. Losses are caused by a variety of physical processes including infiltration into soil, interception by vegetation, evapotranspiration and storage on the surface of the catchment, such as in depressions. There are a variety of loss models available to represent these losses. Loss models widely used in the Wellington Region include:

- **Initial and continuing loss/initial and proportional loss:** a simple and widely used conceptual method that lumps losses from all sources into an initial loss, subtracted from rainfall at the start of the storm, and a continuing or proportional loss subtracted throughout the simulation.

  The initial loss is the amount of rainfall in millimetres that must be exceeded before any runoff can occur from the start of the simulation. This represents an initial wetting of surfaces and filling of soil moisture stores before any runoff is generated.

  The continuing loss (millimetres per hour) or proportional loss (a fixed proportion of the event rainfall lost at each timestep) is applied on an on-going basis after the initial loss has been satisfied and represents on-going infiltration and storage within the catchment. In highly impervious catchments the continuing loss may be zero.

- **Horton's infiltration model (Standard and Modified):** Horton's method is a theoretical model based on infiltration equations. It assumes that all other losses are minor relative to infiltration or are accounted for in the model in another way. Horton's method assumes that runoff is only generated once the rainfall intensity exceeds the soil infiltration capacity and that infiltration capacity declines over the course of a storm as the catchment becomes more saturated and soil moisture stores fill. The standard Horton's equation assumes that the decay of the infiltration rate over time is independent of the rainfall rate and is valid only when the soil infiltration rate is less than the rainfall rate for the entire storm.

  The modified Horton's equation is adjusted to prevent the cumulative infiltration rate from exceeding the cumulative rainfall depth and should be used where the initial infiltration rate exceeds the initial rainfall intensity.

- **SCS curve number:** loss is calculated based on a curve number derived from soil drainage characteristics and catchment land use. A higher curve number represents a lower loss / higher runoff rate. Curve numbers theoretically range from 0 – 100 with zero representing total loss, and 100 representing total runoff. A curve number of 98 is typically used for impervious surfaces such as concrete or open water.

  The SCS curve number method is typically used in stormwater runoff modelling and is the method of choice under Wellington Water's Reference Guide for Design Storm Hydrology, and Auckland Council's guideline TP108.

The loss model applied within the rainfall-runoff modelling should be described in the hydrological report. Loss parameters should be realistic and justifiable based on physical catchment characteristics such as soil type, soil infiltration characteristics and land cover. Loss parameters may vary between sub-catchments based on these characteristics.

7 Runoff Routing

Runoff routing is used to represent the flow of runoff over the surface of a catchment and within channels by routing the runoff through conceptual non-linear storages represented by a storage equation.

Runoff routing occurs following the removal of losses from rainfall. It is the conversion of the resulting rainfall excess to a hydrograph and routed through the catchment. There is often two components to it: sub-catchment routing and river reach routing. Runoff routing allows variability within the catchment to be accounted for as the catchment can be divided into a series of sub-catchment with differing catchment parameters related to their catchment characteristics (eg, soil type, land cover and topography).

Routing parameters vary by routing model but typically include parameters relating to catchment storage, lag time and a non-linearity parameter. These parameters should be adjusted during model calibration. Where catchments are ungauged and limited calibration data is available, routing parameters should be determined based on consideration of routing parameters for nearby gauged catchments that have been previously modelled and calibrated.

8 Calibration and validation

8.1 Calibration

Calibration involves the adjusting of model parameters to alter model results to improve agreement between modelled and recorded hydrographs. Calibration should aim to match all aspects of the hydrograph, including hydrograph peak, volume and timing, where possible.

Calibration should be undertaken for all hydrological models developed under the FHMS where sufficient data is available. Ideally, calibration would utilise rainfall and flow records for at least three flood events of differing magnitudes, with at least one event being greater than a 2% AEP event to ensure that modelled parameters accurately represent catchment runoff behaviour, losses and routing across a range of events.

However, it is noted that data for calibration is often limited within the Wellington Region, and sufficient data for three events may not be available. It is also noted that the confidence in the recorded hydrograph should be considered during this process, particularly with regard to the upper end of rating curves. Calibration should also consider how the catchment may have changed since the calibration event, for example land use change.

The calibration process should be documented in full, including final parameters, and how data quality and changes in the catchment and any other factors were accounted for.

8.2 Validation

Validation is undertaken following model calibration and is used to verify that the model can acceptably reproduce events that are different to the calibration event. This ensures that the calibration parameters are representative of a wide range of possible events that could occur in the catchment.

Where possible, validation should be undertaken for a minimum of three events of varying magnitude. However, it is recognised that for the majority of watercourses in the region sufficient data is unlikely to be available.

8.3 Comparison to alternate methods

Alternative methods of peak flow estimation such as frequency analysis and the regional flood frequency method derived by Pearson and McKerchar (1989), should be used to provide an estimate of peak flow during design storms for comparison to modelled results.

8.3.1 Regional flood frequency method

Pearson and McKerchar (1989) developed a regional method for estimating peak flow for design floods of various magnitudes using contour plans of specific discharge and flood frequency factors. This method was updated with specific maps for the Wellington Region by Pearson in 1990.

If using the regional flood frequency method to validate peak flows, the Pearson (1990) method should be applied. A summary of this analysis should be provided in the hydrological modelling report.

8.3.2 Frequency analysis

Where available, frequency analysis of peak flows should be undertaken using at-site flow data. The results of this analysis should be compared to the modelling results, and reported in the hydrological modelling report.

Care should be taken when estimating peak flows for return periods that are double the flow record length. Consideration should also be given to the record length, level of confidence in the flow gauge and the high flow portion of the rating curve.

9 Design runs

A suite of design runs is required to inform the hydraulic model and the ultimate outputs of the flood hazard modelling process. These design runs include:

- A suite of runs across a range of event probabilities, based on current climate conditions.
- A suite of runs across a range of event probabilities with an allowance for climate change.
- An over-design event for calculation of residual flood hazard. It is noted that the 0.1% AEP event is used as the over-design event. The probable maximum flood is not applied.

The minimum requirements for these runs are listed in Table P2-7 below. Additional design runs may be requested by Greater Wellington on a project by project basis.

Table P2-7 Minimum design runs

Suite	Recurrence intervals
Current climate	• 39% AEP • 20% AEP • 10% AEP • 5% AEP • 2% AEP • 1% AEP (1,900 m^3/s for Hutt River only) • 2,300 m^3/s flow (Hutt River only)
Climate change	• 39% AEP with allowance for climate change • 20% AEP with allowance for climate change • 10% AEP with allowance for climate change • 5% AEP with allowance for climate change • 2% AEP with allowance for climate change • 1% AEP with allowance for climate change
Residual hazard	• 0.1% AEP • 2,800 m^3/s flow (Hutt River only)

9.1 Storm durations

A range of storm durations should be run for each of the recurrence intervals listed in Table P2-7 to ensure that the critical duration of the catchment can be correctly determined for application to the hydraulic modelling undertaken under **Procedure 4: Hydraulic Modelling**.

Appropriate storm durations are likely to vary based on catchment size and level of urbanisation, with smaller and more urbanised catchments likely to have shorter critical durations than larger catchments with less impervious area. A range of storm durations should be selected based on the catchment characteristics, with at least 5-10 durations run for each scenario.

The shortest duration selected should be no less than 10 minutes in small catchments, and is unlikely to be greater than 72 hours in larger catchments within the region.

9.2 Sensitivity analysis

Sensitivity analysis is the adjustment of model parameters within realistic ranges to determine the impact on model results. Sensitivity analysis can be used as an indication of model uncertainty resulting from input parameters that are unsupported by data, particularly where minimal calibration and/or validation data is available.

Sensitivity analysis can also be used to investigate possible peak flows, hydrograph shapes and timing that could occur under conditions outside of those included in the base model run, for example, during wet or dry antecedent conditions, or where there is an increase in impervious area (i.e. urban development) in the catchment.

Sensitivity analysis of key parameters should be undertaken on all hydrological models prepared for flood hazard modelling projects. Sensitivity parameters should include, but are not limited to:

- Antecedent conditions
- Temporal pattern
- Losses
- Land use change, such as new urban development, where likely in the catchment.

Sensitivity analysis should be fully documented in the hydrological modelling report. Output hydrographs from the sensitivity scenarios should be provided to the hydraulic modeller to be included in the hydraulic model sensitivity testing, and for development of uncertainty scenarios.

10 Outputs

The required outputs of the hydrological modelling are outlined in Table P2-8. These outputs are required to:

- Provide inputs for hydraulic modelling.
- Assist the peer reviewer to undertake the peer review.
- Keep records for future model updates and additional design runs if required.

Table P2-8 Hydrological model outputs

Element	Requirement
Hydrographs	All current climate, climate change and residual hazard runs. The hydrographs should be provided in a timeseries format for input into the hydraulic modelling.
Model files	All model files to be provided to the peer reviewer for review, and to Greater Wellington for their records.
Model log	A detailed model log should be kept and provided on completion of the modelling. This is described in Section 11.2.
Geospatial files	All geospatial files used during modelling, eg, catchment boundaries, Thiessen polygons, etc.

11 Documentation

The hydrological modelling should be fully documented to:

- Provide background information, reasoning and assumptions for the peer review.
- Ensure that the model can be reproduced in another modelling software at a later date if required.

- Ensure transparency for the end users of the model results, including the community.

The methods of documentation outlined in the sections below are required for all hydrological models constructed under the FHMS.

11.1 Data register

A data register will be prepared for each flood hazard modelling project as part of works undertaken under **Procedure 1: Gather and Assess Data**. Details of the format of the data register is provided in Procedure 1, and a template is provided in Appendix P1-A.

The data register should be updated with any data gathered or reviewed as part of this procedure. On completion of this component of work the updated data register should be appended to the hydrology report, and provided in electronic format to Greater Wellington.

11.2 Model log

A detailed model log should be kept while undertaking the modelling. This log should be appended to the hydrological report, and should document the model build, assumptions made, and all inputs. The model log should assist with version control and will describe the model naming convention.

The model log should be provided to the peer reviewer to assist with the peer review. A model log template is provided in Appendix P2-A.

11.3 Report

A detailed technical report should be prepared to outline the hydrological modelling undertaken. The report should include, but is not limited to:

- Details of the software used
- Model extent
- Data availability and quality
  - Detailed summary of the analytical process and findings of the data collection and review undertaken as part of **Procedure 1: Gather and Assess Data**
- Details of the rainfall inputs, including:
  - Gauges located within and near to catchment, length of record, and quality of data
  - Method of interpolation between gauges, where undertaken
  - Any areal reduction factors applied
  - Development of design rainfall depths (i.e. frequency analysis or HIRDS)
  - Temporal pattern used, and details of method used to derive the temporal pattern
  - Details of how the rainfall is applied in the model
  - Details of how climate change has been applied to future climate scenarios
  - Storm events used in calibration and validation
- Hydrological methods
  - Summary of the method used including the loss model and routing model and discussion of suitability for the flood hazard modelling project
  - Summary of how sub-catchments were delineated
  - Summary and justification for all parameters used
- Calibration
  - Flood events selected for calibration

  - Results of calibration
- Validation
  - Flood events selected for validation
  - Results of validation
- Alternative methods of peak flow estimation
  - Description of application of alternative methods of peak flow estimation
  - Discussion and comparison to model results

11.4 Feedback form

It is anticipated that the work undertaken under **Procedure 1: Gather and Assess data** and this procedure will increase the understanding of the limitations of the hydrometric stations used in this assessment. As such, a feedback form has been prepared to provide this information to Greater Wellington for consideration for future data collection.

For example, the analysis undertaken under the FHMS may indicate that a flow gauge would be more useful if it was located in a different position in the catchment. This information can be provided in the feedback form.

The feedback form is provided in Appendix P2-B and should be filled out and provided to Greater Wellington on completion of the hydrological modelling.

12 Procedure review

This procedure is intended to be a living document that can be revised as technology advances and industry accepted practice evolves.

The need for review of the procedures within the FHMS, including this one, will be determined at the end of each modelling project at the ‘process review / lessons learnt’ checkpoint on the FHMS flow chart.

13 References

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PROCEDURE 03

PEER REVIEW

This procedure has been prepared to outline the protocols to be followed by any person undertaking peer review of Greater Wellington flood hazard modelling projects.

Greater Wellington
Te Pane Matua Taiao

Procedure 03

Table of Contents

1 Introduction

This document forms **Procedure 3** of Greater Wellington Regional Council's (Greater Wellington) **Flood Hazard Modelling Standard** (FHMS). This procedure has been prepared to outline the protocols to be followed by any person undertaking peer review of Greater Wellington flood hazard modelling projects.

This document should be read in the context of the wider FHMS, and has a particular relationship to **Specification 4: Hydrology Peer Review Specification** and **Specification 6: Hydraulics Peer Review Specification** which provide a template Request for Proposal for engaging external suppliers to undertake peer review.

A peer review template is provided in Appendix P3-A of this procedure. This template should be used as the basis of all peer reviews undertaken as part of the FHMS process.

1.1 What is a Peer Review?

In the context of this procedure, a peer review is an independent, thorough technical assessment of a hydrological or hydraulic model, or outputs of a hydraulic model. The review is based on a 'hands-on' interrogation of a model by a suitably qualified and experienced professional who uses their technical expertise, current best-practice and unbiased judgement to review the work.

The peer reviewer's role is to determine whether the work reviewed meets accepted industry standard, and is of suitable quality to proceed to the next step of the FHMS process.

The suitability of the model should be assessed in the context of the purpose of the model. For example, a model prepared for the purpose of providing flood hazard information to support district planning, may be able to proceed to next stage of the FHMS process even though it does not have sufficient detail for bridge design, given that bridge design is not the purpose of the model, and is not the responsibility of Greater Wellington.

It is noted that a peer review is distinct from an Independent Audit which is the subject of **Procedure 6** of the FHMS.

