State Planning Policy – state interest technical manual

Natural Hazards, Risk and Resilience

Technical Manual

A ‘fit for purpose’ approach in undertaking natural hazard studies and risk assessments

April 2016

Queensland Government

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Summary

The Queensland Government established the State Planning Policy (SPP) to define the specific matters of state interest in land use planning and development. To support the implementation of the SPP, each state interest in the SPP is supported by a state interest guideline.

The state interest *natural hazards, risk and resilience* is supported by both a state interest guideline and this technical manual.

As described in the state interest guideline for n*atural hazards, risk and resilience,* it is recommended that councils use a 'fit-for-purpose' approach to undertaking natural hazard studies and risk assessments.

This technical manual must be read in conjunction with the SPP and the state interest guideline for *natural hazards, risk and resilience.*

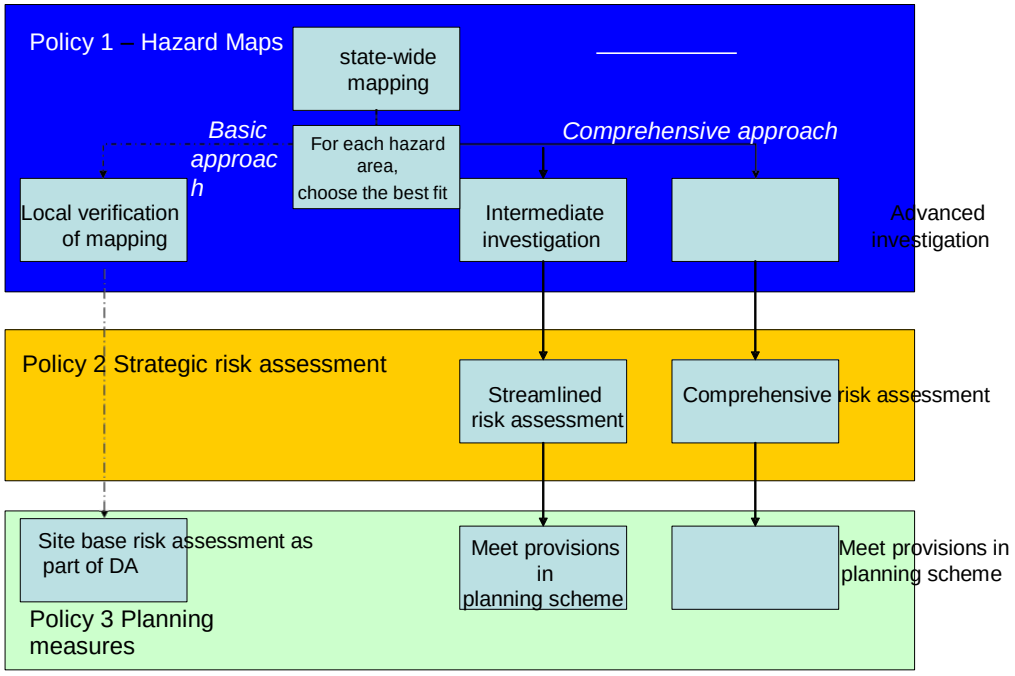
The following guidance outlines reliable methodology which may be used to undertake flood, bushfire, landslide and coastal hazards investigations and develop natural hazard maps, including natural hazards areas, in a planning scheme.

PART A – Flood hazard

Figure 1 illustrates how flood hazard investigations will inform land use planning and development.

After the appropriate mapping has been undertaken, a local government will need to identify if a strategic risk assessment across all or part of the local government area will be undertaken and the level of assessment, or if site based management plan will be required as part of a development application.

Figure 1 Flood hazard investigations and land use planning and development.



A.1 Flood hazard investigation and mapping options – 'fit for purpose' approach

The most appropriate form and quality of mapping should be determined at a local level by the relevant council, informed by local needs, knowledge and issues. The choice of a flood investigation in a local government area (LGA) is influenced by:

- the characteristics of the flood hazard that have occurred and are forecast in the future
- the current population (both numbers and spatial extent) and types of land use exposed to flooding
- future development and growth pressures that are foreshadowed
- community resilience to flooding.

It is important that flood mapping be fit for purpose. It can be delivered in varying forms for differing uses which include:

- flood events - recording flooding under an actual event, such as in 1974 or 2011
- flood-related models - representing flooding simulated from mathematical hydrology and hydraulic modelling with a nominated probability, such as one per cent Annual Exceedance Probability (AEP). This type of mapping is used mainly for detailed flood studies of a defined locality Defined Flood Event (DFE) — the flood event that is adopted by the local government for the management of development in a particular area. Generally a one per cent AEP flood has been adopted for flood management, however it may be appropriate to adopt a different DFE depending on the circumstances of individual localities
- probable maximum flood (PMF) — simulated flood modelling of extreme precipitation events, used mainly for dam safety assessments. The PMF defines the extent of the flood-prone land that is the floodplain, which is not based on an element of risk or defined flood event. It gives broad-scale flood hazard mapping.

Each of these types of mapping can be undertaken to varying levels of precision depending on the proposed use.

A 'fit-for-purpose' technique for a flood hazard investigation may include one or both of the following:

1. ***Basic approach*** (Level 1[1]) — utilising a state-wide map for assessment, further discussed at section A.2 below

2. ***Comprehensive approach*** (Level 2 or Level 3[1]) — utilising a localised investigation approach, further discussed at section A.3 below

The choice of either approach is governed by the forecast type of settlement and rate of growth.

A basic approach (Level 1) is adequate for areas with a low population and no future growth pattern. It is not recommended for urban areas, however, it may be a suitable 'fit for purpose' risk management approach in low growth, non-urban areas.

In densely settled areas with ongoing growth and an exposure to flooding events, a more comprehensive approach (Level 2 or 3) should be undertaken. As part of the comprehensive approach, a localised flood hazard investigation can estimate future flood hazard scenarios either through a simple application of flood models (Level 2) or through an advanced and sophisticated use of flood models (Level 3).

The application of the 'fit-for-purpose approach' is provided in Table 1 below, which suggests the level of flood investigations suitable for particular settlement patterns.

[1] Reference to Level 1, 2 and 3 are included to ensure alignment with QRA (2012b) guideline.

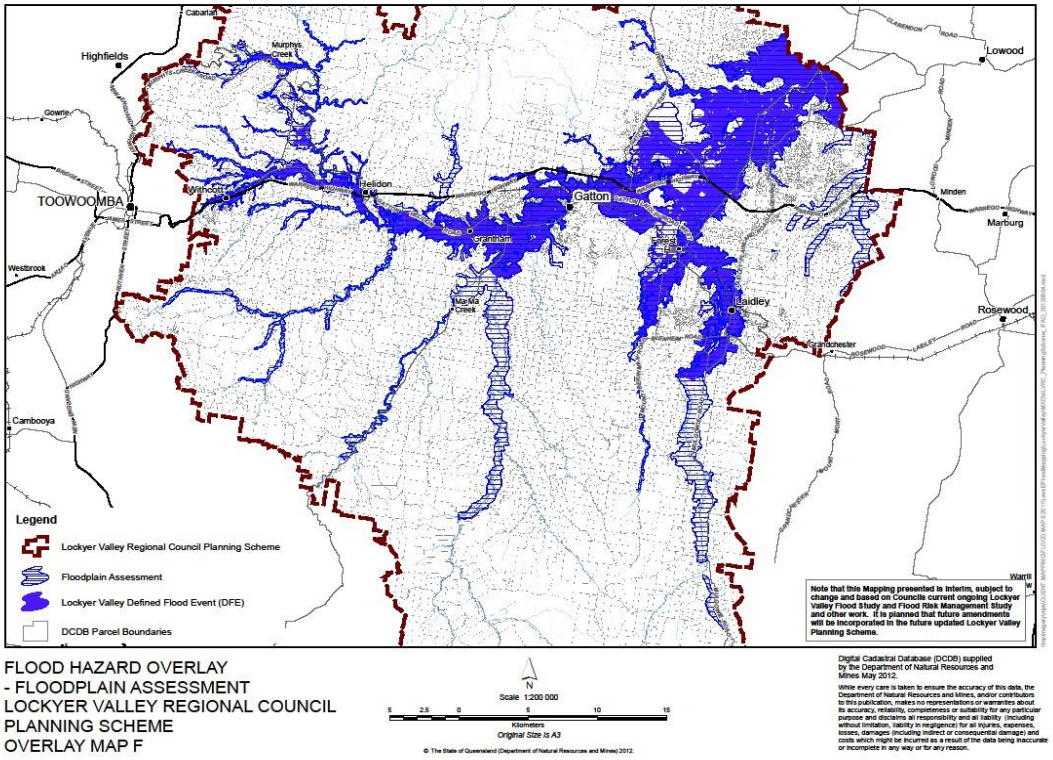
Table 1 – Selecting the appropriate flood investigation (adapted from QRA 2012b)

Investigation area	Baseline mapping	Expected growth		
		None to very low	Low	Medium – high
Regional landscape low-intensity rural	Level 1	Level 1	Level 1	NA
Intensive rural production including large-scale irrigation development	Level 1	Level 1	Level 2	Level 2
Low-density rural towns and settlements	Level 1	Level 1	Level 2	Level 3
Urban areas	Level 1	Level 2	Level 3	Level 3
Industry or infrastructure of regional or state significance (e.g. mines, state development areas)	Level 1	Level 3	Level 3	Level 3

The appropriate mapping for particular areas within the LGA will depend on the type of land use and expected levels of future growth. As a result, flood maps derived for a LGA can be a combination of two or three different levels of flood hazard investigations.

In these instances, flood maps should clearly identify the different types of mapping so that the data inputs and the limitations associated with different levels of mapping can be understood. For example, Figure 2 below is an extract from a planning scheme overlay of the Lockyer Valley Planning Scheme, where Level 3 mapping (solid blue colouring) and Level 1 mapping (hatched blue colouring) are both used to identify the flood hazard area for this LGA.

Figure 2 **Combination of different levels of flood investigation to provide complete local government area coverage for flood hazard (Ref: Locker Valley Planning Scheme)**



The locations of flood hazard investigations in each LGA should be documented so both the community and prospective developers are fully aware of the flood risks in each area. Details to be included in a public document may include a list of:

- completed studies and their locations
- locations not requiring future studies
- locations where studies are yet to be undertaken (along with the details of a schedule to complete the investigations).

