Australian Institute for Disaster Resilience

COMPANION DOCUMENT

AUSTRALIAN DISASTER RESILIENCE HANDBOOK COLLECTION

Application of the Total Warning System to Flood

Companion to *Flood Emergency Planning for Disaster Resilience (2020)* and *Public Information and Warnings* (2021)

This document complements *Flood Emergency Planning for Disaster Resilience* (2020) and *Public Information and Warnings* (2021).

They are available as an online resource on the Australian Disaster Resilience Knowledge Hub:
knowledge.aidr.org.au/resources/handbook-flood-planning
knowledge.aidr.org.au/resources/public-information-and-warnings-handbook

Attribution

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Introduction

Flood warning in Australia

Australian communities, infrastructure and industries are exposed to the effects of flooding. Impacts can be direct, such as the flooding of homes and businesses, environmental and cultural damage, death and injury, or indirect, such as business and life disruption or mental health impacts.

Given the significant consequences of flooding, proactive emergency plans and warning systems need to be developed between authorities and communities to prepare to respond to flooding.

Flood warnings are essential to achieve two outcomes:

1. To inform those at risk of a future or current threat
2. To encourage those at risk to undertake appropriate protective actions

(Comrie, 2011).

Effective flood warnings enable emergency responders and community members to take proactive action to lessen the impacts of flooding.

Warnings have been linked to reductions in flood fatalities and damages (Haynes et al., 2017). As telecommunication technologies have increased so has community expectation for accurate, timely and specific flood information before, during and after flooding.

Recent reviews following major floods have highlighted the importance of flood warning systems, such as the Victorian Floods Review in 2011. Key recommendation themes include:

- clarifying flood warning arrangements, including the roles and responsibilities for flood warning systems
- coverage of flood warning systems, including for flash flooding
- availability and reliability of flood warning infrastructure
- incorporation of local knowledge into flood warning systems
- availability and use of flood intelligence
- flood warning communication challenges
- community preparedness to respond to warnings.

While some geographic areas are well covered by flood warning systems, others are not. Flood warning systems may not be feasible in some areas or may not address the flood risk faced by the community. Some flood warning systems can provide advice to the community on how to respond to a flood threat, whereas other cases may only provide general information on the potential for a flood threat in a general area.

Investment in new or upgraded flood warning systems is made in consideration of the risks, the cost-benefit of these systems, their feasibility and sustainability.

Since the 1990s flood warning systems have been structured around the concept of the 'Total Flood Warning System' and consisted of elements including: prediction, interpretation, message construction, dissemination, response and review. With the establishment of an all-hazards approach to emergency warnings known as the 'Total Warning System' (AIDR 2021) this guideline focuses on the application of this holistic warnings framework to flooding. There are many elements of flood warning systems that are unique and warrant further guidance beyond the all-hazards framework.

In March 2021 the Australian Warning System was endorsed by ANZEMC, which aims to provide consistent levels of warning, hazard icons and calls to action, to Australian communities so that people know what to do when they see a warning level. This applies to flooding as part of an all-hazards warning system.

For guidance on the Australian Warnings System see *Australian Warnings Systems* (AIDR 2021)
knowledge.aidr.org.au/media/9105/aidr_australian-warning-system_companion_2021.pdf

Purpose

This guideline provides broad guidance for the application of the Total Warning System for flooding.

This guideline acknowledges that emergency management arrangements for each state and territory are well defined in existing legislation and plans. It is intended to guide and assist those that have a legislated responsibility in flood warning. Detailed flood warning requirements are provided for in jurisdictional plans and arrangements.

Context

This guideline is a companion document to two handbooks in the Australian Disaster Resilience Handbook Collection: *Flood Emergency Planning for Disaster Resilience* (AIDR 2020) and *Public Information and Warnings* (AIDR 2021). It fulfils a critical role in ongoing improvement to the sector's disaster preparation, response, and recovery under the policy framework established by the *National Strategy for Disaster Resilience* (COAG 2011).

The guideline supersedes the *Flood Warning Handbook* (Manual 21).

Over the last decade, post flood reviews and inquiries have identified lessons learnt that are incorporated into this guideline.

Scope

This guideline includes warning systems related to riverine and flash flooding. Its primary focus is the development and application of flood monitoring and predictions and flood intelligence. Further information about warning construction, communication and review can be found in *Public Information and Warnings* (AIDR 2021). Additional guidance on nationally consistent warning levels, hazard icons and calls to action can be found in *Australian Warning System* (AIDR 2021).

Flood warning systems are a component of broader flood risk management and focus on the management of residual flood risk. Therefore, the need for a flood warning system or the upgrade to an existing system may need consideration. One way to consider this need is through a risk-based flood risk management framework such as that outlined in *Managing the Floodplain* (AIDR 2017).

Information on flooding – from flood studies and floodplain management studies and plans, along with historical information on flooding – is integral to the interpretation component of effective flood warning systems. More information on the flood risk management framework and consideration of the need for new or upgraded flood warning systems under the framework can be found in *Managing the Floodplain* (AIDR 2017).

This guideline also integrates with knowledge available in the Australian Disaster Resilience Handbook Collection, including:

- *Australian Emergency Management Arrangements* (AIDR 2019)
- *Public Information and Warnings* (AIDR 2021)
- *Flood Emergency Planning for Disaster Resilience* (AIDR 2020)
- *Managing the Floodplain* (AIDR 2017)
- *National Emergency Risk Assessment Guidelines* (AIDR 2020)
- *Evacuation Planning* (AIDR 2017)
- *Emergency Planning* (AIDR 2020)
- *Community Engagement for Disaster Resilience* (AIDR 2020).

Audience

The audience for this guideline includes:

- emergency service workers
- flood risk managers
- flood hydrologists
- dam owners and operators
- the community including businesses, community sector organisations, primary producers and individuals
- local government
- recovery agencies
- infrastructure operators
- researchers
- government departments and agencies
- private warning providers
- media.

The guideline is supported by an additional companion document titled *Emergency Management Engagement of Flood Prone Communities* (AIDR 2021)

1. Total Warning System

The Total Warning System is described in *Public Information and Warnings* (AIDR 2021). The handbook presents nationally agreed principles for warning policy and practice and explores the essential elements of effective public information and warning delivery. For more detailed information on the decision to warn see section 2.1 of *Public Information and Warnings* (AIDR 2021).

The Total Warning System is illustrated in Figure 1.

Figure 1: Total Warning System

1.1 Roles and responsibilities

Flood warning in Australia involves all levels of government (Commonwealth, state, territory and local), regional authorities and organisations that contribute to data observing networks, and communities. The development and implementation of flood warning systems requires a cooperative approach involving each of these stakeholders.

Roles and responsibilities for flood warning services are detailed in the *National Arrangements for Flood Forecasting and Warning* (BOM 2018) and are affirmed by the Intergovernmental Agreement on the Provision of Bureau of Meteorology Hazard Services to the States and Territories. These are reflected in the membership of Flood Warning Consultative Committees servicing jurisdictions across Australia.

