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Introduction

Flood modelling refers to the application of hydrologic and hydraulic models to understand flood behaviour within a defined catchment. Flood modelling is an important tool that contributes to the overall management of stormwater in South Australia. Entities commission flood models, often as part of a broader flood study or stormwater management plan (SMP) to:

- Understand and maintain the natural flood functions of flow conveyance and floodplain storage
- Recognise the impacts of floods on the community
- Enable effective decisions to be made on stormwater management works and measures.

While flood models are often commissioned by local government engineers, the information obtained from flood models can benefit a range of end-users including:

- Land use planners
- Transport planners and operators
- Utility planners and operators
- Emergency management planners and responders
- Flood forecasters
- Risk managers and insurers
- Property owners and developers
- Residents, business owners and the community-in-general.

This circular has been developed by the Stormwater Management Authority (SMA) to assist entities who are commissioning flood models, so that they will meet the needs of a range of end-users.

Using This Circular

Scope and Purpose

This circular outlines requirements that should be considered when commissioning a flood model in South Australia. The purpose of this circular is to:

- Promote a consistent approach to flood modelling in South Australia, while recognising and allowing for differences between entities in governance arrangements, resources and level of flood risk
- Ensure that the outputs of flood modelling are suitable for and accessible by a range of end-users.

Application

This circular presents a range of requirements that should be considered when commissioning a flood model. These requirements are general in nature and can be considered as a set of 'minimum requirements' which aim to ensure that the outputs of flood models are applicable to the needs of a wide range of end-users. The requirements should be considered concurrently with specific requirements that each entity will have as a result of their own local knowledge and understanding of flood risk

This circular has been prepared to assist in the specification of flood modelling requirements and subsequent engagement of a consultant with the requisite expertise and experience. Compliance with this circular is encouraged to promote consistency of approach across South Australian flood management entities.

Principles

The following principles underpin development of flood models in South Australia:

- Flood risk information serves multiple purposes and is required by multiple audiences. Therefore, flood models should be developed considering the needs of all end-users
- Flood models should make use of the best available information, while acknowledging limitations
- Flood risk information should be accessible to those who need it
- Flood models and their outputs should be stored in their most abstract form and in a way that does not preclude their future analysis or re-use.

Terminology

Throughout this circular:

- **Entity** means the person or organisation that commissions a flood model
- **Consultant** means the person or organisation who is commissioned to develop a flood model, and who possesses the necessary expertise and experience to do so.

Elements of Good Practice

Guidelines and References

A range of national and state guidelines, manuals and technical references exist that can assist entities and consultants alike. These resources cover both the technical assessment of flood behaviour and, more generally, aspects of flood risk management.

Appendix A lists current guidelines, manuals and technical reference documents that are applicable in South Australia.

When commissioning a flood model, the entity should direct the consultant as to which, if any, of these documents are to be adhered to and which are advisory only. The entity should also provide the consultant with access to any locally relevant guidelines and references not listed in Appendix A, such as policies and standards on:

- Flood risk classification
- Flood damage assessment
- Flood evacuation planning
- Design standards
- Climate change.

The consultant should refer to the latest and most current versions of reference documents when preparing a flood model.

Data and Information

The consultant should use the best available data and information that is available from the entity and other organisations to develop the flood model. While this may seem obvious, all too often flood models have been developed without first obtaining all of the necessary and relevant available information. Missing or inaccurate information can lead to unnecessary project delays, gross errors in model outputs, and difficulties in achieving model calibration.

Before commencing work on a flood model, the consultant should access and familiarise themselves with all pertinent information including:

- Any previous hydrological studies
- Relevant land use planning policies, emergency management policies and local design standards of the entity
- Geo-spatial data relating to the natural and built environments from the entity and government agencies
- Records of hydro-meteorological observations from the entity, Department for Environment and Water (DEW) and the Bureau of Meteorology (BoM).

The entity has a responsibility to make the consultant aware of any data sets either at its disposal or that it is aware of. Appendix B lists the types of data that may typically be required to support flood modelling.

