



Developing a Coastal Hazard Adaptation Strategy:

Minimum Standards and Guideline for
Queensland Local Governments

Developing a Coastal Hazard Adaptation Strategy: Minimum Standards and Guideline for Queensland Local Governments

October 2016

Prepared by: The Local Government Association of Queensland and The Department of Environment and Heritage Protection

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List of Acronyms

AEP	Annual Exceedance Probability
ARI	Annual Recurrence Interval
CBA	Cost Benefit Analysis
CHAS	Coastal Hazard Adaptation Strategy
DEHP	Queensland Department of Environment and Heritage Protection
EPA	Erosion Prone Area
GIS	Geographical Information System
HAT	Highest Astronomical Tide
IPCC	Intergovernmental Panel on Climate Change
LGAQ	Local Government Association of Queensland
MCA	Multi Criteria Assessment
NPV	Net Present Value
PRG	Project Reference Group
SPP	State Planning Policy
STIA	Storm Tide Inundation Area

Key Terminology

Adaptation: Actions undertaken to eliminate or limit the risks posed by a coastal hazard.

Adaptation Pathway: An approach for enabling systematic adjustment of adaptation strategies in response to new information or changing circumstances.

Adaptive Management: Similar to an adaptation pathway, adaptive management is a structured approach to decision making commonly used in natural resource management, that allows a response to a 'trigger' or 'event' to be altered where required.

Average Recurrence Interval: The average, or expected, value of the periods between exceedance of a given storm tide level.

Consequence: A term commonly used in a risk assessment to estimate the impacts of an event.

Cost Benefit Analysis: A technique used to determine the benefits or costs of a project, option or decision to aide decision-making.

Erosion Prone Area: Statutory erosion prone areas are declared under the *Coastal Protection and Management Act 1995*, and are areas subject to coastal erosion or tidal inundation.

Likelihood: A term commonly used in a risk assessment to estimate the chance of an event occurring.

Multi Criteria Analysis: A decision-making tool that enables options to be prioritised using multiple qualitative criteria.

Storm Surge: A localised increase (or decrease) in ocean water levels caused by high winds and reduced atmospheric pressures associated with a storm event.

Storm Tide: The effect on coastal water of a storm surge, combined with the normally occurring astronomical tide.

Storm Tide Inundation Area: The area of land determined to be at risk from inundation associated with a storm tide.

Threshold: A pre-determined event/impact that if crossed, would result in impacts deemed 'unacceptable' in the CHAS.

Trigger Point: A pre-determined point that is set to 'trigger' the commencement of planning and implementation of an adaptation option to avoid crossing a 'threshold'.



Photo: Boigu Island, Torres Strait. © Buckley Vann Planning + Development, 2012

1. Introduction

Many coastal communities currently face coastal erosion and inundation risks. However, projected sea level rise and more intense storms from a changing climate may increase and extend these risks to areas currently at low or no risk. These hazards may adversely impact both tangible and intangible community values such as:

- existing and future buildings and infrastructure
- natural assets, such as environmentally significant areas, parks and reserves and local biodiversity
- the local economy, by disrupting businesses and services
- social and cultural assets, such as beaches and indigenous heritage
- recreational opportunities and shoreline accessibility for the community at large.

Local coastal councils increasingly have to make difficult decisions about managing and responding to coastal hazards faced by the community.

A Coastal Hazard Adaptation Study (CHAS) is the product of a series of studies that seek to:

- identify coastal hazard areas
- understand vulnerabilities and risks to a range of assets (including tangible and intangible assets)
- engage with the community to understand their preferred approach to adaptation
- determine the costs, priorities and timeframes for their implementation.

1.1 Purpose of this document

The purpose of this document is to provide guidance to coastal councils in preparing a CHAS. These guidelines set minimum requirements that are to be included in a CHAS as well as providing information on leading practices to facilitate continuous improvement. The purpose of defining minimum standards is to set a benchmark for undertaking such studies in Queensland so that coastal hazard decision-making is approached in a consistent and systematic manner. There is some flexibility in these minimum standards however, so they may be easily adapted to the needs and resources of individual councils. The guidelines draw upon the experience of a number of experts in coastal hazard and climate change adaptation.

1.2 What are the benefits to councils of preparing a CHAS?

Councils have always had a role in managing coastal lands within their boundaries, however a CHAS can further assist councils to:

- identify the likelihood and consequence of coastal hazards having an adverse impact on council operations and community assets
- reduce future exposure to the risks of coastal flooding, storm-tides and erosion
- reduce or avoid significant financial costs of future coastal hazard impacts
- clarify their role in responding to future coastal hazard risks and setting the direction for this response
- embed coastal hazard adaptation responses into decision making processes and planning frameworks
- respond effectively to statutory planning and policy direction at the State level e.g. State Planning Policy
- plan for the long-term protection of coastal infrastructure, built environment and services within at-risk areas
- build the knowledge and capacity of staff to respond to coastal hazard planning needs and events
- prepare for engagement and consultation with the broader community to inform decision-making.

1.3 Intended audience

Queensland coastal councils are the primary audience of these guidelines. As coastal hazards are managed by a range of departments and technical disciplines, they have been written to provide assistance to a broad audience including planners, engineers, consultants and decision-makers.

1.4 Structure

These guidelines have been structured to address the key phases of a CHAS:

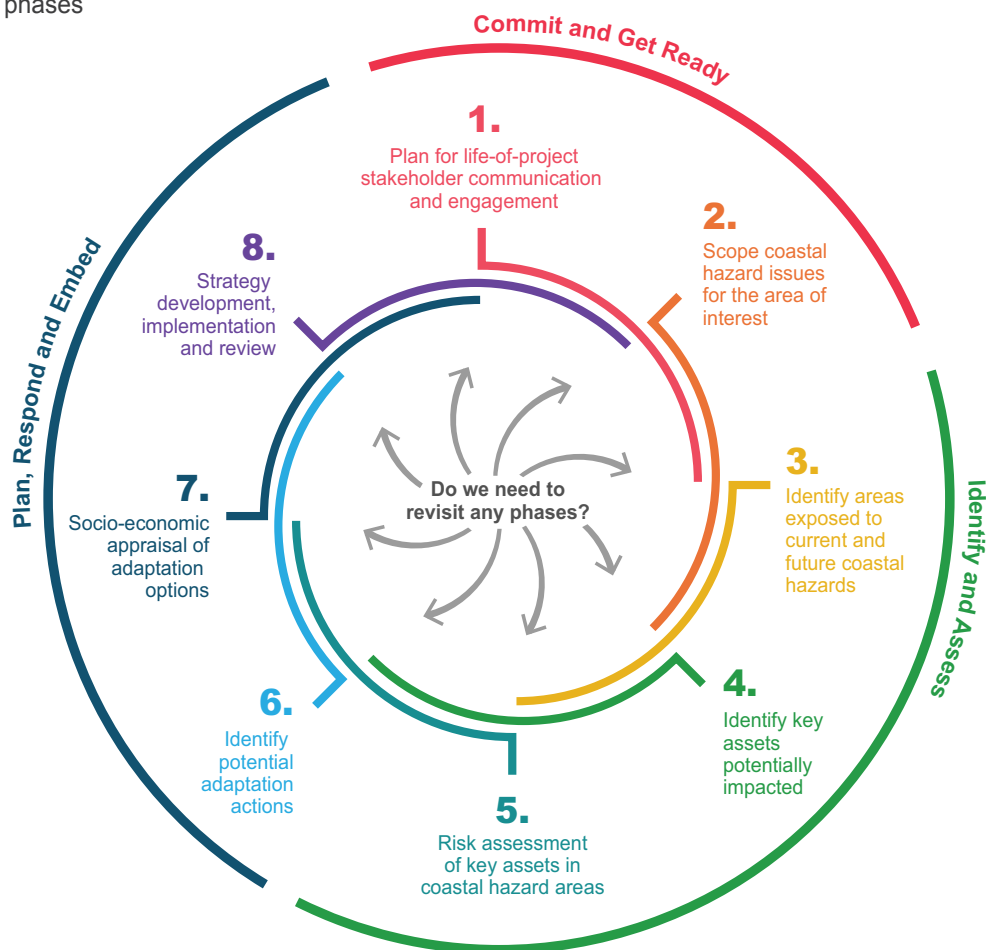
- PHASE 1:** Plan for life-of-project stakeholder communication and engagement
- PHASE 2:** Scope coastal hazard issues for the area of interest
- PHASE 3:** Identify areas exposed to current and future coastal hazards
- PHASE 4:** Identify key assets potentially impacted
- PHASE 5:** Risk assessment of key assets in coastal hazard areas
- PHASE 6:** Identify potential adaptation options
- PHASE 7:** Socio-economic appraisal of adaptation options
- PHASE 8:** Strategy development, implementation and review

Each of the following sections begin with a summary of the purpose and objectives of each phase, followed by a description of the minimum standards that **must** be followed and additional leading practices that a council may **choose** to employ depending on the scale of the CHAS being undertaken and the individual needs of a council. Following each phase, references and additional reading materials are provided.

The reader may choose to examine a specific phase where detail is needed, or gain an overall impression of the core concepts of a CHAS by reading this introductory section.

A CHAS should be approached as a cyclic process, whereby each phase is interconnected and can be revisited and refined where necessary, as shown in **Figure 1**.

Figure 1. Project phases



1.5 CHAS scope

Timing

A CHAS should encompass adaptation actions to be undertaken by councils over the short, medium and long term (typically up to 2100) planning horizon. It is to be regularly reviewed and updated between a 5 to 10 year period.

Extent

A CHAS should identify all council and non-council assets within its coastal hazard area. Some key assets (airports, ports, natural areas) may be privately owned or managed by a dedicated entity (e.g. Great Barrier Reef Marine Park) and may not require further consideration. Where possible, councils are encouraged to include other stakeholders and asset owners in the CHAS process to promote coordinated adaptation decision-making. While the CHAS is primarily to focus on risks that are within its authority or influence to control, it is also an opportunity to achieve agreed roles and responsibilities for adaptation activity with critical stakeholders.

1.6 Guiding principles for preparing a CHAS

The following principles have been identified to guide the overall development of a CHAS:

- it is fit for purpose and based on the best available science, data and information
- It adopts an adaptive management approach to allow flexibility over time. This recognises that sea level rise and cyclone intensity projections may change, as well as how a community responds to risks. An adaptation strategy should be considered a 'living' document that is amended over time to deal with changing risks, uncertainties and innovative responses
- it considers locally-specific objectives within a regional context
- stakeholder communication and engagement (both internal and external) is critical for the endorsement and successful implementation of a CHAS.

1.7 Dealing with Uncertainty

Uncertainty is a key characteristic of climate change and long-term coastal management, and can be viewed as a key barrier to progressing adaptation options. This uncertainty should not however be an excuse to delay planning or action. A sound approach to dealing with uncertainty is to plan over multiple time horizons or scenarios, and adopt flexible management options that are adjusted over time. This guideline takes a 'risk-based' approach to dealing with uncertainties in data and event timing, which allows for a range of circumstances to be identified and planned for.

1.8 Compliance with state policies and other legislation

CHAS projects respond to a wide range of community needs and it is important that, like broader climate adaptation strategies, the outcomes of a CHAS project are embedded across council business areas and implemented using a range of delivery tools and mechanisms available to local government.

Land use planning is one council function where a CHAS can guide decisions on strategic planning and the location and design of new development and infrastructure. Integration of the CHAS into the planning scheme will ensure that new development is appropriate for the level of existing and future coastal hazard risks, and that the development provides an adaptation response consistent with the intent of the CHAS.

The preparation of a CHAS must therefore align with the *State Planning Policy 2016* (SPP), a key component of Queensland's statutory land use planning system. Natural hazards, risk and resilience is one of 16 State interests identified in the SPP that must be considered when preparing or amending planning schemes and in some cases, assessing development applications. A CHAS specifically addresses the coastal hazards component of the *State interest policy for natural hazards, risk and resilience*, which states:

'The risks associated with natural hazards are avoided or mitigated to protect people and property and enhance the community's resilience to natural hazards'

While not a mandatory requirement, a coastal hazard adaptation strategy is considered a practical and integrated means for coastal councils to achieve this state interest.

Other state interests listed in the SPP directly related to coastal hazard adaptation include:

- Biodiversity
- Coastal environment

Indirectly, SPP interests may also relate to a CHAS depending on the proposed adaptation options, including for instance: energy and water supply, liveable communities, agriculture, water quality, tourism, development and construction, transport infrastructure or cultural heritage.