General government level responsibilities for flood warning in Australia consistent with the national arrangements are summarised in Table 2. Depending on arrangements in individual jurisdictions and locations, flood warnings can be issued by Commonwealth, state, territory or local government. The Commonwealth Government does not provide location-specific flash flood warnings.

Table 1: Summary of government responsibility for riverine and flash flood warning in Australia

	Monitoring/ prediction	Interpretation	Message construction/ communication	Response lead
Riverine	Commonwealth State/Territory Local	State/Territory Local Emergency services	Commonwealth Local Emergency services	Local Emergency services
Flash flood	State/Territory Local	State/Territory Local Emergency services	Local Emergency services	Local Emergency services

Note: arrangements differ across jurisdictions

2. Applying the Total Warning System elements to flood

2.1 Situational awareness

Situational awareness relates to continuous attention to and connection with the past, current and emerging situation, in this case the development of a weather system and the flooding it may produce.

A core element is to maintain awareness of potential flood-producing weather systems and to monitor catchments. Weather forecasts and data are made available online and through the media. The Bureau of Meteorology (BOM) will also undertake a significant number of briefings to support emergency services, dam operators and all levels of government at all stages of a flood event.

2.2 Building community resilience to flooding

Flood prone communities must be made ready to understand and act on flood warnings and floods themselves. Community engagement is critical to building and maintaining awareness of flooding and flood warning systems. Community engagement should take place in the implementation stage and as part of the ongoing operation of the flood warning system. More information can be found in *Emergency Management Engagement of Flood Prone Communities* (AIDR 2021).

2.3 Organisational readiness to warn

It is essential that organisations with accountabilities within the Total Warning System have sufficient capability and capacity to undertake their roles for the majority of flood events. This will include:

- adequate numbers of trained, skilled, experienced and exercised personnel
- adequate physical resources to support warning functions, including well maintained monitoring and communications infrastructure
- defined roles and accountabilities that are understood by all stakeholders
- processes in place to assure the readiness of flood warning systems
- systems that are fit for purpose and support the warning function
- community needs are well understood.

2.3.1 Operational coordination and communication

Operational coordination and communication are essential between the organisation formulating flood predictions and the lead response agency (where these organisations are different). During floods, the information on the ground and intelligence reports can provide valuable feedback on the accuracy of the predictions as well as on the relative priority of response and actions in one location over another. Confusion or doubt over flood predictions can be mitigated by near real-time communication during a flood which adds value to predictions and warnings by providing additional context.

2.4 Flood monitoring and prediction

If riverine flooding is expected in an area serviced by a warning system, predictions may provide information on the expected location and scale of both the storm and flood events. Forecasts in relation to storm events may provide advice on the area likely to be affected, the severity of the event and the likely impacts expected. These forecasts provide the basis for warnings even when there is no flood warning system in place. This can include severe thunderstorm and weather warnings, and in some cases generalised flood watches (See Appendix B for information of flood warning products).

Predictions provide the basis for understanding the severity and timing of an oncoming flood. Riverine flooding predictions may include:

- advice on the catchment affected
- the expected flood classification (minor, moderate or major)
- stream heights and timing during the flood (e.g. the height which will be reached at specified gauge stations at particular times).

In many flash flood instances, advice may not include predictions of flood levels but, where possible, provide advice on the location and scale of the event.

Response agency personnel and community members should have clear awareness of the limitations associated with the flood prediction process, including accuracy and timing. A response agency can use information on prediction accuracy to examine the sensitivity of its response actions within the prediction limits. This allows the agency to be better prepared, should a 'worst-case' situation eventuate, and be more confident that the actions planned are the most appropriate.

2.4.1 Catchment monitoring

Routine catchment monitoring is carried out to maintain continual awareness of rainfall amounts that are needed to produce flood runoff. This is part of many broader government flood warning networks. Where this occurs, data from networks of rainfall and river-level stations and soil moisture models may be used to monitor catchment wetness (e.g. soil moisture) and river conditions, normally on a daily basis (See: http://www.bom.gov.au/water/landscape). This is done in close liaison with the 24-hour meteorological monitoring and detection role of routine weather forecasting, which includes future rainfall forecasts by global and regional Numerical Weather Prediction models with specialist local interpretation. The combination of current catchment state and future rainfall data allows an early assessment to be made of the possibility of future riverine flooding and the river levels likely to be reached.

Effective routine monitoring of the potential for riverine flooding requires:

- sufficient rainfall and river level data to provide a representative picture of what is happening over the river basin
- close liaison between meteorological and hydrological forecasting groups
- a hydrological prediction capability to assess the impact of changes (predicted or detected) in meteorological conditions.

Different procedures may apply for locally developed warning systems.

2.4.2 Making predictions

Where riverine flood warning services are available, people threatened by a flood can be provided with locality specific information on the event. The amount of information that can be provided will depend upon the systems and arrangements in place, as well as the available time to warn the community and for them to respond. In many flash flood locations advice may be limited to the location and scale of the event.

Riverine systems should be able to inform people as accurately as possible on how high the flood will be, and with enough time to protect themselves and their belongings. Time available for warning depends on the rate at which streams respond to rainfall. A small urban creek may respond within minutes, producing flash flooding where only limited warning advice will be possible, while floods on the Darling and Murray rivers may take months to reach some downstream communities.

Even where a riverine flood warning service is provided, flood heights can usually only be predicted with high accuracy in the later stages of the flood development when information, such as observed upstream water levels and river rises, becomes available. There is a trade-off between prediction accuracy and warning time. For sufficient warning time to be provided it is often necessary to accept a less accurate prediction. A problem exists with flash floods, where warning time is unavoidably short and prediction is likely to have a high degree of uncertainty.

Predictions and uncertainty

Early in a flood event, predictions are often made using estimates of catchment wetness and forecast rainfalls rather than observed rainfall or stream heights. Because of the uncertainty in using forecast rather than recorded rainfall, predictions will generally not be very precise. To address uncertainty, it is common to use a range of possible forecast rainfalls to make this initial assessment. Modern numerical weather modelling systems are able to attach specific probabilities (i.e. percent chance) to such rainfall amounts and it is possible to get some estimates of the uncertainty involved.

Early flood predictions can be used as the basis for warning products such as a Flood Watch, which is issued by the BOM or warning service providers as a 'heads up' for emergency management agencies and the public to the possibility of flooding in the near future (usually over the next few days). Uncertainty should be known and understood through appropriate public education and in the design of the service. While such products provide more time to prepare for flood, this benefit has to be traded off against the possibility that flood conditions will not develop as anticipated. Predictions are normally made for larger areas covering several river basins, again to cater for uncertainty in the movement of rainfall-bearing weather systems. In the case of flash flooding, early and less certain predictions may be all that is possible in the time available.