Where the frequency, extent or severity of the hazard may change over time, this should be factored into a program of hazard mapping to ensure that effective risk assessment can take place. Where issues such as climate change might alter the severity of a hazard, mapping may need to be updated more frequently than the planning scheme. Also, as populations grow and development pressures and/or land-use patterns change, flood hazard investigations should be revised. Improvements in mapping quality, data and availability may also enable a revision of the investigations.

A.2 Basic approach using state-wide flood mapping (Level 1)

The state-wide flood mapping—formerly the Interim Floodplain Assessment Overlay—depicts areas of soil and vegetation characteristics compatible with the land having been previously inundated by floodwaters, at some point in history, adjusted to take into account current contour information and the 2010/2011 flood line.

The data layers utilised and interpreted to derive what was called the Interim Floodplain Assessment Overlay[2] (QRA 2012a) include:

- landsat imagery
- stream orders 5-9
- pre-cleared vegetation mapping of Landzones 1 and 3 combined with soil flooding limitation mapping
- gauging stations
- flood extent for 2010–2011 generated from aerial photography
- aerial photography taken near to flood peak
- 10 metre contours.

The state-wide flood mapping is available on the SPP Interactive Mapping System.

It is important to note that the state-wide flood mapping does not depict depth or velocity, nor an annual exceedance probability, nor provide any information about the risk or probability of flooding occurring in the future, nor the frequency of past flooding.

As such, when used in a planning scheme, the state-wide map should be used to identify areas requiring further investigation.

Prior to incorporating the state-wide mapping in a planning scheme, verification by a local government is required. This will result in both confirmation and, where required, adjustment of the state-wide flood mapping. The local verification process may involve:

1) reviewing existing flood studies
2) reviewing the historical flood record and data (including photographs)
3) seeking community advice and/or confirmation from long-time residents or elders on the possible extent of flood events.

A.2.1 Reviewing existing flood studies

Many of the flood studies of river systems in Queensland are either limited in their scope or conducted some years ago. Ideally, they should be updated with current data and techniques and/or extended to cover the full range of floods and incorporate catchment development changes as well as future scenarios.

[2] The name Interim Flood Assessment Overlay is now referred to as state-wide flood mapping

Existing studies can be valuable sources of information provided their relevance is established. A suitably qualified professional should review the study to determine if an existing flood study is relevant and appropriate to use. This review should include, but not be limited to:

- study outputs
- study assumptions
- the data on which the study was based
- the techniques used to model the hydrology and floodplain hydraulics
- the range of AEP
- changes in the catchment since the flood study
- future development scenarios.

Assuming an existing flood study can be established as relevant, it may be appropriate to adopt the study outputs directly, or revise them through interpretation by a suitably qualified professional, as the basis for further studies/assessments of flood risks and mitigation measures.

Existing flood studies should then be overlapped with the state-wide flood mapping to determine the coverage of the mapping. In areas with no existing flood study information, the state-wide mapping (locally verified through either steps 2 or 3) should be used.

A.2.2 Reviewing the historical flood record and data (including photographs)

Where historical flood data is of a suitable quality, it may be possible to use this information without any further detailed hydrologic or hydraulic analysis.

The minimum requirements would be for a suitably qualified professional to:

- carry out a flood frequency analysis of the historical data to indicate the likely AEP of the recorded events
- consider floodplain and catchment modifications (e.g. changed land use) that may affect run-off or flow regimes
- plot the extent of inundation as estimated from the data available for the flood event(s) on which development controls are to be based
- identify the likely significant flow paths (floodways that need to be preserved if adverse changes to the flooding regime are to be avoided).

Historical data may include:

- formally recorded gauge height records
- formally surveyed peak flood levels
- photographs
- high-water marks recorded on public or private property.

Caution must be exercised in dismissing the importance of flood risk considerations on the basis of a lack of recorded flood history or recollections by the community. Community consultation can be used to source historical data records as part of the state-wide mapping local verification. Every effort should be made to source as much historical data as possible and all avenues should be pursued (e.g. council records, newspapers, the community).

Where historical records or data can identify a flood level from a previous event it should be considered when locally verifying the state-wide mapping. Where a historical flood level is chosen as the DFE, some assessment of its AEP is necessary to give an indication of the level of flood risk that is accepted.

Where no historical records or data from a previous event are found, then the local government should identify a fit-for-purpose response that considers the current and expected level of risk to people, property, economic activity, social wellbeing, infrastructure and the environment. Options that a council could consider include:

- incorporate the state-wide mapping into the planning instrument
- undertake new flood modelling and mapping (level 2 or level 3) and incorporate this mapping in the planning instrument
- incorporate the state-wide mapping into the planning instrument in the short term and establish and undertake a program of future mapping to identify and prioritise areas for further flood hazard investigations.

A.2.3 Seeking community advice and/or confirmation from long-time residents or elders on the possible extent of flood events

Community consultation during the preparation of a planning instrument is an opportunity to collect historical records and data. It is likely that these records will be different to the area for further investigation identified by the state-wide mapping.

Community consultation in relation to flooding has shown that:

- it is unlikely that the ‘community view’ will be totally unanimous and so some people may feel aggrieved by the majority view
- the community’s views are limited by the level of flood information available and the experience of that community. This view is likely to change as new information becomes available either through a new, more comprehensive study or an actual flood event
- community acceptance is often predicated on the level of appreciation of flood impacts (risk and consequence) and the extent to which individuals understand and accept how a flood will actually affect them.

Previously thought ‘flood-free’ localities have turned out to be the opposite. It may be that no one recorded earlier events due to the area being undeveloped and/or the last flood was poorly recorded and/or long enough ago to have dropped from the community’s memory. Population turnover and large proportions of ‘rentals’ can also have an effect on the community’s consciousness in relation to flooding.

Following community consultation, a local government should undertake a risk-based assessment, incorporating the feedback, to determine if the state-wide flood mapping requires adjustment. This could be based on new localised mapping. Alternatively, the state-wide mapping may be accepted and a program of future mapping developed to identify and prioritise areas for further investigations.

When undertaking a risk-based assessment of the state-wide flood mapping the local government should consider:

- potential economic and social impacts of flood events on the community's expectations
- environmental values of the floodplain
- consistency with adjoining localities (whether or not within the same LGA)
- emergency response requirements e.g. warning times, refuges, evacuation routes, recovery measures
- management and mitigation measures.

Importantly, there may be circumstances where a community has clearly indicated the level of flood risk it will accept and has communicated this to its local government. This could mean adjustments to the state-wide flood mapping. Alternatively, the state-wide mapping may be accepted in the short term and a program of future mapping developed to identify and prioritise areas for further flood hazard investigations based on community desires and expectations.

In any case, it is recognised that it may not be cost effective and/or practical for a local government to go beyond the state-wide flood mapping. This may be particularly relevant where a local government is not subject to significant development pressures, especially in small and/or low-growth areas.

Updates to mapping to reflect the best information available may be included in a planning scheme through a minor amendment in accordance with 04/14: *Making and Amending Local Planning Instruments* (MALPI 04/14).

A.3 Comprehensive approach using localised flood mapping (Level 2 or 3)

In locations where there are significant existing populations or expected growth, and/or development pressures in natural hazard areas, a comprehensive investigation (level 2 or 3) should be undertaken to provide localised flood hazard mapping. The comparison of flood extent and proportion of affected community is then a basis for determining which type of comprehensive flood study is required.

The handbook *Managing the Floodplain* identifies that a comprehensive investigation (either the intermediate or advanced approach) should aim to:

- gain an understanding of the flood problem and the impacts of flooding upon the community across the full range of floods
- update the council knowledge hub in the study area as relevant and facilitate communication across government and to the community
- inform land-use planning decisions:
    - in undeveloped areas to provide an understanding of the flood constraints and management considerations for potential future development, and
    - in areas already identified for development in statutory planning instruments to provide information to support development controls to reduce risk
- inform emergency planning in relation to evacuation and transportation logistics . It is important for such information to be related to relevant flood gauges where practical
- facilitate the availability of flood insurance by providing information to enable insurers to make informed decisions on the availability and pricing of insurance
- account for uncertainty. Every step in hydrologic and hydraulic assessment should consider the potential uncertainty associated with assumptions and the possible consequences these may have on the estimates of the design levels, velocities and extent of flooding. Uncertainty needs to be identified and its implications in terms of study objectives and desired outcomes quantified for decision-makers. In general the greater the quantity and quality of available data, the greater the confidence in the final design estimates. Sensitivity analysis of key input variables can be used to provide indications of the degree of risk associated with errors in adopted criteria, coefficients or assumptions made. The results of sensitivity analyses should be considered in management decisions and may influence the freeboard selected to provide the desired degree of protection from flooding
- understand the potential impacts and implications of climate change on flood behaviour.

These broad outcomes can provide multiple benefits to a variety of stakeholders and ensure that land-uses planning responses are considered in conjunction with other flood risk-management measures.

Council, as the ultimate custodian of the flood models, should consider the acceptability of any limitations placed on the flood study by the consultant and the future usability of the flood model by the council.

Supporting information

The national handbook *Managing the floodplain* describes how a comprehensive approach can be undertaken.

https://ema.infoservices.com.au/items/HB7-2ND

A.3.1 Determining flood hazards

Consideration of the flood hazard should not be limited to one type of flood event. Multiple scenarios across the full spectrum of flood events, from very frequent to highly infrequent, is recommended. For example, infrequent events such as up to the PMF may be considered as their extent and impact would be considerable. This is important when considering the nomination of a DFE. By understanding the impact of a series of events across a floodplain, a more informed decision can be made on the appropriate event to nominate as the DFE.

It may also be necessary over time to revisit the existing flood mapping to take into account the changes that occur within the floodplain as a result of development and construction of infrastructure.