Disaster management and planning is another important council function and the CHAS outcomes must align with and inform council disaster risk reduction, mitigation and resilience plans. The *Disaster Management Act 2003*, forms the legislative basis for disaster management activities within all levels of Government and the Queensland disaster management arrangements. Under this Act, there is a statutory requirement for local governments to prepare Local Disaster Management Plans (LDMP) that address the matters in the Queensland District Disaster Management Guidelines (QDDMG) (2012). While climate change is not explicitly mentioned in the Act, the *Strategic Policy Framework for Disaster Management* (Emergency Management Queensland, 2010) and the QDDMG are explicit about the requirements to consider the future impacts of climate change and take preventative and adaptive measures to mitigate these impacts.

Coastal hazard adaptation may also need to consider other state regulatory controls outside of the SPP, the principal one being the Marine Park Zoning Plans.

Details of relevant state policies are included in Annex II.



Photo: Iama (Yam) Island, Torres Strait. © Buckley Vann Planning + Development, 2014

Figure 2. Project phases and key considerations

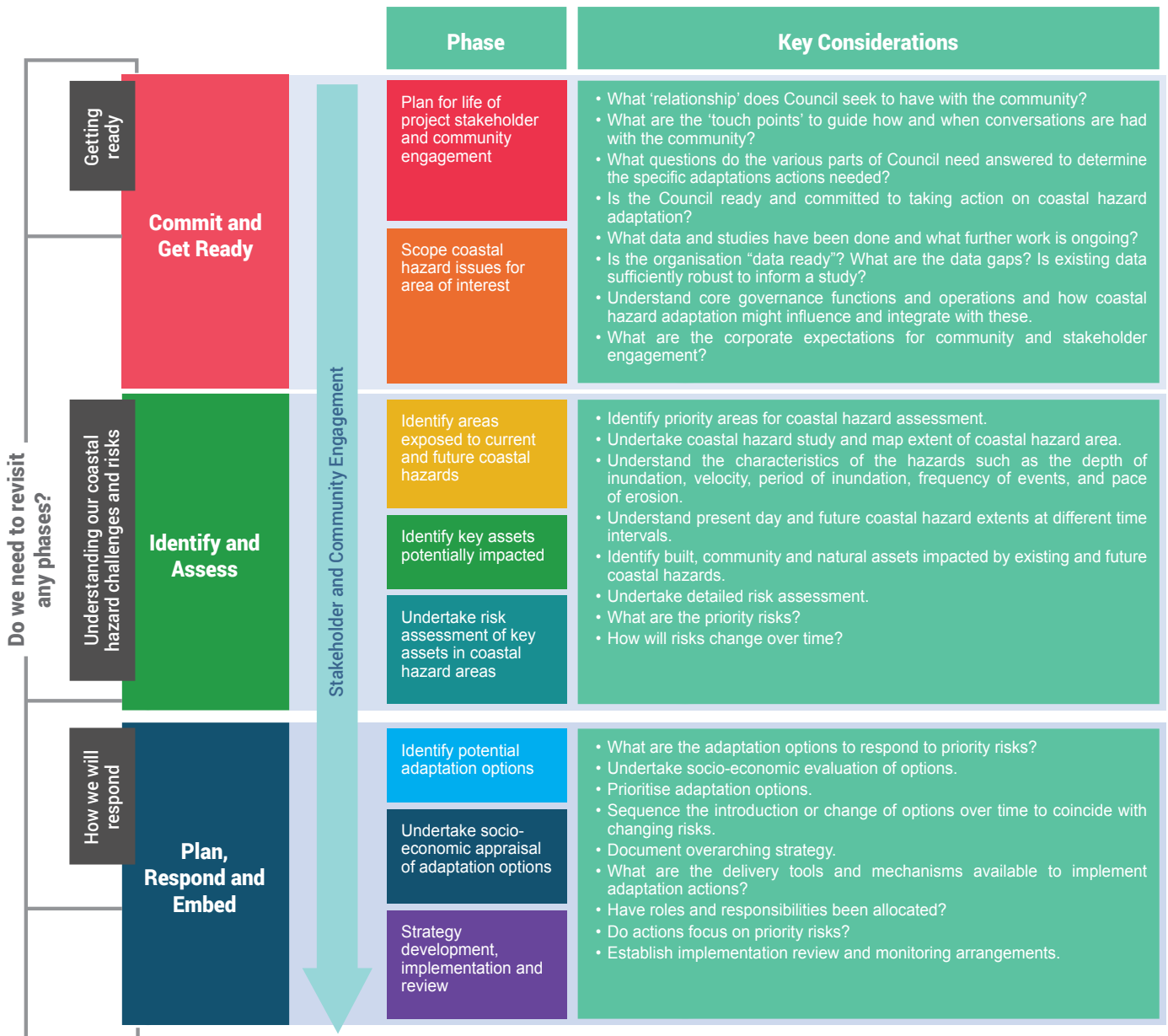




Photo: Point Danger, Coolangatta. (CC BY 2.0) Rob Deutscher, 2013. <https://www.flickr.com/photos/bobarc/>

2. Phases of a CHAS

PHASE 1. Plan for life-of-project stakeholder communication and engagement

2.1.1 Purpose of this phase

Active engagement with internal and external stakeholders is critical to building shared understanding of the risks councils face from coastal hazards, and gaining community and political endorsement of proposed coastal adaptation measures.

As part of this phase, councils are to prepare a stakeholder engagement plan that documents the approach to consultation for all future CHAS phases.

The objectives of this phase include:

- determining all key internal and external stakeholders and the depth of consultation to be undertaken with these stakeholders
- identifying the optimal timing and delivery method of communication and engagement activities
- agreeing on council's roles and responsibilities in communicating and engaging with stakeholders
- documenting the agreed communication and engagement activities.

2.1.2 Minimum requirements

A stakeholder engagement plan must be prepared in this phase, documenting at least the following:

1. Council's preferred overall approach to identifying, communicating and engaging with the community and key external stakeholders i.e. active, passive or 'arm's length' participant
2. all relevant internal and external stakeholders, including the community
3. the process for undertaking targeted consultation in each subsequent phase of a CHAS, including:
 - key communication objectives and messages for each phase
 - timing
 - relevant stakeholders
 - engagement method e.g. one-on-one, workshops, on-line survey
 - notification mechanisms e.g. print media, social media, newsletters etc.
 - engagement and communication materials required e.g. print media, social media, newsletters etc.
 - consultation risks and mitigation strategies

- available resources and responsibilities for undertaking engagement activities

Prior to the finalisation of a CHAS, a minimum 28-day formal public consultation period is recommended (where the public are able to make formal submissions on the CHAS). All consultation outcomes (i.e. internal meetings, workshops etc.) should be documented for internal purposes, but do not need to be publically released.

Upon completion of the consultation period, a document setting out council's response to the submissions received must be prepared and made publicly available.

As Phase 2 of the CHAS will influence stakeholder identification and engagement, it is recommended that Phase 1 be developed concurrently with Phase 2.

2.1.3 Leading practices

Because of the often-contentious nature and politicisation of climate change related matters, councils can be reticent to engage broadly with the community and other stakeholders outside their organisation. Councils are however, faced with making difficult decisions with regards to coastal hazard adaptation responses, and adopting a consultative and transparent approach to communication with the public will enhance decision-making. Effective communication and engagement with a wide range of internal and external stakeholders is encouraged to:

- educate internal and external stakeholders about coastal hazards and risks
- understand the level of risk acceptable to the community
- inform decision-making for adaptation options
- assist stakeholders to understand their role and responsibilities in managing coastal hazards.

The *Communication guidelines – coastal hazard adaptation* (LGAQ 2014) provides support for local government staff and elected members in preparing for and conducting public participation in coastal adaptation planning. It is recommended that these guidelines are followed when preparing a CHAS, as they are tailored specifically for Queensland coastal councils.

Value of Effective Communication

Effective communicating and engaging with the owners, managers and users of built, cultural and natural assets of value to the community will help foster support for coastal management and adaptation.

Often a council's responsibilities are affected by other agencies' actions. Communication and engagement with other land management agencies active in coastal areas can help coordinate actions in a way that improves outcomes, reduces costs and develops a consistent approach to issues.

Effective communication and engagement by council about coastal hazard assessment and adaptation projects can:

- educate the community about coastal hazards and the associated risks, including increasing awareness and understanding of normal coastal dynamics, which many coastal residents do not understand well
- provide information and mapping about the location and severity of the hazards, allowing community members to make informed decisions about property investments in the area
- broaden community awareness of possible adaptation responses, including understanding of options, implications, effectiveness and costs; improved awareness can also reduce anxiety and enable positive responses

- clarify roles and responsibilities, specifically making clear what responsibility council does or does not have in regard to adaptation, including for assets that it does not own
- demonstrate leadership in terms of adaptation
- engage the community in decision-making.

Engaging with the community can make decision-makers more aware of:

- the community's values and priorities
- the concerns and issues that need to be addressed
- gaps in information and understanding that need to be dealt with
- new options not previously considered that may have merit.

Where residents feel they have been heard and their concerns acknowledged, they are more likely to support the plans and responses that come out of the process. Engagement and communication also enhance the community's ability to adapt by enabling them to make informed choices about where and what to invest in. Public participation processes can help people better understand the sometimes conflicting views of groups within the community. Part of the engagement should be communicating about how conflicting interests will be managed and decisions and policies determined.

Source: LGAQ 2014 (*Coastal Hazard Adaptation Communication Guidelines*).

The *Communication guidelines* set out 10 key elements of a comprehensive communications plan:

- Strategic context
 - agree on council's role and commitment
 - clarity about scope and objectives
 - understand the context, risks and priority.
- Core elements
 - establish a spokesperson or representative
 - establish clear, agreed communication principles
 - address conflict or different priorities and values.

- The details
 - define target audiences and key messages
 - general messages and message by stage
 - identify communication instruments and their use
 - timeframes and resourcing.

There are many techniques and approaches available to councils to engage with a range of stakeholders. A number of different tools should be employed to reach a wide audience. The Queensland government's *Engaging Queenslanders: A guide to community engagement methods and techniques* (2016) provides information on various tools for community engagement and may be useful for councils with limited engagement experience.

Table 1 summarises the suggested level of engagement and the possible techniques that may be employed in each of the CHAS Phases.

Table 1. Suggested level of engagement in each phase of the CHAS

CHAS Phase	Description	Consultation type and possible techniques
1. Plan for life-of-project stakeholder communication and engagement	Identify relevant internal and external stakeholders	Brainstorming/discussion with internal stakeholders, review of previous studies
2. Scope coastal hazard issues for the area of interest	Key stakeholders should be consulted to assist in the identification of coastal hazards and their potential impacts	Review of previous studies, direct engagement with key stakeholders, project reference group, on-line survey/tool, social media campaign
3. Identify areas exposed to current and future coastal hazards	Stakeholders and technical experts may be consulted for the validation of identified hazard areas	Direct engagement with key stakeholders and technical experts, workshop, project reference group
4. Identify key assets potentially impacted	Internal and external stakeholders should be consulted or actively engaged to assist in this phase	Direct engagement with asset owners, project reference group, community consultation (website, online surveys/tools, mail outs)
5. Undertake a risk assessment of key assets in coastal hazard areas	Internal and external stakeholders may be consulted for the identification and validation of vulnerabilities, consequences, losses and risks	Internal questions/discussion, workshop with key stakeholders, project reference group
6. Identify potential adaptation options	Internal and external stakeholders should be involved in the identification of options. The broader community should be informed and engaged in the consideration of options	Stakeholder workshop, community consultation (project reference group), website, online surveys/tools, information sheets, mail outs to those directly impacted
7. Undertake a socio-economic appraisal of adaptation options	Internal stakeholders must be involved in the selection and scoring of values for a multi-criteria assessment	Internal workshop involving key stakeholders and technical experts, online survey/tool, project reference group
8. Strategy development, implementation and review	Internal and key stakeholders should be informed and asked for feedback	Direct engagement with key stakeholders, online access to draft strategy for a minimum period of 28 days, targeted consultation with potentially affected communities (e.g. information sessions, newsletters, fact sheets)

The following provides some further guidance on consultation techniques that can be used to engage with stakeholders in an effective way:

- **Snowballing techniques** (Areizaga *et al.* 2012): or **social network analysis** (Markantonatou *et al.* 2015) can be used to identify key stakeholders and understand their relationships. They are effective in reducing the risks of poor stakeholder identification and in describing relationships and roles.
- **Online tools** (White *et al.* 2010, Almoradie 2014, Evers *et al.* 2016) provide a mechanism for collecting data and information from key stakeholders. Numerous tools are available for different situations. In particular, they can be effective in collecting data from remote stakeholders.
- **Geographical Information Systems (GIS):** Graphical outputs, such as layers, can be used to collect spatial data from stakeholders (e.g. known hazards, past event experiences or key assets relevant to a particular location).
- **Project Reference Groups (PRG):** (Cox *et al.* 2013) may be created and consulted throughout the project. This may include local government and community representatives, academics or consultants. The role of the PRG should be to periodically meet and have input into technical outputs of the project. Terms of Reference (TOR) may be prepared to engage the PRG throughout the duration of the project.