The trade-off between accuracy and uncertainty can be summarised as follows in relation to the basis on which predictions can be made:

- Predictions based on forecast rainfall can only be approximate. High levels of uncertainty need to be communicated in forecasts and predictions.
- Predictions based on amounts of recorded rainfall are likely to be more accurate, but they need to take account of rainfall losses due to evaporation, seepage and water that has flowed into and been impounded or modified by dams. There is significant uncertainty in how the catchment and river will respond. This includes the amounts of seepage, interception and how the flood will flow down-stream.

- Predictions based on measured stream heights upstream of a specified gauge are generally the most accurate, especially in streams with little additional inflow between the two gauges. However, prediction capability may be limited if upstream gauges are in close proximity to the gauge for which warnings are being provided due to time limitations.

All of these assumptions and known uncertainties need to be considered when establishing a flood warning system, undertaking associated emergency planning and when engaging the community in relation to flood warning.

2.4.3 Flood height and time

Predictions of flood heights or levels and times may be possible where the systems, arrangements and time allow.

During a riverine flood event, predictions are typically for expected stream levels at specific times at key locations on a river. Predictions can be of:

- flood stages (the levels reached at specified times as the flood rises towards the peak)
- flood classification levels (when the river is expected to reach, or exceed the minor, moderate or major flood level)
- the peak flood level
- particular significant levels that reach a threshold (e.g. the lowest point on the crest of a levee) that will be reached or exceeded as the river rises. These can be tipping points for changes in the impacts on the community and for community response to an event.

River level predictions as the river recedes are also useful to guide post-flood recovery activities.

A prediction is normally made for a particular location and time and best expressed as a specific river level at a nominated gauge. This requires confidence that available data and prediction techniques allow the hydrologic behaviour of the catchment and the hydraulic behaviour of the river to be reliably modelled. Where this is not possible, a prediction may be given as a range, which is an indication of the classification of flood impacts on the community (minor, moderate or major) to be expected. Each classification corresponds to a range of river levels and associated impacts.

A prediction of the expected river level at a single location in isolation is of limited use for response. The meaning of a predicted level needs to be established for areas at risk in the floodplain surrounding that location, including likely impacts on the community. This can be made using flood intelligence (refer to Section 2.5).

2.4.4 Flood classifications

In Australia, standard flood classifications describe the severity of flooding at stream gauges linked to the potential effects in their reference areas. The classification of minor, moderate and major flooding can be used as a general guide for response agencies and

Table 2: Flood severity classifications

Flood severity	Impact
Minor flooding	• causes inconvenience • low-lying areas next to watercourses are inundated • minor roads may be closed, and low-level bridges submerged • in urban areas inundation may affect some backyards and buildings below the floor level as well as bicycle and pedestrian paths • in rural areas removal of stock and equipment may be required.
Moderate flooding	In addition to the above: • the area of inundation is more substantial • main traffic routes may be affected • some buildings may be affected above the floor level • evacuation of flood affected areas may be required • in rural areas removal of stock is required.
Major flooding	In addition to the above: • extensive rural areas and/or urban areas are inundated • many buildings may be affected above the floor level • properties and towns are likely to be isolated and major rail and traffic routes closed • evacuation of flood affected areas may be required • utility services may be impacted.

communities. Classification can also provide examples of how to translate numerical results into impacts on the ground that can be graphically or verbally communicated to the public. The Australian Warning System proves a nationally consistent set of hazard icons, including flood, that increase as the warning level increases. See the *Australian Warning System* for further guidance (AIDR 2021). Flood severity classifications are outlined in Table 2. It is important to recognise that whilst major flooding as a classification is an upper threshold for warnings it is somewhat open ended. This classification can represent a range of consequences from several homes being flooded to a flood of record with extreme consequences for a community.

Flood classification levels are determined for each forecast and information location corresponding to the river level (gauge reading) at which the impacts, described above, commence.

2.4.5 Warning lead time

Warning lead time is the time between the issuing of a warning containing a prediction and the time when the predicted height is reached or when the stream peaks below that height. The longer the lead time, the more time there is to undertake protective behaviour and action. The value of flood prediction is determined by both the accuracy of the prediction itself and the amount of warning lead time provided.

The potential warning lead time depends on the hydrology of the catchment draining to the forecast location and the technical components of the flood prediction system. Where a location can be flooded by runoff from small catchments which respond very quickly to rainfall (flash flooding) the potential warning lead time is very small (from less than an hour up to several hours). In these situations, forecast rainfall is often utilised to increase the available lead time, but this can be at the expense of forecast accuracy.

As catchment size increases so does the 'natural' delay between rainfall and the flow at a gauge increases. A combination of rainfall and river level observations with rainfall-runoff modelling can be used to capture this natural delay as the warning lead time. Such modelling approaches are also subject to forecast uncertainty, but this is normally less than methods that rely mainly on forecast rainfall such as flash flood warning systems.

Locations flooded by large, slow-moving, low-gradient rivers can have potential warning lead times of many days and up to weeks or longer. In these cases, predictions are based on observations of upstream river levels which allows for greater accuracy. Predictions can be challenged by evolving landscape features that vary from flood to flood. Recognition of this inter-relationship between accuracy and lead time should be built into the development of response strategies and communicated through community awareness strategies.

Precise predictions are not always achievable as no two floods behave in exactly the same way. This is due to variability in factors such as the spatial variability of rainfall or changes in catchment and soil characteristics from event to event. Often a prediction range within tight bounds (e.g. 0.3 metres) is sufficient to guide the flood response. A high degree of accuracy may be required for locations where tipping points and consequences of reaching these tipping points are critical to the response and potential safety of a community (e.g. change in response where a levee protecting part of a town has the potential to overtop).

Flood predictions take time to prepare. Time is required for:

- collection and management of data from the network of gauges in a catchment area
- communication of collected data in near real time to a prediction agency
- meteorological forecasting
- running the flood prediction models
- preparing the message containing the prediction.

Identification of critical stream levels and the protective actions that need to be taken before these are reached should be undertaken as part of flood emergency planning and intelligence (e.g. the evacuation of an area behind a levee which would be overtopped at a known gauge height, or height at which an evacuation route is cut). Warnings should consider these critical levels and actions, and they can be built into objectives of the warning system.

2.4.6 Warning frequency

Frequency of predictions varies from area to area and reflects the rate of change of flood conditions. In flatter valleys and long rivers where floods can travel long distances, predictions need to be revised less often and less quickly compared to places where gradients are steep and flood travel distances are short. In flash flood, catchment predictions usually need to be updated more frequently to reflect the likely rapid change in flood conditions.

Warning messages should include the period of time over which the prediction applies. They should also include the time when the next prediction will be issued. This allows for those relying on the predictions to plan for the changes and adapt their strategies as needed.

2.4.7 User requirements

User requirements need to be developed in consideration of the flood characteristics at the location and the associated emergency response. This ensures that practical and achievable actions are clear when developing user needs and do not unreasonably raise user expectations.