For each type of flood event, it is recommended that the extent of low, medium and high hazard be determined and mapped. Commonly the extent of the hazard is determined based on criteria such as:

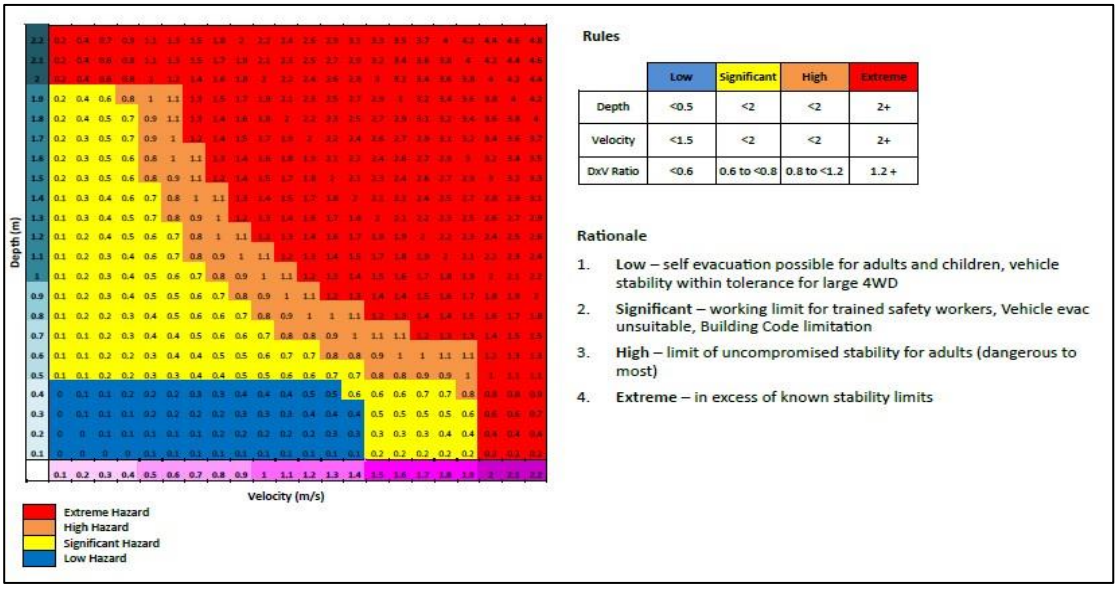
- depth
- velocity
- a combination of the two.

Additional consideration of the hazard may require estimation of factors such as:

- duration of inundation across an investigation area
- prior warning time for a peak flood event
- rate of rise of floodwater
- creation of isolated “island” locations, where high points are totally surrounded by hazardous flows
- evacuation routes.

In the example provided at Figure 3 below, a combination of two hazard characteristics – depth and velocity - can be combined to provide a way that hazard classes can be assigned (QRA 2012b). In other flood investigations, the boundaries of the hazard classes may not be identical as in Figure 3, but the intent and application of use is similar.

Figure 3 - Hazard categories determined from a combination of two hazard attributes (QRA 2012b)



	Low	Significant	High	Extreme
Depth	<0.5	<2	<2	2+
Velocity	<1.5	<2	<2	2+
DxV Ratio	<0.6	0.6 to <0.8	0.8 to <1.2	1.2 +

In all cases of a hazard categorisation process, the assumptions behind the calculations need to be clearly stated. References and standards will also assist to substantiate the various assignments of combined values to a hazard class.

The landforms, geography and rainfall characteristics of each LGA, in combination with the types of land uses in the floodplain, will determine which combination of flood frequency investigations (AEPs) are best required for the various risk-management requirements. Hazard criteria such as flood depth and flow velocity are fundamental hazard criteria. Each investigation can also select additional flood hazard criteria that best suit evaluating the flood management risk for that LGA.

Technical resources

Rainfall analysis options, types of rainfall events and specifications for runoff calculations—Engineers Australia (1999) – Australian Rainfall and Runoff (update projects are underway and revised designed rainfall events will be included in future revisions—the current version of AR & R should always be used)

Forecast rainfall intensity changes due to future warmer weather—Queensland Government 2010—Inland Flooding Study

A.3.2 Features of an intermediate (Level 2) flood hazard investigation

An intermediate flood hazard investigation for a local area is a good fit for locations where:

- there is an absence of any flood hazard evaluation in locations or settlements
- the current or proposed land uses match a low level of growth (Table 1)
- the potential exposure to a flood hazard is not trivial.

An intermediate flood hazard investigation is based on local knowledge, historic information and a basic flood frequency analysis. These utilise either simple hydraulic modelling or GIS-based spatial mapping techniques (Table 2).

In undertaking an intermediate flood hazard investigation, the intention should be to create as many AEP maps as the data inputs can confidently support, so that the local community can understand the broad range of the flood hazard events to which it is subject. This means including maps for AEPs in excess of the required design or planning objectives for flood immunity for residential and mixed commercial uses.

As a holistic evaluation, understanding the extent and characteristics of less frequent flood events and their impacts on community infrastructure and for disaster management purposes ensures that the broader planning needs of a council are achieved.

Table 2 - Indicative outputs of the different methodologies available using the intermediate flood hazard investigation approach (QRA 2012b)

Features of different types of intermediate flood hazard Investigation		
Validated Model	**Validated GIS**	**Non-validated GIS**
Flood details on extent, depth and velocity	Flood details on extent and depth	Flood details on extent and depth
Range of AEP maps	Range of AEP maps (where stream flow data permits)	Range of AEP maps (where stream flow data permits)
Validated against historic event(s)	Validated against historic event(s)	
Time sequence of inundation		

Technical resources

Through the Queensland Reconstruction Authority, the Queensland Government has created an interactive flood portal which provides information on flood studies that have been undertaken across Queensland.

A.3.3 Features of an advanced (Level 3) flood hazard investigation

An advanced investigation is recommended for major centres and in locations where ongoing growth and populations are significant (Table 1 above). These investigations involve a comprehensive flood study based on hydrologic and hydraulic modelling and analysis at a detailed topographical level. Managing the Floodplain (NFRAG 2013) details the various aspects of an advanced localised investigation.

The results for a range of flood events generated in the study and the types of outputs include:

- detailed flood extent and level information
- the scale and variation in flood impacts, which can include the number of properties affected and potential flood damage
- variations in flood functions (flow conveyance, flood storage and flood fringe) across the floodplain
- disaggregation of the floodplain into hazard categories to identify areas of relative severity
- factors influencing emergency response, including the identification of areas with different rates, durations and severity of inundation
- key flooding characteristics to assist with issues such as emergency management planning, land-use planning, development assessment and community flood awareness
- information to facilitate understanding of the natural variation and unpredictability of flood events and the relative degrees of uncertainty in flood estimates.

A section titled ‘Scoping a Terms of Reference - Flood Hazard Investigation’ is a component of the Technical Manual.

A.4 Risk management measures

When choosing the appropriate land use strategy it is important to recognise that different parts of the floodplain perform different functions during a flood. Namely:

- Floodways provide the major flow paths for floodwaters and are typically aligned with creeks, rivers and other natural channels.
- Flood storage areas fill and then empty during the passage of the flood peak and are typically low velocity zones.
- The remainder of the floodplain can be described as flood fringe areas.

These locations need to be managed so that these functions can continue. The primary means of protection is to avoid the location of any land use that may have an unwanted impact on flood behaviour.

Table 3 provides examples of a broad range of risk management measures that may be relevant to a holistic risk management plan.

Table 3 Management measures for different types of flood risk

Existing development	**Future development**	
Existing flood Risk	**Future flood risk**	
Community / area scale	**Greenfield, new development and redevelopment areas**	**Infill development within existing zoned areas**
Flood control dams Retarding and detention basins Permanent levees Flow conveyance improvements Flood gates Temporary barriers Change in property zoning	Zoning Development controls Building controls	Development controls Building controls
Property Scale		
House raising House purchase Relocation of development Flood proofing Temporary measures		
Residual Flood Risk	**Residual Flood Risk**	
Community Scale	**Development Scale and Impacts on Community Scale**	
Flood prediction and warning Community scale emergency response plans Evacuation route upgrade Community flood readiness Community recovery plans	Flood prediction and warning Flood access and evacuation routes Emergency response arrangement for new areas Development scale, flood awareness and readiness Impacts upon community-scale emergency management plans Residential or commercial emergency management plans	

Supporting tools and links

- Engineers Australia (1999) Australian Rainfall and Runoff. https://www.engineersaustralia.org.au/water-engineering/australian-rainfall-runoff-revision-project
- Hawkesbury-Nepean Floodplain Management Steering Committee (2006), *Managing flood risk through planning opportunities*. Guidance on land use planning in flood prone areas.
- Middelmann, M.H. (Editor) (2007*), Natural Hazards in Australia: Identifying Risk Analysis Requirements.* Chapter 5: Flood. Pp 41-58. Geoscience Australia. Canberra
- Australian Emergency Management Institute (2013), Managing the floodplain: a guide to best practice in flood risk management in Australia.
  - Understanding and evaluating flood risk—Section 2
  - The strategic management of flood risk—Section 4
- The flood risk management process described in appendix E of Floodplain management in Australia: Best practice principles and guidelines (2007), CSIRO Publishing. http://www.publish.csiro.au/Books/download.cfm?ID=2260
- Queensland Chief Scientist (2011), Understanding floods: Questions & Answers. Queensland Government. http://chiefscientist.qld.gov.au/images/documents/chiefscientist/understanding-floods_full_colour.pdf
- Queensland Government (2010), Increasing Queensland's resilience to inland flooding in a changing climate: Final report on the Inland Flooding Study. http://www.ehp.qld.gov.au/climatechange/pdf/inland-flood-study.pdf
- Queensland Reconstruction Authority – QRA (2012a), Planning for stronger, more resilient floodplains: Part 1—Interim measures to support floodplain management in existing planning schemes. Specific sections is Details on the Level 1—Interim Floodplain Assessment Overlay – Section 2 Analysis pp 10-11
- Queensland Reconstruction Authority – QRA (2012b), Planning for stronger, more resilient floodplains: Part 2—Measures to support floodplain management in future planning schemes. Specific sections
  - Details on undertaking a flood investigation—Section 2 Analysis, pages14–21
  - Level 2 mapping Terms of Reference—Schedule 2 page 41
  - Level 3 mapping Terms of Reference—Schedule 3 pages 42–44
- Department of Infrastructure, Local Government and Planning, Statutory guideline 04/14. Making and amending local planning instruments (MALPI) http://www.dilgp.qld.gov.au/resources/planning/planning/statutory-guideline-04-14.pdf

PART B – Bushfire hazard

B.1 Bushfire hazard investigation and mapping options – 'fit for purpose' approach

The scale of bushfire hazard mapping in a LGA is best tailored to the characteristics of the hazard, the size and characteristics of the affected population, types of land use exposed to bushfire, predicted development growth pressures and other factors affecting risk.