- **Participatory stakeholder workshops:** (Ross *et al.* 2015, Richards *et al.* 2015, Smith *et al.* 2014) can be used to identify or prioritise coastal hazards and adaptation options. They can be employed to identify, map and understand co-dependency between coastal hazards, assets and adaptation responses.
- **Deliberative engagement techniques:** (Kenyon 2007, Victoria Government 2010) are a process where stakeholders can actively contribute and deliberate in an engagement process. In particular, Kenyon (2007) describes effective methods of deliberation in multi-criteria assessments of adaptation options (e.g. flood walls, flood warnings, wetland creation etc.), including the identification of participants, and the identification, weighting and scoring of criteria.

The following additional references provide useful background information on relevant concepts for effective stakeholder engagement:

- Adger (2010) provides an insight into the concept and use of social capital in public participation, where social capital refers to the value of all social networks. His analysis can be useful to improve the quality of the stakeholder engagement.
- Barnett *et al.* (2014) explores the legal, institutional and cultural barriers to adaptation in Australia, with examples of public engagement and perceptions at the local government level. The study covers a number of examples in Australia, concluding that there are five key barriers to adaptation: governance, policy, uncertainty, resources, and psychosocial factors.



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PHASE 2. Scoping coastal hazard issues for the area of interest

2.2.1 Purpose of this phase

The primary purpose of this phase is to define the scope of a future CHAS. By undertaking a scoping study, a solid foundation and framework for future phases will be set. A well-developed study should also assist in gaining buy-in from senior officers and executives across council departments to proceed to the next phases of a CHAS.

The objectives of this phase include:

- identifying and collating existing information available to inform a CHAS, and determining whether it sufficiently meets the requirements of this guideline
- determining further studies or investigations required to inform a CHAS
- understanding and addressing barriers to preparing and implementing a CHAS
- gaining support for a CHAS from decision-makers and executives
- establishing the parameters of a CHAS e.g. purpose, timing, resources, depth of investigations.

The outcomes of this phase are to be documented in a scoping study.

2.2.2 Minimum requirements

As a minimum, a scoping study is to be prepared in this phase and must:

1. Identify existing information that may inform the development of a CHAS:
 - collate existing information from across the organisation and other external sources e.g. coastal modelling, hazard mapping, shoreline management plans, asset management plans, evaluation of past coastal management activities
 - identify relevant council instruments (policies, strategies, operating procedures or plans).
2. Analyse the information gathered, to determine whether further investigations are required to meet the requirements of this guideline
3. Identify the timescales and planning horizons which the CHAS is to address (refer to the Introduction of this document for further guidance)

4. Estimate the internal and external resource requirements of the project e.g. hours, timing, costs, resources and responsibilities to support each phase of the project
5. Prepare a scoping study report that addresses:
 - decision-making needs of each relevant council department e.g. what is the physical impact on an asset? When should an asset be upgraded? Which species are more vulnerable to sea level rise?
 - known coastal hazard issues, including future hazards, and the localities potentially affected
 - a broad description of assets (tangible and intangible) of potentially affected assets (both council and non-council). A list of the types of assets to consider, including tangible and intangible assets, is included in Annex III
 - the risks and benefits to council of preparing a CHAS
 - information gaps and how these are to be addressed
 - integration of a CHAS with other council instruments and processes
 - barriers to the commencement or implementation of a CHAS (e.g. demonstrating need, data uncertainties, budgetary constraints, resource and capability gaps, and how they may be overcome
 - key objectives and desired outcomes of a CHAS
 - governance structures for the next phases of a CHAS i.e. communication protocols, responsibilities, reporting etc.

A 'fit for purpose' and 'value for money' approach should be taken and information needs prioritised accordingly. For example, consider whether seeking high-resolution data is justified for the magnitude of decisions that need to be made.

2.2.3 Leading practice

A scoping study should consider the following steps:

1. Prepare a preliminary list of potential coastal hazard impacts on tangible and intangible council and non-council assets (key assets will be further analysed in Phase 4) including:
 - population at risk
 - anticipated population expansion in coastal hazard areas

- areas allocated for, or likely to be allocated for urban expansion in coastal hazard areas
- critical community infrastructure and services i.e. water, sewerage, roads, telecommunications etc.
- industry or private infrastructure
- agricultural land and enterprises
- tourism or commercial enterprises dependent on current coastal form/amenity e.g. if the beach is a key driver of tourism, is there a potential impact in terms of tourism dollars and job losses?
- cultural heritage and traditional owner uses, values and sites
- ecology and biodiversity values (RAMSAR sites, Matters of National, State or Local Environmental Significance as declared in relevant legislation or planning schemes, remnant vegetation etc.)
- biosecurity risks and threats
- community values e.g. recreational opportunities or amenity)
- coastal hazard impacts on complex coastal landforms e.g. river mouths and low delta plains

Examples of scoping studies are provided in the further reading material below and include Rollason *et al* (2010), McDonald *et al* (2010), State of California (2012), Local Government Association of South Australia (20102), Western Australia Department of Planning (2014) and Gibbs (2015).

2. Describe the potential vulnerability and resilience of an asset and/or the community to a coastal hazard(s).
3. Identify owners of non-council assets and other relevant stakeholders, including potential CHAS partners and community networks
4. Prepare a business case for development of a CHAS or elements of a CHAS, if required by internal council processes.
5. Identify knowledge and information gaps and seek input from critical stakeholders to address these gaps before engaging further studies.

The decision to include these leading practice items in the scoping study will depend on the funding available to collect, collate and document the finer scale information. The need to do so will also depend on the level of resolution of a CHAS in terms of assets at risk.

2.2.4 References and further reading material

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State of California (2012) California climate adaptation planning guide [http://resources.ca.gov/climate/safeguarding/adaptation_policy_guide/](http://resources.ca.gov/climate/safeguarding/adaptation_policy_guide/http://resources.ca.gov/climate/safeguarding/adaptation_policy_guide/)

PHASE 3. Identify areas exposed to current and future coastal hazards

2.3.1 Purpose of this phase

Modelling of storm tide, coastal erosion and permanent inundation from sea level rise is used to delineate the areas exposed to coastal hazards and the scale of the exposure. This information is then used to identify exposed tangible and intangible assets (Phase 4) and the risk they may be subject to (Phase 5). This will also assist in the conceptual design of adaptation options. In this phase, the type of modelling information required will depend on the complexity and scale of the potential problem as identified in Phase 2.

As described in the Coastal Hazard Technical Guideline Determining Coastal Hazard Areas (DEHP 2013) (the Guide), the implications of climate change-induced sea level rise and the potential increase in tropical cyclone intensity for Queensland's coast include a progressive worsening of coastal hazards, including:

Coastal erosion:

- Increased water levels will accelerate coastal erosion
- Sediment transport patterns may be altered by shifts in wave direction triggering changes to the form and location of shorelines
- Low-lying land may be permanently inundated
- Increased cyclone and storm activity will escalate the severity of coastal erosion events.

Storm tide inundation:

- Sea level rise will increase the apparent severity and frequency of storm tide inundation and will cause inundation to occur further inland
- Increased cyclone and storm intensity will add to the magnitude of storm tide events and the extent of inundation.

Figure 3 provides an illustration of the concepts outlined above.

Key terms

Erosion Prone Area: Statutory erosion prone areas are declared under the *Coastal Protection and Management Act 1995*, and are areas subject to coastal erosion or tidal inundation.

Storm Tide: The effect on coastal water of a storm surge, combined with the normally occurring astronomical tide.

Storm Tide Inundation Area: The area of land determined to be at risk from inundation associated with a storm tide.

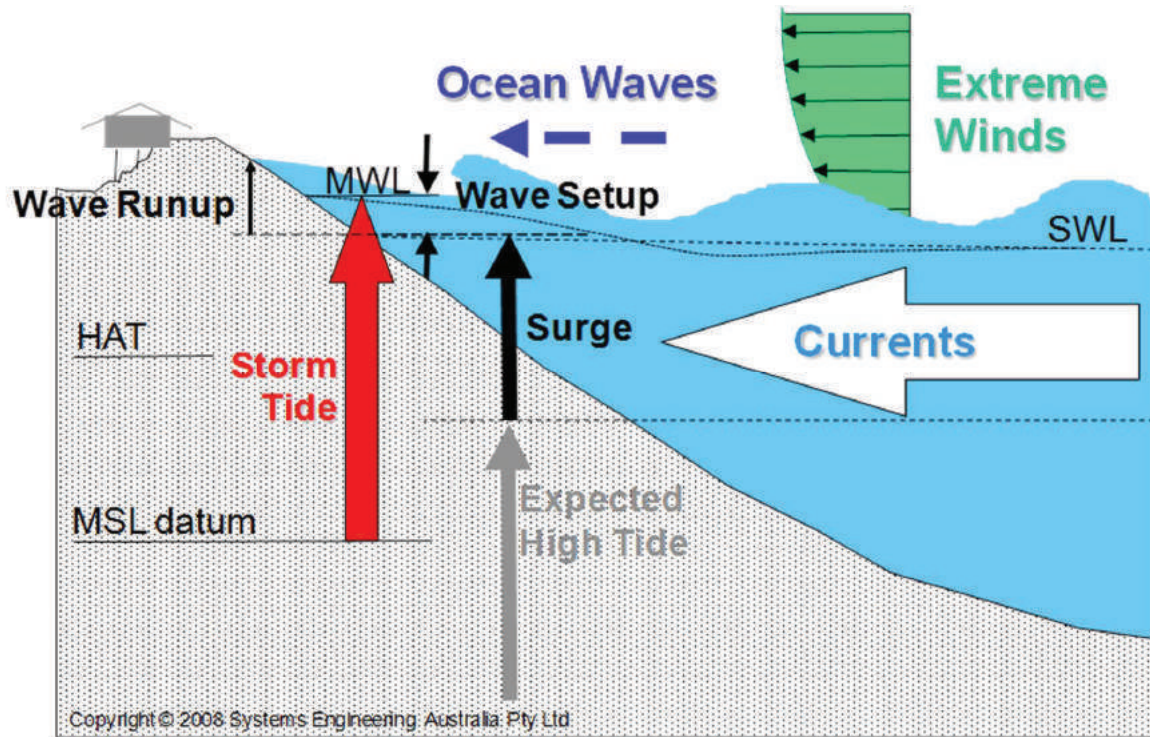
2.3.2 Minimum requirements

The Queensland Government provides coastal hazard areas maps for projected conditions in 2100 (<http://www.ehp.qld.gov.au/coastalplan/coastalhazardareas.html>) to establish coastal hazard areas. These use default storm tide levels of 1.5 m above Highest Astronomical Tide (HAT) for south east Queensland, and 2.0 m above HAT for the rest of Queensland. The scoping study (Phase 2) should determine whether this mapping is sufficient, or whether more detailed mapping is required. The methods described in the *Guide* are to be used to calculate the extent of storm tide inundation, and Erosion Prone Areas (EPAs) including permanent inundation due to sea level rise.

EPAs are determined using methodologies set out in the *Guide*, combining short-term erosion due to storm wave action, longer-term erosion due to variability and trends in coastal processes, shoreline recession due to sea level rise and other site-specific factors.

Storm Tide Inundation Area (STIAs) are typically defined for a range of Annual Exceedance Probability (AEP) water levels. Throughout Queensland, the inundation associated with the 1% AEP water level is often adopted for planning purposes.

Figure 3. Illustration of a storm tide event



Source: NDRP Storm Tide Hazard Interpolation Study, 2014.

If councils are preparing a location specific storm tide study, it should determine storm tide statistics at the coastline, involving analyses of tropical cyclone and other non-cyclonic weather events (e.g. east coast lows), climatology and numerical modelling of tides, storm surge and wind waves. Climate change scenarios, include sea level rise projections, and may consider changes to climatology such as an increase to storm intensity. Upon completion of a storm tide study, an inundation study should be conducted, based on the storm tide level at the coastline. This is then to be mapped, dividing the storm tide inundation area into two zones:

- High hazard area - areas where the inundation depth is more than one metre (>1 m)
- Medium hazard area—areas where the inundation depth is less than one metre (=<1 m)

The influence of wave setup and run-up on the extreme water level is not considered in the Queensland Government's storm tide inundation mapping. These processes can be significant on open coast beaches and may influence the inundation hazard for some coastal communities. For basic assessments, the influence of wave processes on the extreme water level may be accounted for though an appropriate freeboard allowance. More detailed, site-specific assessments typically use a combination of spectral wave model output and empirical methods (e.g. Neilsen and Hanslow, 1991; Hanslow and Neilsen, 1993; Stockdon *et al.* 2006) to estimate wave setup and run-up potentials.