Where sufficient warning time is available to derive flood heights and timing to support community response, the prediction should consider an understanding of flood impacts at different river levels and the types of protective behaviour most appropriate to each situation. When considering user requirements, there is a need to determine:

- the location(s) on the river system where predictions are needed
- the flooding level(s) in the reference area of specific gauges that will trigger community warnings (these levels will create 'entry levels', usually defined as 'minor flood' heights, for the prediction agency)
- tipping points where changes to river levels trigger significant changes in flooding impacts (e.g. the gauge level when farmland is inundated, roads cut, houses flooded, levee overtopped or evacuation routes closed) or how the community needs to respond to the flood threat
- the time needed to undertake the necessary protective responses (e.g. relocating livestock, door knock, evacuate communities, implementation of operational levee plans)
- the likely frequency that updates to predictions will be made.

In the early stages of an event, the prediction may be that a particular level will be reached or exceeded, with the expectation that the river will later peak at a higher level particularly in situations where there is a high likelihood of further forecast heavy rainfall. Not all predictions are of peak levels.

It is important that the expected trend of the river (rising, steady or falling) is indicated in messages containing flood predictions. As a flood is developing, many users also seek information on the rate of rise in the period immediately before the prediction is issued.

2.5 Interpretation: using flood intelligence

Predictions of likely flood heights at a gauge are of little use by themselves. Research has shown that most members of the community cannot easily interpret gauge or flood heights, particularly if they lack direct experience with flooding in their local area.

Communities need to be informed about the meaning of flood heights in terms of potential flood consequences. This requires the use of flood intelligence to interpret the meaning of flood predictions in terms of impacts. Flood intelligence is outlined in *Flood Emergency Planning for Disaster Resilience* (AIDR 2020).

The potential impacts from an event can be communicated to the public in a variety of ways that translate the numerical predictions into tangible experiences through:

- flood markers throughout a town
- pictures of previous events
- maps
- written descriptions of the potential extent of inundation.

Flood markers can be placed on bridges and in other prominent locations to provide residents with a visible point of reference for flood events. Markers such as these have the potential to be linked to the flood warning system, effectively 'personalising' the warning system. They help make it possible for residents to assess the likely impacts in their local area, enabling them to make effective decisions about protecting property and evacuation. For example, in the township of Wangaratta local residents understand the potential impacts of flooding based upon the level of flooding at a statue of Yogi Bear (Figure 2).

Figure 2: Yogi Bear Statue as a flood marker in Wangaratta, Victoria. (Image: Border Mail and VIC SES).

Using such markers requires an education campaign to ensure that community members understand what they represent and can interpret them correctly when a prediction of a particular height is in a warning message.

Example: Flood warning interpretation arrangements in South Australia

During a flood, data from a variety of sources must be understood in context to get a picture of likely flood behaviour. In South Australia, the Department for Environment and Water (DEW) provides technical support to the South Australian State Emergency Service (SASES) to assist with this activity. The SASES is the state control agency for flood hazard and is the lead response agency during a flood incident. DEW is the flood hazard leader, which means the agency leads and coordinates activities that help South Australia prepare for, manage and respond to such floods.

DEW staff with expertise in flood hydraulics and hydrology are deployed to the SASES State Control Centre as part of the intelligence functional area in the Australasian Inter-Agency Incident Management System (AIIMS). During floods, they interpret many forms of information, including Bureau of Meteorology warning messaging, near real-time rainfall and water level information, historical data, existing flood maps and flood studies. This enables them to provide advice that includes emergent risk areas, likely locations, severity and extent of floods, direction to ground and air observers and oversight of DEW spatial products showing flood risk information and/or flood intelligence, including target area polygons for emergency alerts to fixed and mobile phones in potentially affected communities.

Formalised in 2016 under a Memorandum of Understanding between DEW and the SASES, the arrangement has assisted the SASES in multiple storm tide, flash and riverine flood events to undertake appropriate response actions. Lessons learnt from providing support to the SASES during incidents has in turn informed priorities for DEW as the flood hazard leader. It has also guided longer-term flood preparedness projects to reduce flood risk such as a dam maintenance and emergency management guidelines for private dam owners, improved information sharing for water supply reservoirs, review and/or development of flood warning triggers, and targeted investment in flood warning infrastructure.

Similar arrangements are also in place in Victoria where Department of Environment, Land, Water and Planning, Catchment Management Authority and private consulting staff assist the Victoria State Emergency Service (VICSES).

2.6 Message construction

The warning message is the critical link between flood prediction and interpretation and taking protective action. It must be 'user friendly' and be based on the needs of communities. The message should explain what is happening and what will happen, when, where, how the flood will affect the recipient of the message and actions communities can take. The message must come from a credible source (such as the BOM or a state or territory emergency service), be informative and persuasive and be clearly understood by those receiving it. The message may be either in written form or communicated verbally.

Where possible, messages related to flooding should specifically address:

- when the floodwaters will arrive or reach certain heights
- when the flood will occur (e.g. during the day or late at night)
- how long the flood will last
- where the water will go (i.e. in terms of areas which may be inundated)
- the depth and velocity of the expected floodwaters
- likely impacts
- public safety advice and protective actions
- who to contact for assistance or further information
- other factors which may affect safety.

Some of this information, specifically which areas will be inundated at the forecast height, should be contained in flood intelligence records.

To assist in communicating flood impacts it can be helpful to benchmark flood levels against previous floods, flood markers or landmarks. Maps can also be a useful way to communicate the spatial extent of flooding.

Detailed guidance on the construction of flood warning messages is provided in *Warning Message Construction: Choosing your words, Additional guidance to support users of the Public Information and Warnings Handbook* (AIDR 2021).

2.7 Communication

Communication of flood warnings should be based on a broad communications strategy which considers messaging and channels in the lead-up, during and after flooding.

There are many channels for communicating flood warnings. The flood warning communication strategy will be dictated by the severity of flooding, warning time available and identified at-risk groups. Many communication mechanisms are utilised across different hazards, but some have been specially used for flooding.

In instances where little warning time is available, communication mechanisms are integrated with automatic monitoring and prediction systems.

Detailed guidance on the communication of warnings is provided in *Public Information and Warnings* (AIDR 2021).

2.8 Community response

To ensure the provision of high-quality flood warning services, community response can be strengthened with community engagement to build flood awareness and preparedness. For further information refer to the companion document *Emergency Management Engagement of Flood Prone Communities* (AIDR 2021).

2.9 Continuous review and improvement

Public Information and Warnings (AIDR 2021) presents general guidance on review and improvement of warning systems. Table 4 outlines factors specific to reviewing the performance of flood warnings.