1.2 Peer Review in the FHMS Process

Peer review is undertaken at three stages within the FHMS process:

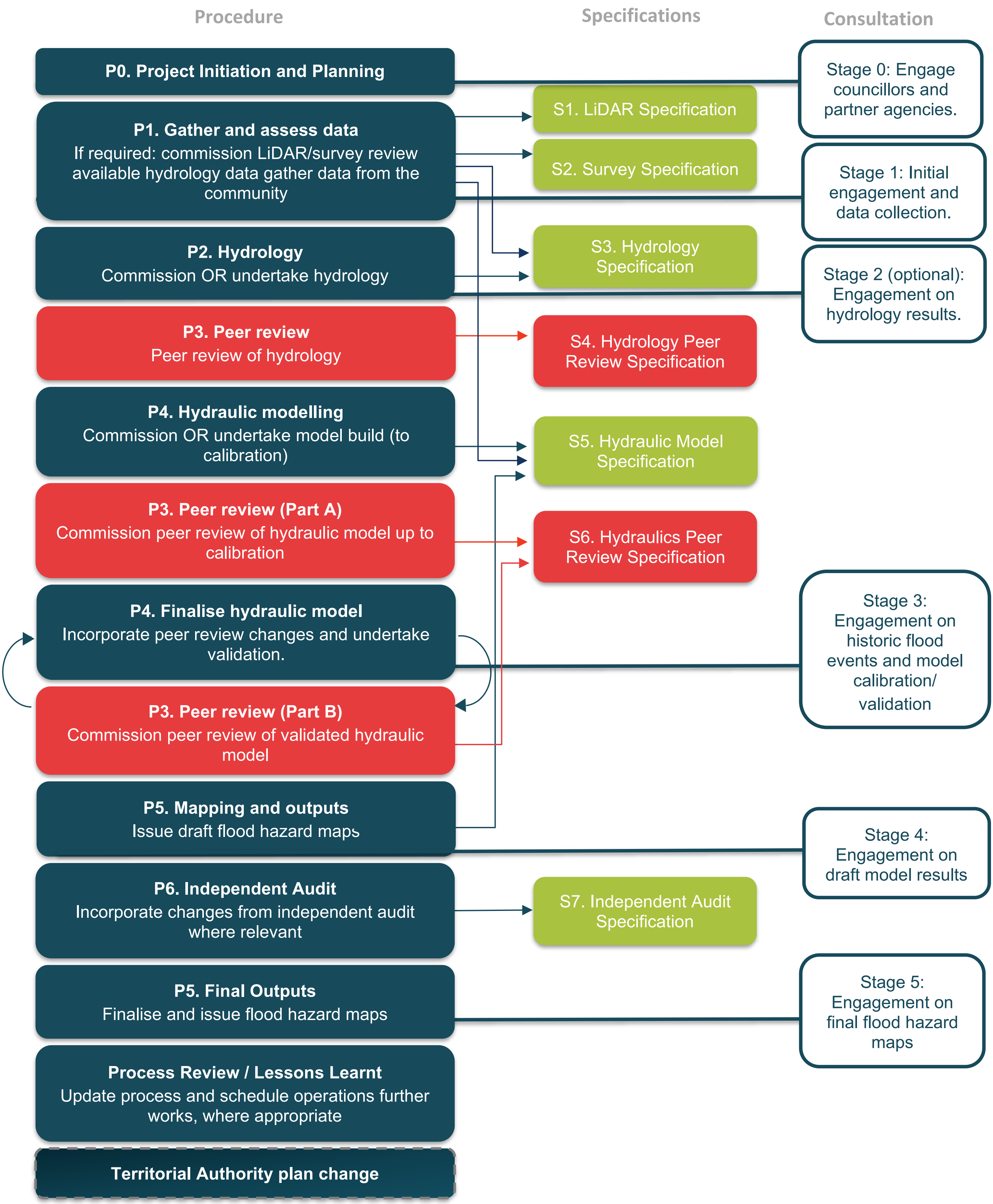
- Peer review of hydrological modelling, on completion of **Procedure 2: Hydrology**
- Peer review of the hydraulic model build and calibration, on completion of Part A of **Procedure 4: Hydraulic Modelling**
- Peer review of the hydraulic model validation, runs, sensitivity testing and draft outputs on completion of Part B of **Procedure 4: Hydraulic Model** and **Procedure 5: Outputs**.

These stages are outlined in red in the FHMS process flow chart provided in Figure P3-1 below. The FHMS process diagram assumes that no large floods occur in the catchment while the process is underway. If a large flood occurs while the process is underway then it may be necessary to return to earlier steps to include data relating to the recent event in the assessment. This is discussed further in Section 1.2 of **Procedure 0: Process**.

Peer review should be undertaken for all new models that proceed through the FHMS process. Peer review may also be undertaken where changes are made to existing models that have the potential to result in changes to district plans or Greater Wellington's flood hazard advice.

Where changes are made to existing models, it is acceptable for the peer reviewer to only review the changes in the context of the model, provided that the model has previously been peer reviewed. If a peer review has not been previously undertaken, then a full peer review is required.

Figure P3-1 FHMS process showing where peer review is undertaken (red)



1.3 Who can be a Peer Reviewer?

Peer reviewers must meet the following criteria:

- Peer reviewers must be independent from the flood hazard modelling project. Independent means that the peer reviewer has not personally been involved with the project at any stage. However, it is acceptable for a peer reviewer to have previously undertaken work separate to the flood hazard modelling project within the catchment.
- The peer reviewer should be from a different organisation than the organisation that undertook the work being reviewed. A person is still eligible to undertake peer review of a model if their organisation was involved in another component of the flood hazard modelling project, as long the peer reviewer was not personally involved in that work. For example, if company A undertook the hydrological modelling, company A is not excluded from peer reviewing the hydraulic modelling, as long as the peer review is undertaken by a different member of staff.
- Greater Wellington staff are not considered independent, and therefore are not eligible to peer review work undertaken under the FHMS process.
- The peer reviewer should not have any form of dependent relationship with the modeller and should have no conflicts of interest relating to the project or modellers organisation including financial or other interests.

1.4 How should a peer reviewer be engaged?

Peer reviewers should be engaged using the request for proposal relevant template in **Specification 4: Hydrology Peer Review Specification** or **Specification 6: Hydraulics Peer Review Specification**.

1.4.1 Liability

Peer reviewers may be liable for damages jointly with the original modeller's organisation if claims against the work are upheld.

The level of liability will be agreed on as part of the contract between Greater Wellington and the reviewer's organisation. All peer reviewers should hold appropriate insurances.

2 Undertaking a Peer Review

When reviewing modelling, the peer reviewer should undertake a detailed hands-on interrogation of the model. The peer reviewer should also review any accompanying documentation such as the inputs (eg, hydrology report and peer review), model log and model report to assist with their understanding of the work undertaken and assumptions made.

The peer reviewer should also consider whether the modelling has been undertaken in accordance with the appropriate procedures of the FHMS (eg, **Procedure 2: Hydrology** or **Procedure 4: Hydraulic Modelling**). If there are departures from the FHMS the peer review is to assess whether these departures and the reasons for them have been recorded and are appropriate, technically correct, and to an industry accepted standard.

The peer review is expected to be an iterative process, and will involve on-going conversations between the modeller and peer reviewer. All comments and each iteration of the work is required to be documented, as outlined in Section 3 below.

It is noted that in undertaking the peer review, the peer reviewer or modeller may place limitations on the use of the model. For example, the peer reviewer may determine that the model is suitable for use for the next 5 years, while additional flow data is gathered, but that the model should be revised after this time.

The peer review is undertaken at three points in the FHMS process:

- Hydrology Peer Review
- Hydraulic Model Peer Review: Part A
- Hydraulic Model Peer Review: Part B and Outputs

The contents of each phase are detailed in the sections below.

2.1 Hydrology Review

A peer review of the hydrological model should be undertaken on completion of the modelling (including calibration, validation and sensitivity testing, and design runs).

The purpose of the review is to assess whether the inputs, assumptions and functioning of the model is technically correct, and has been built according to the requirements of the FHMS and industry accepted practice. The review should also consider the sensibility of the model results.

The peer reviewer should assess all aspects of the model including, but not limited to:

- Suitability of software
- Rainfall inputs, including the suitability of event rainfall used in calibration and validation, suitability of method used for design storm generation, and the suitability of the temporal pattern(s) and areal reduction factors applied.
- Input parameters such as time of concentration and catchment drainage parameters, with consideration given to historical and proposed changes within the catchment.
- Hydrological method
- Run parameters
- Calibration – including calibration data used and approach to calibration
- Review of validation and sensitivity testing
- Review and sensibility check of design storm results
- Review and sensibility check of sensitivity and optioneering results
- Model documentation is complete.

A more detailed list of review parameters is provided in the review template in Appendix P3-A. The peer reviewer may add items to the review template as needed.

The findings of each iteration of the peer review should confirm whether the reviewer's comments have been addressed sufficiently for the project to proceed to the next stage of the FHMS process (i.e. input to the hydraulic model). For the comment to be considered to be addressed sufficiently, the amendments or decision not to amend must be agreed between both the modeller and peer reviewer.

2.2 Hydraulic Model Review: Part A

The first peer review of the hydraulic modelling, referred to as Part A, should be undertaken following the initial hydraulic model build and calibration.

The purpose of this review is to assess the inputs, assumptions and functioning of the model to confirm that the model is technically correct, is stable, and has been built according to the requirements of the FHMS and industry best-practice. This review is undertaken prior to model validation, design runs, sensitivity testing and optioneering.

The peer reviewer should assess all aspects of the model including, but not limited to:

- Model schematisation
- Channel and floodplain modelling – topography (DEM), cross-sections, roughness, structures
- Boundary conditions
- Inputs
- 1D/2D connectivity
- Run parameters

- Model stability, convergence and mass balance
- Calibration – including calibration data used and approach to calibration
- Model results, including 1D long-sections
- Model documentation (model log and internal QA) is complete.

A more detailed list of review parameters is provided in the review template in Appendix P3-A. The peer reviewer may add items to the review template as needed.

The peer reviewer of the hydraulic modelling review is not required to review the hydrology as this will have been peer reviewed prior to the preparation of the hydraulic model. However, the peer reviewer should consider how the hydrology is impacting the hydraulic results and whether this is appropriate or requires further investigation.

For large models, it is acceptable for the peer reviewer to review a random sample of at least 25% of cross-sections, and a random sample of at least 25% of structures for correctness rather than reviewing every element. The sample should include sections and structures from every modelled watercourse within the model.

If a large number of errors are found in the random sample, the model should be returned to the modeller for correction prior to resuming the review. If the reviewer considers that cross-sections or structures in a certain reach are likely to have a larger impact on the results, then these should be reviewed in more detail. It is noted that Greater Wellington may specify areas to be reviewed in more detail, in addition to the random sample. The peer reviewer should confirm with Greater Wellington whether this is the case prior to commencing the review.

The findings of each iteration of the Part A peer review should confirm whether the reviewer's comments have been addressed sufficiently for the project to proceed to the next stage of the FHMS process. For the comment to be considered to be addressed sufficiently, the amendments or decision not to amend must be agreed between both the modeller and peer reviewer.

2.3 Hydraulic Model Review: Part B and Outputs

The Part B hydraulic model review commences following the completion of Part B of **Procedure 4: Hydraulic Modelling**. The purpose of this review is to:

- Review validation and sensitivity testing
- Review and sensibility check of design storm results
- Review and sensibility check of sensitivity and optioneering results
- Sensibility check of preliminary outputs.

The review should include a review of both the changes to the model set up and results as part of the validation, design runs, sensitivity testing and any optioneering.

A more detailed list of review parameters is provided in the review template in Appendix P3-A. The peer reviewer may add items to the review template as needed.

The Part B review includes a sensibility check of the preliminary outputs. After the peer reviewers Part B comments are addressed, the peer reviewer is required to undertake a further review of the revised outputs.

The findings of each iteration of the Part B peer review should confirm whether the reviewer's comments have been addressed sufficiently for the project to proceed to the next stage of the FHMS process.

3 Documentation

The initial peer review and subsequent iterations must be clearly documented. The following documents are required to be prepared to record the peer review, and subsequent revisions:

- Peer review spreadsheet (a template is provided in Appendix P3-A).
- Peer review report

- Peer review close-out

These documents are detailed in the sections below. All correspondence between the reviewer and the modeller should be documented.

3.1 Peer Review Spreadsheets

A template of the peer review spreadsheets is provided in Appendix P3-A. A separate spreadsheet is provided for the hydrology and hydraulics (Part A and Part B) reviews. These spreadsheets must be used to record the peer reviewer and modeller's comments for all peer reviews. The peer reviewer may add additional items to the template, as required.

The peer review template is made up of a number of tabs (blue/green) to record the peer reviewers' findings while interrogating the model. The time and date of issue of the reviewer's comments should be recorded in the spreadsheet to assist with version control.

Each of the comments in the summary table is then given a rating in line with the criteria in Table P3-1 below.

Table P3-1 Review rating table

Review ratings		Model suitable to move to next step in FHMS?
Ok	The element or parameter being used is modelled correctly	Yes
Minor	Issue is unlikely to significantly affect model results	Yes
Major	Issue or approach that may impact model results. Options for resolving a major issue include amending the model or acceptance of model limitations where the objectives of the study are not compromised.	To be determined in discussion with Greater Wellington
Critical	Issue compromises the model and should be rectified before moving to the next step of the FHMS.	No
Other categories		
Future data collection	Identifies where additional future data collection could result in model improvements in the future.	Yes

Source: modified from Beca (2015). Pinehaven Stream Flood Mapping Audit.

The spreadsheet is then issued to the original modeller. The modeller will review each comment and amend the model as necessary. Any changes made to the model and/or responses to the reviewer's comments are recorded in a separate column in the review summary tab of the spreadsheet. The time and date of issue is to be recorded in the spreadsheet.

The peer reviewer is then required to review the comments and changes to the model made by the original modeller, and provide further comments (if necessary) and a further review rating for each comment in a separate column. This process continues until all of the issues have been resolved and the model is deemed suitable to continue to the next stage of the FHMS.

A review log is provided within the peer review spreadsheet. The reviewer and modeller should record the date and the overall outcome of each iteration of the review in this table. Outcome should be defined in accordance with the categories in Table P3-2 below.

Table P3-2 Outcome descriptors

Outcome categories	Description
Action Required	Issues have been identified within the model that are likely to affect the results and should be rectified before the model moves the next stage of the FHMS process.
Suitable to proceed	Issues identified in the model have been rectified (if any), and the model is considered to be of sufficient quality to move to the next stage of the FHMS process.

An example of a completed review log is provided in Table P3-3.

Table P3-3 Example review log.

Hydraulic Model - Part A Review	Date of review/comments	Outcome
Review V1	23 January 2020	Action Required
Modeler's comments V1	30 January 2020	
Review V2	5 February 2020	Suitable to proceed

3.2 Peer Review Report

A brief report should be provided by the peer reviewer following the initial peer review to accompany the review spreadsheet. The review spreadsheet should be appended to this report.

The report should be a clear and concise summary of the peer review process and findings. The peer review report should outline:

- The methodology used to undertake the peer review
- The version of the model and model log reviewed, and any other documents or files reviewed.
- A description of the issues identified. A clear summary of the issues should be provided as list in the executive summary.
- Clear section on data gaps or model improvements that should be filled in the future, where possible.

The report must include a history table that outlines any changes made to the report, and the reasons for those changes.

3.3 Peer Review Close Out

A close out document should be provided after all of the peer reviewer's comments have been addressed. The close out document can be in the form of a short letter or memo.

The close out document should include the following items:

- Confirmation that a peer review was undertaken.
- Confirmation that all of the peer reviewers' comments have been satisfactorily addressed and that the model is suitable to proceed to the next stage of the FHMS process.
- Any caveats or limitations that the reviewer has placed on the model.
- The peer review spreadsheet should be included as an appendix.

The close out document should be dated.

4 Procedure Review

This procedure is intended to be a living document that can be revised as technology advances and best-practice evolves.

The need for review of the procedures within the FHMS, including this one, will be determined at the end of each modelling project at the 'process review / lessons learnt' checkpoint on the FHMS flow chart.