All councils should interpret the precision of hazard delineation in the context of local conditions such as topography, existing coastal hazard management strategies, and the uncertainty of the assessments.

More detailed modelling and coastal hazard assessment methods are described in section 2.3.3 below. These approaches should yield more accurate coastal hazard definitions and provide additional hazard metrics (such as the inundation flow velocity) which will improve the subsequent coastal hazard risk assessment process that is described in Phase 5.

2.3.3 Leading practice

Coastal erosion and inundation processes are complex and vary for different Queensland locations. To improve the risk assessment process described in Phase 5, councils should consider exploring multiple scenarios over a variety of planning horizons (e.g. 2030 or 2050) or hazard events. Adopting a multiple outcome approach will allow councils more flexibility when determining adaptation options and implementation timeframes. This approach should be adopted where critical infrastructure or highly valued natural and cultural values are at risk.

The *Guide* sets out the recommended AEP for such vulnerable land uses. In the case of critical infrastructure or high risk of socio-economic disruption, council may choose to estimate hazards for events rarer than the nominal 1% AEP (100 year ARI). These may include for instance, events with a lower probability of occurrence (e.g. 0.5% and 0.2% AEP, respectively representing events with 200 and 500 year ARI).

In addition, considering that numerous assets are likely to be in place and retrofitted over decades and sometimes centuries, progressive hazard assessments for a number of planning horizons may be required (e.g. 2040, 2070 and 2100). An AEP (probability of occurrence) should not be confused with the 'planning horizon', which is the period being planned for.

In establishing EPAs, a variety of modelling techniques have been developed for determining the various components of the assessment. An overview of leading practice model capability for determining shoreline erosion is provided in Mariani *et al* (2012) and Woodroffe *et al* (2012).

- For short-term storm erosion rates, leading approaches include:
 - process-based models such as X-Beach (Roelvink *et al*, 2009) - most commonly used
 - parametric equilibrium shoreline evolution models (Rollason *et al* 2010) for short-term (storm erosion) and long-term combined alongshore and cross shore erosion impacts.
- For long-term erosion rates, the empirical sediment budget or historical trend analyses recommended in the *Guide* are the preferred approaches, however, shoreline evolution models (if calibrated) may provide suitable rates
- For erosion due to sea-level rise alternatives to the Bruun Rule minimum standard include:
 - Shoreface Translation Model (Cowell *et al* 1995)
 - Probabilistic Coastal Response Model (PCR) (Woodroffe *et al* 2012).

However, in practice, the applicability of these models depends on the availability of calibration data. For example, studies show that incorporation of sediment budgets are critical in the long-term prediction of shoreline change and are more significant than sea level induced changes. Without site-specific profile and sediment process data, sea-level rise erosion techniques either reduce back to basic Bruun rule formulations or in the case of PCR, are impractical to apply.

For STIAs, leading practice guidance on modelling of storm surge water levels, wave setup and wave run-up has been provided by the Queensland Government (DRNM 2001, "Blue Book"). The methodology involves the development of numerical coastal models capable of simulating tides, storm surge and wave action due to tropical cyclones and other non-cyclonic weather events (such as East Coast Lows), and adopts statistical methods to define design water levels and wave height. GHD (2014) provides a review of previous storm tide studies completed throughout Queensland.

Guidelines to model and map complicated inundation processes in a reasonable manner are provided by Lee *et al* (2013). These guidelines include a description of available numerical modelling techniques and their strength and limitations. A ranking of modelling techniques from zero-dimensional (bathtub) to three-dimensional hydrodynamic modelling is provided in Annex IV Table 10, along with a summary of their weaknesses and capabilities in Table 11).

In some cases, special consideration should be paid to the hazard of overtopping and flooding in terms of tolerable "depth x velocity" for people, vehicles and structures. For example, $D \times V > 1 \text{ m}^2\text{s}^{-1}$ poses a significant threat to adults, while $D \times V > 2 \text{ m}^2\text{s}^{-1}$ poses a significant threat to buildings and infrastructure.

Guidelines for determining flood hazard include:

- Australian Government (2014). Managing the floodplain: a guide to best practice in flood risk management in Australia (commonly referred to as 'Handbook 7'): <https://www.aidr.org.au/media/1410/handbook-7-managing-the-floodplain-a-guide-to-best-practice-in-flood-risk-management-in-australia.pdf>
- Queensland Department of Natural Resources and Mines (2016). Guide for Flood Studies and Mapping Queensland: https://www.dnrm.qld.gov.au/__data/assets/pdf_file/0010/332695/guide-flood-studies-mapping-qld.pdf

Leading practice methods for determining wave overtopping at coastal structures are described in the EurOtop Manual (2007): <http://www.overtopping-manual.com/eurotop.pdf>

It is important to note that to improve the detail of the risk assessment (Phase 5), the identification of more detailed inundation scenarios will be required, including the creation of a scale for the probability of occurrence for each scenario. See Rollason *et al* (2010) and Phase 5 for more details on how to create probability scales.

Figure 4 provides a guide for selecting the most appropriate coastal hazard model. Annexes III and IV provide information on selecting a model.

2.3.4 References and further reading material

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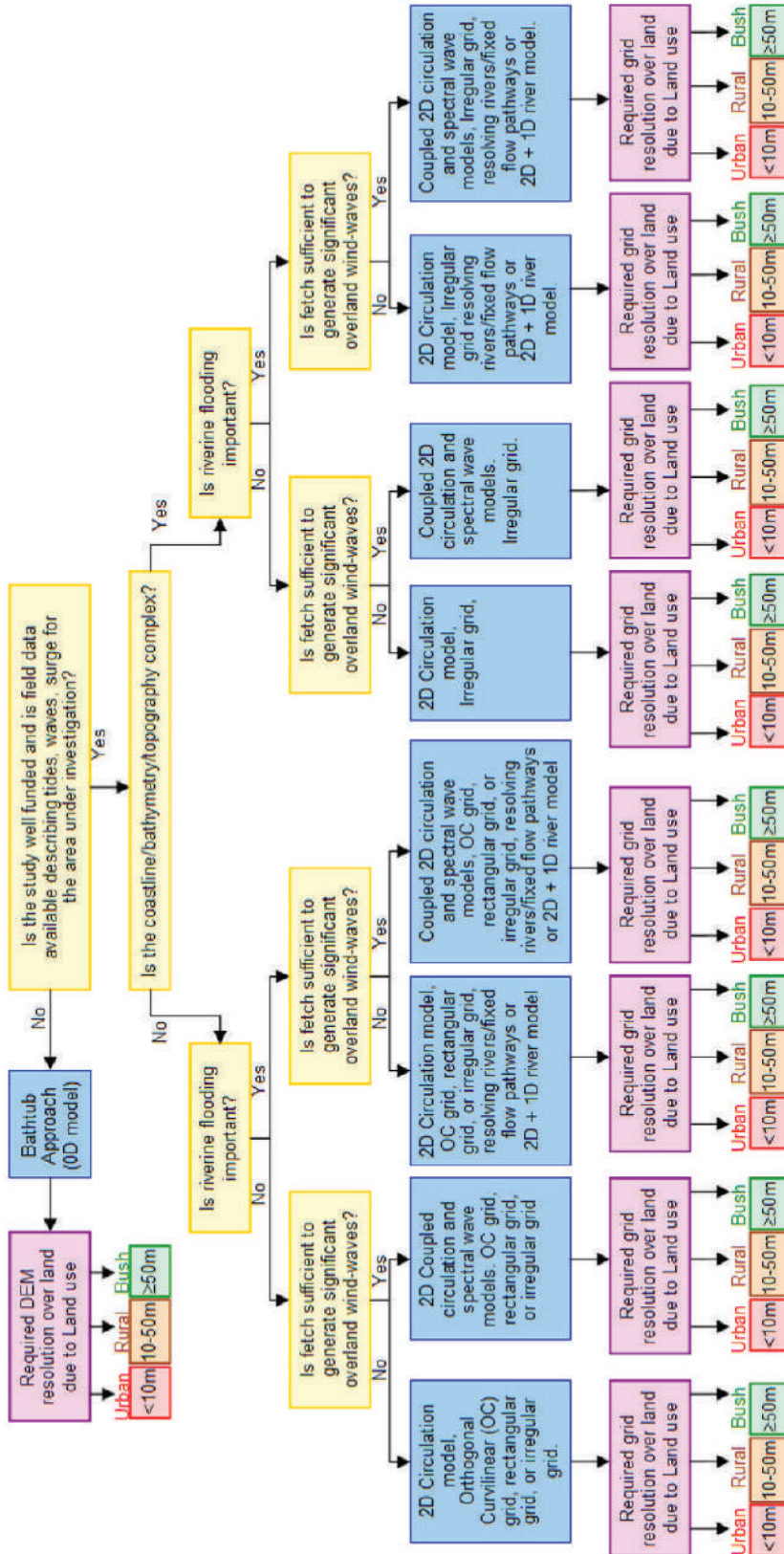
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Figure 4. Model selection flow chart



Source: Lee et al 2013, Fig.5.

PHASE 4. Identify key assets potentially impacted

2.4.1 Purpose of this phase

The purpose of this phase is to identify **key built, community or natural assets** which can be directly or indirectly impacted by coastal hazards now or in the future. These should be classified as tangible and intangible assets and may include buildings, coastal infrastructure, services, coastal parklands or reserves, community infrastructure or environmentally or culturally sensitive areas that are located in hazard areas identified in Phase 3.

Future assets should be included if planned or predicted with a significant degree of confidence (e.g. included in a future land use plan or infrastructure plan). It is important to acquire appropriate levels of data to adequately inform the next phase, in particular data related with the asset value which will be used in the risk assessment (Phase 5) and the socio-economic appraisal (Phase 7).

The objectives of this phase include:

- identifying and mapping assets within the coastal hazard area that will form part of a CHAS
- identifying and understanding potential impacts to other interdependent infrastructure
- determining the value of an asset
- prioritising key assets for further evaluation.

2.4.2 Minimum requirements

Assets broadly identified in Phase 2 are to be examined in more detail to gain an understanding of their value and vulnerability to coastal hazards. Tasks to be included are:

1. Mapping assets exposed to coastal hazards using spatial analyses (e.g. overlay assets mapping with coastal hazard mapping layers). As a starting point, the Queensland government provides mapping of some physical and natural assets, via its Development Assessment mapping system, available at: <http://www.dilgp.qld.gov.au/about-planning/da-mapping-system.html>

2. Identifying owners of significant built, community or natural assets within the coastal hazard area, and determining their level of involvement in a CHAS. Some key assets (e.g. airports, ports) may be privately owned or managed by a dedicated entity (e.g. Great Barrier Reef Marine Park)
3. Engaging with internal and external stakeholders in the identification of assets within the coastal hazard area, as well as other interdependent assets. As an example, the loss of an electricity substation within a coastal hazard area may affect the ability of a hospital located outside of the coastal hazard area to function effectively
4. Estimating the value of identified assets to prioritise key assets. Prioritising assets may assist councils with limited resources by constraining the focus of a CHAS to key coastal assets or values. As well as monetary value, councils should also consider non-monetary values such as cultural importance or ecological significance. Dassanyake *et al.* 2015 provides some further guidance on non-monetary valuation techniques and Costanza *et al.* 2014 or Marre *et al.* 2015 provide techniques for ecosystem valuation. NCCARF has also provided a discussion paper on valuing natural and built coastal assets (Kirkpatrick, 2011)
5. Agreeing on a list of priority assets for further consideration
6. Identifying potential impacts or risks to priority assets e.g. permanent inundation, loss of function temporarily during an event etc.

A list of the types of assets to consider, including tangible and intangible assets, is included in Annex III. Councils should also consider defined *essential community service infrastructure*, as provided in the State Development Assessment Provisions, when evaluating asset importance.

2.4.3 Leading practice

Wherever possible, all relevant data available on an asset should be collated. This may include its locality, a description of its key components, value, maintenance requirements, design life etc. to inform an assessment of potential risks in Phase 5. The value of an asset can be assessed in many ways.