The resources available to assess the bushfire hazard will also determine the choice of mapping option. Two approaches are:

1) using available state-wide bushfire hazard mapping
2) applying state-wide mapping methodology using local-scale vegetation and slope maps

Both approaches utilise the state-wide bushfire hazard mapping methodology (CSIRO, 2013). The first approach uses the best available state-wide vegetation, slope and severe weather data sets, whereas the second incorporates locally refined vegetation mapping.

Where both types of mapping are used in one LGA, SPP Policy 1 can be satisfied by utilising a combination of the two approaches.

Major development that results in the clearing of hazardous vegetation may require preparation of a specialised hazard map using the second approach, to indicate the hazard before and after clearing.

B.2 State-wide bushfire hazard mapping

A state-wide bushfire hazard mapping methodology for Queensland is used to define five potential bushfire hazard classes (discussed below at section B.2.1, step 5)

The potential class is determined by combining three mapping inputs:

1) vegetation hazard class and a corresponding potential fuel load
2) slope
3) fire weather severity (based on Forest Fire Danger Index (FFDI) levels estimated at 2050).



The hazard class and associated fire-line intensity are derived from McArthur fire spread equations represented above. The methodology used to develop state-wide Bushfire Hazard Area Maps for Queensland is described below. Further details about the methodology are provided in a detailed report available from the Queensland Spatial Catalogue at http://qldspatial.information.qld.gov.au/catalogue/custom/index.page

B.2.1 Preparing State-wide bushfire hazard area maps

Step 1. Create Vegetation Hazard Class and Potential Fuel Load maps

Vegetation Hazard Classes (VHC) and associated Potential Fuel Load maps are prepared from a combination of regional ecosystem maps, foliage project cover maps, land use maps, water body maps and tree plantation maps (Table 1).

Regional ecosystem types are amalgamated to form VHCs based on their membership of Fire Regime Groups (FRGs) used by the Queensland Parks and Wildlife Service, or land use classes used by the Department of Science Information Technology and Innovation.

Table 1: Vegetation Hazard Classes (VHC) and associated Potential Fuel Loads

Vegetation Hazard Class	**Potential Fuel Load** (tonnes per hectare)
1.1 Complex mesophyll to notophyll vine forests	2.6
2.1 Complex to simple, semi-deciduous mesophyll to notophyll vine forest	3.5
3.1 Notophyll vine forest	4.5
3.3 Notophyll vine thicket	4.4
4.1 Notophyll and notophyll palm or vine forest	4.5
5.1 Notophyll to microphyll vine forests	3.9
5.2 Notophyll to microphyll vine forest with sparse overstorey	3.9
5.5 Sedgeland within Notophyll to microphyll vine forests	3.9
6.1 Montane Notophyll vine forest and microphyll fern forest	3.9
6.3 Montane Notophyll vine thicket and microphyll fern thicket	3.9
7.1 Semi-evergreen to deciduous microphyll vine forest	6.0
7.2 Sparse semi-evergreen to deciduous microphyll vine forest	6.0
8.1 Wet eucalypt tall open forest	35.0
8.2 Wet eucalypt tall woodland	23.9
9.1 Moist to dry eucalypt open forests on coastal lowlands and ranges	24.1
9.2 Moist to dry eucalypt woodland on coastal lowlands and ranges	17.2
9.3 Shrubland within moist to dry eucalypt on coastal lowlands and ranges	12.7
10.1 Spotted gum dominated open forests	20.8
10.2 Spotted gum dominated woodlands	18.0
11.2 Moist to dry eucalypt woodlands on basalt areas	13.0
12.1 Dry eucalypt open forest on sandstone and shallow soils	21.0
12.2 Dry eucalypt woodlands on sandstone and shallow soils	17.3
13.1 Dry to moist eucalypt open forests on undulating metamorphics and granite	21.7
13.2 Dry to moist eucalypt woodlands on undulating metamorphics and granite	14.4
13.3 Shrubland associated with dry to moist eucalypt woodlands on undulating terrain	7.5

Vegetation Hazard Class	Potential Fuel Load (tonnes per hectare)
14.1 Open forest dominated by Darwin stringybark, Melville Island bloodwood or scarlet gum	27.8
14.2 Woodlands dominated by Darwin stringybark, Melville Island bloodwood or scarlet gum	12.6
14.3 Shrubland associated with woodlands dominated by Darwin stringybark, Melville Island bloodwood or scarlet gum	8.8
14.6 Sparsely vegetated areas associated with Darwin stringybark, Melville Island bloodwood or scarlet gum	1.6
15.1 Temperate open eucalypt forests	26.7
15.2 Temperate eucalypt woodlands	13.8
16.1 Eucalyptus dominated forest on drainage lines and alluvial plains	15.9
16.2 Eucalyptus dominated woodland on drainage lines and alluvial plains	11.5
16.3 Shrubland associated with Eucalyptus woodlands on drainage lines	8.6
16.4 Grassland associated with Eucalyptus dominated woodlands on drainage lines	2.4
16.5 Sedgeland associated with Eucalyptus woodlands on drainage lines	10.8
16.6 Sparsely vegetated areas associated with Eucalyptus woodlands on drainage lines	3.2
17.1 Dry open forests dominated by poplar box, silver-leaved ironbark or White's ironbark on sand or depositional plains	14.9
17.2 Dry woodlands dominated by poplar box, silver-leaved ironbark or White's ironbark on sand or depositional plains	9.6
18.1 Dry eucalypt open forests on sand or depositional plains	14.8
18.2 Dry eucalypt woodlands on sand or depositional plains	11.0
18.5 Sedgeland associated with dry eucalypt woodlands on sand or depositional plains	10.8
19.2 Low open eucalyptus woodlands dominated by snappy gum, Cloncurry Box or Normanton box	9.1
19.3 Shrubland associated with low open eucalypt woodlands dominated by snappy gum, Cloncurry Box or Normanton box	4.5
19.4 Grassland associated with low open eucalypt woodlands dominated by snappy gum, Cloncurry Box or Normanton box	5.1
20.1 Open forests dominated by white cypress pine or coast cypress pine	16.4
20.2 Woodlands dominated by white cypress pine or coast cypress pine	9.3
21.1 Melaleuca dry open forest on sandplains or depositional plains	14.9
21.2 Melaleuca dry woodlands on sandplains or depositional plains	8.7
21.3 Shrubland associated with Melaleuca dry woodlands on sandplains or depositional plains	7.5
21.6 Sparsely vegetated areas associated with Melaleuca dry woodlands on sandplains or depositional plains	4.5
22.1 Melaleuca open forests on seasonally inundated lowland coastal swamps	28.4
22.2 Melaleuca woodlands on seasonally inundated lowland coastal swamps	19.7
22.3 Shrubland associated with Melaleuca woodlands on seasonally inundated lowland coastal swamps	7.5
22.4 Sedgeland associated with Melaleuca woodlands on seasonally inundated lowland coastal swamps	4.5
23.2 Mulga dominated woodlands on red earth plains, sandplains or	5.0

Vegetation Hazard Class	Potential Fuel Load (tonnes per hectare)
residuals	
23.3 Shrubland associated with mulga on red earth plains, sandplains or residuals.	4.7
23.4 Grassland associated with mulga on red earth plains, sandplains or residuals	5.1
24.1 Acacia open forest on residuals	10.1
24.2 Acacia woodlands on residuals	8.1
24.3 Acacia shrublands on residuals.	6.8
24.4 Grassland communities associated with Acacia on residuals.	5.1
24.6 Sparsely vegetated areas associated with Acacia on residuals.	3.9
25.1 Brigalow belah open forests on heavy clay soils	14.9
25.2 Brigalow belah woodlands on heavy clay soils	6.2
25.3 Shrubland communities associated with brigalow belah on heavy clay soils	3.8
26.1 Gidgee blackwood dominated open forest	8.4
26.2 Gidgee blackwood woodland	3.8
26.3 Shrubland communities associated with Gidgee blackwood woodland	4.7
27.1 Mixed species open forests dominated by western whitewood, boree or wooded downs	2.8
27.2 Mixed species woodlands dominated by western whitewood, boree or wooded downs	4.8
27.3 Shrubland communities associated with mixed species woodlands	2.0
27.4 Grassland communities associated with mixed species woodlands	4.1
27.5 Sedgeland communities associated with mixed species woodlands	6.0
28.1 Open forests in coastal locations with species such as she-oak or swamp box	26.8
28.2 Woodlands in coastal locations with species such as she-oak or swamp box	18.3
28.3 Shrubland associated with woodlands in coastal location	16.9
28.4 Grassland associated with woodlands in coastal locations	4.1
28.5 Sedgeland associated with woodlands in coastal locations	10.8
28.6 Sparsely vegetated areas associated with woodlands in coastal locations.	1.6
29.1 Forests associated with heathlands and scrubs	24.9
29.2 Woodlands associated with heathlands, scrubs and shrublands	24.3
29.3 Heathlands and associated scrubs and shrublands	20.1
29.4 Grassland communities associated with heathlands, scrubs and shrublands	11.2
29.5 Sedgeland communities associated with heathlands, scrubs and shrublands	11.5
29.6 Sparsely vegetated areas associated with heathlands, scrubs and shrublands	2.6
30.2 Woodlands associated with Mitchell grass or bluegrass	4.0
30.3 Shrublands associated with Mitchell grass or bluegrass	4.2
30.4 Mitchell grass or bluegrass tussock grasslands	4.8
30.5 Sedgelands associated with Mitchell grass or bluegrass	6.0
31.2 Woodlands associated with inland forblands to tussock grasslands	4.7

Vegetation Hazard Class	Potential Fuel Load (tonnes per hectare)
31.3 Shrublands associated with inland forblands to tussock grasslands	4.2
31.4 Mixed open forblands to tussock grasslands in inland locations	2.8
31.5 Mixed open sedgelands associated with inland tussock grasslands	0.9
32.2 Woodlands associated with coastal closed tussock grasslands	6.9
32.3 Shrubland associated with coastal closed tussock grasslands	4.2
32.4 Closed tussock coastal grasslands	6.0
33.3 Shrublands associated with Hummock grasslands	4.2
33.4 Hummock grasslands dominated by spinifex or sandhill canegrass	2.1
33.5 Sedgeland associated with hummock grasslands	2.7
34.1 Open forest dominated wetlands	16.4
34.2 Woodland dominated wetlands	8.0
34.3 Shrubland dominated wetlands	6.9
34.4 Grass dominated wetlands	5.0
34.5 Sedgeland dominated wetlands	9.5
34.6 Sparsely vegetated wetlands	4.2
35.1 Closed to open forest mangroves	0.0
35.3 Shrubland associated with mangroves and tidal saltmarshes	0.0
35.4 Tidal saltmarshes	4.0
35.5 Sedgeland associated with mangroves and tidal saltmarshes	1.7
35.6 Sparsely vegetated areas associated with mangroves and tidal saltmarshes	2.9
36.1 Exotic & hardwood plantation	26.0
37.1 Hoop plantations	5.0
38.5 Cropping and horticulture	3.8
39.2 Low to moderate tree cover in built-up areas	8.0
40.4 Low grass or tree cover in rural areas	5.0
41.4 Low grass or tree cover in built-up areas	3.0
42.6 Nil to very low vegetation cover	2.0
43.6 Water bodies or very low vegetation cover	0.0

Patches of a single VHC with an area of less than 0.5 hectares are merged with the surrounding VHC that is most common to the boundary of the vegetation patch. In addition, small patches or corridors of higher fuel load VHCs (8 tonnes / ha or more) less than 100m wide are merged with surrounding lower fuel load VHC classes where they are isolated from other patches of high fuel load VHCs by more than 100m.