PROCEDURE 04

HYDRAULICS

This procedure has been prepared to allow for flexibility of approach, in recognition that the optimal modelling approach may be dependent on catchment and/or project specific factors, the availability and quality of input data, and the end use of the model.

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Procedure 04

Table of Contents

Greater Wellington
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1 Introduction

This document forms **Procedure 4** of Greater Wellington Regional Council's (Greater Wellington) **Flood Hazard Modelling Standard** (FHMS). This procedure has been prepared to outline the protocols to be followed by any person undertaking hydraulic modelling for Greater Wellington's flood hazard modelling projects.

The protocols in this procedure have been developed to ensure that hydraulic modelling for flood hazard modelling projects is undertaken in a robust and consistent way, and is in line with accepted industry practice. This procedure has been prepared to allow for flexibility of approach, in recognition that the optimal modelling approach may be dependent on catchment and/or project specific factors, the availability and quality of input data, and the end use of the model.

This document should be read in the context of the wider FHMS, and in conjunction with **Specification 5: Hydraulic Model**.

1.1 Hydraulic modelling in the FHMS process

In the FHMS process, hydraulic modelling is undertaken in order to convert estimates of catchment runoff from hydrological modelling into flood levels and velocities by modelling the hydraulic behaviour of flow in the river channel and floodplain.

Results from hydraulic modelling are used to prepare the final outputs of the FHMS process including maps of flood extent, level, depth, velocity and hazard across various storm events.

Hydraulic modelling is undertaken at two stages in the FHMS process:

- **Part A: Hydraulic model build**

  Part A of the hydraulic modelling process is undertaken following close out of the hydrological model peer review. Under the FHMS, hydrological modelling is undertaken in accordance with **Procedure 2: Hydrology** while the peer review of the hydrological model is undertaken in accordance with **Procedure 3: Peer Review**. All aspects of **Procedure 1: Gather and Assess Data** should also be complete prior to commencing hydraulic modelling. This includes a review of the data gathering and suitability assessment documentation by the hydraulic modeller (if they were not the party that completed this assessment). This is discussed in more detail in Section 1.4 and 7.3 of **Procedure 1: Gather and Assess Data**.

  Part A of the hydraulic modelling process includes the model build and calibration. On completion of Part A, a Part A peer review of the hydraulic model is to be undertaken in accordance with **Procedure 3: Peer Review**. This is likely to be an iterative process between the hydraulic modeller and peer reviewer, and may result in changes to the hydraulic model. The Part A peer review is closed out when the peer reviewer is satisfied that the model is suitable to progress to the next stage of the FHMS process.

- **Part B: Finalise hydraulic model**

  Part B of the hydraulic modelling process occurs following close out of the Part A peer review. Part B involves undertaking validation, sensitivity testing, design runs, and the preparation of preliminary outputs.

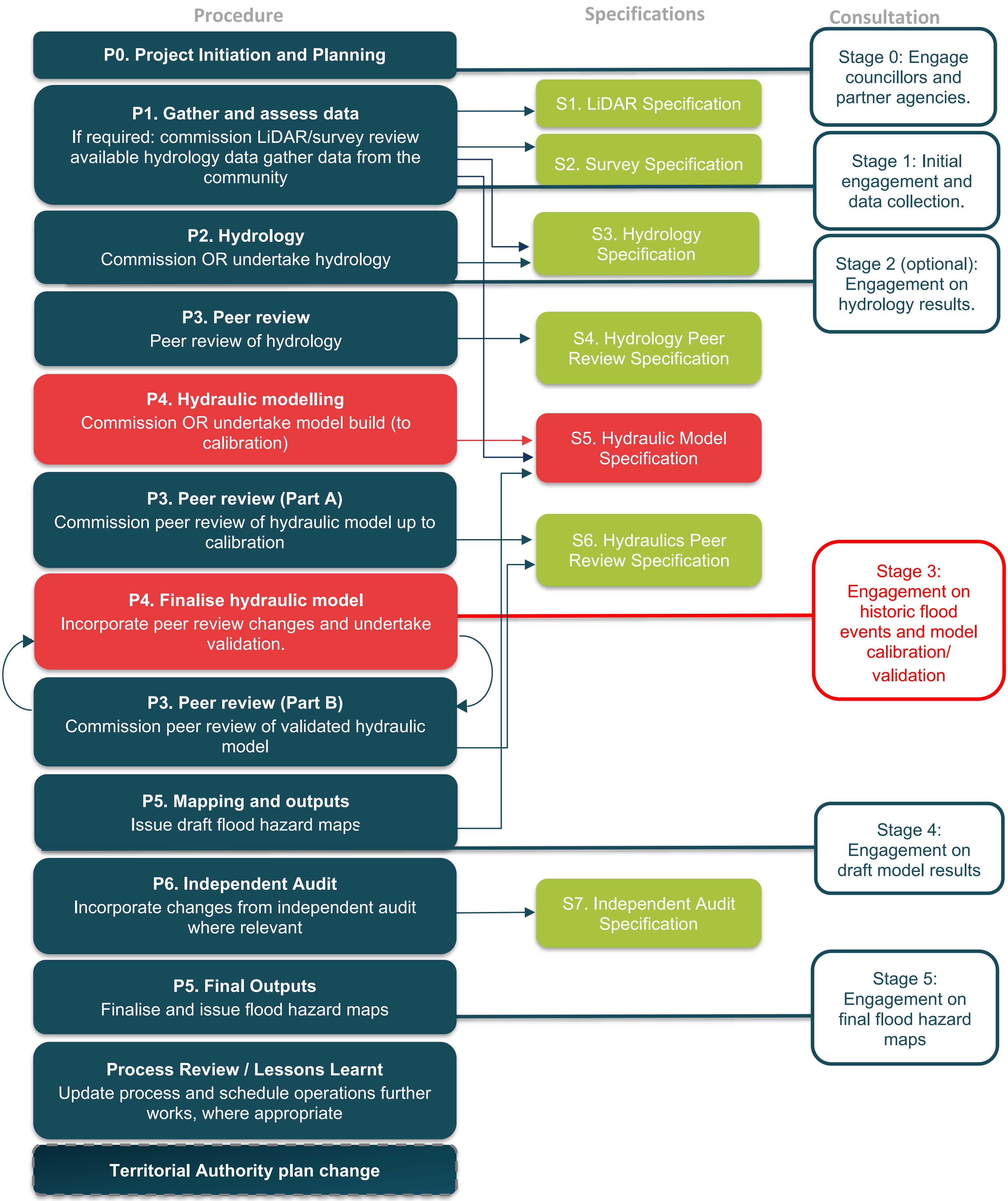
  Outputs should be prepared in accordance with **Procedure 5: Outputs**.

The stages of the FHMS process that are related to hydraulic modelling are outlined in red in Figure P4-1 below. The FHMS process diagram assumes that no large floods occur in the catchment while the process is underway. If a large flood occurs while the process is underway then it may be necessary to return to earlier steps to include data relating to the recent event in the assessment. This is discussed further in Section 1.2 of **Procedure 0: Process**.

1.2 Software

Hydraulic modelling should be undertaken using the software package nominated by Greater Wellington. The preferred software package is Mike by DHI, although consideration will also be given to TUFLOW.

Figure P4-1 FHMS process showing where hydraulic modelling is undertaken (red)



1.3 Model extent

The model extent is to be provided by, or confirmed with Greater Wellington prior to commencing modelling. Greater Wellington will confirm the model extent prior to preparation of the hydrological model.

1.4 Naming convention

A logical naming convention should be adopted for all hydraulic models and output files. The naming convention should clearly outline the details of the model run and/or scenario.

It is acknowledged that the appropriate naming convention is likely to vary between software packages, due to differing methods of packaging versions and scenarios. The nomenclature used in the model file naming convention should be described in detail in the hydraulic model report and model log, and should be broadly based on the naming convention for model outputs.

Outputs should follow the naming convention listed in Table P4-1, Table P4-2 and Table P4-3 below. This naming convention has been adopted to ensure consistency between projects, for ease of use for the end user. The output naming convention shall be:

Project ID _RunType-RunScenario_ Event_Version

For example,

> For the first version of the hydraulic model calibration (calibration event on 20 December 1976) for the Hutt River model, the output name would be:
>
> **HUTTRIVER_C-19761220_001**
>
> For the final (peer reviewed) version of the design run of the 1% AEP event with allowance for climate change for the Hutt River the output name would be:
>
> **HUTTRIVER_D_1PC-AEP-CC_F**

Table P4-1 Naming convention – run types

Code	Run Type	Run scenario	Description
W	Working	N/A	Working files during initial model build.
C	Calibration	YYYYMMDD	Calibration scenario described by date of event in year month date format.
V	Validation	YYYYMMDD	Validation scenario described by date of event in year month date format.
D	Design Run	N/A	Design runs using the calibrated and validated model.
R	Residual Hazard Run	BRE-01	Stopbank breach run. If multiple breach scenarios are tested a number (eg, 01, 02...) should be assigned to each scenario. The breach location and size applied for each scenario should be outlined in the modelling report.
		DWN-01	Stopbank down run. If multiple stopbank down scenarios are tested a number (eg, 01, 02...) should be assigned to each scenario. The stopbank down locations applied for each scenario should be outlined in the modelling report.
		DEF-01	Areas benefiting from defences. If multiple scenarios are tested a number (eg, 01, 02...) should be assigned to

			each scenario. The areas tested in each scenario should be outlined in the modelling report.
S	Sensitivity Run	BLK-01	Sensitivity runs for blockage. If multiple blockage scenarios are tested a number (eg, 01, 02...) should be assigned to each scenario. The blockage applied for each scenario should be outlined in the modelling report.
		RGH-01	Sensitivity runs for roughness. If multiple roughness scenarios are tested a number (eg, 01, 02...) should be assigned to each scenario. The roughness applied for each scenario should be outlined in the modelling report.
		BDY-01	Sensitivity runs for boundary conditions. If multiple boundary scenarios are tested a number (eg, 01, 02...) should be assigned to each scenario. The details of the boundary condition applied for each scenario should be outlined in the modelling report.
		DEB-01	Sensitivity runs for debris loading. If multiple debris loading scenarios are tested a number (eg, 01, 02...) should be assigned to each scenario. The details of the debris loading applied for each scenario should be outlined in the modelling report.
		SHP-01	Sensitivity runs for changes to channel shape to account for bank erosion or bed aggradation or degradation. If multiple scenarios are tested a number (eg, 01, 02...) should be assigned to each scenario. The details of each scenario should be outlined in the modelling report.
		LUC-01	Sensitivity runs using the outputs of the hydrology sensitivity scenario for Land Use Change. If multiple land use change scenarios are tested a number (eg, 01, 02...) should be assigned to each scenario. The land use change applied for each scenario should be outlined in the modelling report.
		ANC-01	Sensitivity runs using the outputs of the hydrology sensitivity scenario for antecedent conditions. If antecedent condition scenarios are tested a number (eg, 01, 02...) should be assigned to each scenario. The conditions applied for each scenario should be outlined in the modelling report.
		LOS-01	Sensitivity runs using the outputs of the hydrology sensitivity scenario for losses. If a number of loss scenarios are tested a number (eg, 01, 02...) should be assigned to each scenario. The conditions applied for each scenario should be outlined in the modelling report.

Table P4-2 Naming convention – versions

Version codes	Version	Description
00X	Versions of model, eg, 001, 002…	Working versions of the model are distinguished by numbering.
F	Final	The final (peer reviewed and accepted) version of the model output.

Table P4-3 Naming convention – events

Recurrence Interval Code	Recurrence Interval/Event	Description
1PC-AEP	1% AEP	Current scenario design runs
2PC-AEP	2% AEP	
5PC-AEP	5% AEP	
10PC-AEP	10% AEP	
20PC-AEP	20% AEP	
39PC-AEP	39% AEP	
1PC-AEP-CC	1% AEP	Design runs with allowance for climate change
2PC-AEP-CC	2% AEP	
5PC-AEP-CC	5% AEP	
10PC-AEP-CC	10% AEP	
20PC-AEP-CC	20% AEP	
39PC-AEP-CC	39% AEP	
0pt1PCAEP	0.1% AEP	Residual hazard run
1900CUMEC	1,900 m^3/s flow	1% AEP flow for Hutt River only
2300CUMEC	2,300 m^3/s flow	Design flow for Hutt River only
2800CUMEC	2,800 m^3/s flow	Design flow and residual hazard for Hutt River only

Where scenarios not listed in these tables are run (for example, a catchment specific sensitivity test) then a new scenario code should be agreed with Greater Wellington and this procedure updated.

1.5 Provision of data

All final model files, input datasets, and outputs are to be provided to Greater Wellington on completion of the modelling. Working files developed as part of the model build do not need to be provided.

2 PART A: Hydraulic model build

In order to ensure ease of transfer of information, a handover session between the hydrologist and hydraulic modeller is recommended prior to commencing the build of the hydraulic model. Greater Wellington's hydraulic modeller and project manager should also be involved in this discussion.

2.1 Model schematisation

The most appropriate schematisation for flood hazard models within the Wellington Region is likely to be 1D-2D linked model. In this type of model schematisation, river channels, and some tributaries and major overland flow paths are represented in 1D, where river bathymetry is interpolated between a series of channel cross-sections. The floodplain is represented in 2D, and water is able to flow between the 1D and 2D model components.

Pure 1D models are generally considered to be insufficient to provide an accurate representation of out of bank flood risk in the majority of catchments where Greater Wellington undertake flood hazard modelling. As such, Greater Wellington should be consulted prior to undertaking any 1D modelling.

2D modelling is not currently widely used in the Wellington Region due to a lack of bathymetry data. However, 2D modelling may be undertaken more widely in future. Care should be taken to accurately reflect the bathymetry within modelled watercourses.

The proposed model schematisation should be discussed and agreed with Greater Wellington prior to commencing modelling, and should be determined on a project-by-project basis based on the purpose of the modelling, and the scale and level of detail required.

2.2 Grid

Grids are used to set the framework for model computation in 2D models and the 2D components of 1D-2D linked models.

As grid type and resolution may have a significant effect on model results, they should be determined by the modeller on a project-by-project basis based on the scale of the model and floodplain features to be captured (such as stopbanks and overland flow paths), while maintaining a practical model run time. Application of a variable grid may be appropriate for some projects, to allow a finer grid size to be applied around key features and flow paths.

The Flood Modelling Guidelines for Responsible Authorities prepared by the Scottish Environmental Protection Agency indicate that a minimum grid resolution of 3 to 4 cells across major flow paths may be appropriate. For example, a major flow path that is 10 m wide would require a grid cell size of 2.5 – 3 m. In 1D-2D linked models these overland flow paths may alternatively be modelled in 1D.

Minimum grid sizes may be limited by the resolution of the DEM as there is unlikely to be any benefit to using a finer grid size than the DEM, and computation times may be significantly increased.

The selected grid type and resolution should be outlined and justified in the hydraulic modelling report.

2.3 Model inputs

All model inputs should be listed and described in the data register prepared for the FHMS project. The function and use of the data register is described in **Procedure 1: Gather and Assess Data**.