Asset prioritisation

A first pass, qualitative evaluation of assets may help identify those which are key to council, government or the broader community. Internal and external stakeholders should be engaged to identify key assets within the coastal hazard area or those assets which may be indirectly impacted through an interdependency on a coastal asset. Hanis *et al.* (2014) provides an overview of the importance of effective asset identification, a range of approaches and data requirements.

A leading practice for prioritisation of key assets is to employ a semi-quantitative multi-criteria approach based on relevance criteria (Johnston *et al.* 2014).

This approach is effective in benchmarking assets against sets of criteria such as value, jurisdiction, relevance to key stakeholders or relevance within the broader coastal system. The limitations of this approach include the need to develop criteria and assess all assets against these to identify those that are key to a coastal community.

Key assets can also be determined by using a systems approach, where interactions between assets can be mapped (see Sanò *et al.* 2012 and Keys *et al.* 2014 for practical advice on how this can be applied to Queensland).

This approach allows assets, relationships and interdependencies to be identified and can be carried out by the project team or, for a more comprehensive assessment, in a stakeholder workshop. The analysis of interdependencies can help to identify critical or essential assets.

Limitations are mainly related to the extent these techniques capture and model the real world and the ability of the team or stakeholders in effectively capturing relevant assets and relationships.

Asset valuation

The monetary and non-monetary valuation of assets is an important step in the assessment of the risk (Phase 5) and of the benefits of adaptation options to mitigate the risk (Phase 6 and 7). State of the art processes for integrating asset valuation, risk assessment and mitigation are described in Jonkman *et al.* (2008), Penning *et al.* (2014) and Dassanyake *et al.* (2015).

It is common to combine a risk assessment with a vulnerability assessment approach when determining coastal hazard or climate change related risks. In particular, a vulnerability assessment is useful for addressing the social and economic aspects of the coastal community (e.g. social vulnerability), where consequences to the community (damage) can be modulated by their capacity to adapt.

Vulnerability assessments

A vulnerability assessment can provide additional information on the susceptibility of the asset to a coastal hazard and is commonly undertaken prior to a risk assessment (refer to Phase 5). IPCC (2014) defines vulnerability as *the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes*. It is generally applied to coastal hazard studies at a broader spatial scale, or applied to a class of assets or a defined spatial area e.g. a catchment area.

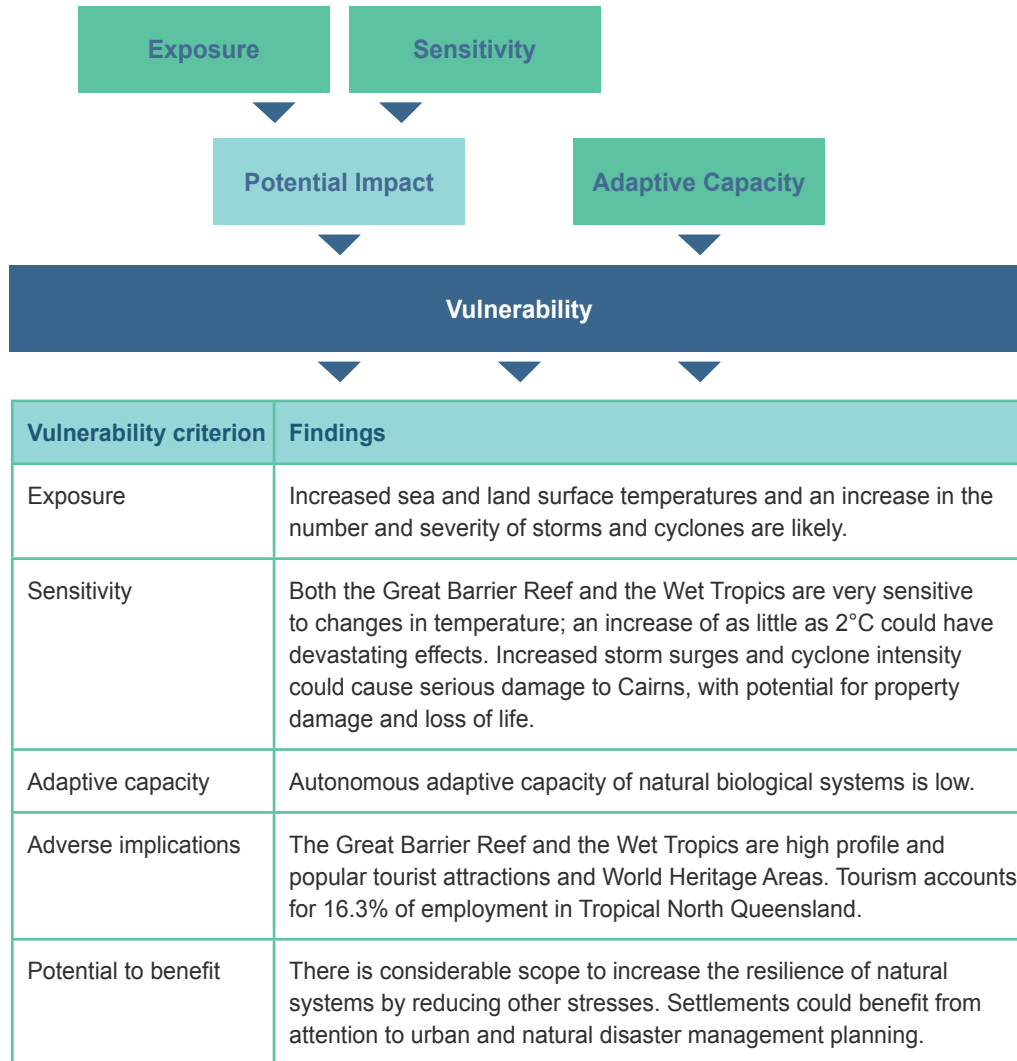
There are many methods of undertaking a vulnerability assessment, with varying levels of complexity, however the *South Australian guidelines for developing a climate change adaptation plan and undertaking an integrated climate change vulnerability assessment* (Local Government Association of South Australia) and the *New South Wales guide to integrated regional vulnerability assessment (IRVA) for climate change* (NSW Office of Environment and Heritage 2013) are useful guides.

Vulnerability can be expressed as a function of three overlapping elements: exposure (equivalent to likelihood), sensitivity (equivalent to consequence) and adaptive capacity. Potential impacts are a function of exposure and sensitivity, while vulnerability is a function of potential impacts and adaptive capacity (i.e. ability to change in a way that enables the asset to 'adapt' to climate change). Understanding vulnerability may assist with identifying threats, opportunities and potential management and adaptation. **Figure 5** provides an example vulnerability assessment, performed as part of a climate change vulnerability assessment for the Great Barrier Reef (GRMPA 2007). This diagram is an example only, is high level and presented at a regional scale (not an asset scale), however it does provide a useful illustration of the concepts associated with a vulnerability assessment.

The estimation of the level of exposure is strictly related to the asset location within the coastal hazard area, and its sensitivity determines the level of possible impact i.e. how the asset is likely to be affected by its exposure.

Adaptive capacity refers to the ability of the asset or service to respond to the impact through changes in behaviour or emergency management, for example.

Figure 5. Example high-level vulnerability assessment



Source: GBRMPA, 2007 (*Climate change and the Great Barrier Reef: a vulnerability assessment*).

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PHASE 5. Risk assessment of key assets in coastal hazard areas

2.5.1 Purpose of this phase

The purpose of this phase is to estimate the level of risk posed to key assets or locations identified in Phase 4 from coastal hazards. A risk assessment should set the foundation for prioritising key localities or assets for further consideration. The assessment is to be applied to both key assets found within the coastal hazard area and those which might be indirectly influenced by coastal hazards.

Seeking input from a broad range of participants and disciplines will be key to the risk assessment process. A CHAS should also consider likely regional trends in land uses, industries and population fluxuations when identifying risks.

The objectives of this phase include:

- determining the most appropriate and effective risk assessment process for identified key assets
- undertaking a risk assessment of impacts to assets from coastal hazards
- identifying intolerable risks that require further action.

2.5.2 Minimum requirements

As a minimum, a risk assessment is to be carried out for each key asset or group of assets identified in Phase 4, using the management framework in the *Australian standard for risk management AS/NZS ISO 31000:2009*. The standard provides a methodology for identifying risks across a broad range of industries and organisations, but is not specific to coastal hazards. The risk management framework establishes a four (4) step process to risk assessment, as follows:

1. risk identification
2. risk analysis
3. risk evaluation
4. risk treatment.

In accordance with AS/NZS ISO 31000:2009, risk is defined as the combination of likelihood of occurrence of an event and the consequence if the event occurs. Councils may make use of internal risk assessment processes provided they are consistent with the risk management framework in the Australian Standard.

Risk = Likelihood x Consequences

Likelihood

The likelihood of occurrence of a risk should be linked with the coastal hazard levels identified in Phase 3 i.e. High or Medium Hazard Area. The Australian Standard suggests that the probability of an event should include the following levels: almost certain, likely, possible, unlikely, and rare. As well as the likelihood of the hazard occurring, a risk assessment should also consider the likelihood of a subsequent impact occurring as a result of the event e.g. the likelihood of a seawall being damaged by a coastal hazard event. Councils may wish to consider the possible timing of an event and when it is most likely to occur.

Consequence

The consequences of the event should be based on a 'risk consequence' scale that should be used to assign a 'consequence level' to different coastal hazards. An example of such a table is shown in [Table 2](#), however there are many other consequence scales that could be utilised, including those in *AS5334-2013 Climate change adaptation for settlements and infrastructure: a risk-based approach* (2013). Council should determine which consequence scale is most appropriate for the assets being evaluated and the scale of coastal hazard. Ideally, consequences should at least include potential governance, economic, environmental and social considerations.

Table 2. Example consequence table

Consequence	Economic	Social	Environmental
Catastrophic	Widespread major damage or loss of property or infrastructure with total value >\$20 million. Regional economic decline, widespread business failure and impacts on state economy.	Widespread semi-permanent impact (~1year) to highly utilised community services, wellbeing, or culture of the community with no suitable alternatives. Loss of lives and/or permanent disabilities.	Severe and widespread, permanent impact on multiple regionally or nationally significant ecosystem services. Recovery unlikely.
Major	Major damage or loss of property or infrastructure with total value ~\$5 million. Lasting downturn of local economy with isolated business failures and major impacts on regional economy.	Major widespread long-term (~1 month) disruption to well-utilised services, wellbeing, or culture of the community with very few alternatives available. Widespread series injuries/ illnesses.	Severe and widespread semi-permanent impact on one or more regionally or nationally significant ecosystem services. Partial recovery may take many years.
Moderate	Major damage to property or infrastructure with total value ~\$1 million. Significant impacts on local economy and minor impacts on regional economy.	Minor medium-to long-term (~1 week) or major short-term disruption to moderately utilised services, wellbeing, or culture of the community with limited alternatives. Isolated series injuries/ illnesses and/or multiple minor injuries/ illnesses.	Substantial impact on one or more locally significant ecosystem services. Full recovery may take several years.
Minor	Substantial damage to properties or infrastructure with total value ~\$200,000. Individually significant but isolated impacts on local economy.	Small to medium short-term disruption (~1 day) to moderately utilised services, wellbeing, finances, or culture of the community with some alternatives available, or more lengthy disruption of infrequently utilised services. Minor and isolated injuries and illnesses.	Small, contained and reversible short-term impact on isolated ecosystem services. Full recovery may take less than 1 year.
Insignificant	Minor damage to properties or infrastructure with total value ~\$50,000. Minor short-term impact on local economy.	Very small short term disruption (~1 hour) to services, wellbeing, finances, or culture of the community with numerous alternatives available. Negligible injuries or illnesses.	Little to no environmental impact.

Risk Categorisation

The assessment of risk needs to be carried out using a risk matrix such as the following in **Table 3** (Rollason *et al.* 2010, Department of Planning 2014). Risk tolerance is based on what ‘society would reasonably accept, tolerate or find intolerable’ rather than what today’s community may think, unless the risk is almost certain within their lifetime.

Risks should then be further categorised into Unacceptable, Tolerable or Acceptable risks, in accordance with the *SPP – state interest guideline: natural hazards, risk and resilience* (April 2014):

Acceptable Risk: a risk that, following an understanding of the likelihood and consequences, is sufficiently low to require no new treatments or actions to reduce the risk further. Individuals and society can live with this risk without feeling the necessity to reduce the risks any further.

Tolerable Risk: a risk that, following an understanding of the likelihood and consequences, is low enough to allow the exposure to continue, and at the same time high enough to require new treatments or actions to reduce the risk. Society can live with this risk but believe that as much as is reasonably practical should be done to reduce the risks further

Intolerable Risk: a risk that, following an understanding of the likelihood and consequences, is so high that it requires actions to avoid or reduce the risk.