Step 2. Create Slope maps

Landscape scale slope maps are created from a 25m resolution digital terrain model by calculating the maximum slope (in degrees) from the central pixel in a group of 9 x 9 cells to the eight adjoining cells in that group.

Step 3. Create Potential Severe Fire Weather Maps

A potential severe fire weather map is developed as a four stage process.

The first stage is to develop a gridded prediction of Forest Fire Danger Index (FFDI) for Queensland at three hourly intervals over the period from 1979 to 2011 from temperature, wind, relative humidity and precipitation weather products produced by the Australian Bureau of Meteorology (BoM).

The second stage is to incorporate future climate trends to 2050 by adjusting temperature and relative humidity using the IPCC A1FI climate scenario.

The third stage is to calculate the 1:20 year or 5% annual exceedance probability (AEP) (5% chance of occurring any year) FFDI based on a statistical distribution of FFDI for each cell of the adjusted BoM weather grid.

The fourth stage is to resample the BoM grid to 25m and to modify near-coastal FFDI estimates to account for an underestimation of FFDI in BoM grid cells that span both land and ocean.

Step 4. Create Potential Fireline Intensity Maps

The three inputs, Potential Fuel Load, Potential Severe Fire Weather and maximum Slope are combined using Equation 1 to calculate Potential Fireline Intensity.

Equation 1. Calculation of Potential Fireline Intensity

PFI = 0.62 PFL^2 FFDI exp(0.069 Slope)

Where:

PFI = Potential fireline intensity (kW/m) PFL = Potential fuel load (tonnes / ha)

FFDI = Potential severe fire weather (FFDI) Slope = Max slope (degrees)

Step 5. Create Potential Bushfire Intensity Maps

Potential Bushfire Intensity Classes are produced by classifying the Potential Fireline Intensity map into five classes as per Table 2 below.

Table 2: Potential bushfire hazards classes

Hazard Class	*Potential Fireline intensity*
1. Very High	40,000+kW/m
2. High	20,000 – 40,000kW/m
3. Medium	4,000 – 20,000kW/m
4. Grass Fire Hazard	Generally less than 4,000 kw/m
5. Low Hazard	0-4,000 kW/m

Grass Fire Hazard (Class 4) is created directly from VHC classes 11 (Native grasslands, sedgelands and balds), 12 (Mixture of rural classes - mainly grassland) and 13 (Cropping and horticulture).

Step 6. Undertake Reliability Assessment

The reliability of maps produced using this methodology should be estimated prior to adoption. The steps are:

Step 6.1 Select representative areas of interest

Identify up to seven (7) areas of interest measuring 5km x 5km representative of the range of landscapes of interest, taking into account future development priorities, the diversity of land forms, vegetation types, and other factors affecting bushfire risk.

Step 6.2 Divide areas of interest into 1km x 1km cells

Divide each 5km x 5km area of interest into twenty-five (25) cells measuring 1km x 1km to create approximately 175 cells (assuming 7 areas of interest). For convenience each cell can be numbered from 1 to 25.

Step 6.3 Assess and record the reliability of mapping for each cell

An expert with experience in bushfire management and vegetation management should estimate the reliability of PBI and VHC of each of the 25 cells in each area of interest by referring to aerial photography, other mapping sources and local knowledge. The assessment of PBI should also consider the methodology used to generate PBI, and relevant input data sets (i.e. FFDI, slope) and take into account the resolution and standards used in regional ecosystem mapping, land use mapping, and information on the extent of non-remnant vegetation. The assessment should also consider the potential applications of the mapping.

The reliability of each cell should be recorded as either:

- Good (G) – mapped boundaries closely align with current vegetation and land use boundaries; mapped classes provide a good approximation of the vegetation type or potential bushfire intensity.
- Satisfactory (S) – mapped boundaries differ in some instances with current vegetation and land use boundaries; mapped classes provide a reasonable approximation of the vegetation type or potential bushfire intensity.
- Not satisfactory (N) - mapped boundaries are quite different to current vegetation and land use boundaries; mapped classes provide poor approximation of the vegetation type or potential bushfire intensity.

Step 6.4 Tally reliability results

Results of the reliability assessment should be summarised for all areas of interest by calculating the percentage of cells assessed as Good or Satisfactory. Data should be aggregated to calculate the mean reliability estimate for all areas of interest.

Step 6.5 Feedback on non-satisfactory cells

Assessors should record feedback on issues with the reliability of potential bushfire hazard and vegetation mapping where the reliability of a cell was assessed as not satisfactory (N). This information can be used to guide further improvements of the bushfire hazard mapping.

Step 6.6 Consider suitability of mapping

A suitability report should be prepared to summarise results of the reliability assessment and the suitability of maps for planning purposes. In general, a reliability of 90% or greater for PBI maps is considered suitable for the preparation of local government planning schemes and other strategic planning decisions. A reliability of 80% or better may also be acceptable.

Where mapping is not of sufficient reliability, local governments may seek to either

a) liaise with the Public Safety Business Agency and the Queensland Fire and Emergency Service to address identified mapping issues in state-wide Bushfire Hazard Area maps, or

b) prepare localised Bushfire Hazard Area Maps (see below), or

c) undertake site assessments on a case-by case basis to resolve mapping issues that are not satisfactory in the state-wide or localised Bushfire Hazard Maps (see below).

Site assessment using an approach that is consistent with the state-wide Bushfire Hazard Area Mapping methodology should be undertaken in landscapes with known lower mapping reliability or where there is reason to believe the mapping may be inaccurate.

B.2.2 Preparing localised Bushfire Hazard area maps

Where state-wide Bushfire Hazard Maps are not considered of sufficient reliability, localised Bushfire Hazard maps can be prepared for all or part of a local government area using the procedures described above using local scale vegetation mapping information in conjunction with slope, and state-wide potential severe fire weather data sets.

Step 1. Create Vegetation Hazard Class and Potential Fuel Load maps

Vegetation Hazard Classes (VHC) and associated Potential Fuel Load maps can be prepared using a combination of local scale regional ecosystem maps, foliage project cover maps, land use maps, water body maps, and tree plantation maps (Table 1 above). Small patches of hazardous vegetation and narrow corridors should also be filtered using procedures described above.

Step 2. Access state-wide or create new local scale slope maps

Landscape scale slope maps used to generate state-wide Bushfire Hazard maps can be accessed from the Queensland Spatial Catalogue at http://qldspatial.information.qld.gov.au/catalogue/custom/index.page .

Alternatively, it is possible to re-create a 25m resolution digital terrain model from higher resolution elevation data and calculate the maximum slope (in degrees) from the central pixel in a group of 9 x 9 cells to the eight adjoining cells in that group.

Step 3. Access potential severe fire weather maps

A state-wide potential severe fire weather map used to generate state-wide Bushfire Hazard maps can be accessed from the Queensland Spatial Catalogue at http://qldspatial.information.qld.gov.au/catalogue/custom/index.page

Step 4. Create local scale Potential fireline intensity maps

The three inputs, Potential Fuel Load, Potential Severe Fire Weather and Maximum slope can be combined to calculate Potential Fireline Intensity using Equation 1 above (Step 4 state-wide Bushfire Hazard Area Mapping).

Step 5. Create local scale Potential bushfire intensity maps

Potential Bushfire Intensity Classes can be produced by classifying the Potential Fireline Intensity map into five classes as described in Table 2 (above).

Step 6. Undertake reliability assessment

The reliability of localised Bushfire Hazard Area maps produced using this methodology should be estimated prior to adoption as described above.

Technical resources

- CSIRO (2013). Methodology for assessing the Queensland state-wide bushfire hazard.
- Middelmann, M.H. (Editor) (2007). Natural Hazards in Australia. Identifying Risk Analysis Requirements. Chapter Seven: Bushfire. Pp 99-112. Geoscience Australia. Canberra
- NSW Rural Fire Service (2006). Planning for bush fire protection. A guide for Councils, Planners, Fire Authorities and Developers. http://www.rfs.nsw.gov.au/dsp_content.cfm?cat_id=900
- Queensland Fire and Research Service – state-wide Bushfire Hazard Mapping http://www.ruralfire.qld.gov.au/Bushfire_Planning/

Supporting tools and links

- NSW Rural Fire Service (web). Bush fire risk management plans. http://www.rfs.nsw.gov.au/plan-and-prepare/know-your-risk/bush-fire-risk-management-plans
- Tran, C. and Peacock, C. (2002). Developing a fire management strategy for local government lands. Southeast Queensland Fire and Biodiversity Consortium. (http://www.fireandbiodiversity.org.au/publications.html)
- Strategic Fire Management Manual: Guidelines for planning and implementing a council or shire wide fire management strategy
  http://www.fireandbiodiversity.org.au/publications.html

This document developed in South East Queensland provides information for large land management agencies, such as local governments to plan and devise a city wide fire management strategy. It also has a broader Queensland wide application.