All model inputs are also to be listed within the hydraulic model log. The model log is discussed further in Section 6.2.

2.3.1 DEM

As outlined in **Procedure 1: Gather and Assess Data**, a digital elevation model (DEM) is a 3D model of the elevation of a portion of the earth's surface. It may be created from topographic survey, photogrammetry or LiDAR data. The DEM may be used to define the bank and floodplain elevations in a 1D-2D linked model or 2D hydraulic model, or to map the flood extents resulting from channel overtopping in a 1D hydraulic model.

The quality of the DEM is assessed earlier in the FHMS process as part of Procedure 1. The requirements for this assessment are outlined in Section 5.2 of that procedure.

During the hydraulic model build, modifications may need to be made to DEM to ensure that features that are not well represented in the DEM (typically linear features such as small open drains or rail embankments) are included in the model. Similarly, where detailed modelling is undertaken in urban areas, kerbed roads may need to be burnt into the DEM to ensure runoff flows along kerbed roads rather than through properties, where this is unlikely to occur in practice.

Bridges, culverts, tunnels or awnings may appear as blockages or barriers to flow in the DEM. These features should be represented through the use of a 1D structure or modification of the DEM.

Buildings may be represented in the DEM by blocking out or creating voids in the DEM. An alternative approach is to increase roughness in building locations, as described in Section 2.3.5. The representation of building should be described and justified in the hydraulic modelling report.

2.3.2 Cross-sections

Where the river channel or tributaries are represented in 1D, surveyed cross-section data will be a key model input. This data is gathered and reviewed as part of **Procedure 1: Gather and Assess Data**. This review will usually be undertaken by the hydraulic modeller prior to the commencement of modelling.

Where additional cross-sections are required and this is discovered after modelling is underway, then this should be discussed with Greater Wellington and procured in accordance with Procedure 1 and Specification 2 of the FHMS.

2.3.3 Hydrology inputs

Hydrology inputs into the hydraulic model are derived from the outputs of the hydrological model. The outputs to be provided are described in **Procedure 2: Hydrology**.

Hydrology inputs will generally form the upstream boundary of the hydraulic model.

2.3.4 Climate change

Climate change should be accounted for in a number of hydraulic model design runs. The design runs where climate change is to be included are outlined in Table P4-3.

Climate change is incorporated into the hydrological inputs as part of the hydrological modelling and as such, input flows do not need to be adjusted further. Refer to **Procedure 2: Hydrology** for further information.

Within the hydraulic model, climate change is accounted for at the downstream boundary where tidal boundaries, river boundaries etc. should reflect future climate conditions in climate change runs. This is outlined further in Section 2.4.

2.3.5 Roughness

Surface roughness is a key input into hydraulic models and is used to represent energy losses due to frictional resistance to flow. Surface roughness is required at channel cross-sections in 1D models / 1D channel representations, and across 2D surfaces such as 2D river beds and floodplains.

Roughness is generally represented in hydraulic modelling using Manning's *n* coefficient. Channel and floodplain roughness should be estimated on the basis of the channel and floodplain conditions for the specific reach considering factors such as bed material, straightness of channel, vegetation type and density.

Table P4-4 provides some example ranges of manning's n roughness values for open channels and closed conduits. More detail is provided in Chow, 1959. Roughness may be derived from other sources such as the Roughness Advisor database within the CES/AES free software developed by the Environment Agency of the UK and others.

Manning's n roughness values used in hydraulic modelling should be stated and justified in the hydraulic modelling report.

Table P4-4 Example ranges of Manning's n roughness values. Source: Summarised from Chow, 1959

Description	Range (Mannings n)
Minor Streams (top width at flood stage <30 m)	
On a plain:	
– Clean to some weeds, straight, full stage	0.025 – 0.040
– Clean to some weeds, winding, some pools and shoals	0.033 – 0.050
– As above, but at lower stages with more ineffective slopes and sections, more stones	0.040 – 0.060
– Sluggish reaches, weedy, deep pools	0.050 – 0.080
– Very weedy reaches, deep pools or floodways with trees and underbrush	0.075 – 0.150
Mountain streams:	
– Bottom: gravels, cobbles, few boulders	0.030 – 0.050
– Bottom: cobbles with large boulders	0.040 – 0.070
Major Streams (top width at flood stage > 30 m) *The n value is less than that for minor streams of similar description as banks offer less effective resistance*	
– Regular section with no boulders or brush	0.025 – 0.060
– Irregular and rough section	0.035 – 0.100
Floodplain	
– Pasture, no brush	0.025 – 0.050
– Cultivated – no crop	0.020 – 0.040
– Cultivated – mature crop	0.025 – 0.050
– Brush – scattered, heavy weeds	0.035 – 0.070
– Brush – light brush and trees	0.035 – 0.080
– Brush – medium to dense	0.045 – 0.160
– Trees – dense willows	0.110 – 0.200
– Trees – heavy stand of timber, little undergrowth, flood stage below branches	0.080 – 0.120
– Trees – heavy stand of timber, little undergrowth, flood stage reaching branches	0.100 – 0.160
Excavated or dredged channels	
– Earth, straight and uniform	0.016 – 0.033

– Earth, winding and sluggish	0.023 – 0.040
– Channels not maintained, weeds and brush uncut	0.050 – 0.140
Closed conduits	
– Concrete – culvert, straight and free of debris	0.010 – 0.013
– Concrete – culvert, with bends, connections and some debris	0.011 – 0.014

Where a hydraulic model is prepared for a watercourse that is within the same catchment as another hydraulic model (eg, Pinehaven Stream and the Hutt River), or within a nearby catchment with very similar catchment characteristics, consideration should be given to the manning's *n* roughness values used in the previous modelling. Where departures are made from the values used in this modelling this should be justified in the hydraulic modelling report.

2.3.5.1 Representation of buildings

Buildings can present significant barriers to flow, and may be represented by increasing roughness to very high levels to simulate the frictional resistance of flow passing through a building. Where it is known the buildings will present a complete barrier to flow (eg, concrete block buildings), buildings may be blocked out of the DEM.

The hydraulic modeller should determine the most appropriate method for representing buildings in the particular catchment based on model set up (eg, grid size) and catchment factors (eg, type of buildings – timber or concrete, whether basements or underground carparks are present).

The method of representing buildings should be detailed in the hydraulic modelling report.

2.3.6 Stormwater network

The inclusion or exclusion of the stormwater network from the hydraulic model should be discussed and agreed with Greater Wellington prior to model commencement. Where included, the stormwater network representation (i.e. a hydraulic model of the network versus an inflow point from the network to the watercourse) should be discussed and agreed with Greater Wellington.

2.3.7 Structures

Hydraulic structures such as bridges and culverts should typically be represented in 1D. However, there may be some situations where representation in 2D is appropriate. The hydraulic modeller should document in the model log how hydraulic structures are represented and justification for this.

The hydraulic modeller has discretion to choose which minor structures are represented in the model i.e. minor structures that only impact flows at low stages may be omitted, however all build decisions should be fully documented in the hydraulic modelling report. Structures should be included where they constrict flow under high flow conditions.

Structures should be modelled based on survey data or as-built drawings collected and reviewed as part of **Procedure 1: Gather and Assess Data**.

2.3.8 Initial conditions

Initial conditions are used to set the starting point for the model. The initial conditions used should be documented in the hydraulic modelling report. Care should be undertaken setting initial conditions where there are significant amounts of storage in the catchment.

2.4 Boundaries

2.4.1 Upstream boundary

Outputs from the hydrological model will be provided to the hydraulic modeller for use as the upstream boundary. This is discussed in Section 2.3.2.

2.4.2 Downstream boundary

Downstream boundary conditions should be applied at downstream model boundaries. The downstream boundary of the model is to be far enough downstream such that any hydraulic conditions that may affect model results are accounted for.

The type of downstream boundary selected should be determined on a project-by-project basis, but may be a tidal boundary, or a riverine boundary (eg, confluence with another watercourse). Downstream boundary conditions may be static or time-variable as appropriate, and should be set in a way that prevents the creation of artificial backwater at the outlet of the model.

Tidal boundaries should be based on mean high water springs. An oscillating tide should generally be used with the high tide timed to coincide with the flood peak.

2.4.2.1 Climate change

Where climate change design runs are being undertaken, downstream boundary conditions should be adjusted to the same time horizon as the climate adjusted design rainfall used in the hydrological model.

A 1 m allowance for sea level rise should be applied to tidal boundaries in climate change scenarios. Further information on expected sea level rises is provided in *Coastal Hazards and Climate Change. Guidance for Local Government* published by the Ministry for the Environment in 2017.

2.4.3 Joint probability assessment

A joint probability assessment is undertaken on the basis that extreme rainfall and events such as storm surge are statistically dependent, and are therefore may occur at the same time. Joint probability assessment is generally not required where factors are independent (i.e. not likely to be caused by, or occur under similar conditions) as the likelihood that a high magnitude low frequency event will occur simultaneously for both factors is low.

Downstream tidal and river boundaries should assume a joint probability scenario of a 5% AEP event at the downstream boundary during the 1% AEP rainfall event. Probabilities for more frequent events should be discussed and confirmed with Greater Wellington.

Joint probabilities applied at downstream boundaries should be described in the hydraulic modelling report.

2.5 Calibration

Calibration involves the adjustment of model parameters to alter model results to improve agreement between modelled and recorded flood extents, levels/depths, velocities and behaviours. Calibration should aim to match all aspects of the flood, including maximum levels, time to peak, inundation time and any known flood behaviours, where possible.

Calibration should be undertaken for all hydraulic models developed under the FHMS where sufficient data is available. Ideally, calibration would utilise flood records for at least three flood events of differing magnitudes, with at least one event being greater than a 2% AEP event to ensure that modelled parameters accurately represent catchment runoff behaviour, losses and routing across a range of events.

However, it is noted that data for calibration is often limited within the Wellington Region, and sufficient data for three events may not be available, and that confidence in available data may be limited. Calibration should also consider how the catchment may have changed since the calibration event, for example whether new development such as a new bridge may change flood levels or behaviour.

The calibration process should be documented in full, including final parameters, and how data quality and changes in the catchment and any other factors were accounted for. Parameter modifications for calibration should take care to remain within realistic ranges.

Calibration data should be gathered as part of **Procedure 1: Gather and Assess Data**, and may include aerial photography during a flood event (ideally at the peak), historical flood levels, surveyed flood extents or records of debris lines, photographs of the flood event, and anecdotal information provided by community members who witnessed the flood. Ideally data would be available to allow calibration of extent, level, timing and behaviour.

2.6 Mass balance

The model continuity error should be maintained at less than 5%. The continuity error measures the total water volume lost from the model by comparing to the total inflow and outflow volumes, and accounting for the volume stored in the model.

3 PART B: Finalise hydraulic model

As outlined in Section 1.1, Part B of the hydraulic modelling process will be undertaken following close-out of the Part A peer review. The Part A peer review is to be undertaken and documented in accordance with **Procedure 3: Peer Review**.

3.1 Validation

Validation is undertaken following model calibration and is used to verify that the model can acceptably reproduce events that are different to the calibration event. This ensures that the calibration parameters are representative of a wide range of possible events that could occur in the catchment.

Where possible, validation should be undertaken for a minimum of three events of varying magnitude. However, it is recognised that for the majority of watercourses in the region sufficient data is unlikely to be available.

Similarly to calibration, validation data should be gathered as part of **Procedure 1: Gather and Assess Data**, and may include aerial photography during a flood event (ideally at the peak), historical flood levels, surveyed flood extents or records of debris lines, photographs of the flood event, and anecdotal information provided by community members who witnessed the flood. Ideally data would be available to allow validation of extent, level, timing and behaviour.

Where no validation data is available, the sensibility of the calibration results should be reviewed to ensure that model results are within reasonably expected values.

It is noted that community engagement will be undertaken during calibration or validation of the hydraulic model, in line with Greater Wellington’s Flood Hazard Modelling Engagement Guidance. The purpose of this engagement is to provide the community with an opportunity to give feedback on how the model results from the calibration and/or validation events compare to their recollections. Updates to the hydraulic model may be necessary after this consultation. Community engagement is outlined further in Section 1.5 of **Procedure 0: Process**.

3.2 Sensitivity analysis

Sensitivity analysis is the adjustment of model parameters within realistic ranges to determine the impact on model results. Sensitivity analysis of key parameters should be undertaken on all hydraulic models prepared for flood hazard modelling projects. The sensitivity parameters listed in Table P4-5 should be tested, where relevant.

Table P4-5 Recommended sensitivity parameters

Recommended	Optional
• Mannings n roughness • Downstream boundary conditions • Structure blockage • Debris loading • Changes to input hydrology • Changes in land-use	• Bed level changes • Changes in channel shape (morphology) • Likely breach scenarios

Sensitivity testing should be undertaken using the 1% AEP event with allowance for climate change. The parameter with the largest and most widespread impacts on model results in this event should be applied to the remaining design events to test the impact.

A list of sensitive parameters should be developed based on the results of the sensitivity analysis. The sensitivity of each parameter should be described in a long-list to inform selection of scenarios for uncertainty testing. Uncertainty testing is described in more detail in Section 4. An example sensitivity analysis long-list is provided in Table P5-6 below.

Table P4-6 Example sensitivity analysis long-list

Parameter	Relative sensitivity	Comment
Roughness	High	The model is very sensitive to changes in roughness within the river channel and floodplain, with increases in water level of up to 0.3 m when roughness is changed within the range of published literature for the known vegetation type. Vegetation along the riverbank is generally not well maintained, and based on historic aerial photography, has become denser in the last 10 years. In some locations along the river channel the quality of aerial photography at the time of the calibration events is poor and as such the true extent, type and density of vegetation is uncertain in some locations.
Boundary conditions	High within approximately 100 m of the confluence with the main river. The model is not sensitive upstream of this point.	The model is sensitive to changes in boundary conditions within approximately 100 m of the confluence with the main river when tested using the 2% AEP event flows in the main river. There is no impact on flood levels upstream of this point. The nearest residential property is approximately 500 m upstream of the confluence.
Bed level	Moderate	Bed level increases in the range of 0.3 m results in approximately 0.5 m of water level increase at the township. The model is considered to be moderately sensitive to this change.
Blockage at state highway bridge	Low	Severe blockage of the state highway bridge has a minor impact (<0.1 m) on overall flood depths. There is a small increase to flood extent due to flows overtopping the road south of the true left abutment of the bridge.

3.3 Design runs

A suite of design runs is required to be undertaken. The required design runs are outlined in Table P4-7.

Table P4-7 Required design runs.