A risk tolerance scale (Western Australia Department of Planning 2014) as illustrated in **Table 4**, describing situations where the risk is unacceptable, tolerable, or acceptable must be developed to inform the identification of adaptation options (Phase 6).

Table 3. Example likelihood and consequence matrix to assess the level of risk.

		Consequence				
		Insignificant	Minor	Moderate	Major	Catastrophic
Likelihood	Almost Certain	Low	Medium	High	Extreme	Extreme
	Likely	Low	Medium	High	Extreme	Extreme
	Possible	Low	Medium	High	High	Extreme
	Unlikely	Low	Medium	Medium	High	Extreme
	Rare	Low	Low	Medium	Medium	High

Source: Australian Standard AS 5334-2013: *Climate change adaptation for settlements and infrastructure*, 2013.

Table 4. Example of risk tolerance scale

Risk level	Action required	Acceptance/tolerance
Extreme	Immediate action required or reduce risk to acceptable levels	Unacceptable/intolerable
High	Immediate to short-term action required to eliminate or reduce risk to acceptable levels	Tolerable
Medium	Short to medium term action to reduce risk to acceptable levels	Tolerable/Acceptable
Low	Accept risk	Acceptable

Source: *Coastal hazard risk management and adaptation planning guidelines*, 2014.

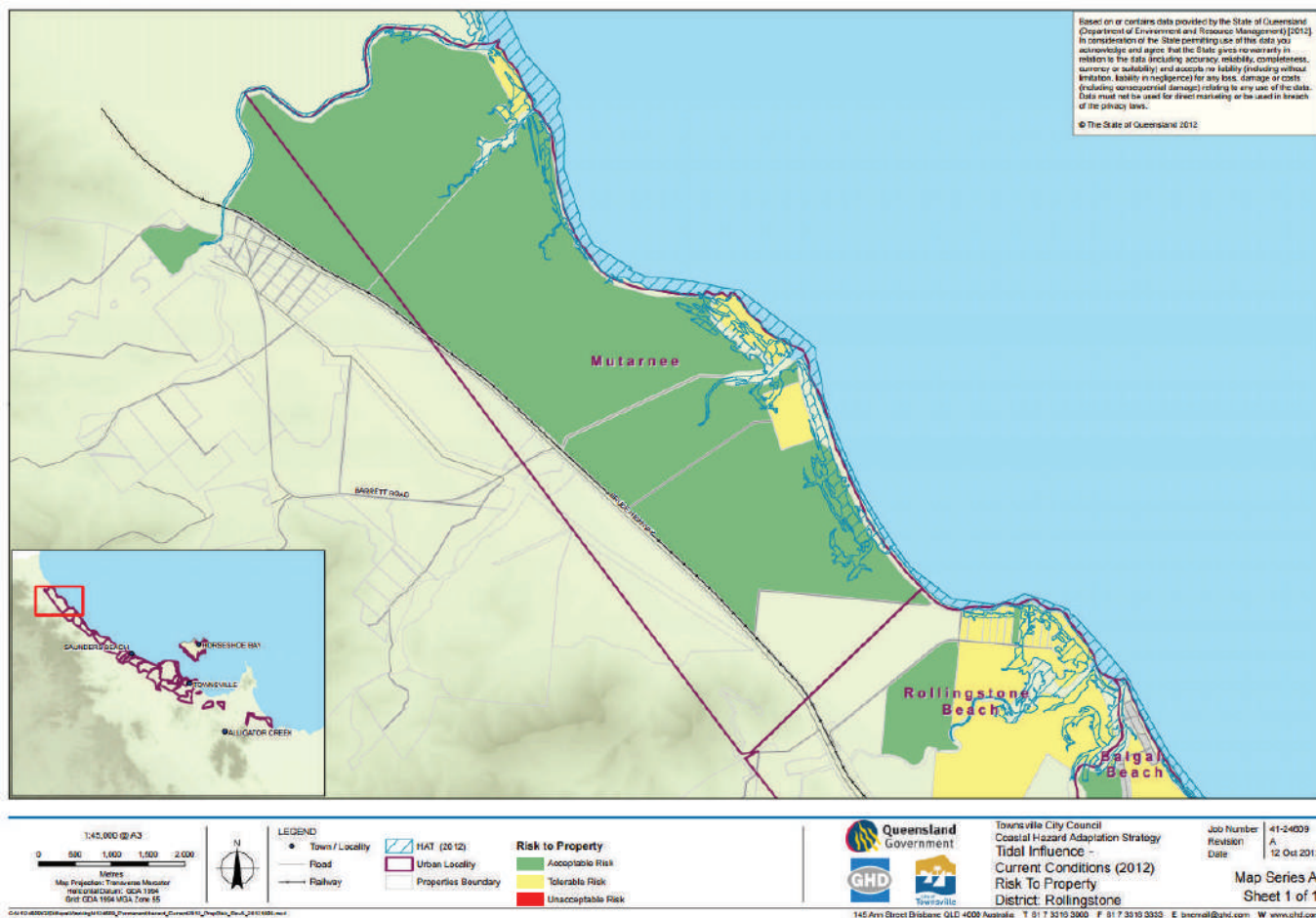
Management measures

The preliminary risk level assigned to an asset or impact can then be reassessed to consider the effectiveness of existing management or other controls to reduce a risk, providing a final risk score.

GIS mapping

The coastal hazard risk is to be mapped and presented spatially, to assist communication and consultation both internally and externally. For example, the Townsville CHAS mapped acceptable, tolerable and intolerable risks to property, as shown in **Figure 6**.

Figure 6. Townsville CHAS risk mapping, identifying acceptable, tolerable and unacceptable risk to property



Source: GHD, 2012.

2.5.3 Leading practice

Councils may consider it sufficient to assess the risk following the minimum standards for risk assessment, however in most cases a more detailed likelihood or consequence scale will be necessary to more accurately assess the level of risk.

Improvements to the estimation of likelihood and consequence scales

The estimate of likelihood of an event occurring can be improved by identifying coastal hazard lines for different levels of probability, as shown in **Table 5** (Rollason *et al.*, 2010). For instance, the AEP can be associated with the coastal hazard line scale as follows, noting that the AEP will increase under different sea level rise scenarios (Hunter 2010).

Table 5. Likelihood of occurrence and relationship to hazard line AEP

Likelihood of Occurrence	Hazard line AEP
Almost certain	10%
Likely	5%
Possible	2%
Unlikely	1%
Rare	0.2%

Source: Rollason *et al.* 2010.

Consequences on assets can be expressed using qualitative approaches and scales (Rollason *et al.* 2010, Department of Planning 2014) or more sophisticated quantitative approaches including:

- use of average annual damage curves to assess the damage to buildings and infrastructure
- quantitative approaches integrating tangible and intangible losses and damage (Dassanyake *et al.* 2015).

These are useful to provide detailed information on the value of the asset, but are data intensive and complex.

2.5.4 References and further reading material

- Dassanayake, D. R., Burzel, A., & Oumeraci, H. (2015). Methods for the evaluation of intangible flood losses and their integration in flood risk analysis. *Coastal Engineering Journal*, 57(01), 1540007.
- Hunter, J. (2010). Estimating sea-level extremes under conditions of uncertain sea-level rise. *Climatic Change*, 99(3-4), 331-350.
- Intergovernmental Panel on Climate Change. (2014). *Climate change 2014—Impacts, adaptation and vulnerability*. Cambridge University Press.
- Mach, K., & Mastrandrea, M. (2014). *Climate change 2014: impacts, adaptation, and vulnerability (Vol. 1)*. Cambridge, New York, NY: Cambridge University Press.
- Rollason, V, Fisk, G., and Haines, P. (2010), Applying the ISO 31000 risk assessment framework to coastal zone management. NSW Coastal Conference 2010. <http://www.coastalconference.com/2010/papers2010/Verity%20Rollason%20full%20paper%202.pdf>.
- State of California (2012) California climate adaptation planning guide http://resources.ca.gov/climate/safeguarding/adaptation_policy_guide/
- Western Australia Department of Planning (2014) Coastal hazard risk management and adaptation planning guidelines. Western Australia Government. http://www.planning.wa.gov.au/dop_pub_pdf/CHRMAP_Guidelines.pdf



PHASE 6. Identify potential adaptation options

2.6.1 Purpose of this phase

The purpose of this phase is to identify and evaluate potential adaptation options to reduce or eliminate the risks identified in Phase 5.

This phase requires good on-ground knowledge and should involve a range of stakeholders who can assist in identifying feasible options.

2.6.2 Minimum requirements

The minimum requirements for Phase 6 are:

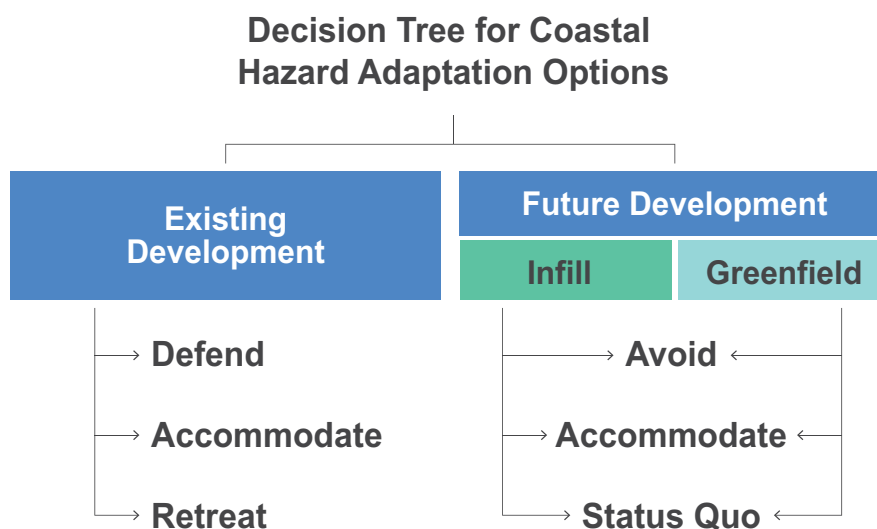
1. Identification of potential options to reduce or eliminate the priority risks identified in Phase 5. A range of options should be identified, drawn from the following categories in order of preference:
 - **avoid** the risk (e.g. develop new urban areas elsewhere or construct new infrastructure in low hazard areas)
 - **retreat** from the hazard zone (e.g. relocate or building setbacks).
 - **accommodate** the hazard (e.g. increase resilience through retrofitting buildings)
 - **defend** from the hazard (e.g. increase buffers, improved awareness and preparedness to extreme events)
2. Hold a workshop with key stakeholders to assist in informing the option identification process. The role of workshop participants is to:
 - Identify existing policies, procedures or management measures which may assist in reducing coastal hazard risks
 - identify resulting changes to risk to current assets
 - provide input into the practical application, acceptability and appropriateness of adaptation options.

An example of how coastal management options should be categorised or approached is provided in **Figure 7**.

When identifying options, interim or temporary measures that may evolve over time (often referred to as 'adaptation pathways') should be considered, as well as the final preferred outcome. By staging adaptation responses, some flexibility in response is retained, in the event that further information or newer technology becomes available over time. This could also assist in avoiding significant up-front costs for councils.

Management effort should be prioritised for risks rated as extreme or high and are considered intolerable.

Figure 7. Example decision tree for considering coastal hazard adaptation options



3. Select adaptation options from *The Compendium* or other sources, adopting a screening methodology to eliminate clearly non-viable adaptation options. Assessment criteria need to be developed for the screening of options and should include the following considerations as a minimum:
 - benefits
 - feasibility and legality
 - costs
 - adverse impacts (environmental, social and economic).
4. Prepare a proposed adaptation options document informed by the outputs of the workshop which:
 - identifies broad categories for each locality and/or key asset (i.e. avoid, defend, accommodate, retreat)
 - informs more detailed stakeholder-driven socio-economic appraisal in Phase 7 by documenting:
 - a description of the selected adaptation options for each location and/or asset, including estimated high level costs (construction, implementation or maintenance costs) using the information in *The Compendium* or other relevant sources (note that costs outlined in *The Compendium* are indicative only, and councils may wish to undertake project-specific costing)
 - a photo or diagram of the option at work
 - assessment of its effectiveness in dealing with coastal hazards and, in particular, future sea levels
 - interaction with other adaptation options and risk of unintended consequences (e.g. adverse safety hazard or environmental impact).