Table 3: Flood warning performance review indicators

Component	Performance review indicators
Monitoring and prediction	· Adequacy of understanding of prediction needs · Adequacy of early advice of potential flood producing rainfall · Adequacy of gauge network density · Adequacy of network redundancies · Adequacy of data collection technology · Adequacy of online data management · Accuracy and timeliness of predictions · Adequacy of communication between dam operators and the prediction agency · Effectiveness of communication between prediction agency and recipients · Effectiveness of communications regarding uncertainty · Adequacy of linkages to local knowledge networks
Interpretation	· Quality of available flood intelligence · Adequacy of flood intelligence collection
Message construction	· Extent to which warning messages were tailored utilising flood intelligence and knowledge of at-risk communities · Extent to which communities understood and took action in response to warnings
Communication	· Extent to which communication methods were appropriate to the severity of flooding · Adequacy of communication to vulnerable people and groups · Extent to which warnings were received in a timely manner · Extent to which at-risk communities were able to validate warnings
Response	· Appropriateness of actions taken by response agencies and individuals
Organisation readiness to warn	· Adequacy of policy and protocols to guide warning function · Extent to which capability was available to support warning function

3. Considerations for developing a flood warning system

3.1 Defining the need for a flood warning system

Flood warning systems can be a measure to manage flood risk to communities. Flood risk is created by many elements and the development of a new, or upgrade of an existing, flood warning system may not be effective in addressing the risks faced by the community.

The need for a flood warning system or the upgrade of an existing flood warning system for a community may be considered in a floodplain management study as part of the flood risk management framework outlined in *Managing the Floodplain* (AIDR 2017).

The need for a flood warning system relates to its ability to improve public safety and allow for associated protective measures to life and property. Where a fit for purpose flood warning system can achieve this aim, and is considered practical, feasible and a priority for the community, it may be recommended in a management plan. Implementation of a flood warning recommendation may lead to further investigation, design and implementation of a new or upgraded flood warning system.

3.2 Investigating the system

Having determined the need, priority and feasibility of a fit for purpose flood warning system, the next step is to investigate the system to confirm its scope, intent and limitations so that these factors can be considered in system design. Table 5 provides a checklist of what needs to be considered.

Table 4. Checklist for investigating a flood warning system

☐	What can the system practically achieve considering associated limitations? Note that: • Systems that provide time for considered analysis and predictions can identify the potential scale of the flood threat and provide effective warning time for response. These systems can support the implementation of flood emergency plans that support coordinated actions (such as self-evacuation) by the community and government in response to a flood threat. • Systems that may be able to identify the potential for heavy rainfall and possible flooding and provide limited time for response. These systems may result in general or limited advice to the community on how to respond to a flood threat. They may also result in more false alarms than systems able to analyse the flood producing conditions.
☐	Will the system achieve the intended outcomes of improving community safety? Flood warning systems are not failsafe and therefore should not be relied upon as the only mitigation measure where there is significant risk to life.
☐	Will the system improve public safety, allowing associated protective measures to life and property?
☐	Does the messaging and message delivery meet community needs?
☐	Is the system likely to be cost effective and sustainable in the long term?
☐	Are all those expected to have a role in implementing and managing the system for its useful life likely to agree?
☐	Is the coordination of roles and responsibilities of agencies and organisations involved clearly identified?
☐	Are the life cycle costs likely to be affordable?
☐	What are the cost sharing arrangements and are all parties able and willing to contribute?

Considering these aspects can assist in scoping a fit for purpose system that is practical, feasible, and sustainable.

This is an essential step for determining the potential system feasibility and capabilities so that these aspects can be clearly identified, outlined in community consultation, agreed, and ultimately considered in system design.

3.3 Designing the system

When developing an effective flood warning system, several factors need to be addressed. Table 6 provides a checklist of these factors. The outcome of this stage is a design report that documents the investigation and design process, the proposed system and its operation and maintenance (including maintaining community awareness), the agreed roles and responsibilities and life cycle costs.

Table 5. Checklist for designing an effective flood warning system

☐	Are the needs of future system managers and the community met, as identified in the investigation? Where relevant identify: • typical triggers identifying the potential for flood producing conditions • typical warning time available considering critical storm duration, rainfall patterns etc • when warnings are required (including the level at which flooding begins and critical levels such as key triggers for changes in response or impacts, e.g. evacuation triggers, the cutting of evacuation routes, and levee heights) • what the impacts of flooding will be at different levels • the classification of flooding in terms of minor, moderate and major floods based on impacts • warning time(s) the community requires to take protective action and the amounts of time which can be provided for meaningful action • appropriate warning message construction • the channels through which warning messages are to be communicated • the frequency of warning updates.
☐	Has the system been integrated with emergency management arrangements established by the relevant state or territory?
☐	Are flood warning arrangements detailed in all flood emergency plans? Do these arrangements specify conditions when warnings will be issued and the organisation or officer responsible for issuing the warnings?
☐	Have the agencies and local governments concerned with situational awareness, prediction and monitoring, interpretation, message construction, communication and response been involved with the system development and review?
☐	Have community members been consulted? Have their needs and warning preferences been addressed?
☐	Are all elements of the system included and integrated?
For each element of the system:	
☐	Are the roles and responsibilities of all agencies and organisations involved clearly identified?
☐	Is the coordination of roles and responsibilities of agencies and organisations involved clearly identified?
☐	Has the wider flood risk management perspective been considered in the system? E.g. has the inter-relationship of flood warning been considered in relation to other flood risk management measures, emergency management arrangements and land use planning?
☐	Have the relevant standards been considered in the system design?
☐	Has there been effective organisation, resourcing, community engagement, training and exercising?
☐	Have maintenance of the flood warning system and associated community awareness been identified?

3.4 Critical considerations for defining and building flood warning systems

3.4.1 Effective collaboration at the design stage

Involving community members in the development of warning systems that generate warnings will enhance the relevance and local ownership of flood warning systems. Each community is likely to have its own unique set of requirements. These need to be considered to a level that is practical and feasible for a fit for purpose system.

Within the context of what a flood warning can achieve considering the outcomes of the investigation, the community should be consulted regarding what is desired in relation to:

- the key trigger levels of flooding (usually at a specified gauge) for which warning will be needed, for example these may relate to minor, moderate and major consequences to the community
- the consequences of flooding at different flood heights in areas around the gauge (i.e. in the gauge reference area)
- the amount of warning time needed to take protective action, evacuation and other tasks for floods of specified severities
- the ways in which warnings should be provided
- other matters related to the various components of the system.

This approach will give the design of warning systems and procedures an appropriate focus and help ensure their relevance to the communities that they are being designed for. The following steps provide practical guidelines:

1. Identify potential clients of flood warning information at different levels of flooding and their information needs. The clients may be farmers, caravan park proprietors, river-boat operators, gravel extracting firms, mining companies, village, town or suburban residents, indigenous communities, operators of industrial or retail premises, and many others. In some circumstances they may include people living below dams which have been classed as structurally deficient or as having inadequate spillway capacity to safely 'pass' big floods. Such dams are at some risk of failure.
2. Use existing flood information and intelligence to develop an understanding of what is known about the impacts of flooding including its spatial extent at different levels and locations.
3. Identify what actions will be required of people impacted by flooding.
4. Determine the amount of time needed to carry out these response actions. Estimating time requirements is critical to ensuring warning services can be planned so necessary actions can be completed before the onset of flooding.
5. Develop appropriate means of disseminating warnings to different end users and at different flood levels.