Risk type	Scenario
Current flood hazard	– 39% AEP (1 in 2-year Average Recurrence Interval (ARI)) – 20% AEP (1 in 5-year ARI) – 10% AEP (1 in 10-year ARI) – 5% AEP (1 in 20-year ARI) – 2% AEP (1 in 50-year ARI) – 1% AEP (1 in 100-year ARI) (1,900 m^3/s for Hutt River only) – 2,300 m^3/s flow (Hutt River only)

Future flood hazard (climate change)	– 39% AEP (1 in 2-year ARI) with allowance for climate change – 20% AEP (1 in 5-year ARI) with allowance for climate change – 10% AEP (1 in 10-year ARI) with allowance for climate change – 5% AEP (1 in 20-year ARI) with allowance for climate change – 2% AEP (1 in 50-year ARI) with allowance for climate change – 1% AEP (1 in 100-year ARI) with allowance for climate change
Residual flood hazard	– Stopbank breach runs with a 1% AEP (1 in 100-year ARI) flow, in areas where stopbanks are present – An overdesign event with a 0.1% AEP (1 in 1000-year ARI) flow – 2,800 m^3/s flow (Hutt River only) with stopbank breaches
Areas benefiting from defences	– Stopbank-down runs for sections of stopbank. Locations and lengths to be determined on a project by project basis. • 1% AEP event • 1% AEP event with climate change and uncertainty • 2,300 m^3/s flow (Hutt River only) – Full stopbanks down run for economic analysis (all projects). • 1% AEP event • 1% AEP event with climate change and uncertainty • 2,300 m^3/s flow (Hutt River only)

3.3.1 Residual hazard runs

Residual hazard is the remaining flood hazard that is present in areas that are protected by structural controls after flood risk has been reduced by the control. Two types of residual hazard are considered in this standard:

- Residual flood hazard: this hazard is present due to the potential for structural failure, such as stopbank breach (rupture).
- Overdesign events: the hazard associated with events that are larger than the structure is designed to accommodate, such as in the case of stopbank overtopping.

These are described in the sections below.

3.3.1.1 Stopbank breach runs

Stopbank breach runs are undertaken to assess the flood extents and hazard of stopbank breaches. The locations of the breaches should be determined based on an assessment of locations considered to be highly likely to breach (eg, in areas with known structural weaknesses). A workshop with Greater Wellington should be held to confirm and agree breach locations. Breach locations will be based on asset management inspections, operational knowledge, channel form, and known overtopping locations.

Stopbank breach runs are undertaken using the 1% AEP event. For the Hutt River stopbank breach runs are undertaken using the 2,800 m^3/s event.

The results of stopbank breach runs will be used to prioritise the implementation of further structural measures, and for emergency management planning.

3.3.1.2 Overdesign events

An overdesign event should be undertaken using the 0.1% AEP event to determine residual flood hazard. An overdesign event run is not required for the Hutt River where residual hazard is determined using a large stopbank breach run.

The results of overdesign event runs will be used to inform options assessments during planning for future flood controls and emergency management. The overdesign event may also be used to inform preferential spill locations to prevent uncontrolled breach.

3.3.2 Areas benefitting from defences

Areas benefitting from defences (stopbank down) runs are undertaken to determine which areas benefit from stopbanks. Areas benefiting from defences are parcels of land located behind structural controls (such as stopbanks) that would become inundated during the 1% AEP or more frequent events (or the 2,300 m^3/s flow in the Hutt River) if the structural control was not in place. The identification of these areas informs asset management and cost-benefit analysis.

Areas benefiting from defences are identified by removing structural controls such as stopbanks from the hydraulic model, and mapping the resulting flood extents. The following scenarios should be modelled:

- Full removal of the structural flood protection controls from the hydraulic model.
- For stopbanks, removal of sections of the stopbank.

The lengths and locations of the stopbanks to be removed are to be workshopped and agreed with Greater Wellington.

4 Uncertainty

Flood hazard modelling is a complex technical process that contains many variables. As such, uncertainty is present in all models. As flood hazard models provide the basis for many critical flood management decisions, it is important that the impact of modelling uncertainties have been considered. Greater Wellington apply the following principles in representing modelling uncertainty:

- **Realistic** – the uncertainties assessed are realistic for the catchment/watercourse being modelled.
- **Communicable and transparent** – the uncertainties assessed are documented, evidence based and clear.
- **Easily understood** – to support our ability to communicate uncertainty, its application must be simple and easy for non-practitioners to understand.
- **Promote a risk-based approach** – the modelled and mapped flood hazard should promote prudent decision making to avoid development in hazard areas and provide suitable safety factors to account for unknowns.

4.1 Terminology

The terminology outlined in Table P4-8 and illustrated in Figure P4-2 is used to describe modelling uncertainty.

Table P4-8 Uncertainty terminology

Term	Definition
Sensitivity testing	Testing to determine how responsive the model is to certain parameters such as roughness and boundary conditions.
Uncertainty testing	Developing uncertainty scenarios based on sensitive parameters and scenarios that could realistically occur in the catchment. Model parameters that were varied in the sensitivity runs and did not result in a significant change to modelled peak water levels, do not need to be further evaluated through uncertainty testing. Uncertainty testing may not require additional runs, or may be a

	refining of the sensitivity analysis to a realistic scenario (i.e. a change in the percentage blockage at a bridge, or combining some scenarios).
Climate change allowance	This is an allowance for the effects of climate change (increased rainfall intensity and sea level rise) per Greater Wellington's latest guidance.
Modelling freeboard	This is an additional depth added to the base model to represent factors that cannot be modelled using uncertainty testing. Modelling freeboard is not used as part of the FHMS process. The results of uncertainty testing are applied to base model results plus climate change allowance to determine flood levels and extents to be used in flood mapping. When providing advisory for recommended minimum building floor levels, Greater Wellington will apply freeboard as defined below.
Freeboard	An allowance applied to account for factors that cannot be modelled, such as wave action from vehicles driving through floodwaters. Greater Wellington typically applies a freeboard of 300 mm when providing flood advice. It is noted that where minimum floor levels recommendations are required an additional 200 mm should be added to meet the minimum freeboard of 500 mm required for dwellings under the Building Act.

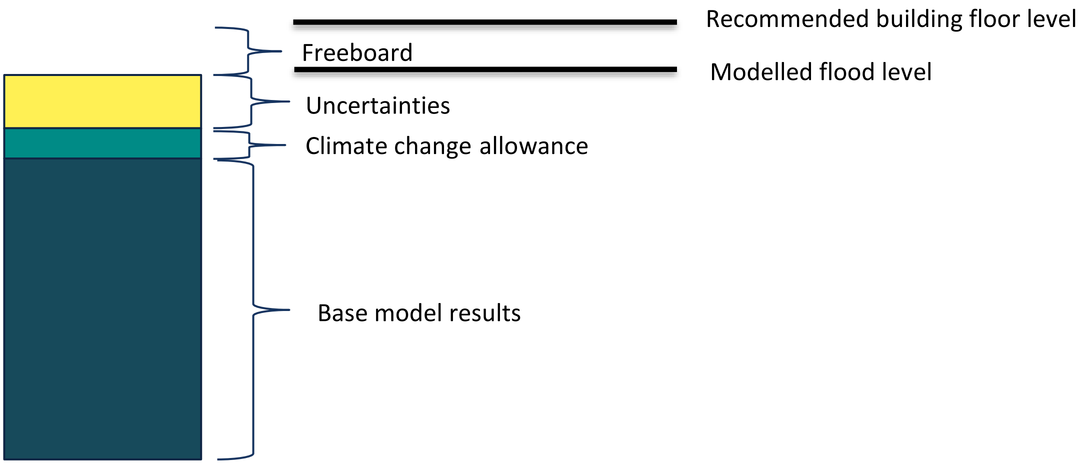


Figure P4-2 Uncertainty terminology

4.2 Process

The following section outlines the process to be followed to determine the uncertainties to be applied to the model results, with the final outputs to be a combination of the base model results , the predicted impacts of climate change, and model uncertainties.

Uncertainty scenarios should be developed to test potential issues that can be modelled. The scenarios to be tested should be developed based on a review of the sensitivity analysis long-list, described in Section 3.2 above and in agreement with Greater Wellington.

Uncertainty scenarios should be scenarios that could reasonably occur in the catchment. Uncertainty testing may not require additional runs or may be a refining of the sensitivity analysis to a realistic scenario (i.e. a change in the percentage blockage at a bridge, or combining some scenarios). The rationale for selecting uncertainty scenarios should be clearly documented in the hydraulic modelling report. For example, based on the example long-list in Table P4-6, the uncertainty scenarios in Table P4-9 may be selected.

Uncertainty scenarios should be evaluated using the 1% AEP event with allowance for climate change. The scenario or combination of scenarios selected for the final mapping should then be run for the remaining AEP runs.

Table P4-9 Example uncertainty scenario long-list

Scenario	Recommend to test?	Rationale
Roughness: Increase roughness in line with published literature from 'brush – light brush and trees' to the 'brush – medium to dense' category in sections of the riverbank not maintained by Greater Wellington.	Yes	Sensitivity analysis has indicated that the model is very sensitive to changes in riverbank roughness. Large sections of the riverbank are not maintained, and changes to vegetation density is likely to occur in these areas over time, particularly as some sections of channel have only recently been fenced from grazing livestock. Changes to riverbed roughness are not proposed as changes to bed composition over time are expected to be minimal.
Boundary conditions: Increase coincident event at river confluence	No	Sensitivity analysis has indicated that the model is sensitive to this parameter within 100 m of the confluence only. There are no dwellings, roads or significant infrastructure within this area.
Bed level: Bed aggradation throughout the channel	No	Sensitivity analysis indicated impacts only occur at the township when bed levels are raised by 0.3 m or greater. This level of aggradation is not considered realistic in this catchment due to Greater Wellington's on-going gravel extraction programme in this location.
Blockage: Blockage at SH2 bridge	Yes	Sensitivity analysis has indicated that the model has low sensitivity to this parameter in terms of flood depth and extent across the model domain, however the state highway may be impacted. As this is a critical access route for the township / emergency services, this scenario should be considered for analysis.

The scenarios to be modelled from the uncertainty long-list should be agreed with Greater Wellington.

The results of the uncertainty analysis should be discussed with Greater Wellington to determine the uncertainty scenario to include in the final outputs. This may be a single uncertainty scenario or a combination of scenarios where these scenarios could reasonably occur at the same time.

All decisions on which scenarios to be included should be clearly documented in the hydraulic modelling report, including scenarios discounted. Scenarios should be selected using risk-based judgement based on the likelihood of the scenario occurring versus the potential impact on flood risk.

5 Outputs

The requirements for hydraulic model outputs are detailed in **Procedure 5: Outputs**. Preliminary outputs should be prepared as part of the hydraulic modelling process to assist with peer review. Outputs are finalised following close-out of the peer review and independent audit undertaken under **Procedure 6: Independent Audit**.

The required final outputs of the hydraulic modelling are outlined in Table P4-10. These outputs are required to:

- Assist the peer reviewer to undertake the peer review.
- Keep records for future model updates and additional design runs if required.
- Provide a visual representation of flood hazard to inform Floodplain Management Plans, provide information for Greater Wellington's advisory role and to feed into District Plan mapping.

Table P4-10 Hydraulic model outputs

Element	Requirement
Flood extents, depths, velocities, hazard	All current climate, climate change and residual hazard runs for a range of scenarios and events, as outlined in **Procedure 5: Outputs**.
Model files	All model files to be provided to the peer reviewer for review, and to Greater Wellington for records.
Model log	A detailed model log should be kept and provided on completion of the modelling. This is described in Section 6.2.
Geospatial files	All geospatial files used during modelling, eg, DEM

5.1 Confidence in results

An estimate of the relative confidence of the model results should be undertaken and presented for each flood hazard modelling project. Confidence may be estimated quantitatively or qualitatively.

Where qualitative estimation is undertaken, the criteria used and justification for the criteria should be provided in the hydraulic modelling report. An example of a qualitative assessment is provided in Table P4-11.

Table P4-11 Example qualitative assessment of model confidence.

Parameter	Qualitative Assessment	Confidence Score
Availability and quality of input data	DEM of high resolution, good correlation between top of bank elevations in DEM and cross-sections. Recent river channel cross-sections at regular intervals. Spacing between data points along cross-section is appropriate. Input hydrology calibrated based on 44 year flow gauge record. Hydrology report indicates good calibration fit, however gauge rating curve is not verified for high flow events greater than the 5% AEP.	Medium
Availability and quality of calibration data	Flow and level data available for one recent event estimated to be approximately 5% AEP. Aerial photographs taken close to peak extent, and anecdotal evidence of flood behaviour are also available for this event. No other calibration events are available.	Medium
Availability and quality of validation data	Historic photographs and anecdotal evidence available for one event estimated to be 2% AEP. Photographs do not show full flood extent but assist with estimates of flood depth at a number of locations. No other validation events are available.	Medium
Calibration fit	Peak flow over-estimated by approximately 1%. Flood extent generally consistent with available aerial photography, although some minor differences at southern extent.	High
Validation fit	Modelled flood depths generally consistent with depths estimated from historical photos and anecdotal evidence. Unable to assess fit of extents due to lack of data.	Medium

Model sensitivity	Model sensitive to changes in manning's *n* roughness within potential ranges. Model also sensitive to blockage at one location known to block frequently during high flow events. As a result the increase in flood extent under this scenario is included in the flood sensitive area.	Medium as mitigated through flood sensitive area
Model performance and mass balance	Model mass balance is within acceptable ranges.	High
	Overall qualitative confidence level	**Medium**

6 Documentation

6.1 Data register

A data register will be prepared for each flood hazard modelling project as part of works undertaken under **Procedure 1: Gather and Assess Data**. Details of the format of the data register is provided in Procedure 1, and a template is provided in Appendix P1-A.

The data register should be updated with any data gathered or reviewed as part of this procedure. On completion of this component of work the updated data register should be appended to the hydraulic modelling report, and provided in electronic format to Greater Wellington.

6.2 Model log

A detailed model log should be kept while undertaking the modelling. This log should be appended to the hydraulic modelling report, and should document the model build, assumptions made, and all inputs. The model log should assist with version control and will describe the model naming convention.

The model log should be provided to the peer reviewer to assist with the peer review. A model log template is provided in Appendix P4-A.

6.3 Report

A detailed technical report should be prepared to outline the hydraulic modelling undertaken. The report should be prepared as part of the Part A works, and issued to Greater Wellington and the peer reviewer. Following close out of the Part A peer review, the report should be updated to incorporate any changes or recommendations following the peer review, and the Part B works. The report should include, but is not limited to:

PART A:

- Details of the software used.
- Model extent.
- Model schematisation.
- Grid type and resolution.
- Data availability and quality.
  - Detailed summary of the analytical process and findings of the data collection and review undertaken as part of **Procedure 1: Gather and Assess Data.**
- Summary of and justification for input parameters including roughness.
- Representation of structures and justification for any structures not modelled.
- Initial conditions.
- Boundary conditions.

- Calibration, including details of the calibration events selected, parameters adjusted and calibration performance.
- Details of model performance, including numerical stability and mass balance errors.

PART B:

- Validation, including details of the validation events selected, parameters adjusted and validation performance.
- Sensitivity analysis including details of the sensitivity scenarios tested and results.
- Design runs.
- Uncertainty scenario runs..
- Details of model performance, including numerical stability and mass balance errors.
- Assessment of confidence in the model results.

7 Procedure review

This procedure is intended to be a living document that can be revised as technology advances and industry accepted practice evolves.