Retrofitting of private assets, such as homes, will be in most cases implemented directly by asset owners which may access, in some cases, ad-hoc grants or funding schemes.

In the process of assessing possible responses to coastal hazards, taking into account their costs and the views of the community, councils may consider “maintain the status quo” approach. Maintaining the status quo allows for continuation of the existing use in an area but prevents any further intensification of those uses (see *The Compendium*).

Approaches should be consistent with the Queensland Government regulatory and planning framework or justification provided where this cannot be met.

2.6.3 Leading practice

Leading practice prioritises the selection of adaptation options according to the following hierarchy:

1. Avoid placing new assets into hazard areas and transition existing assets out over time.
2. Build resilience by protecting or reinstating natural coastal ecosystems.
3. Build community resilience by providing the means to strengthen their capacity to absorb stress and maintain economic, social and cultural functions.
4. Adapt existing and future assets to accommodate identified coastal risks and timeframes.
5. Defend existing assets to the impacts of a defined event/s.

The Compendium was prepared specifically to provide guidance on coastal adaptation options for coastal ecosystems and the built environment, and is recommended as an example of a leading practice resource. It includes a technical description of the options, positives and negatives of each option, failure risks, estimated costs (in 2012 monetary value) and other considerations. In relation to Step 1 of the minimum requirements, *The Compendium* groups coastal hazard adaptation options into 4 themes to assist in identifying and evaluating potential response options:

- **Regenerative adaptation** options usually mimic natural processes and design to either improve or create existing coastal ecosystems and landforms to reduce the risk of coastal hazards on human settlements. These options are referred to as ‘soft’ engineering methods and are the preferred options over hard engineering methods where feasible
- **Coastal engineering adaptation** options are designed to reduce the risk of coastal hazards on human settlements through control of coastal erosion and protection from storm tide inundations. These options are referred to as ‘hard’ engineering methods
- **Coastal settlement design** options are the combination of accommodation measures to improve the resilience of current buildings or to apply new design standards for future developments. This can include measures to waterproof buildings or accommodate water flows through the building while preventing major damages to structures and facilities
- **Planning** options are designed to reduce the risk of coastal hazards on existing and future human settlements by controlling development in coastal hazard areas and preventing development in high hazard risk areas.

The spectrum of coastal adaptation options in the compendium is summarised in **Table 6**.

Table 6. List of adaptation options of the compendium

Category	Option
Regenerative options	Beach nourishment Dune construction and regeneration Riparian corridors restoration and generation Wetland restoration
Coastal engineering options	Artificial reefs Detached breakwaters Groynes and artificial headlands Sea dykes or levees Seawalls Storm surge barriers
Coastal settlement design options	Building retrofitting and improved design Flood resilient public infrastructure Raise land and floor levels
Planning options	Development setbacks Land buy-back Land swap Land-use planning

Source: Griffith Centre for Coastal Management and GHD 2012.

More than one option or combination of options may apply at different points in time e.g. soft defence measures followed by hard defence in X years' time, followed by planned retreat commencing in X+Y years (i.e. an adaptation pathway approach).

A limitation of *The Compendium* is that not all coastal hazard risks identified will be fully addressed as it mainly covers options to protect physical assets or restore coastal ecosystems. The internal workshop and the output document should identify other types of options to address:

- Risk to services, natural resources and values (e.g. disaster preparedness and response, ecosystem services, recreation and tourism opportunities and indigenous connection to land)
- Education and awareness programs or other social programs. Burston *et al.* (2015) provide a discussion of options to improve community awareness and preparedness for storm tide risk in Queensland. When considering essential services, council may follow the Australian standard for asset management (ISO 55000) approach and consider the resilience of the services, rather than simply focusing on the resilience of specific infrastructure and assets.
- Planning instruments that avoid increasing future risk (e.g. preventing intensification of use in coastal hazard areas). A basic tenant of the State policy is that decisions on future development in coastal hazard areas should not increase the existing exposure of a community to coastal hazards risks. Avoidance will generally be the most cost-effective long term response in undeveloped or rural areas.

Other resources considered to be leading practice can be found in Low Choy *et al* (2012) and using Terranova (The Australian Climate Change Adaptation Portal).

The limitations of this approach are:

- more detailed information is needed to provide a meaningful assessment
- care is needed to reject only those options which could not possibly work at the site and rely on the more detailed option analysis
- screening will require expert opinions including from coastal engineers and planners
- a workshop environment is required to properly discuss and integrate the opinions

- in the case of coastal engineering options, the Engineers Australia (2012a) guidelines provide a useful structured framework for the selection of options:
 - identify range of suitable adaptation options – planning and/or protection/amelioration options
 - prepare a schedule for implementation of adaptation options, particularly if a staged development is being considered including preliminary short-term works
 - undertake sensitivity analysis for key climate/process changes for each preferred option (i.e. different climate change scenarios and timeframes, as described in Phase 3)
 - select preferred option/suite of options.

A conceptual design process is recommended for coastal engineering options to inform the screening process. This can be based on the hazard information required in Phase 3. However, where funding is limited this step may not be required for more standardised options such as seawalls.

The identification and selection of adaptation options should be mindful of the risks of maladaptation, where the social and environmental costs of the adaptation are higher than the actual benefits. In particular, adaptation options should:

- take into account the level of uncertainty of the hazard they are designed to address
- consider the system as a whole and possible negative unintended consequences of adaptation action for the overall system.

2.6.4 References and further reading material

Burston, J., Ware, D., & Tomlinson, R. (2015). The real-time needs of emergency managers for tropical cyclone storm tide forecasting: results of a participatory stakeholder engagement process. *Natural Hazards*, 78(3), 1653-1668.

Engineers Australia (2012a) Climate change adaptation guidelines in coastal management and planning

Engineers Australia (2012b) Guidelines for responding to the effects of climate change in coastal and ocean engineering.

Griffith Centre for Coastal Management (2012), Coastal hazard adaptation options – A compendium for Queensland coastal councils. Prepared for GHD Pty Ltd, Dept. of Environment and Heritage Protection, Local Government Association of Queensland, Townsville City Council and the Commonwealth Dept. of Climate Change and Energy Efficiency. Oct 2012.

Low Choy, D., Serrao-Neumann, S., Crick, F., Schuch, G., Sanò, M., van Staden, R., & Baum, S. (2012). Adaptation options for human settlements in South East Queensland. *Main report*. SEQ CARI, Brisbane.

Macintosh, A. (2013). Coastal climate hazards and urban planning: how planning responses can lead to maladaptation. *Mitigation and Adaptation Strategies for Global Change*, 18(7), 1035-1055.

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PHASE 7. Socio-economic appraisal of adaptation options

2.7.1 Purpose of this phase

Having gathered information on potential adaptation options, it is necessary to undertake more detailed analyses of these using a range of social, environmental and economic criteria. This will support council's decision-making when selecting the final preferred option or suite of options to respond to identified risks and meet the outcomes sought.

The objectives of this phase are to:

- perform an appraisal of adaptation options
- determine the preferred adaptation option(s) to be employed.

2.7.2 Minimum requirements

A socio-economic appraisal of proposed adaptation options is to be undertaken, employing a combination of multi-criteria and cost-benefit assessment techniques. For councils with limited resources or where coastal hazard risks are assessed as being low risk/acceptable, simpler forms of MCA or CBA may be employed.

MCA should be applied to all viable adaptation options identified in Phase 6 while CBA should only be applied to those selected through the MCA process. If detailed adaptation option specifications are not available (e.g. detailed costing), council may decide to postpone the CBA to the CHAS implementation phase.

Key terms

Cost Benefit Analysis: A technique used to determine the benefits or costs of a project, option or decision to aide decision-making.

Multi Criteria Analysis: A decision-making tool that enables options to be prioritised using multiple criteria.

Multi-Criteria Analysis (MCA)

An MCA provides a qualitative framework to rank adaptation options based on their performance in reducing the risk to assets. The MCA must:

- identify assessment criteria and score the adaptation options against these criteria. This process should be undertaken in collaboration with stakeholders, ideally in a workshop environment
- ensure criteria reflects a range of environmental, social, economic and cultural issues to benchmark the adaptation option. Suggested criteria include, but are not limited to:
 - **capital cost and maintenance costs**, established in Phase 6
 - **environmental or social impact**, to identify where the option may have trade-offs upon the surrounding environment, including beach amenity and access
 - **community acceptability**, which is based upon general feedback from stakeholder engagement
 - **the ability for the option to be reversible / adaptable in the future**, which is particularly relevant where there is considerable uncertainty and/or long time frames for a future impact
 - **effectiveness over time**, to consider where an option presents a long term solution or a short term solution that would require additional management action or upgrades in the future
 - **legal / approval risk**, to highlight the legislative and approval requirements (or impediments) to implementing an option within the current legal framework
 - **the technical viability**, to highlight where certain options may or may not be technically feasible or would require significant engineering (or other) investigations and construction/implementation capabilities.

These are only suggested criteria, and council may develop their own criteria that is specific to their needs:

- the criteria should reflect the ability of the option to reduce the risk on the asset
- the criteria should result in a reduction of adaptation options, so that cost-benefit analyses are only undertaken on a select number of options.

Cost-Benefit Analysis (CBA)

A CBA is a process commonly used to prioritise options and inform decision-making about alternative courses of action. It can assist in identifying the option that achieves maximum value for money benefit for a council. It identifies many costs and benefits of an option, including social and environmental values according to their net economic benefit.

The costs and benefits of an option are forecast over the life of the project, costs are subtracted from benefits to determine the net present economic value (NPEV) of the project. The option with the greatest NPEV should provide the greatest net benefit to the community or the most economic use of resources (i.e. Benefit/cost ratio greater than one or a positive NPEV).

The Queensland Government has published a guide to undertaking CBA (*Project assessment framework: Cost-benefit analysis*), and the methodology used in that guide, or an equivalent standard should be used.

A full CBA may not be appropriate for smaller, or less complex adaptation options, as significant resources can be required, and may be difficult to justify in the context of net benefits anticipated. Councils should consider the level of analysis required for an option having regard to the likely size, sensitivity and impacts.

It is important that the outcomes of the socio-economic appraisal are recorded and made accessible to relevant council areas to ensure continued organisational awareness and knowledge of the reasons why certain options were not progressed.

2.7.3 Leading practice

It is leading practice to combine two socio-economic appraisal techniques: MCA and CBA (DEFRA 2005, Penning *et al.* 2013).

A socio-economic appraisal is required to determine the most cost-effective adaptation options, taking into account long-term social, economic and environmental factors. There is not a single or pre-determined socio-economic appraisal methodology that is applicable to all situations, the availability of reliable data being a major limiting factor.

Multi-Criteria Analysis (MCA)

MCA is a cost effective means of narrowing down the range of identified options that can then be tested under a CBA. Multi-criteria analysis is performed by screening each adaptation option through a range of qualitative or semi-quantitative criteria, including for instance, criteria under the categories of adaptation effectiveness, climate uncertainty, social and environmental impacts, complexity and costs. It is leading practice in MCA to:

- Identify criteria in consultation with key stakeholders. Stakeholders will also need to provide weighting of criteria and scores of adaptation options against each criterion. This can be done either remotely (using poll or survey instruments) or during a workshop.
- Inform stakeholders on the MCA process mechanisms. If a workshop is being held, council needs to ensure that workshop participants are familiar with the MCA process and theory prior to the workshops being held.
- Apply the MCA to all options identified in Phase 6. The weighted score of the MCA will allow identifying those options that will be assessed in detail with CBA.

Great care needs to be taken when performing an MCA. MCAs can easily collapse down into an identification of the values of the stakeholders who happen to turn up at workshops. MCAs are therefore often not repeatable or transparent. MCAs undertaken through community workshops also do not encapsulate the values of future residents and are prone to being dominated by special interests. These shortfalls can be partially mitigated through very careful selection of workshop participants, and ensuring that any weighting applied are carefully thought through, and that inappropriate trade-offs are not presented.

The Compendium has developed a number of criteria to assess the performance of adaptation options. These can be used as a starting point to develop location-specific criteria for a MCA (GHD *et al.* 2012). As an example of criteria setting, Preston *et al.* (2012) provides an application to case studies in NSW, including results of an analysis of their performance. In this case Bayesian modelling was used to assess the utility of different adaptation options given performance evaluations and weights while also incorporating the variance in individual stakeholder responses. While this approach can provide a better, in depth insight, its main limits are time availability and the capacity of the team in using Bayesian models.