It is important that limitations in the system design are identified and transparent throughout the process. This will help stakeholders understand and manage expectations around what can and cannot be achieved.

3.4.2 Ongoing planning, operation, maintenance and review

Several agencies may need to be involved in planning, establishing, operating and maintaining flood warning systems. The establishment of a flood warning system requires:

- commitment of funds and resources to developing the various components of the system
- willingness to maintain investment in these components, even when flooding is not frequent or regular
- willingness to upgrade systems with technological change
- willingness to review the performance of systems considering lessons learnt from events.

Many flood warning elements can be set up inexpensively as they involve defining arrangements and tasks rather than investment in hardware and maintenance. Many of the problems associated with operating flood warning systems relate to these aspects not being adequately defined. Where possible, flood warning system design should look to leverage existing infrastructure.

Flood Warning Consultative Committees should consider the accountability of the various agencies involved in flood warning system design, development and operation. Responsibilities could be defined in writing and performance indicators designed to help assess the degree to which agencies meet those responsibilities.

While planning for warning, activities cannot address unpredictable circumstances, plans must be sufficiently flexible and robust to allow for rapid adjustment to new situations whilst remaining effective. Plans are to be regularly exercised on a multi-agency basis in ways that provide opportunities for examining the implications of different levels of flooding. Exercises provide practice in receiving predictions, interpreting them and generating appropriate messaging. They also allow for periodic reassessment of the amount of time needed after a warning is received to carry out specified tasks.

This reassessment can be used in renegotiating warning lead times.

Reviewing the performance of the flood warning system and the associated arrangements and system elements after a flood is important. This can provide lessons for making modifications or improvements to current arrangements or identifying the need to consider future modifications or upgrades.

3.4.3 System documentation

The system and its operation and maintenance need to be documented. Documentation is to be reviewed and updated in line with lessons learnt and changes to the system or roles and responsibilities. Documentation needs to include:

- agreed roles and responsibilities
- warning system design
- warning system operation and maintenance
- community awareness
- infrastructure specifications and suppliers
- site access instructions
- site security
- communications
- data access.

3.4.4 Role of technology

The use of technology needs to be determined. The technical rigour of flood predictions (accuracy, timeliness and reliability) can vary considerably depending on the type of technology used. The choice of technology should always be driven by client needs. Technological alternatives should be assessed as a balance between the potential reduction in flood damage from an improved quality of prediction and the cost of the technology needed to gain that improvement.

This approach can often be difficult to implement in practice as there are many other considerations that dictate the eventual prediction system used. The need to achieve this balance should guide decisions on the choice of technology as far as is practicable.

3.4.5 Flood warning monitoring infrastructure

The nature of infrastructure to be used needs to be determined. A Flood Warning Infrastructure Standard has been published to identify the specific performance requirements for infrastructure, sensing collecting and communicating data for flood forecasting purposes (See: **www.bom.gov.au/water/standards/floodwarning.shtml**).

A National Framework for Flood Warning Infrastructure has been developed that provides guidance for future flood warning infrastructure planning and investment, based on jurisdictional analyses of their flood warning infrastructure. The Australia and New Zealand Emergency Management Committee endorsed the *National Framework for Flood Warning Infrastructure* and the *Flood Warning Infrastructure Standard* in August 2019.

Gauge infrastructure and monitoring provision is a partnership involving organisations such as Bureau of Meteorology (BOM), local government, water authorities, catchment managers and dam operators. Needs for flood warning infrastructure are often identified through the flood risk management process outlined in *Managing the Floodplain* (AIDR 2017).

3.4.6 Data communication

Communication systems to be utilised must be decided upon. Data can be communicated to the prediction centre using a range of telemetry systems. Further information is available from the Flood Warning Infrastructure Standard (See: **www.bom.gov.au/water/standards/documents/Flood_Warning_Infrastructure_Standard.pdf**).

3.4.7 Model-based prediction

Flood models are used to convert rainfall and streamflow data and catchment information into a prediction of the height that will be reached at a downstream gauge at a specified time. Hydrologic and hydraulic modelling techniques vary widely. The forecast model to be used is an important consideration.

In some cases, simple procedures can predict river behaviour with reasonable levels of accuracy. In other cases, improved accuracy requires investment to increase the density of real-time rainfall and river level measurement, better data on physiographic characteristics of the river and sophisticated modelling tools. These tools can improve the accuracy of prediction for the more common flood events and can also provide a greater confidence in predictions for the more severe events not yet experienced. The choice of technique should be based on a consideration of prediction needs and the value returned from investment in improved procedures.

3.4.8 Considerations for flash flood environments

The responsibility for establishing and operating flash flood warning systems lies with the states and territories, working in collaboration with local councils where appropriate. As part of its role in providing support to the development of flash flood warning

systems, BOM has developed and coordinates The Flash Flood Advisory Resource (FLARE) as a community of practice for assisting responsible agencies to design, implement and manage flash flood warning systems. FLARE is a registered-user website and telephone and email advisory service, and a platform for sharing the knowledge of experts from BOM and other agencies around the country.

Automated rain and river level measuring equipment allows for the availability of real time or near real time data. These systems automate the detection of predefined threshold conditions for flooding and can deliver messages to response agency personnel or community members by mobile devices or applications when designated rainfall intensities are recorded or critical stream levels are reached. They also make a wide range of flood data readily available to response agencies for subsequent extension into a wide range of warning products suited to broadcasting via the internet, landline telephone, SMS, social media, and applications.

Flash flood warning systems will likely have some limitations, including:

- warnings will likely be a simple alert of impending flooding rather than a detailed prediction
- warning system success relies on the effective dissemination of alerts
- warning times provided will be limited
- given limited warning time the key objectives of the system will be focused on life safety rather than property protection
- community awareness is critical to ensuring effective response to warnings
- the system must be maintained.

3.4.9 Setting up local community systems

For small creeks and some rivers there are often no formal, scientifically based warning systems. There may be a case for developing an alternative system if people and property are affected by flooding and if local demand for warning information exists. This can be done by gaining access to local community system networks that have been passing flood information from upstream to downstream locations, often from farmer to farmer, for decades.

Local response agencies may wish to gain access to these networks and formalise them to an appropriate degree (e.g. by recognising them within flood emergency plans) and use them to develop situational awareness and spread information to the affected community more broadly. In many situations, local agencies already tap into such sources to fine-tune predictions and to obtain valuable local historical flood information.

Locally based monitoring and prediction systems can be effective, particularly for small creeks. One approach is for a local response agency to set up an information-gathering system where individuals along a stream can be contacted for details of current flood situations. Assessments can then be made by the response agency, by comparing an existing flood with past ones in terms of apparent severity, developing response actions accordingly and providing warning information to the wider community as necessary. These local systems are best established in coordination with agencies such as BOM and the response agencies and flood risk managers who can advise on available technologies and other aspects of system design and operation.