Hydrologic Analysis

The purpose of hydrologic analysis is to calculate all flows entering a study area as either rainfall, point inflows, or from an oceanic boundary. While the method and complexity of hydrological analysis will be influenced by the availability and adequacy of existing hydro-meteorological data sets, an accurate representation of the hydrology of the study area is a critical factor in determining the ultimate accuracy and usefulness of the resulting flood model.

Relevant hydrologic analysis methods are described in *Australian Rainfall and Runoff: A guide to flood estimation* (Ball, Babister, Nathan, Weeks, Weinmann, Retallick & Testoni 2019) and subsequent revisions. There is no single 'correct' method of analysis, and indeed Ball *et al.* advise that the application of more than one method to any design situation, and the process of reconciling different estimates, can provide insight into errors or assumptions that might otherwise have been missed.

Regardless of the method(s) selected, it is important that the analysis reflects any historical evidence available for the study area. Within South Australia the following local guidance should be observed:

- Observed data from gauging stations in the study area should be used as the first basis for analysis. If record periods are short, then results should be compared with regional information such as the Regional Flood Frequency Estimation (RFFE) procedure described in *Australian Rainfall and Runoff: A guide to flood estimation* (Ball *et al.* 2019).
- Design flows predicted from any calibrated runoff-routing model should be consistent with flood frequency analysis of observed data, or in the absence of observed data, RFFE predictions.
- The RFFE estimates should be applied to catchments within the Mount Lofty Ranges where there are no observed data unless local evidence suggests that the RFFE estimate is not suitable.
- A suitable model should be used to develop estimates for urban catchments where there are no observed data, using appropriate parameters such as those suggested by Kemp & Lipp (2002), and verified against local evidence where possible.

If the entity does not possess the appropriate expertise to prescribe a method (or methods) of hydrologic analysis, then they should request that the consultant nominates and details the types of analyses necessary for the study area and project scope and how they will be undertaken. In any case, the consultant should provide adequate detail on the method of hydrologic analysis used and the basis for its selection, justification for any estimates and assumptions made, and an assessment of the sensitivity of the analysis (to variations in input parameters and assumptions) to permit peer review of the analysis.

Hydraulic Modelling

The purpose of the hydraulic model is to simulate the behaviour of flood waters in the study area. The model must be able to represent all natural and man-made topographic features of the study area that significantly affect flood behaviour, including:

- Waterways
- Overland flow paths
- Subsurface drainage (pits and pipes)
- Structures such as bridges, culverts, levees, dams and detention basins
- Oceanic inundation.

The hydraulic model must be capable of simulating the behaviour of flood waters, including their extent, depth and velocity.

Unless the entity has a specific reason to specify a particular hydraulic model, the entity should request the consultant to nominate a hydraulic modelling software platform and configuration that is suitable to achieve the required outcomes of the study. The consultant should apprise the entity of any limitations or shortcomings of the proposed approach.

The entity should ensure as far as practicable that the hydraulic model software platform is an 'industry standard' software package and, if in doubt, seek advice from the SMA.

Modelled Events and Scenarios

The maximum value in the applicability of a flood model to the management of flood risk is achieved when the flood model is used to consider the full range of flood events and scenarios. Events should be selected from a set of 'standard' annual exceedance probability (AEP) events and should include—at minimum—selection of the:

- 1 in 20, or 5% AEP event
- 1 in 50, or 2% AEP event
- 1 in 100, or 1% AEP event
- 1 in 500, or 0.2% AEP event.

For each of the defined flood events modelled, the flood study should consider a range of relevant scenarios:

- The flood study must consider both the current level of floodplain development and the ultimate level of floodplain development
- The flood study must consider both the current level of flood protection and the future proposed level of flood protection, if any (post-mitigation scenario).

Where flooding results from more than one flooding mechanisms, enveloping of model results is permitted so as to provide a single 'worst case' flood characteristic for the study area. The methodology for enveloping the individual cases must be clearly documented.

Other scenarios that may need to be considered are outlined following.

Climate Change

Flood models provide an opportunity to assess and report on the potential impacts of flood behaviour under climate change scenarios. This is usually achieved by factoring up rainfall events using factors obtained by downscaling a hierarchy of (global, regional and local) climate models; however, there are no nationally consistent guidelines for doing so.