The need for review of the procedures within the FHMS, including this one, will be determined at the end of each modelling project at the 'process review / lessons learnt' checkpoint on the FHMS flow chart.

8 References

Chow, V.T. (1959). Open Channel Hydraulics. McGraw-Hill Book Co. Singapore.

Ministry for the Environment (2017). Coastal Hazards and Climate Change. Guidance for Local Government.

Scottish Environmental Protection Agency (2015). Flood Modelling Guidance for Responsible Authorities.

PROCEDURE 05

OUTPUTS

This procedure has been prepared to outline the protocols to be followed by any person preparing outputs from hydraulic modelling on Greater Wellington's flood hazard modelling

Procedure 05

Table of Contents

Greater Wellington
Te Pane Matua Taiao

1 Introduction

This document forms **Procedure 5** of Greater Wellington Regional Council's (Greater Wellington) **Flood Hazard Modelling Standard** (FHMS). This procedure has been prepared to outline the protocols to be followed by any person preparing outputs from hydraulic modelling on Greater Wellington's flood hazard modelling projects. This document should be read in the context of the wider FHMS, and has a particular relationship to **Specification 5: Hydraulic Model**.

The outputs of the hydraulic modelling are the 'final product' of the flood hazard modelling process. Outputs include maps, tables of results, long-sections, and geospatial files such as raster and shape files. The outputs specified in this document are the minimum requirements for all flood hazard modelling undertaken under the FHMS. This procedure has been prepared to ensure that the outputs of flood hazard modelling projects meet the needs of their end users, and are clear and consistent for ease of interpretation.

1.1 What are the outputs used for?

The outputs of the FHMS process are used to support of wide range of functions. These are summarised in Table P5-1 below. It is noted that outputs may be used for other purposes at Greater Wellington's discretion.

Table P5-1 Greater Wellington functions supported by FHMS outputs

Greater Wellington function	Use of outputs
Emergency management	Civil Defence Emergency Management (CDEM) intelligence, development of evacuation plans, identification of vulnerable areas, dam safety planning.
Flood Risk Management Planning	Identifying hazard areas, optioneering potential mitigation solutions, cost-benefit analysis, erosion risk analysis.
District Planning	Provided to Territorial Authorities for inclusion in District Plans. Provides critical information to inform planning controls and building floor levels.
Advisory services	Provided in response to requests for information. Generally used to inform structure design, fish passage, erosion protection and some building floor levels where not addressed in district planning.
River management	To inform river engineering and management, such as setting design lines for watercourses.
Asset management	Identifying critical assets, identifying level of service etc.

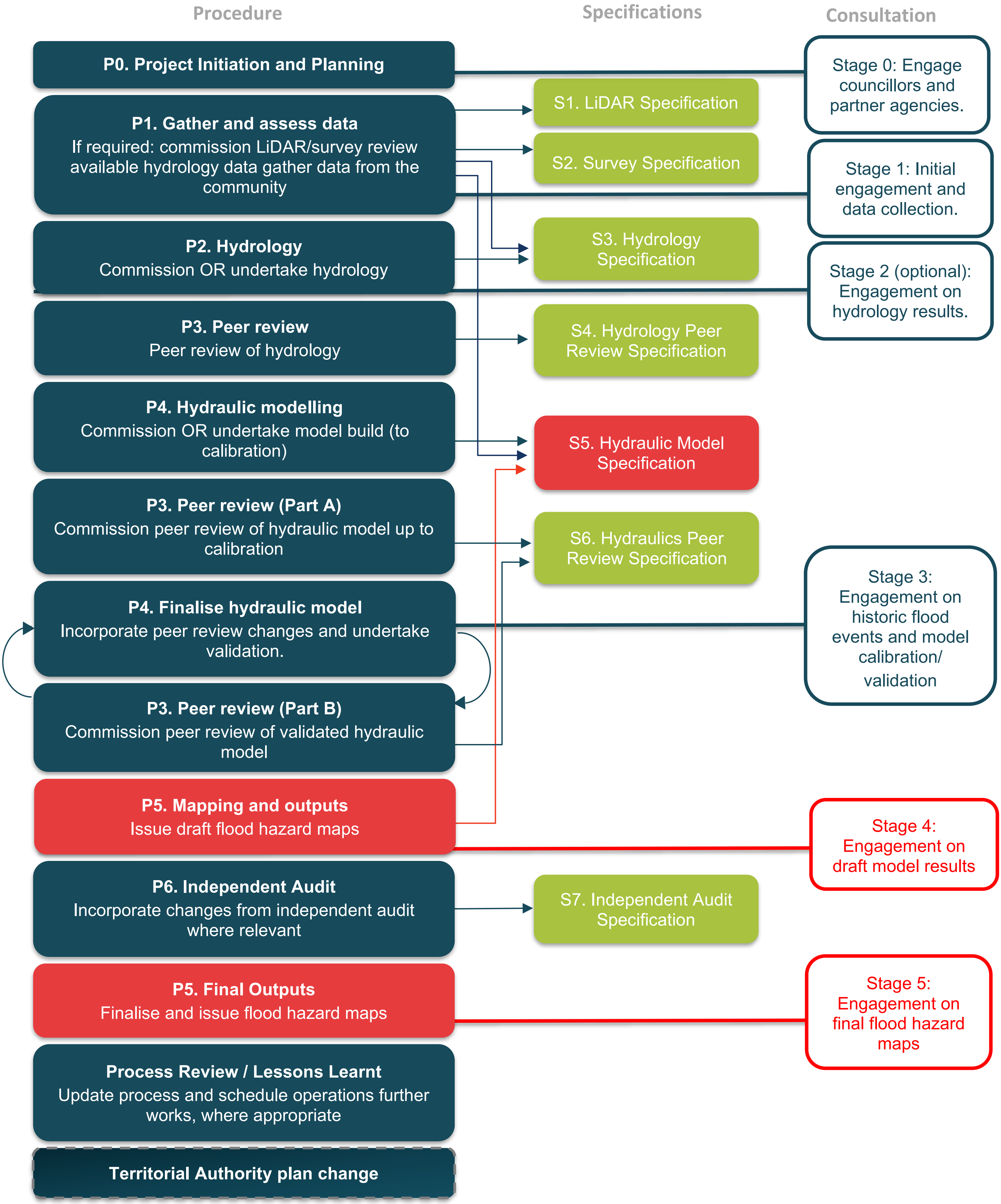
1.2 Outputs in the FHMS Process

Preliminary outputs are created following finalisation of the hydraulic model. The review of these preliminary outputs is included in the Part B hydraulic model peer review.

The Part B hydraulic model peer review is an iterative process where the model runs, validation and sensitivity analysis will be reviewed and modified. Due to the iterative nature of this process, the preliminary outputs will also be updated iteratively at this time. The peer review is described in more detail in **Procedure 3: Peer Review**. Following close-out of the peer review, the preliminary outputs may be issued to interested parties such as WREMO, TAs and the public as drafts.

Final outputs are prepared and issued following the independent audit of the flood hazard modelling process, which is the subject of **Procedure 6: Independent Audit**. The stages of the FHMS process that are related to the preparation of outputs are outlined in red in the Figure 5-1 below.

Figure P5-1 **FHMS process showing where preparation of outputs is undertaken (red)**



1.3 Who produces the outputs?

The outputs should be prepared by the hydraulic modeller as part of the hydraulic modelling scope.

2 Output Types

The following output types are required to be prepared under the FHMS. These have been broadly grouped below based on purpose. Outputs that are used for a wide range of purposes, have been listed under the general category in Section 2.1 below.

2.1 General

2.1.1 Extent

Flood extent is the area of land to be inundated under a particular scenario, such as a 1% AEP event.

Flood extents include all land inundated during a particular scenario and are **not** adjusted to remove areas with very shallow inundation.

2.1.2 Level, depth and velocity

Flood level is the maximum elevation of flood water during a particular scenario at a particular location.

Flood depth is the difference between the maximum flood level and ground elevation at a particular location, during a particular scenario.

Velocity is the maximum velocity of flood waters at a particular location during a particular scenario. Velocity may be used to differentiate flow paths from ponding areas.

2.1.3 Hazard

Hazard is a function of the depth and velocity of flood waters at a particular location. It informs the likely risk to people and property as a result of flooding. Hazard is low in shallow slow-moving waters and increases with increasing depth and velocity.

Hazard raster grids are to be prepared based on the general flood hazard classification from Book 6: Flood Hydraulics of Australian Rainfall and Runoff (2016), unless otherwise requested by Greater Wellington and external stakeholders. The Australian Rainfall and Runoff hazard classification is provided in Figure P5-2 below. Hazard extents should match the flood extent.

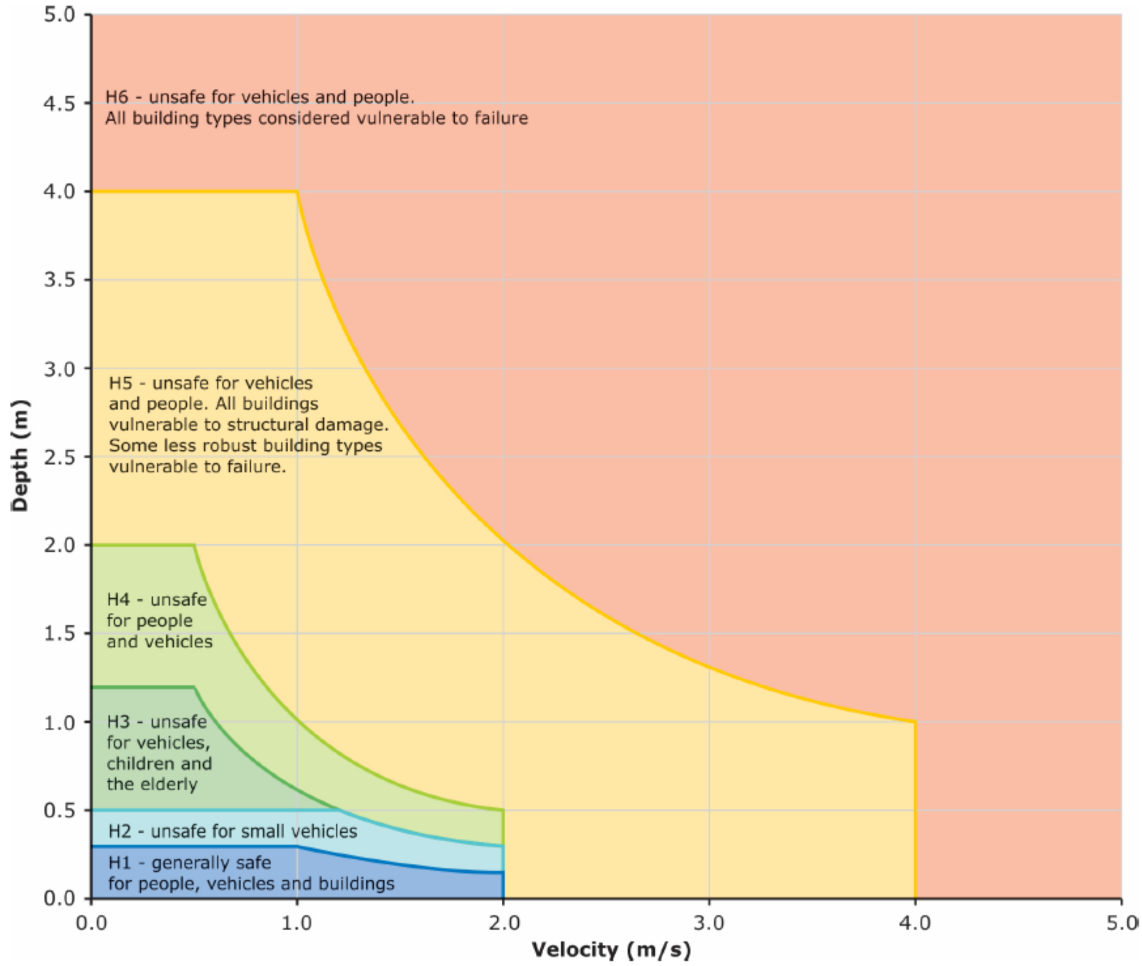


Figure P5-2 Hazard Classification. Source: Australian Rainfall and Runoff – Book 6 Flood Hydraulics (2016), after Smith et al., 2014.

2.2 Emergency Management

The outputs from flood hazard models can provide valuable intelligence for emergency preparedness and response.

The outputs generated under **Procedure 5: Outputs** of the FHMS largely focus on providing a snapshot of the *maximum* flood extent, depth or hazard. However, flood hazard models can also provide intelligence about likely flood behaviour as water levels rise, and how hazard develops over the event. This information can assist emergency responders to more effectively plan for and prioritise flood response activities, resulting in less reactive decision-making which may lead to better outcomes.

Details of the outputs required to inform emergency management are outlined in Sections 2.1.3 (hazard), and sections 2.2.1 to 2.2.4 below. Further information is provided in **Supplementary Guide 1 Emergency Management**.

2.2.1 Time to inundation

Time to inundation is the time taken for particular features (i.e. access roads) within the modelled catchment to become inundated. Time is measured from the exceedance of the first alarm level in the catchment, or as determined by Greater Wellington, in consultation with WREMO. This information is used for emergency planning and management, such as determining evacuation timeframes and routes.

The alarm levels and features of interest that time to inundation should be provided for are to be determined by Greater Wellington in consultation with WREMO; these may be developed iteratively as preliminary flood levels and extents become available.

An example of the alarm levels and features of interest for calculation of time to inundation is provided in Table P5-2.

Table P5-2 Example of alarm levels and features of interest for calculation of time to inundation

Gauge Height Hutt River at Birchville (m)	Recurrence Interval	Flow (m^3/s)	Description
3.5			First alarm level
4.0	63% AEP	400	Block Road floods
4.3	63% AEP	460	HCC carpark floods
5.0			Second alarm level

2.2.2 Duration of inundation

Duration of inundation is the amount of time that an area or a feature of interest (i.e. an access road) is inundated. The areas or features that duration of inundation should be measured for are to be determined by Greater Wellington in consultation with WREMO and may be developed iteratively as preliminary flood levels and extents become available.

2.2.3 Areas likely to become isolated

Developed areas that are likely to become isolated (i.e. areas that may become islands) can be hazardous during a flood event, due to:

- The risk of water levels rising further and drowning the island, which may result in stranded people entering the flood waters.
- The risk of stranded people self-evacuating through the flood waters.
- The risk to emergency services when rescuing stranded people.

Developed areas that are likely to form islands during the development of the flood should be identified and mapped to assist emergency services to evacuate these areas while hazard is low. A series of maps should be produced to show the development of the island and the point at which the island becomes cut off from evacuation routes.

2.2.4 Residual hazard

Residual hazard is the flood hazard that is present in areas that are protected by structural controls such as stopbanks. This hazard is present due to the potential for structural failure, such as stopbank breach (rupture) and events that are larger than the structure is designed to accommodate, (e.g., stopbank overtopping).