- Gold Coast City Council Bushfire Management Strategy
  http://www.goldcoast.qld.gov.au/council/bushfire-2228.html
  Includes:
  - supporting the emergency response to a bushfire in the city, directly with QFRS and through Council's Disaster Management Centre
  - developing fire management plans, both strategic and operational
  - planning, coordinating and implementing our annual hazard reduction burn program in conjunction with the Gold Coast Rural Fire Brigade Group, Queensland Parks and Wildlife Service and other fire agencies
  - advising on bushfire management issues for Council policies and strategies
  - assessing development applications against Our Living City's Bushfire Management Code
  - constructing and maintaining fire trails and water tanks on Council land
  - mapping bushfire footprints and hazards
  - monitoring and reducing bushfire fuel, such as dead wood and undergrowth, on selected priority Council reserves and land
  - supporting community bushfire education programs.
- Logan—Bushfire Risk Management Strategy
  http://www.logan.qld.gov.au/ data/assets/pdf_file/0004/117148/Bush.pdf
- Fraser Coast Regional council Bushfire Management Strategy 2010
  http://www.frasercoast.qld.gov.au/documents/4362881/41227905/Bushfire%20Management%20Strategy.pdf

PART C – Landslide hazard

C.1 Landslide terminology

For the purposes of the SPP, a number of key terms are used in accordance with the National Guidelines for Landslide Risk Management (AGS 2007 a, b, c and d). These terms have specific meaning under these guidelines which, on occasion, differ from terminology used for other natural hazards.

Terminology adapted from the AGS (2007a) guidelines and used in this guidance material includes:

Landslide – The movement of a mass of rock, debris, or earth (soil) down a slope.

Note: The term landslip is sometimes used to describe landslides but is not the recommended term as used by the geotechnical professionals. It is however acknowledged that the term landslip is commonly used in many planning applications and schemes.

Landslide inventory – A compilation of information and records on the location, classification, volume, activity and date of occurrence of individual landslides in an area.

Landslide susceptibility – A quantitative or qualitative assessment of the classification, volume (or area) and spatial distribution of landslides which have occurred, or potentially may occur, in an area. Susceptibility may also include a description of the velocity and intensity of the existing or potential landslides.

Landslide hazard – A location where the conditions have the potential for causing an undesirable consequence. The description of landslide hazard should include:

- the location
- volume (or area)
- classification
- velocity of the potential landslides
- any resultant detached material
- area that an “up slope” landslide may travel on to or regress into, and
- the probability of their occurrence within a given period of time.

Landslide risk – A measure of the probability and severity of an adverse effect to health, property or the environment. Risk is often estimated by the product of probability and consequences. For these guidelines risk is further defined as:

- for life loss, the annual probability that the person most at risk will lose his or her life taking account of the landslide hazard and the temporal spatial probability and vulnerability of the person.
- for property loss, the annual probability of the consequence or the annualised loss taking account of the elements at risk, their temporal spatial probability and vulnerability.

Zonation **–** The division of land into homogeneous areas or domains and their ranking according to degrees of actual or potential landslide susceptibility, hazard, or risk.

Zoning – The AGS guidelines uses the term to describe the assessment processes/investigations and is used internationally. To avoid confusion with land use zones, any landslide zoning assessment tasks should specifically refer to either landslide susceptibility zoning, landslide hazard zoning or landslide risk zoning.

Landslide Hazard Assessment Systems (LHAS) – is used to describe local government landslide planning scheme controls in Queensland. In the context of the AGS guidelines terminology, the equivalent would be the combination of Landslide Zoning Maps in use with an appropriate Landslide Risk Assessment Process for land use planning (such as that described in the AGS Practice Note AGS 2007c).

C.2 Landslide hazard investigation and mapping options – 'fit for purpose' approach

The development of a landslide hazard map in a local government area is best tailored to the characteristics (e.g. extent and severity) of the landslide hazard, the population and types of land use exposed, and predicted development growth pressures. Also the resources available for a local government to assess the natural hazard may influence the type and scope of an investigation.

Two approaches are:

(1) ***Basic approach*** – using a 15% slope to trigger site based assessment or
(2) ***Comprehensive approach*** – that develops a local area map using detailed local information

A comprehensive approach may be appropriate for local governments that have significant development pressures in areas with significant landslide hazard. Such areas will have been part of a local area landslide mapping investigation that is detailed and uses local assessments. This approach entails a landscape-wide landslide risk assessment, where the land use planning responses can be combined with other proactive slope stability management practices.

Alternatively, a basic approach may better suit areas that are not subject to significant development pressures in landslide prone areas.

A summary on landslides, scale of impact and range of responses to manage the impacts is detailed in the overview publication on Natural Hazards in Australia (Middelmann, M.H. 2007*).*

National guidelines and practice notes for undertaking landslide zoning (investigations) or mapping and for undertaking landslide risk assessment were developed by the Australian Geomechanics Society in 2007.

This specialist advice best directs how investigations can map and assess landslide risk and full reference details are listed in the supporting tools and links – landslide section. In the following sections, options for landslide zoning tasks are summarised from these guidelines and practice notes.

C.2.1 Determining if a basic or comprehensive approach should be undertaken

In determining a 'fit for purpose' approach, the relevant council may consider the following:

- is there a history of landslides
- does the topography indicate that landslides may occur
- does the geological and geo-morphological conditions indicate that landslides are possible
- what is the extent of the landslide hazard
- how many developments are expected to be exposed to a landslide hazard
- what capability does the council have to assess site based risk assessment reports
- what is the most cost effective manner to identify landslide hazard
- what is the level of community awareness and acceptance of a basic approach

A comprehensive approach is justified where the spatial extent of the landslide hazard overlaps with areas of planned development sufficiently to warrant a local area – 'landscape-wide' strategic assessment of landslides.

C.2.2 Comprehensive approach and local area mapping

A comprehensive approach will be based on a landslide inventory that provides knowledge and evidence of pre-existing landslides. It is also the basis for predicting other potential areas of landslide occurrence. However unlike other natural hazards, there is usually a limited amount of available information on landslides.

As an example of a landslide inventory, Townsville City Council compiled evidence for previous landslides using aerial photograph interpretation, historic records and discussions with local residents/road maintenance personnel and field mapping.

This information collated and identified landslides where characterised by location, landslide type, inferred volume and travel distance (where relevant), state of activity (active or relic) and inferred date of occurrence.

Supporting tools and links

Landslide inventory

- Detailed information on the development of a landslide inventory is contained in Australian Geomechanics Society guidelines (AGS 2007a). http://australiangeomechanics.org/admin/wp-c content/uploads/2010/11/LRM2007-a.pdf
- Flentje P. (2012) Landslide Inventory and Susceptibility Zoning across South-eastern Australia. Session 3 Sub aerial and submarine landslide hazards (IGCP585). 34th International Geological Congress (IGC): Australia 2012, Brisbane 5–10 August 2012.
- Townsville City Council approach
  http://www.townsville.qld.gov.au/business/planning/planningscheme/cityplan2014/documents/landslide%20hazard%20study_part1.pdf

Landslide recognition

- Miner A.S., Flentje. P., Mazengarb, C. and Windle, D.J. (2010) – Landslide Recognition using LiDAR derived Digital Elevation Models-Lessons learnt from selected Australian examples. 11th Congress of the IAEG "Geologically Active" 5-10 September 2010 Auckland, New Zealand

Queensland Government GIS data for landslip locations

- A series of past assessments that can be utilised for locations in South East Queensland

  http://mines.industry.qld.gov.au/geoscience/slope-stability.htm

Further resources

- AGS (2007a) Guideline for Landslide Susceptibility, Hazard and Risk Zoning for Land Use Planning. Australian Geomechanics Vol 42, No 1 March 2007
  - Landslide zoning map scales and descriptors for susceptibility, hazard and risk zoning – Section 7 pp 20-23
- AGS (2007c) Practice Note Guidelines for Landslide Risk Management 2007 Australian Geomechanics Vol 42, No 1 March 2007
  - Landslide risk assessment Appendix C pp 91-91

C.2.2.1 Local area mapping

A range of factors can influence the type and format that a local area mapping approach can take. These factors may include:

- overall requirements for zoning which might include assessments for regional land use planning, disaster and emergency management planning or local government level planning for urban development.
- the types of development being considered
- the classification, activity, volume of intensity of landslide present in a particular area
- the amount and quality of available information
- the history of land use
- the required accuracy of the zoning boundaries
- linkage to any proposed planning controls
- available funding.

Landslide zoning/investigations can either be undertaken in one of the following forms as defined in the AGS 2007a guidelines:

- landslide susceptibility zoning which is sometimes known in Queensland as landslide susceptibility mapping;
- landslide hazard zoning or
- landslide risk zoning.

C.2.2.1(a) Landslide susceptibility zoning

Landslide susceptibility is a quantitative or qualitative assessment of the classification, volume and spatial distribution of landslides which exist or potentially may occur in an area.

Typically landslide susceptibility zoning involves developing an inventory of landslides which have occurred in the past together with an assessment of the areas with a potential to experience landslide in the future.

Ideally, it also includes areas of retrogression and areas that the landslide mass will travel or run out. Not included is any assessment of the frequency (annual probability) of the occurrence of landslides.

Local governments in Queensland and around Australia have utilised landslide susceptibility zoning as an initial step at defining the spatial extent of the potential for landslide occurrence in their local government area.

Where more detailed analysis methods are utilised to produce landslide susceptibility zoning, it is probable that a number of different rankings or ratings of susceptibility will be developed and included in the mapping.

The AGS2007a guidelines recommend the use of standardised terminology across local government throughout the state which included classes defined as *very low, low, moderate, and high.*

Methodologies for producing landslide susceptibility are varied and range in complexity of both required input and modelling techniques. They may include:

- knowledge based/heuristic approaches
- empirical and geomorphic based techniques
- deterministic methods
- statistical
- data mining.

A variety of approaches have been cited in published literature. The methodology adopted should be appropriate primarily to the nature and quality of the available data.

Figure 3 provides examples of landslide susceptibility mapping.

Townsville City Council approach to landslide susceptibility mapping

The landslide inventory was used in combination with geological experience and observations during site visits to make a qualitative assessment of the susceptibility of different geomorphological and geological environments to landslide. This assessment is based upon:

- Knowledge based expert judgement including:
  - professional experience,
  - professional expertise, and
  - understanding the general mechanical principles of the observed
  - landslide types.

- The concept of "the past and present are guides to the future" by Varnes 1984 which leads to the assumption that:
  - - 'It is likely that landsliding will occur where it has occurred in the
  - - past, and
  - - landslides are likely to occur in similar geological, geomorphological and hydrological conditions as they have in the past.'