Australian Rainfall and Runoff: A guide to flood estimation (Ball *et al.* 2019) provides interim advice on selecting appropriate planning horizons and climate change projections and the suitability of different methods when calculating the impact of climate change on design rainfall intensity. Sensitivity analysis (see Model Calibration) remains important in testing the sensitivity of the flood model to climatic assumptions.

Dam Break

Where a significant dam exists within the study area and its failure represents a risk to life, the entity should specify that the consultant includes a dam break assessment.

Dam break assessment is a highly specialised field that should only be undertaking by persons with appropriate expertise and in adherence with the *Guidelines on the Consequence Categories for Dams* (ANCOLD 2012) and other relevant references.

Levee Failure

Where a community is protected by a flood levee, the entity should consider a range of factors associated with the levee, including the level of protection is provided, proportion of the community protected, likelihood of failure and consequences of failure.

The entity should specify that the consultant includes both:

- An assessment of levee failure, either by removing the levee from the terrain (simplistic approach), or by 'breaching' the levee at one or more locations and levels in the model (more realistic approach)
- An assessment of the impact of flood events exceeding the design height of the levee, and the potential for flooding within the levee protected area.

Storm Surge and Sea Level Rise

Where flooding occurs in lower coastal waterways, the entity should consider the effects of both storm surge and future sea level rise on flood events. In the absence of specific local policies and standards, guidance may be found in *Coastal Erosion, Flooding and Sea Level Rise Standards and Protection Policy* (CPB 1992) or specific advice obtained from the consultant.

Joint Probability Events

Where the study area may be impacted by two or more independent events at the same time, the joint probability of these events should be considered. Example of joint probability scenarios include:

- An area subject to both riverine flooding and coastal inundation
- An area that can be inundated by riverine flooding from two separate watercourses.

The assessment of joint probability can be complex, and should be assessed by an appropriately qualified practitioner in adherence to Book 4 of *Australian Rainfall and Runoff: A guide to flood estimation* (Ball *et al.*, 2019).

Model Calibration and Validation

Model calibration and validation are important aspects of developing a flood model. While a well calibrated model greatly increases the confidence in the results that the model produces, the ability to undertake a good calibration process is often limited by the information available.

After reviewing the data and information available for calibration and validation, the consultant should apprise the entity as to the possibility of undertaking a reasonable calibration process.

Before the consultant commences any design flood modelling the entity should review and approve the proposed model calibration process.

Sensitivity Analysis

Model sensitivity analysis is also an important aspect of flood modelling, especially in situations where model calibration is poor or not possible. Sensitivity analysis assesses the degree of influence that different model parameters have on the calibration and on the modelled results, and should be carried out to ascertain the relative uncertainty associated with each of the modelled design floods.

The principal parameters that should be considered in a sensitivity analysis are shown in Table 1.

Documentation of sensitivity analysis is often overlooked. This can unfairly cast doubt on the veracity of the model when—in future years—it cannot be established whether a sensitivity analysis was appropriate or even undertaken at all. The consultant should therefore provide sufficient documentation of the sensitivity analysis so as to permit peer review.

Table 1: Principal parameters to be considered in a sensitivity analysis.

Hydrologic	Hydraulic
• Rainfall (spatial and temporal) variation	• Friction
• Rainfall loss	• Energy loss
• Antecedent soil moisture	• Bridge coefficients
• Catchment lag	• Blockage at structures
• Catchment storage	• Boundary conditions
• Time of concentration	

Model Outputs

The outputs of flood models can be manipulated to show different attributes of flood behaviour including flood inundation (area), flood depth, flood level (reduced level), flood velocity and flood hazard. It is preferable that outputs should show at least the area inundated, flood depths and flood hazard for each of the modelled events and scenarios.

When flood depths are provided it is imperative that the digital elevation model used to derive those flood depths is also provided.

Flood hazard should be calculated in accordance with *Flood Hazard* (AIDR 2017).

Spatial and File Format Requirements

The entity may request that model outputs are provided in either raw, post-processed or both formats, however the raw format must be provided. The raw data provides the greatest utility should there be a need to represent or reanalyse the model results in the future.