The following outputs are required to address residual hazard:

- Flood extents and hazard resulting from stopbank breach runs. The locations of the breaches should be determined based on an assessment of locations highly likely to breach (e.g., areas with known structural weaknesses). A workshop with Greater Wellington should be held to confirm and agree breach locations. Breach scenarios may not be required if there are no locations considered highly likely to breach.
- Flood extents and hazard resulting from over-design events (i.e. overtopping of stopbanks). A 0.1% AEP event (approximately a 1 in 1000-year ARI event) will be applied in this scenario. In this scenario protection structures such as stopbanks are modelled as remaining intact.

2.3 District Planning

District Plans in the Wellington Region contain policy and rules relating to flood hazards. Greater Wellington provides outputs from flood hazard models to territorial authorities, including flood extents, depths, velocities and hazard information to inform district policy development. Flood hazard categories are also provided to assist territorial authorities to undertake risk-based planning and provide mapping for district planning.

Further information is available in Greater Wellington's **Floodplain Management Planning Guidelines**.

2.3.1 Flood hazard categories

The following categories should be provided for the 1% AEP event with allowance for climate change, based on the following hazard classification:

- **Low hazard areas:** slow moving, shallow flooding. These areas may be ponding areas or residual flood hazard areas.
- **Moderate hazard areas:** deeper or faster moving.
- **High hazard areas:** deep or fast-moving flood water.

Table P5-3 Flood Hazard Categories for District Planning

Classification	Depth (m)	Velocity (m)	Hazard
Low	≤0.5	<0.5	<0.25
Medium	≥0.25 and ≤0.5	≥ 0.5 and ≤ 2	≥0.25 and ≤0.5
	<0.5	≤2	<0.25
High	>0.5		
		>2	
			>0.5

Adjustments may be made to these categories to reflect the land use in the hazard areas (e.g., urban or rural, or high-risk activities) if required by Greater Wellington at the request of the territorial authority.

2.4 Advisory Services

Greater Wellington provides an advisory service that provides technical advice on flood and erosion hazards, hazard management plans, consent applications that require river works, and on any national, regional, and local plan that pertains to flood and erosion risk management. The service was developed to fulfill Greater Wellington's obligations under various legislation and to ensure communities are safe guarded from flooding. Further information on flood advisory services can be found in Greater Wellington's **Flood Advisory Guidelines**.

Outputs required for the Flood Advisory Service include:

- Extent (section 2.1.1),
- Level, depth and velocity (section 2.1.2),
- Hazard (section 2.1.3).

2.4.1 Freeboard

When supplying minimum building floor levels as part of the Flood Advisory Service an additional 300 mm will be applied to account for all uncertainties that cannot be modelled, such as wave action from vehicles driving through floodwaters and wind impacts.

Freeboard will not be included in mapped flood extents or depths.

2.5 Asset Management

Greater Wellington requires flood hazard information to inform asset management, including:

- Extent (section 2.1.1),
- Level, depth and velocity (section 2.1.2),
- Hazard (section 2.1.3).

- Areas benefiting from defences (section 2.5.1)

2.5.1 Areas benefiting from defences

Areas benefiting from defences are parcels of land located behind structural controls (such as stopbanks) that would become inundated during the 1% AEP or more frequent events (or the 2,300 m^3/s flow in the Hutt River) if the structural control was not in place. The identification of these areas informs asset management and cost-benefit analysis. Areas benefiting from defences may not be required in every flood hazard model and should be determined at Greater Wellington's discretion.

Areas benefiting from defences are identified by removing structural controls such as stopbanks from the hydraulic model and mapping the resulting flood extents. The following scenarios should be modelled:

- Full removal of the structural controls from the hydraulic model.
- For stopbanks, removal of sections of the stopbank. The lengths and locations of the stopbanks to be removed are to be determined by Greater Wellington.

3 Schedule of outputs

The outputs to be prepared for each flood hazard modelling project are to be agreed with Greater Wellington. A schedule of the outputs that will usually be required are listed in Table P5-4 (outputs by purpose) and Table P5-5 (outputs by risk type) below.

Table P5-4 Schedule of Outputs – by Purpose

Purpose	Scenario(s)	Output type
Emergency Management	– 39% AEP (1 in 2-year Average Recurrence Interval (ARI)) – 20% AEP (1 in 5-year ARI) – 10% AEP (1 in 10-year ARI) – 5% AEP (1 in 20-year ARI) – 2% AEP (1 in 50-year ARI) – 1% AEP (1 in 100-year ARI) – A series of breach runs with 1% AEP (1 in 100-year ARI) flow and uncertainty scenario. – An overtopping run with a 0.1% AEP (1 in 1000-year ARI) flow Hutt River only: – 1,900 m^3/s flow (approximately the 1% AEP event) – 2,300 m^3/s flow (approximately the 1% AEP event with allowance for climate change) – 2,800 m^3/s flow (residual hazard event)	Hazard (section 2.1.3) Time to inundation (section 2.2.1) Duration of inundation (section 2.2.2) Areas likely to become isolated (section 2.2.3) Residual hazard (section 2.2.4)
Flood Risk Management Planning	– 5% AEP (1 in 20-year ARI) with allowance for climate change and uncertainty – 2% AEP (1 in 50-year ARI) with allowance for climate change and uncertainty – 1% AEP (1 in 100-year ARI) with allowance for climate change and uncertainty – An overtopping run with a 0.1% AEP (1 in 1000-year ARI) flow	Extent (section 2.1.1) Level (section 2.1.2) Depth (section 2.1.2)

	Hutt River only: – 1,900 m^3/s flow (approximately the 1% AEP event) – 2,300 m^3/s flow (approximately the 1% AEP event with allowance for climate change) – 2,800 m^3/s flow (residual hazard event) – Stopbank-down runs for sections of stopbank. Locations and lengths to be determined on a project-by-project basis. • 1% AEP event with uncertainty scenario • 1% AEP event with climate change and uncertainty scenario • Hutt River only: 2,300 m^3/s flow – Full stopbanks down run for economic analysis (all projects). • 1% AEP event with uncertainty scenario • 1% AEP event with climate change and uncertainty scenario • Hutt River only: 2,300 m^3/s flow	Velocity (section 2.1.2) Hazard (section 2.1.3)
District Planning	– 1% AEP (1 in 100-year ARI) with allowance for climate change and uncertainty	Flood hazard categories (section 2.3.1)
Advisory Services	– 2% AEP (1 in 50-year ARI) with allowance for climate change and uncertainty – 1% AEP (1 in 100-year ARI) with allowance for climate change and uncertainty	Extent (section 2.1.1) Level (section 2.1.2) Depth (section 2.1.2) Velocity (section 2.1.2) Hazard (section 2.1.3)
River Management	– 5% AEP (1 in 20-year ARI) with allowance for climate change and uncertainty – 1% AEP (1 in 100-year ARI) with allowance for climate change and uncertainty	
Asset Management	– 5% AEP (1 in 20-year ARI) with allowance for climate change and uncertainty – 1% AEP (1 in 100-year ARI) with allowance for climate change and uncertainty – Stopbank-down runs for sections of stopbank. Locations and lengths to be determined on a project by project basis. • 1% AEP event with uncertainty scenario • 1% AEP event with climate change and uncertainty scenario • Hutt River only: 2,300 m^3/s flow – Full stopbanks down run for economic analysis (all projects). • 1% AEP event with uncertainty scenario • 1% AEP event with climate change and uncertainty scenario	

Table P5-5 Schedule of Outputs – by Risk Type

Risk type	Scenario
Current flood hazard	– 39% AEP (1 in 2-year Average Recurrence Interval (ARI)) – 20% AEP (1 in 5-year ARI) – 10% AEP (1 in 10-year ARI) – 5% AEP (1 in 20-year ARI) – 2% AEP (1 in 50-year ARI) – 1% AEP (1 in 100-year ARI) Hutt River only: – 1,900 m^3/s flow (approximately the 1% AEP event)
Future flood hazard (allowance for climate change)	– 5% AEP (1 in 20-year ARI) with allowance for climate change – 2% AEP (1 in 50-year ARI) with allowance for climate change – 1% AEP (1 in 100-year ARI) with allowance for climate change Time horizons for climate change events are to be determined on a case-by-case basis in consultation with Greater Wellington. Hutt River only: – 2,300 m^3/s flow (approximately the 1% AEP event with allowance for climate change)
Uncertainty runs	– 2% AEP (1 in 50-year ARI) with uncertainty – 1% AEP (1 in 100-year ARI) with uncertainty – 5% AEP (1 in 20-year ARI) with allowance for climate change and uncertainty – 2% AEP (1 in 50-year ARI) with allowance for climate change and uncertainty – 1% AEP (1 in 100-year ARI) with allowance for climate change and uncertainty
Residual hazard	– A series of breach runs with 1% AEP (1 in 100-year ARI) flow and uncertainty scenario. – An overtopping run with a 0.1% AEP (1 in 1000-year ARI) flow Hutt River only: – 2,800 m^3/s flow
Undefended scenario	– Stopbank-down runs for sections of stopbank. Locations and lengths to be determined on a project by project basis. • 1% AEP event with uncertainty scenario • 1% AEP event with climate change and uncertainty scenario • Hutt River only: 2,300 m^3/s flow – Full stopbanks down run for economic analysis (all projects). • 1% AEP event with uncertainty scenario • 1% AEP event with climate change and uncertainty scenario

3.1.1 Hutt River events

The 1,900 m^3/s, 2,300 m^3/s and 2,800 m^3/s flow events are required to be run in all Hutt River flood hazard models in addition to the standard suite of events required under this standard. These flows are the design standards for flood protection structural controls outlined in the Hutt River Floodplain Management Plan 2001.

The 1,900 m^3/s flow is approximately equivalent to the 1% AEP event in the Hutt River under current climate conditions and is the design standard for a small portion of the floodplain. The 2,300 m^3/s design standard applies to the majority of the floodplain including all main urban areas and is approximately equivalent to a 1 in 100-year ARI plus climate change flood event. New bridges are required to meet a 2,800 m^3/s design standard, which is approximately equivalent to a 1 in 440-year ARI flood event.

Further detail is provided in the Hutt River Floodplain Management Plan (Greater Wellington, 2001).

4 Output Formats

A summary of the required format for each of the outputs is provided in Table P5-6 below. A detailed description of the outputs for each output type is provided in the Sections below.

Table P5-6 Outputs

Output format	Output type	Scenario
Hydraulic modelling report	See **Procedure 4: Hydraulic Model** for reporting and documentation requirements.	
Raster grids (2D)	Level	Current and future flood hazard scenarios and uncertainty runs in Table P5-4 / P5-5 Residual flood hazard scenarios in Table P5-4 / P5-5 Alarm levels – project specific
	Depth	Current and future flood hazard scenarios and uncertainty runs in Table P5-4 / P5-5 Residual flood hazard scenarios in Table P5-4 / P5-5 Alarm levels – project specific
	Velocity	Current and future flood hazard scenarios and uncertainty runs in Table P5-4 / P5-5 Residual flood hazard scenarios in Table P5-4 / P5-5 Alarm levels – project specific
	Hazard	Current and future flood hazard scenarios and uncertainty runs in Table P5-4 / P5-5 Residual flood hazard scenarios in Table P5-4 / P5-5 Alarm levels – project specific
Maps (PDF)	Extent	Current and future flood hazard scenarios and uncertainty runs in Table P5-4 / P5-5 Residual flood hazard scenarios in Table P5-4 / P5-5 Alarm levels – project specific

	Hazard	Current and future flood hazard scenarios and uncertainty runs in Table P5-4 / P5-5 Residual flood hazard scenarios in Table P5-4 / P5-5 Alarm levels – project specific
Tabulated in-channel (1D) results at representative locations such as bridges and major structures	Level	Current and future flood hazard scenarios in Table P5-4 / P5-5
	Velocity	Current and future flood hazard scenarios in Table P5-4 / P5-5
Shape files	Extent	Current and future flood hazard scenarios and uncertainty runs in Table P5-4 / P5-5 Residual flood hazard scenarios in Table P5-4 / P5-5
	Flood hazard categories	Based on 1% AEP event with climate change and uncertainty
	Areas benefiting from defences	1% AEP event with uncertainty 1% AEP event with climate change and uncertainty Hutt River only: 2,300 m^3/s flow
Tabulated emergency management data	Discharge and key inundated features (eg, access roads) at alarm levels	To be determined on a project-by-project basis.
	Time to inundation and duration of inundation	Current and future flood hazard scenarios in Table P5-4 / P5-5
	Areas likely to become isolated (islands)	1% AEP event with uncertainty 1% AEP event with climate change and uncertainty Hutt River only: 2,300 m^3/s flow
Optional outputs		
Animations	Extent over time	1% AEP event with uncertainty 1% AEP event with climate change and uncertainty

All outputs should be developed in accordance with the styles and formats outlined in this procedure. This requirement is to ensure that all outputs are clear and consistent for ease of interpretation.

4.1 Terminology and units

Annual Exceedance Probability (AEP) should be used to describe recurrence intervals on all outputs.

Results should be provided in appropriate SI units. Recommended units are listed in Table P5-7.

Table P5-7 Recommended units

Parameter	Unit
Velocity	Metres per second (m/s)
Flow / discharge	Cubic metres per second (m^3/s)
Depth	Metres (m)
Area	Square kilometres (km^2), square metres (m^2)
Level (elevation)	Metres above mean sea level (m aMSL)

4.1.1 Projection

All geospatial data should be projected in New Zealand Transverse Mercator 2000 (NZTM2000).

The Wellington Vertical Datum (1953) should be used as the height datum for projects within Kapiti Coast, Hutt Valley, Porirua and Wellington City.

For projects in Wairarapa, Greater Wellington should be consulted on whether the Greater Wellington Wairarapa Datum should be used. This datum is an unofficial datum based off the Wellington Vertical Datum (1953) +9.22 m.

4.2 Mapping

Flood maps should be prepared and provided in pdf format. Maps should be clearly labelled with the location, event and scenario details. All maps should be dated. Maps should include a north arrow and scale.

Maps should use the colour scheme provided in Table P5-8 below. These colours have been selected as colour blind friendly options based on research published in The Cartographic Journal (Harrower and Brewer, 2003).

Table P5-8 Map style guide

Category	Style Description	Example
Extent	Discrete colours. 50% transparency. Overlaid over aerial imagery. Where extent is displayed on separate maps only one colour needs to be used. The 39% AEP colour should be selected.	
	39% AEP	R69 G117 B180
	20% AEP	R145 G191 B219
	10% AEP	R225 G243 B248
	5% AEP	R254 G224 B144
	2% AEP	R252 G141 B89

	1% AEP	R215 G48 B39
Depth*	Sequential colours. 50% transparency. Overlaid over aerial imagery.	
*Depth bands may be altered on a case-by-case basis if the range is outside of, or within a small number of bands on this scale.	0 m	R0 G0 B0
	0-0.05 m	R225 G247 B251
	0.05 – 0.1 m	R236 G231 B242
	0.1 – 0.3 m	R208 G209 B230
	0.3 – 0.5 m	R166 G189 B219
	0.5 – 1.0 m	R116 G204 B51
	1.0 – 1.5 m	R54 G144 B192
	1.5 – 2.0 m	R5 G112 B176
	2.0+ m	R3 G78 B123
Velocity	Arrows overlaid over depth mapping, arrow size should increase with increasing velocity. A clear scale should be provided.	→
Hazard	H1	R255 G255 B178
	H2	R254 G217 B118
	H3	R254 G178 B76
	H4	R253 G141 B60
	H5	R240 G59 B32

	H6	R189 G0 B38

4.2.1 Geospatial files

Raster grids and shape files (or similar), should be provided in a file format that is compatible with ArcGIS.