Qualitative assessments were also made on the potential volume, velocity and intensity of landslide types in different environments used in Townsville landslide inventory. http://www.townsville.qld.gov.au/business/planning/planningscheme/cityplan2014/documents/landslide%20hazard%20study_part1.pdf

City of Gold Coast—Landslip Hazard Assessment System utilising landslide susceptibility zoning/mapping

The methodology undertaken in assessing potential Landslide Susceptibility Management (LSM) Areas in this study was based on a review of the available information which included:

- the existing 1999 susceptibility zoning by Sadegh-Vaziri and Taylor (2002) which used a GIS platform to produce a zonation based a combination of the slope, geology, history of instability, topography and geomorphology

- the slope susceptibility zoning undertaken in parts of the city by Willmott in 1981, 1983 and Willmott and Hayne in 2001
- historical landslide information from GCCC and from Geoscience Australia, and
- literature review of pertinent reports, publications and approximately 4000 development application records.

Following the review of the above mentioned items the landslide hazard management areas were reassessed with the following modifications to the previous model;

- 1m contour information was used instead of the previous 10m (at best) contour interval to determine slope angles
- slope trigger criteria for various zones were modified downwards slightly to result in the trigger value for moderate susceptibility complying with the 110 in the GCCC Constraint Code for Sloping Sites
- aerial photographic interpretation of the entire city, supplemented by review of available imagery of the internet; identified substantial additional areas apparently affected by slope instability
- use of a 25m by 25m grid in the GIS platform instead of the previous 50m by 50m grid substantially refined the zonation by the reducing the extent of the averaging across the grid cells for the calculation of slope angles
- the site specific information available from site specific stability assessments undertaken for development applications allowed updating of the zoning where available; and
- modifications to the boundaries of the zoning undertaken by Willmott and Hayne were undertaken due to the appreciably better terrain model available.

Sunshine Coast Regional Council—landslide susceptibility zoning/mapping

A map of the Maroochy component of the Sunshine Coast Region classifies the area in terms of five landslip hazard categories, and then further identifies specific locations for closer assessment of landslip hazard.

http://www.goldcoast.qld.gov.au/documents/bf/landslide-susceptibility-assessment-report-201108.pdf

C.2.2.1(b) Landslide hazard zoning/mapping

Landslide Hazard maps (as per the AGS 2007a definition) are developed from the susceptibility zonation maps with the areas classified according to the frequency (annual probability) of landslide. The way the frequency is expressed will depend on the classification and volume of the potential landslides which could include rock falls, slides from cuts, fills and retaining walls, small landslides and large landslides.

The landslide hazard map should be at the same scale as the susceptibility zonation map and show the topography and cadastral information as well as the hazard zonation classifications for the area being mapped.

Landslide Hazard Maps are rarely developed at a regional zoning scale (1:25,000 to 1:250,000) and might be typically expected to be used at local (1:5,000 to 1:25,000) and site specific (>1:5,000) zoning scales.

Landslide Hazard Zoning/investigations are used less frequently than Susceptibility Zoning/investigations. However an example of a complete hazard zoning/investigation is one undertaken in Townsville (see Example 4 below).

Example 4 Hazard mapping

Townsville City Council—Landslide Hazard Zoning and Risk Assessment

STUDY AREA	EXISTING AND INFERRED PROPOSED DEVELOPMENT	SLOPE PROCESSES	LANDSLIDE HAZARD	LANDSLIDE FREQUENCY	LANDSLIDE CONSEQUENCE ANALYSIS	LANDSLIDE RISK ESTIMATION
PALUMA VILLAGE	Existing very low density development comprising single to double story dwellings and some public buildings. . Large areas of vacant land. Inferred potential for low to medium density development.	No signs of land instability were observed. Possible soil creep on some localised, short, moderate slopes.	▪ Shallow Slumping – very low. ▪ Rock roll – very low.	No evidence of relic or active landsliding.	Elements at risk: ▪ existing houses ▪ radio mast ▪ future development	Very low risk.
TOOMULLA	Existing low density development comprising single to double story dwellings and some public buildings. . Large areas of vacant land. Potential for low to medium density development.	Shallow regolith failures and soil creep observed in places, particularly where driveways/pads have been excavated. Small relic scarp on shoreline, inferred to be remnant of previous wave erosion during raised sea-level?	▪ Shallow Slumping – very low to moderate hazard. ▪ Rock roll – very low to low hazard.	No evidence of significant recent instability. Some active erosion noted in places.	Elements at risk: ▪ existing houses ▪ future development	Very low to low risk.
MT LOW	Existing low to medium density development comprising single to double story dwellings and some public buildings. Large areas of vacant land. Potential for low to medium density development.	Hummocky ground indicates shallow regolith slumping and soil creep on moderate to steep slopes. Some 'scars' of bedrock inferred to be exposed when soil layer has slid off leaving smooth bedrock mounds. No evidence of debris flows. Some evidence of fluvial depositions along base of small gullies. Some small boulders (up to 0.5m) loose on surface, generally near bedrock source. No signs of instability on gentle slopes apart from isolated small failures related to development earthworks.	▪ Shallow Slumping – very low to low hazard. ▪ Rock roll – very low to low hazard.	No evidence of significant recent instability. Some active erosion noted in places.	Elements at risk: ▪ existing houses ▪ above-ground sewer pipe on northwestern slope of western hill. ▪ water tank on southwestern end of western hill. ▪ future development	Very low to low risk.
JENSEN (SEAVIEW PARK)	Existing low to medium density development comprising single to double story dwellings. Large areas of vacant land. Potential for low to medium density development.	Some hummocky ground in places. 'Scars' of bedrock inferred to be exposed from soil sliding. Limited evidence of rock roll (boulders on ground surface away from bedrock source).	▪ Shallow Slumping – very low to moderate hazard. ▪ Rock roll – very low to low hazard. ▪ Rockfall – inferred to be isolated moderate hazard immediately below bedrock outcrops.	No evidence of significant recent instability. Small (0.3m) boulders observed next to pipeline. Some active erosion noted in places.	Elements at risk: ▪ existing houses ▪ above-ground water pipes on north eastern and north western slopes. ▪ water tank on northern end of hill. ▪ future development	Very low to low risk.

C.2.2.1(c) Landslide risk zoning

The application of the mapping to provide landslide susceptibility, hazard or risk zoning requires a mix of data attributes. Simple methods may only utilise a few attributes (e.g. a simple correlation between slope angle and geology) whilst more complicated multivariate statistical methods may include many attributes.

For example, an Australian approach for estimating and predicting landslide susceptibility by the University of Wollongong (Flentje 2012) uses the following factors:

- landslide occurrence (as per a landslide inventory)
- geology
- vegetation
- flow accumulation
- soil landform
- slope aspect
- slope angle
- digital elevation model.

Other data sets that may be used in the development of landslide zoning maps include:

- rock mass characteristics
- soil landform units
- geomorphological units
- land use
- rainfall
- depth of residual soil or colluvium over rock
- depth to groundwater
- proximity to waterways
- proximity to geological faults
- proximity to roads and other anthropogenic features.

In addition, interpretations of aerial imagery and remote sensing data as well as field observations and anecdotal evidence can also be utilised.

Supporting tools and links

- AGS (2007a) Guideline for Landslide Susceptibility, Hazard and Risk Zoning for Land Use Planning. *Australian Geomechanics* Vol 42, No 1 March 2007 http://australiangeomechanics.org/admin/wp-content/uploads/2010/11/LRM2007-a.pdf
- AGS (2007b). Commentary on Guideline for Landslide Susceptibility, Hazard and Risk Zoning for Land Use Management, Australian Geomechanics Society, *Australian Geomechanics*, Vol 42, No1. http://australiangeomechanics.org/admin/wp-content/uploads/2010/11/LRM2007- b.pdf
- AGS (2007c). Practice Note Guidelines for Landslide Risk Management Australian Geomechanics Society. *Australian Geomechanics*, Vol 42, No1. http://australiangeomechanics.org/admin/wp-content/uploads/2010/11/LRM2007-c.pdf
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- Cammack, R and Grocott, G. (2011). Townsville landslide hazard study. J.I and News of the Australian Geomechanics Society Vol 46, No 2, pp 125-140.
- Fell, R., Corominas, J, Bonnard C., Cascini, L, Leroi, E, and Savage, W. (2008). Guidelines for landslide susceptibility, hazard and risk zoning for land use planning. Published on behalf of the JTC-1 joint technical Committee on Landslides and Engineered Slopes in Engineering geology 102, 2008), pgs 85-98.
- Flentje P. (2012) Landslide Inventory and Susceptibility Zoning across South-eastern Australia. Session 3 Sub aerial and submarine landslide hazards (IGCP585). 34th International Geological Congress (IGC): Australia 2012, Brisbane 5–10 August 2012.
- Middelmann, M.H. (Editor) (2007*). Natural Hazards in Australia. Identifying Risk Analysis Requirements.* Chapter Eight: Landslide. Pp 115-132. Geoscience Australia. Canberra
- Miner A.S., Flentje. P., Mazengarb, C. and Windle, D.J. (2010) – Landslide Recognition using LiDAR derived Digital Elevation Models-Lessons learnt from selected Australian examples. 11th Congress of the IAEG "Geologically Active" 5-10 September 2010 Auckland, New Zealand
- Department of Infrastructure, Local Government and Planning, Statutory guideline 04/14. Making and amending local planning instruments (MALPI) http://www.dilgp.qld.gov.au/resources/planning/planning/statutory-guideline-04-14.pdf

PART D – Coastal hazards

D.1 Coastal hazard investigation and mapping options – 'fit for purpose' approach

To identify coastal hazard areas in a local government area, it is recommended that local governments undertake a 'fit for purpose' coastal hazard investigation. It is important that coastal hazard mapping be fit for purpose and best tailored to the location, nature and extent of coastal hazard risks for the local government area.

As part of the investigation into coastal hazards it is important to identify coastal hazard areas using maps as a way of considering the risks associated with the coastal hazard and determining appropriate land use planning responses in local planning schemes.

An important step in this process is to determine the level of detail in the coastal hazards mapping required to achieve good planning outcomes. While the SPP Interactive Mapping System displays indicative coastal hazard mapping, local government may choose to undertake their own localised coastal hazards investigation when determining their own coastal hazard areas.

The state government can work with local government when identifying coastal hazards areas to provide guidance and appropriate responses to planning for coastal hazards in their local government area.