Appendix A: Different types of warning products and services

The various services which the Bureau of Meteorology (BOM) provides in relation to flood prediction include:

Tropical Cyclone Warnings

BOM will issue a Tropical Cyclone Watch or Tropical Cyclone Warning for threat to coastal communities from a tropical cyclone for very damaging winds, heavy rainfall, and sometimes abnormally high tides due to storm surge (particularly dangerous if coinciding with high tides). BOM also provides more detailed tropical cyclone storm tide advice to emergency services to assist their emergency response decision making.

Severe Weather Warnings

Severe Weather Warnings alert those damaging weather conditions not already covered by tropical cyclone, severe thunderstorm or fire weather warnings. They include warnings of very heavy rainfall leading to flash flooding or storm surge, which is sometimes exacerbated by abnormally high tides within the next 24 hours. The storm tide advice is only available to limited parts of the Australian coastline.

Severe Thunderstorm Warnings

These warnings are issued when severe thunderstorms are likely to develop or extend into a specified area over the next few hours. Severe thunderstorm warnings can refer to damaging winds, large hailstones, and heavy rainfall that may lead to flash flooding in the warning area.

Flood Watches

BOM will issue a Flood Watch when the combination of forecast rainfall and catchment conditions indicates riverine flooding is possible. A Flood Watch may cover a large area due to uncertainty associated with the location and amount of forecast rainfall. A Flood Watch may also make reference to the severity of flooding that may be experienced in the catchment being highlighted. The types of flooding that may be referred to include riverine and/or local flooding (for areas without a well-defined river where intense rainfall is expected to cause high runoff volumes). Note that Flood Watches may cover catchments that do not have established BOM flood warning services.

The primary purpose of a Flood Watch is to provide early advice to communities and the relevant emergency service organisations of the potential flood threat from a developing weather situation. Typically, a Flood Watch is issued 1 to 4 days before an anticipated flood event depending on the confidence in rainfall forecasts.

Flood Warnings

In general, Flood Warnings are issued by BOM based on the following criteria:

- The river level of at least one forecast location is expected to reach and or exceed or has exceeded the minor flood level.
- The flood classification levels or trigger heights defined at forecast locations are expected to be exceeded. Forecast locations are where a forecast of future water level is provided either as the classification of flood that is predicted (minor, moderate or major) or as a level and classification.
- The flood classification levels defined at information locations are exceeded. Information locations are where flood classifications are defined and observations of water level data are provided but forecasts of future water level are not produced.

Flood Warnings may include either qualitative or quantitative predictions at forecast locations or a statement about future flooding in more generalised terms.

Quantitative predictions include expected flood classifications (minor, moderate or major) with more specific information on the height and time of water levels at the forecast locations. A quantitative prediction can be a specific level or a range of levels, and has detailed timing down to blocks of a minimum of 3-6 hours.

Qualitative predictions include expected flood classifications (minor, moderate or major) and timing of flooding at the forecast locations. The timing is indicated in blocks of six, 12 or 24 hours, using the terms such as early morning, afternoon or overnight.

BOM may also issue Flood Warnings with more generalised predictions and information when there are not enough data to make specific predictions or in the developing stages of a flood. These warnings contain generalised statements advising that flooding is expected and may include forecast trend (rising or falling).

For BOM to be able to provide a quantitative prediction at a location, it is essential to have access to real time data from a suitable network of rainfall and river level sites upstream, sufficient historical data to calibrate the flood forecasting model, a reliable rating table and documented flood impacts and flood classifications.

Local Flood Warning Services

For some communities, local government or emergency services may provide some form of localised flood warning service. This occurs in areas where BOM does not provide a flood warning service and are often in areas subject to flash flooding.

Local Flood Bulletins

Flood Bulletins are provided in some jurisdictions to value add BOM flood warning products and provide tailored advice to communities on actions to take in response to the flood threat.

Appendix B: Case studies

Charlton flood warning system development

Figure 3: Charlton during the January 2011 flood. Source: DELWP.

Charlton was severely impacted by flooding in January 2011 when up to 220 mm of rain fell across the Avoca River Catchment. This was the worst flood on record, inundating some 350 properties, causing widespread damage to infrastructure and crop and leaving a traumatic mark on the community.

Following the 2011 flood, Buloke Shire Council initiated the *Charlton Flood and Drainage Management Study and Plan* (2014) and a revision of the *Municipal Flood Emergency Plan* (MFEP) with the support of the Department for Environment, Land, Water and Planning (DELWP). A community reference group was formed to guide the study and elicit community feedback and support for implementing the final plan. The study identified the improvement of the existing flood warning service as a high priority for the town, and particularly important to help manage flood risks while structural mitigation options were being investigated.

Buloke Shire Council requested government assistance in 2016 to improve the flood warning system.

The Bureau of Meteorology (BOM) and DELWP worked closely with the Buloke Shire Council and emergency services to help them determine the level of service required by the community. This meant detailing the actions that council and emergency responders needed to undertake once a flood warning is received and estimating how long these actions would take to implement. Once preferred lead times were understood, a fit for purpose network of river and rain gauges was designed to provide a level of service that meets local needs and is affordable for the community to maintain.

In line with Victorian Government policy set out in the *Victorian Floodplain Management Strategy* (2016), the capital cost of installation of the gauge network was met by government, with Buloke Shire Council committing to the ongoing ownership and maintenance costs.

Implementation of the additional network is ongoing as of April 2020. BOM will use the upgraded network to improve understanding of flooding in the catchment, improve flood forecasting model and, with time, increase the flood warning service level to meet the community and agencies' preferred emergency response requirements.

The overall process for the development process is summarised in Figure B1.