4.3 Animations

Animations may be used to communicate the development and behaviour of a flood event. The use of animations will be determined on a case by case basis for individual flood hazard modelling projects. Where possible, the animations should use similar colours to those specified in Table P5-7 above.

Animations should be provided in a format suitable for playing on standard PC video playing software.

5 Procedure review

This procedure is intended to be a living document that can be revised as technology advances and best-practice evolves.

The need for review of the procedures within the FHMS, including this one, will be determined at the end of each modelling project at the 'process review / lessons learnt' checkpoint on the FHMS flow chart.

PROCEDURE 06

INDEPENDENT AUDIT

This procedure has been prepared to outline the protocols to be followed by any person undertaking independent audits of Greater Wellington's flood hazard modelling projects.

Greater Wellington
Te Pane Matua Taiao

Procedure 06

Table of Contents

Greater Wellington
Te Pane Matua Taiao

1 Introduction

This document forms **Procedure 6** of Greater Wellington Regional Council's (Greater Wellington) **Flood Hazard Modelling Standard** (FHMS). This procedure has been prepared to outline the protocols to be followed by any person undertaking independent audits of Greater Wellington's flood hazard modelling projects.

This document should be read in the context of the wider FHMS, and has a particular relationship to **Specification 7: Independent Audit Specifications** which provide a template Request for Proposal for engaging external suppliers to undertake independent audits.

An independent audit template is provided in Appendix P6-A of this procedure. This template should be used as the basis of all independent audits undertaken as part of the FHMS process.

1.1 What is an Independent Audit?

In the context of this procedure, an independent audit is an independent review of an entire flood hazard modelling project from project initiation to the production of the modelling outputs. The audit is focused on determining whether the FHMS process has been followed and whether any deviations from the process are reasonable and appropriate. The independent audit provides an additional layer of scrutiny to give confidence that the outputs of the process are suitable for their intended uses.

It is noted that an independent audit is distinct from a peer review which is a hands-on technical review of the hydrological and/or hydraulic modelling, and the subject of **Procedure 3** of the FHMS.

1.2 Independent Audit in the FHMS Process

Independent audit is undertaken following the production and peer review of the modelling outputs. This stage is outlined in red in the FHMS process flow chart provided in Figure P6-1 below.

Independent audit should be undertaken for all new models that proceed through the FHMS process. Independent audit may also be undertaken where changes are made to existing models that have the potential to result in changes to district plans or Greater Wellington's flood hazard advice.

1.3 Who can be an Independent Auditor?

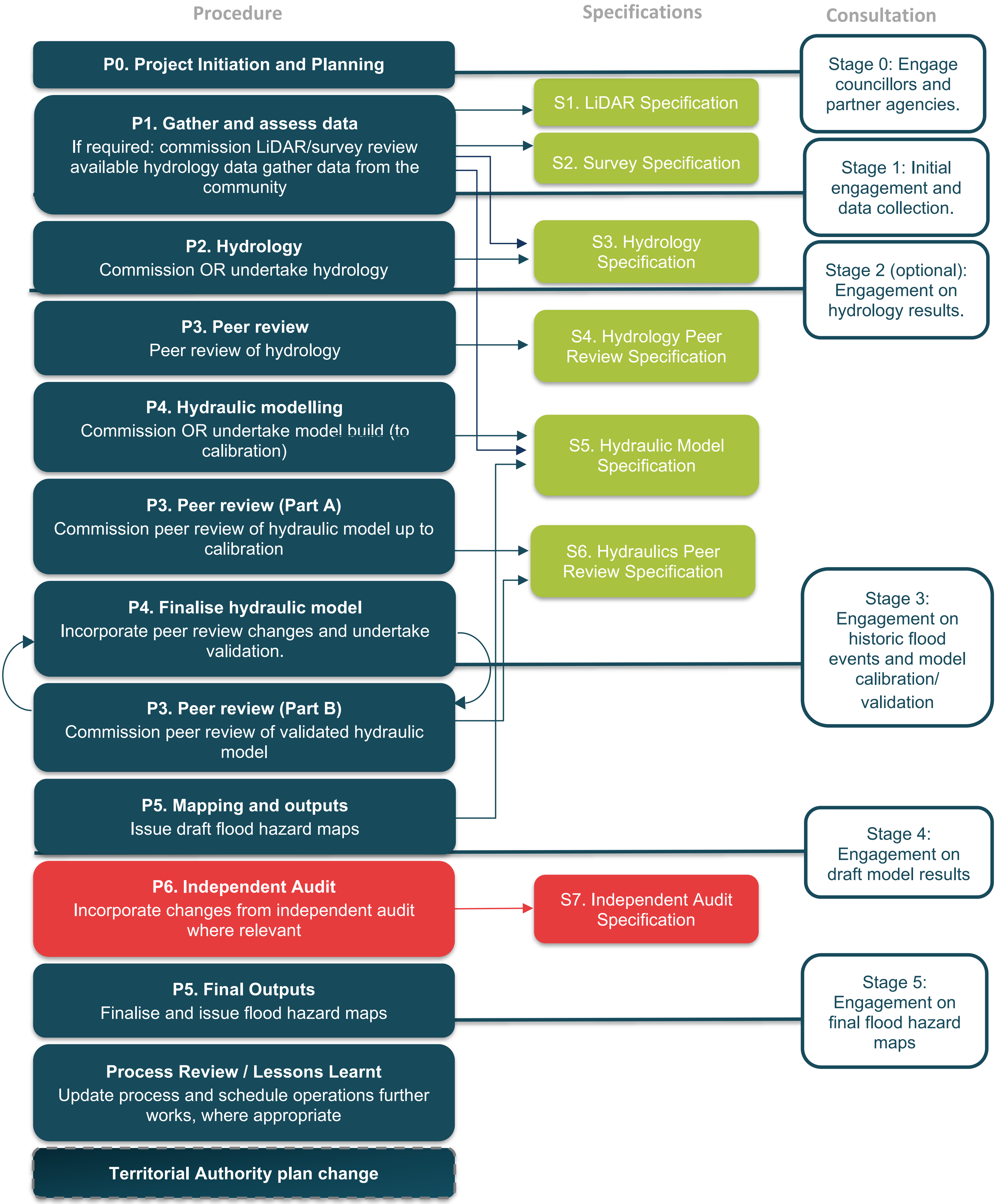
Independent auditors must meet the following criteria:

- Independent auditors must be completely independent from the flood hazard modelling project. Independent means that they, or their organisation, have not been involved in the process at any stage.
- Greater Wellington's staff are not considered independent, and therefore are not eligible to undertake independent audits of work undertaken under the FHMS process.
- The independent auditor should not have any form of dependent relationship with the modellers or peer reviewers who undertook work on the project, and should have no conflicts of interest relating to the project or modellers/peer reviewers' organisations including financial or other interests. Additionally, independent auditors should not have personal assets or other conflicts of interest within the modelled flood hazard area.
- The independent auditor should be familiar with the development of hydrological and hydraulic models.
- There is no requirement for an independent auditor to be based in the Wellington Region, however the independent auditor should be familiar with the mechanisms of flooding with the region, or in similar environments.
- Territorial authorities may assist Greater Wellington to determine additional criteria for independent auditors for specific projects, if necessary.

1.4 How should an Independent Auditor be engaged?

Independent auditors should be engaged using the request for proposal template in **Specification 7: Independent Audit Specification**.

Figure P6-1 **FHMS process showing where independent audit is undertaken (red)**



Greater Wellington should provide to the auditor, a report that includes:

- A high-level summary of the catchment, including its history of flooding, and key areas previously identified as having high flood risk potential.
- A summary of the flood hazard modelling project history including consultants engaged to undertake all aspects of the FHMS process.
- A summary of key decisions made by Greater Wellington during the FHMS process.
- A summary of all community consultation undertaken, including records of where community feedback was incorporated into final outputs.

Greater Wellington should also provide the following files to the auditor:

- Hydrological modelling report
- Hydrology peer review report and spreadsheet
- Hydraulic modelling report
- Hydraulic model peer review report and spreadsheet
- Minutes of community consultation or key emails.

1.4.1 Liability

Independent auditors may be liable for damages if claims against the flood hazard modelling are upheld. The level of liability will be agreed as part of the contract between Greater Wellington and the auditor's organisation and will generally be limited to a multiple of the contract value.

All independent auditors should hold appropriate insurances.

2 Undertaking an Independent Audit

The independent audit should assess whether the FHMS process has been correctly applied at all stages. The auditor should assess:

- Whether all steps of the FHMS process have been undertaken and have been undertaken in accordance with the requirements of the relevant procedures of the FHMS. If there is deviation from the FHMS process, the independent auditor should determine whether the deviation has been documented, the reasons for the deviation and whether the deviation is reasonable and appropriate.
- Whether peer reviews of the hydrology, hydraulic modelling (both part A and part B reviews) have been undertaken, whether all items raised by the reviewer have been addressed, and the reviews closed out.
- Whether all of the required outputs have been prepared in accordance with requirements of the FHMS process.
- Whether community consultation has been undertaken, and whether this consultation was undertaken at the appropriate stages in the FHMS process.
- The auditor should undertake a sensibility check of the peer reviewed outputs.
- The auditor should determine whether the documentation prepared to support the process (e.g., modelling reports, peer review reports, peer review close-out documents) are clear.
- The auditor should determine whether the modelling and peer reviews are robust and defendable.
- The auditor should confirm whether community queries and concerns raised through the consultation undertaken have been addressed, or whether further work is required.

A more detailed list of audit parameters is provided in the independent audit spreadsheet template in Appendix P6-A.

It is noted that the auditor is not required to assess the technical detail of the models, as a detailed technical review is undertaken during the peer review. The auditor is encouraged to liaise with the project team (i.e. the modeller and peer reviewers) for clarification, where needed. All correspondence should be recorded.

The independent auditor may be required to appear as an Expert Witness in Environment Court proceedings related to District Plan changes that result from the flood hazard modelling.

2.1 Process

It is expected that the Independent Audit will follow the following process:

1. Review and audit of all documentation provided by Greater Wellington.
2. Audit meeting with Greater Wellington and members of the project team as necessary (i.e. the hydrological modelers, hydraulic modellers and peer reviewers). The meeting will discuss any potential issues identified.
3. Delivery of the independent audit spreadsheet (see Section 3.1 below).
4. Iterative discussion with the project team to resolve any issues identified, including update of the independent audit spreadsheet iteratively.
5. Delivery of the independent audit close-out / Flood Hazard Model Certificate.

3 Documentation

The initial audit and subsequent iterations must be clearly documented. The following documents are required to be prepared to record the audit, and subsequent revisions:

- Independent audit spreadsheet (a template is provided in Appendix P6-A).
- Independent audit report.
- Independent audit close-out / Flood Hazard Model Certificate (a template is provided in Appendix P6-B).

These documents are detailed in the sections below. All correspondence between the auditor and members of the project team should be documented.

3.1 Independent Audit Spreadsheet

A template of the independent audit spreadsheet is provided in Appendix P6-A. The spreadsheet must be used to record the auditors and project teams' comments for each iteration of the audit. The auditor may add additional items to the spreadsheet as required.

Each item on the audit spreadsheet is to be given a rating in line with the criteria in Table P6-1 below.

Table P6-1 Audit rating table

Review ratings	
Ok	The FHMS process has been correctly applied, or deviations are reasonable and appropriate.
Minor	Issue has been identified that is unlikely to affect the robustness of the final model outputs.
Major	Issue has been identified that compromises the integrity of the final outputs. Options for resolving a major issue include amending the outputs or acceptance of project limitations where the objectives of the study are not compromised.
Critical	Issue severely compromises the integrity of the final outputs and should be rectified.
Other categories	
Future data collection	Identifies where additional future data collection could result in improvements in the future.

Source: modified from Beca (2015). Pinehaven Stream Flood Mapping Audit.

The spreadsheet is then issued to the Greater Wellington project manager. The project manager will arrange for the action items to be addressed as necessary. Any changes made and/or responses to the reviewer's comments are recorded in a separate column in the spreadsheet. The time and date of issue is to be recorded in the spreadsheet.

The auditor is then required to review the comments and changes made, provide further comments (if necessary) and provide a further review rating for each comment in a separate column. This process continues until all of the issues have been resolved and the outputs of the FHMS process are deemed suitable for their intended uses.

An audit log is provided within the independent audit spreadsheet. The auditor and Greater Wellington project manager must record the date and the overall outcome of each iteration of the audit in this table. Outcome should be defined in accordance with the categories in Table P6-2 below.

Table P6-2 Outcome descriptors

Outcome categories	Description
Action Required	Issues have been identified that are likely to affect the integrity of the final outputs and should be rectified.
Suitable for Use	Issues identified in the model have been rectified (if any), and the assessment is considered to be of sufficient quality for use.

An example of a completed audit log is provided in Table P6-3.

Table P6-3 Example audit log

Independent Audit	Date of review/comments	Outcome
Audit V1	14 April 2020	Action Required
Greater Wellington PM's comments V1	28 April 2020	
Audit V2	5 May 2020	Suitable for Use

3.2 Independent Audit Report

A brief report should be provided. The audit spreadsheet should be appended to this report.

The report should be a clear and concise summary of the audit process and findings. The audit report should outline:

- The methodology used to undertake the audit.
- The documents reviewed as part of the audit.
- A description of the issues identified. A clear summary of the issues should be provided as list in the executive summary.
- A section on any community concerns raised, and how these have been addressed.
- Clear section on data gaps that should be filled in the future, where possible.

The report must include a history table that outlines any changes made to the report, and the reasons for those changes.

3.3 Independent Audit Close Out

A close out document should be provided after all of the auditor's comments have been addressed. The close out document can be in the form of a short letter or memo.

The close out document should include the following items:

- Confirmation that an independent audit has been undertaken.

- Confirmation that all of the auditor's comments have been satisfactorily addressed and that final model outputs are suitable for their intended use.
- Any caveats or limitations that the auditor and/or modeller has placed on the work.
- The independent audit spreadsheet should be included as an appendix.

The close out document should be dated. The independent auditor should also provide a Flood Hazard Model Certificate which documents key information relating to the flood hazard modelling process. A template for this certificate is provided in Appendix P6-B.

4 Procedure Review

This procedure is intended to be a living document that can be revised as technology advances and best-practice evolves.

The need for review of the procedures within the FHMS, including this one, will be determined at the end of each modelling project at the 'process review / lessons learnt' checkpoint on the FHMS flow chart.

Flood Hazard Modelling Standard

Prepared by Stantec

March 2025

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