The Department of Environment and Heritage Protection (EHP) has undertaken extensive investigation of coastal hazards in Queensland and has published mapping of coastal hazard areas. These maps have been prepared for the entire Queensland coast although remote areas in far north Queensland have been mapped at a lower resolution. This mapping can be used where more detailed regional or local assessments have not yet been undertaken.

State-wide coastal hazard mapping was updated in July 2015 to reflect projected impacts of climate change to 2100. This included incorporating a 0.8 metre sea level rise consideration into erosion prone area and storm tide inundation area mapping. The State Planning Policy state interest in Natural hazards, risk and resilience, requires that risks associated with natural hazards are avoided or mitigated to protect people and property and enhance the community's resilience to natural hazards. Local government can use the State's mapping or undertake their own fit for purpose natural hazard studies when making or amending a planning scheme. This may include a number of technical investigations and studies which consider the impact of sea level rise on storm tide inundation and coastal erosion.

A fit for purpose approach is recommended and is based on a response to natural hazards that is tailored to the characteristics of the hazard, the population exposed and development growth pressures experienced, and the resources available to address the natural hazard.

As part of the coastal hazards investigation the following steps are recommended:

- Prepare and provide mapping for areas at risk from coastal erosion and storm tide inundation
- identify the nature (e.g. temporary or permanent inundation) and level of severity of the hazard(s) within the mapped coastal hazard areas (e.g. high and medium coastal hazard areas)

A fit for purpose approach is recommended and is based on a response to natural hazards that is tailored to the characteristics of the hazard, the population exposed and development growth pressures experienced, and the resources available to address the natural hazard.

Coastal hazard maps for the local government area can identify coastal hazard areas through the following:

(1) localised or regional coastal hazard area maps. Local Government or a developer may wish to prepare local storm tide inundation studies and local erosion prone area studies.
(2) the state government coastal hazard area maps available on the SPP Interactive Mapping System http://www.dilgp.qld.gov.au/about-planning/spp-mapping-online-system.html and the Department of Environment and Heritage website where the mapping is more fullyexplained http://www.ehp.qld.gov.au/coastal/management/coastal_plan_maps.php

When determining high and medium coastal hazard areas it is recommended reference is made to the best practice categorisation of these hazard areas relative to at least, imminence of erosion vulnerability, and storm tide inundation height and velocity.[3]

A high coastal hazard area includes one or more of the following:

- the part of the erosion prone area that is within the coastal management district
- the part of the storm-tide inundation area that is projected to be temporarily inundated to a depth as determined by local government (or as otherwise determined based on water depth and velocity) during a defined storm-tide event.

Local government may also choose to include land that is projected to be permanently inundated from sea level rise over a specific time period.

A medium coastal hazard area includes land that is within the storm-tide inundation area that is projected to be temporarily inundated to a depth of less than one metre during a defined storm-tide event.

Determining the depth of temporary or permanent storm tide inundation within the coastal hazard area is important. It will assist in determining whether existing and proposed land uses and future development is compatible with the inundation depth associated with the hazard.

The coastal hazard area layers of the SPP Interactive Mapping System show areas of high and medium hazard storm tide inundation as well as erosion prone areas. The unmapped coastal hazard areas available on the SPP Interactive Mapping System are considered as having 'low' or no coastal hazard risks (the risk of the hazard occurring in unmapped areas is less than 1 per cent in any one year).

As part of the state interest review process for a local planning scheme, it is anticipated that a local government report will demonstrate:

- what level of mapping has been undertaken in particular locations of the local government area
- where future mapping is proposed
- locations where mapping is unavailable or not considered necessary due, for example, to very low risks.

[3] In the context of this outcome, coastal hazard risk is that level of risk generated by the defined storm tide event or erosion from a one-in-100 year average return interval storm.

Supporting information

- Declared erosion prone area plans available at https://www.ehp.qld.gov.au/coastal/development/assessment/erosion_prone_areas.html
- Coastal Hazards Technical Guide available on the https://www.ehp.qld.gov.au/coastalplan/pdf/hazards-guideline.pdf
- Digital elevation data for vulnerable coastal areas and coastal hazard area maps. These are available from the Queensland Spatial catalogue http://qldspatial.information.qld.gov.au/catalogue/custom/index.page gateway to Queensland Government spatial information, in a geographic information system (GIS) format
- Property scale maps of coastal hazard areas are available from the EHP website (lot and plan details required)

D.2 Coastal hazard risk assessment

A coastal hazard risk assessment should be prepared:

- considering the acceptable, tolerable and intolerable levels of risk for each land use type[4]
- considering locations where particular land use planning strategies are required to achieve acceptable or tolerable levels of risk to people and property.

To achieve the policy intent it is recommended to use The Australian and New Zealand Risk Management Standards (AS/NZS ISO 31000:2009) as the basis of any risk assessment.

The risk assessment should:

1) consider the risks presented by coastal hazards to existing and future communities and infrastructure for at least the defined storm tide event level and coastal erosion risk for the relevant planning period. Council may wish to adopt a staged approach to benchmark risk. For example: 0.2 metre sea level rise projection by 2040 or 0.5 metre sea level projection by 2070 or 0.8 metre sea level rise projection by 2100, and
2) consider the vulnerability of particular types of land use or development and level/s of risk appropriate for these, and
3) consider high coastal hazard areas unsuited to new urban development, and
4) set a measurable goal for managing the risk and specify the role of land use planning to achieve the identified goal, and
5) develop land use responses as part of a holistic risk management or adaptation strategy for the local government area.

[4] The Coastal Hazard Adaptation Strategy pilot project for Townsville City Council (GHD, 2012) includes vulnerability analysis thresholds which can be used by local government as a suitable reference:

Acceptable risk	Individuals and society can live with this risk without feeling the necessity to reduce the risks any further.
Tolerable risk	Society can live with this risk but believe that as much as is reasonably practical should be done to reduce the risks further. *Note that individuals may find this risk unacceptable and choose to take their own steps, within reason, to make this risk acceptable.*
Unacceptable risk	Individuals and society will not accept this risk and measures should be put in place to reduce risks to at least a tolerable level.

6) identify how land use planning will work in conjunction with other risk management strategies including building controls, mitigation infrastructure, early warning systems, community awareness and emergency managements to address the risk of coastal hazards.
7) consider the need to maintain natural landforms, vegetation and coastal processes that mitigate erosion risk.

The defined storm tide event level (i.e. the one per cent AEP storm tide level) is considered an acceptable level of risk for urban development generally however certain development types should be planned with a higher level of protection.

The vulnerability of a development to the impact of a coastal hazard will largely relate to the type, nature and extent of the development proposed. For example, a nursing home or hospital will be more vulnerable to coastal hazard impacts relative to an industrial area. Conversely, the inundation of industrial areas might result in inherent risks such as the escape of toxic or hazardous materials. For commercial land uses, the loss of stock or productive capacity should be considered.

It may not be cost-effective and/or practical to undertake comprehensive risk assessments for planning purposes where there may be no likelihood of a change in an existing low intensity land use such as agricultural production or small coastal settlements. For these areas a streamlined approach could use the zone as the basis for the risk assessment. A risk assessment can also be undertaken for individual key assets such as an education facility. The risk assessment can be undertaken by consultants or by council.

In considering land use planning strategies required to achieve acceptable and/or tolerable levels of risk to people and property, a compendium of adaptation actions suitable for the Queensland coast have been described. This compendium identifies a comprehensive range of coastal hazard adaptation options including planning options (for example, retreat or land use change). The compendium can assist councils in identifying potential strategies to achieve acceptable or tolerable levels of risk.

As part of the state interest review process for a local planning scheme, a local government report can include the findings of a risk assessment and the broad land use planning strategies to address the identified coastal hazard.

D.2.1 Applying the risk assessment

A risk assessment should be captured at all levels of the planning instrument, from strategic to detailed development provisions.

For high growth, high risk coastal hazard areas (where significant infrastructure or population growth is anticipated or already exists), a coastal hazard adaptation strategy can be developed to plan for how people and property in these areas will be protected from adverse coastal hazard impacts over time.

A coastal hazard adaptation strategy is a strategic mechanism to guide risk mitigation for coastal communities through informed, coordinated and timely actions over the long term. For example, a long term management option for a community at risk may be to defend the area from current and future risks. Other strategic options may be to accommodate the risk (e.g. through building standards) or retreat to areas of less risk. More information about mitigating coastal hazard impacts and preparing adaptation strategies can be found in the Supporting Information section.

Coastal and island communities located in local government areas between and including Wujal Wujal Aboriginal Shire and Burke Shire may be subject to shire wide coastal hazards and all development is subject to this constraint. In these cases, the priorities are:

- firstly, consolidation of existing settlements and
- secondly development of less vulnerable areas
- thirdly ensuring that risk are addressed in all new development areas.

Supporting information

- GHD 2012, Coastal Hazard Adaptation Strategy for Townsville City Council—Pilot Project (and associated vulnerability and risk assessment, Learning's Report and Compendium of adaptation options information) http://www.townsville.qld.gov.au/council/projects/Pages/TownsvilleCoastalHazardAdaptationStrategyPilotProject.aspx

- Rollason, V, Fisk, G, Haines, P (2010), 'Applying the ISO 31000 Risk assessment framework to coastal zone management', 19th NSW Coastal Conference, 10–12 November, Batemans Bay http://www.coastalconference.com/2010/papers2010/Verity%20Rollason%20full%20paper%202.pdf

- Standards Australia, 2004. Handbook HB436 Risk management

- Standards Australia, 2009 AS/NZS ISO 31000-2009 Risk management—Principles and guidelines

- Guideline for Preparing a Coastal Hazard Adaptation Strategy. Department of Environment and Heritage Protection, Queensland Government (2012) http://www.ehp.qld.gov.au/coastalplan/pdf/adaptation-strategy-guideline.pdf

- National Strategy for Disaster Resilience developed by the Federal Government (Council of Australian Governments).

- Guideline – A risk assessment approach to development assessment in coastal hazard areas, EHP Queensland Government (2013). http://www.ehp.qld.gov.au/coastal/development/pdf/guideline-risk-assessment-approach.pdf

- Coastal Construction Manual: Principles and Practices of Planning, Siting, Designing, Constructing, and Maintaining Residential Buildings in Coastal Areas (Fourth Edition). FEMA (2011). http://www.fema.gov/media-library/assets/documents/3293

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