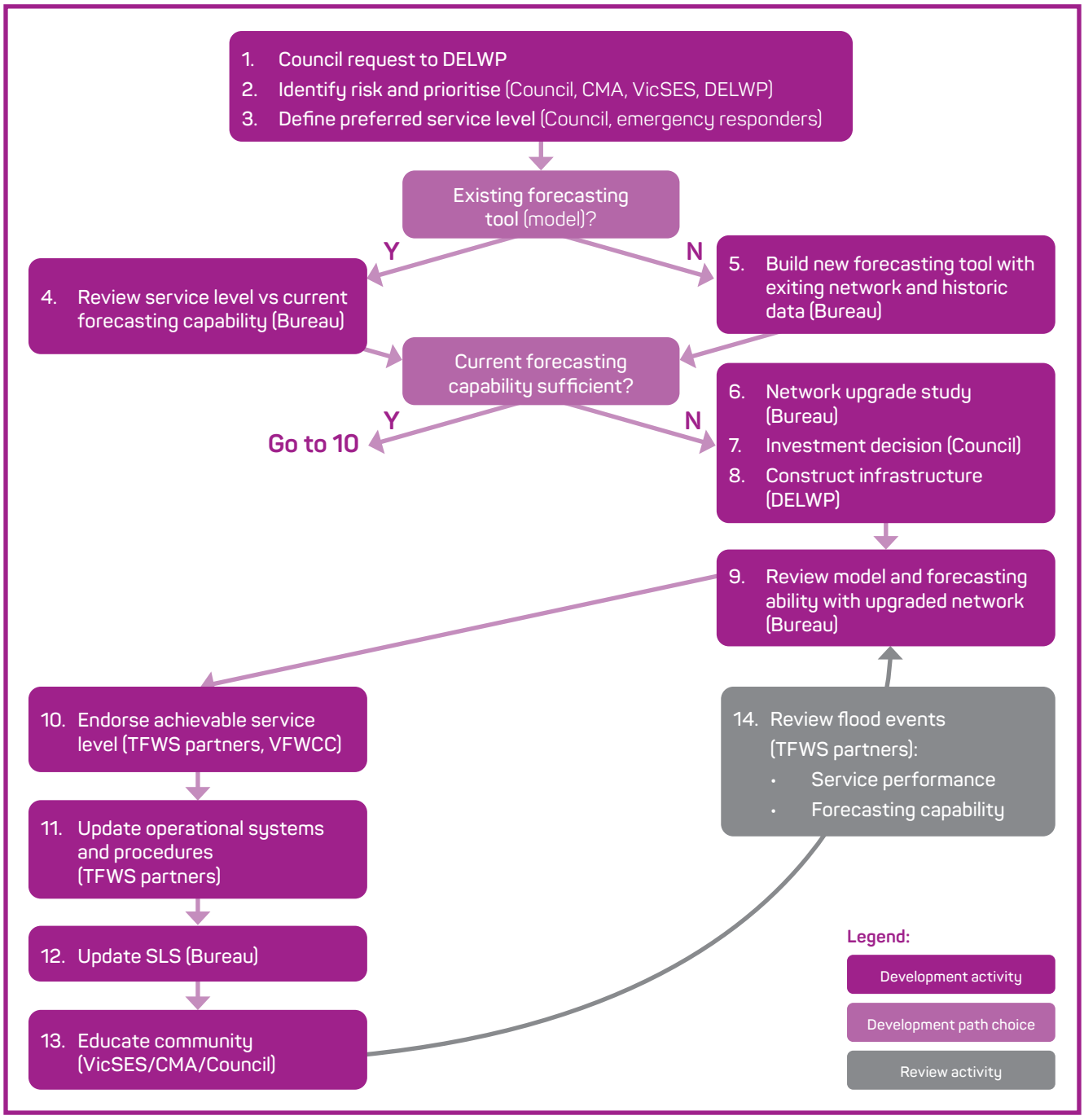

Figure B1. Victorian flood warning service development process and lead agencies.

Fitzroy Regional Resilience Strategy: A best practice flood warning infrastructure network for the Fitzroy Basin, Queensland

The Queensland Government partnered with six councils to deliver the *Fitzroy Regional Resilience Strategy* (February 2020). The Strategy provides a consistent and coordinated approach to manage flood warning infrastructure throughout the region that will enhance community safety and resilience.

The Strategy develops Queensland's first catchment-scale and multi-stakeholder approach to a Total Warning System concept. It seeks to integrate optimised flood warning infrastructure with collective governance to support better warnings, forecasts and shared situational awareness, community messaging, and disaster management operations.

The operation of a best-practice, catchment scale Total Warning System is outlined in the diagram below. The focus of the Strategy is providing the right infrastructure that can collect and transmit appropriate data so that:

- agencies like BOM can provide their services
- councils and others can interpret the information and determine the consequences
- the participants in the Queensland Disaster Management Arrangements can message and communicate correct information to their constituents.

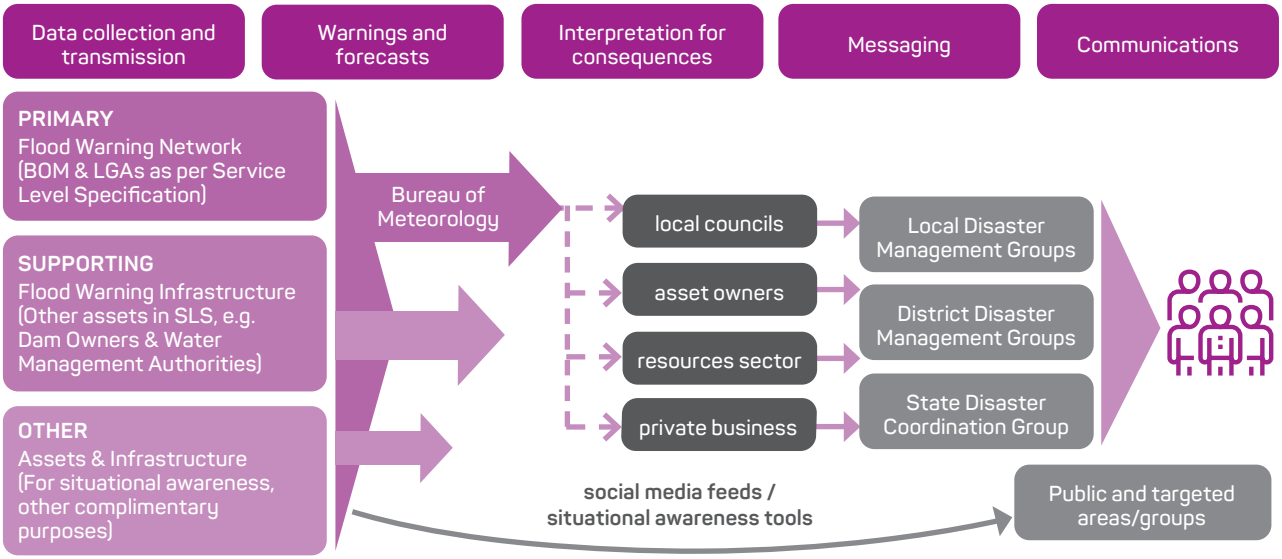

Figure B2. Operation of a best practice, catchment scale Total Warning System

Note:

- **PRIMARY** - purpose built flood warning infrastructure
- **SUPPORTING** - primary purpose of the assets is for functions other than flood warning
- **OTHER** - assets not used for flood warning but can assist situational awareness

Parramatta flash flood warning system

City of Parramatta – in partnership with the Office of Environment and Heritage, New South Wales State Emergency Service, BOM and Sydney Water – developed a flash flood warning system to provide flood warnings to at-risk businesses and households. The project involved an external steering group and an SES working group on message consistency. The State Flood Warning Consultative Committee was also involved.

The design adopted the various components of the Total Warning System. Data is collected through rainfall and stream gauges and processed via a modelling platform that provides forecasts on a continual basis based on real time rainfall and predicted gridded rainfall. Alerts are then sent to partner organisations and the public via SMS, email and voice call.

The system is supported by the flood education program 'FloodSmart', focused on flood risk awareness, preparedness and encouraging people to sign-up to receive warnings.

www.cityofparramatta.nsw.gov.au/environment/floodsmart-parramatta

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