Model outputs are preferred in a raster (grid) file format. The raster should be prepared to:

- A vertical datum of the Australian Height Datum (AHD)
- A horizontal datum of the Geocentric Datum of Australia 1994 or 2020
- A coordinate system that is either a Map Grid of Australia (MGA) or South Australian Lambert's projection.

Model Files

Even though the entity may lack the capacity or capability to read or run hydrologic or hydraulic model files, it is still preferable that the entity takes possession of these files at the time of developing the flood model. This ensures that the model files remain available in the future should the entity:

- Need to undertake further work or reuse the model
- Need to provide the model to a third party
- Develop the capacity to run the model in-house.

Entities often invest significant public funds in developing flood models and collecting the underlying data and information. It is only prudent then that the entity manages this information appropriately and retains it for future use.

Metadata

Model outputs and model files should be accompanied by descriptions which enable a user to become informed about the content of the files (metadata). For example, a table or document which describes:

- The file name
- The defined flood event and scenario being modelled
- The structure of the data in the file (eg contents of fields)
- References to figures or sections in the accompanying flood study report or SMP, if applicable.

Intellectual Property

The real value in flood risk information lies in its reuse by those, across all levels of government, who rely on it to reduce risk and increase resilience. In its contractual arrangement with the consultant, the entity should ensure that it either obtains a right or a licence to the intellectual property that is delivered as part of the study or in the course of undertaking the study.

References

AIDR [Australian Institute of Disaster Resilience] 2017, *Flood Hazard*, 2nd ed., Australian Disaster Resilience Handbook Collection Guideline 7-3, Australian Government, Canberra.

ANCOLD [Australian National Committee on Large Dams] 2012, *Guidelines on the Consequence Categories for Dams*, ANCOLD, Hobart.

Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M & Testoni I (eds) 2019, *Australian Rainfall and Runoff: A Guide to Flood Estimation*, Australian Government, Canberra.

CPB [Coast Protection Board] 1992, *Coastal Erosion, Flooding and Sea Level Rise Standards and Protection Policy*, South Australian Government, Adelaide.

Kemp, D and Lipp, W 2002, 'Predicting Storm Runoff in Adelaide–How Much do we Know?', *Living With Water Seminar October 1999*, Hydrological Society of South Australia, Adelaide.

Other References

Stormwater Management Planning Guidelines

Stormwater Management Fund Guide for Applicants

Refer also to Appendix A

Acronyms

AEP	annual exceedance probability
AHD	Australian Height Datum
ANCOLD	Australian National Committee on Large Dams
CPB	Coast Protection Board (SA)
DEW	Department for Environment and Water
LGA	Local Government Association (SA)
MGA	Map Grid of Australia
RFFE	regional flood frequency estimation
SES	State Emergency Service (SA)
SMA	Stormwater Management Authority
SMP	stormwater management plan

Acknowledgement

Elements of this circular have been adapted from *Using the National Generic Brief for Flood Investigations to Develop Project Specific Specifications* and the *Technical Brief Project Template*, which can be downloaded from the Australian Disaster Resilience Knowledge Hub at knowledge.aidr.org.au.

Further Information

For more information contact:

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Appendix A: Current Guidelines and References

Title	Publisher	Edition	Date	Internet Reference
Australian rainfall and runoff	Geoscience Australia		2019	arr.ga.gov.au
Coastal planning information package. A guide to coastal development assessment and planning policy	Department for Environment and Water (SA)		2013	www.environment.sa.gov.au/topics/coasts/research-reports-policies
Coastal erosion, flooding and sea level rise standards and protection policy	Coast Protection Board (SA)		1992	www.environment.sa.gov.au/topics/coasts/research-reports-policies
Guidelines on the consequence categories for dams	Australian National Committee on Large Dams		2012	www.ancold.org.au
Managing the floodplain. A guide to best practice flood risk management in Australia (Handbook 7)	Australian Institute for Disaster Resilience	3rd ed	2017	knowledge.aidr.org.au/resources/handbook-managing-the-floodplain/
Using the national generic brief for flood investigations to develop project specific specifications (Guideline 7-1)	Australian Institute for Disaster Resilience	2nd ed	2017	knowledge.aidr.org.au/resources/handbook-managing-the-floodplain/
Flood emergency response classification of the floodplain (Guideline 7-2)	Australian Institute for Disaster Resilience	2nd ed	2017	knowledge.aidr.org.au/resources/handbook-managing-the-floodplain/
Flood hazard (Guideline 7-3)	Australian Institute for Disaster Resilience	2nd ed	2017	knowledge.aidr.org.au/resources/handbook-managing-the-floodplain/
Technical project brief template (Template 7-4)	Australian Institute for Disaster Resilience		2017	knowledge.aidr.org.au/resources/handbook-managing-the-floodplain/
Flood information to support land-use planning (Guideline 7-5)	Australian Institute for Disaster Resilience		2017	knowledge.aidr.org.au/resources/handbook-managing-the-floodplain/
Assessing options and service levels for treating existing risk (Guideline 7-6)	Australian Institute for Disaster Resilience		2017	knowledge.aidr.org.au/resources/handbook-managing-the-floodplain/
Considering flooding in land-use planning activities (Practice Note 7-7)	Australian Institute for Disaster Resilience		2017	knowledge.aidr.org.au/resources/handbook-managing-the-floodplain/

Appendix B: Data Typically Required for Flood Modelling

Data Category		Description
Natural Landscape		
Hydrology	*Catchment*	Location and extent of the catchment
	Watercourses & Waterbodies	Location and alignment of watercourses
		Location and extent of lakes and other natural storages
		Storage curves (depth-area-volume relationships) represented as a table, graph or equation
	Observations & Predictions	• Observed rainfall pluviograph records for storm events related to flood events • Observed stage and discharge hydrographs for flood events related to storm events • Historic data indicating the extent of flood surfaces (from maps, aerial and satellite images, still photography, videography and anecdotal records) • Observed volume changes as may have been recorded at a storage during flood events • Observed tide levels and/or storm surge recorded during flood events • Observed aquifer levels as may have been recorded during and prior to flood events, especially if groundwater contributes to flooding • Observed soil moisture levels as may have been recorded during and prior to flood events • Tide level predictions for the defined flood event (if relevant)
Terrain	*Topography & Bathymetry*	• Cross sections of channel and floodplain profiles • Digital Terrain Model (DTM) or Digital Elevation Model (DEM) spatially representing the terrain and drainage features of the catchment
Vegetation		Extent and classification of vegetation associations within the catchment
Geology	*Soils*	Extent and classification of soil associations within the catchment
	Regolith	Extent and classification of surface geology within the catchment
	Hydrogeology	Details of regional hydrogeology, especially if groundwater contributes to flooding
Biodiversity		Location of the habitat of threatened or vulnerable species and/or ecological communities
Built Landscape		
Land Administration	*Cadastre*	Land division, land tenure and value of land and improvements
	Land Use	Extent and classification of land use classes within the catchment
	Planning Controls	Extent and classification of planning zones and rules, regulations and determinations associated with planning zones
	Imagery (Aerial & Satellite)	Aerial and satellite imagery as may be available for the catchment, showing the current conditions in the catchment as well as historic flood events in the catchment
Buildings & Facilities	*Residential & Non-residential*	Number, locations and purpose of buildings within the catchment Building footprint and elevation of lowest habitable floor
Transport Infrastructure	*Land*	• Location, alignment and carriageway elevations of the road network within the catchment • Location, alignment and track elevations of the rail network within the catchment • Location and geometry of ancillary structures including bridges, culverts, fords and causeways
Water Infrastructure	*Drainage & Flood Mitigation*	• Location and geometry of channelized streams, drains, pipes and pits, natural or constructed levee banks, flow regulating structures (weirs, locks, gates, valves), man-made dams and storages, pumps and siphons • Plans and procedures documenting the operating rules for structures, dams/storages, pumps and siphons. • Dates of construction, materials, performance data and asset condition
Public Administration		
Administrative Boundaries	*Local Government*	Location of local government boundaries
	Suburbs & Localities	Location of suburb and locality boundaries
	Other	Other relevant regions and zones, e.g. landscape regions