Cost-Benefit Analysis (CBA)

There is no one-size fits-all approach when undertaking CBA, however the following should be a consideration when scoping the preferred approach:

1. Cost inputs should include the whole-of-life costs associated with the implementation of an adaptation option. The benefit inputs should represent the reduction in impact from the implementation of an adaptation option (van der Pol *et al.* 2015).
2. The accurate determination of an assets value (both tangible and intangible) and implementation costs undertaken in Phase 6, is critical to effectively carrying out a CBA.
3. An appropriate discount rate should be employed. A discount rate is a way of allowing future costs or benefits to be compared to today's equivalent value. The value of the discount rate can have a significant impact on whether an options net benefit is positive or negative. The CBA undertaken for the Townsville pilot CHAS employed a discount rate of 3%. The discount rate to be used should be identified in consultation with the Queensland Treasury (Queensland Treasury 2015).
4. A sensitivity analysis should be included, to account for variations and uncertainties in costs and benefits assumed for an option. Sensitivity analysis allows for examination of how sensitive the financial and economic outcomes are to these assumptions. A 1%, 5%, 7% and 9% sensitivity test was undertaken for the Townsville pilot CHAS.
5. The CBA should include information about the optimal timing for investment, i.e. the time when the benefits of adaptation break even with the potential damage caused by coastal hazards (GHD 2012). The optimal timing can be defined as the point in time where the benefits (the avoided impact) is greater than the costs of the adaptation option (GHD 2012).
6. When the costs of the adaptation option are higher than the benefits (avoided damage or reduced risk), the adaptation option is not considered viable, however, other socio-economic considerations may come into play (e.g. community willingness to pay to avoid damage and minimise risk which was not accounted for in the valuation process) and may still be a valid reason to proceed with an option.
7. It should be noted that sea level rise will increase the risk of potential damage or consequences over time (GHD 2012), and this should be factored into the CBA. The use of non-market valuation techniques is encouraged to price non-market goods and services (i.e. those values that don't have a market value, such as community or environmental values). Care should be taken when using market-based prices for private housing. This is because in many cases market prices do not reflect the true present or future inundation risk. In other words in some cases the market is not correctly capturing the vulnerability of the asset. This can lead to some adaptation options becoming overly expensive to implement. Due consideration must also be taken to avoid perverse incentives (unintended consequences of policies). For example signalling that an asset may be earmarked for future coastal protection as a result of the present level of economic intensity can incentivise further intensification under the assumption that as the risk rises, the asset will be prioritised for coastal protection works.

2.7.4 References and further reading material

Australian Government (2014) The Australian government guide to regulation https://www.cuttingredtape.gov.au/sites/default/files/files/Australian_Government_Guide_to_Regulation.pdf

Dassanayake, D. R., Burzel, A., & Oumeraci, H. (2015). Methods for the evaluation of intangible flood losses and their integration in flood risk analysis. *Coastal Engineering Journal*, 57(01), 1540007.

GHD (2012) Economic Analysis. Coastal hazard strategy for the City of Townsville.

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Preston, B.L., Maloney, M., Thomsen, D., Smith, T., Mangoyana, R., Conlon, B. (2013) A Multi-Criteria analysis of coastal adaptation options for local government. Prepared for the Sydney Coastal Councils Group by Oak Ridge National Laboratory and the University of the Sunshine Coast, Oak Ridge, Tennessee and Sippy Downs, Queensland. http://www.sydneycoastalcouncils.com.au/sites/default/files/MCA_of_Coastal_Adaptation_Options_for_Local_Government.pdf

Queensland Treasury (2015) Project assessment framework – Cost benefit analysis <https://www.treasury.qld.gov.au/publications-resources/project-assessment-framework/paf-cost-benefit-analysis.pdf>

van der Pol, T. D., van Ierland, E. C., & Gabbert, S. (2015). Economic analysis of adaptive strategies for flood risk management under climate change. *Mitigation and Adaptation Strategies for Global Change*, 1-19.



PHASE 8. Strategy development, implementation and review

2.8.1 Purpose of this phase

The purpose of this phase is to collate and summarise all the findings of previous phases and to develop a final CHAS document. The CHAS provides the overarching strategic direction and framework for a coordinated and integrated 'whole of council' response to coastal hazard adaptation. The CHAS is an important means of guiding change, informing decision making and prioritising actions across the organisation to respond to current and future coastal hazard risks.

It will also provide information on implementation of actions to support delivery of the CHAS by identifying priority actions, timing and staging delivery tools, roles and responsibilities, funding and establish monitoring and review processes.

While council is not solely responsible for coastal hazard adaptation action, it has an important role. Councils are balancing various priorities across their organisations and making decisions on how to prioritise and allocate budgets to fund various operations, programs and services to the community. Many coastal adaptation options will be clearly unaffordable for some councils. It can be unhelpful for council if a CHAS recommends options clearly unaffordable as it sets unrealistic expectations. Ideally such options would be disregarded during the options development and selection process (Phase 6 and 7).

The CHAS should therefore prioritise, stage and sequence actions over time and focus on treating priority risks. This will enable council to plan ahead and budget for capital investment to deliver priority adaptation actions, rather than leaving council with a plan that may not be implementable because of unaffordability and too many actions competing with other council priorities.

Adaptation actions need to be embedded across core governance functions and implemented using a range of tools including:

- risk management framework
- long term financial planning and annual budgets
- asset management and planning
- disaster management and planning
- corporate and operational planning
- land use and infrastructure planning
- organisational development and workforce planning
- community and stakeholder engagement policy and plans.

Identifying priority actions will also assist other stakeholders and agencies involved in delivering adaptation actions. For example, in the event of a natural disaster and adaptation action is required at short notice and/or relief funding becomes available, the CHAS can provide direction on what actions should be undertaken and where funding should be targeted. Actions undertaken by council, other agencies and stakeholders should be consistent with the direction and outcomes intended by the CHAS avoiding the potential for ad-hoc decisions that may result in maladaptation or prevent actions that may be sensibly required in the future.

The objectives of this phase are to:

- summarise the findings of previous phases in a format suitable for public consultation purposes
- document the strategy and overarching strategic direction for how council will provide an integrated and coordinated response to coastal hazard adaptation
- explain how the CHAS is to be effectively implemented, reviewed and monitored.

2.8.2 Minimum requirements

The final strategic document will be informed by and summarise the findings of the CHAS studies and evaluations, in particular the previous two Phases (6 and 7) and include the following components:

1. an overview of findings of previous phases to provide context to the strategy, including:
 - information about the extent of the coastal hazards addressed in the CHAS
 - key assets identified within the coastal hazard area
 - the findings of the risk assessment, including identification of priority risks
 - an overview of the options analysis phase
2. an Implementation Strategy (may be an internal document), including:
 - the overarching strategic direction describing the long term intent or vision for coastal hazard adaptation for the local government area
 - an overview of the adaptation actions which have emerged from the options analysis of phases 6 and 7
 - identification of priority adaptation options to treat priority risks (this may include a more detailed description of priority actions over the short term (say 5 to 10 year period) in the context of any medium and longer term actions)

- timeframes for the implementation of adaptation options (this may include decision-making triggers or thresholds for future implementation of actions) over the short, medium and long term
 - the specific instruments, plans, processes and other 'tools' that will need to be modified or created to integrate and deliver adaptation options
 - clear definition of the stakeholder, agency or entity responsible for leading the implementation of the action and stakeholders responsible for supporting the action
 - an action plan showing indicative costings of actions to inform annual labour, capital and operational budgets of council and other stakeholders
 - a financial plan indicating how actions will be funded including the identification of new or increased revenue sources during the life of the plan
 - arrangements for monitoring, reporting and reviewing including indicators used to monitor key areas and assets for impacts of coastal hazard risks.
3. an internal organisational change management plan, to provide a structured and systematic way to guide the integration of CHAS implementation with organisational governance arrangements. To the extent relevant to the local government, the internal organisational change management plan should identify:
- what elements of the current organisational culture (e.g. values, roles, processes, attitudes, assumptions, communication practices and behaviours) that need to change to align with and support the CHAS implementation
 - proposed communication and participative involvement of relevant staff across the organisation to ensure they have an appreciation of the goals of the CHAS and have a say in how the 'system' or governance arrangements should change to support the CHAS implementation. Change needs to be supported by clear rationale and justification
 - the proposed corporate approach to community engagement necessary to implement and sustain the CHAS over time
 - the corporate documents, plans and strategies to be amended or updated to integrate and align with the CHAS, including proposed timing and responsible branch/officer
 - the internal procedures, processes and systems across the organisation that need to be amended, updated or created to support the CHAS implementation including, but not limited to, monitoring and review
 - team capabilities, skills and knowledge including any training needs and additional resources to support staff and increase their capacity to implement the CHAS
 - roles, management tools and any team reorganisation that may be required to reinforce implementation of the CHAS
 - the prioritisation of organisational change management actions, proposed timing, roles and responsibilities.

2.8.3 Leading practice

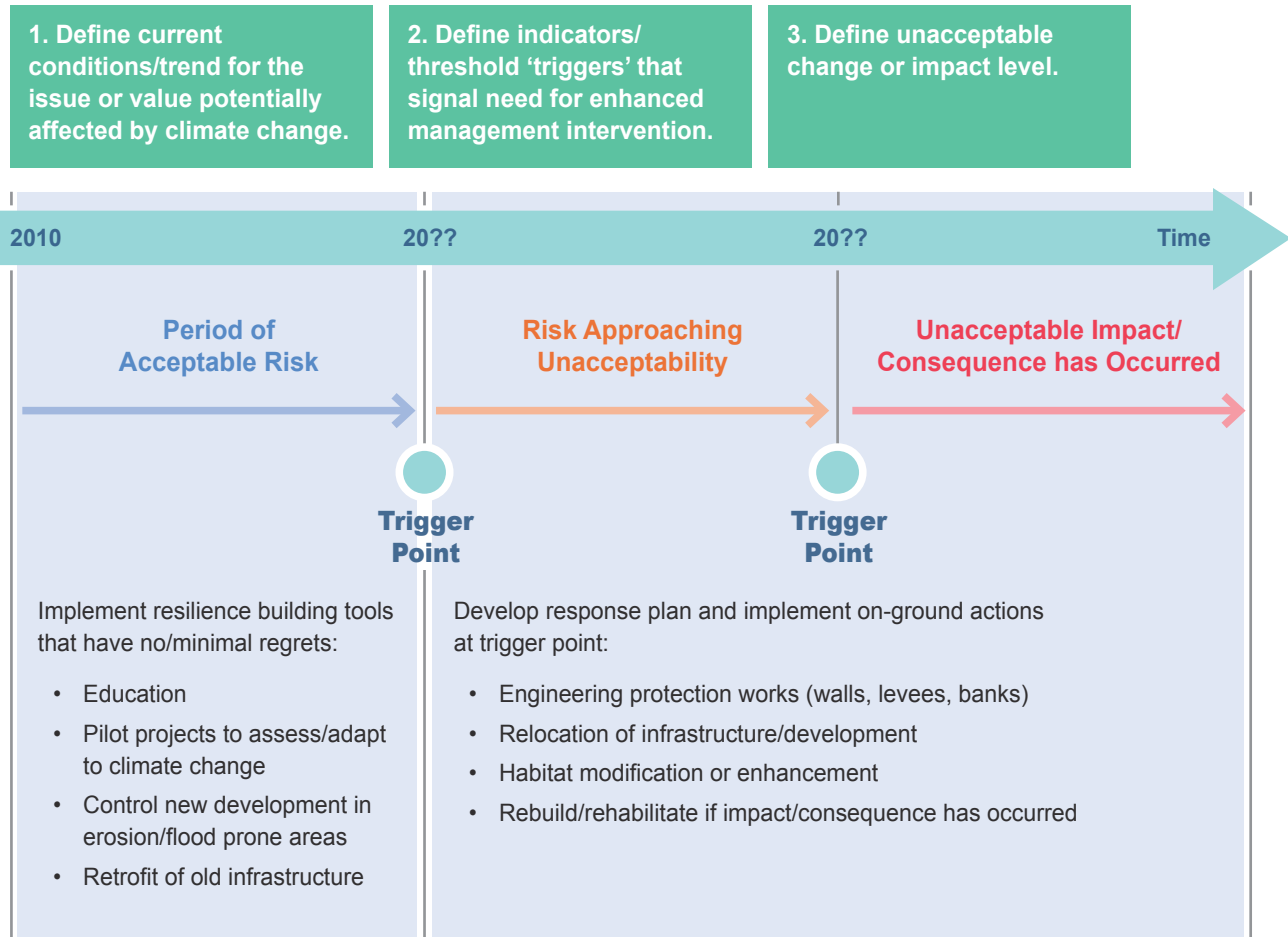
Trigger points and thresholds

Trigger points can be set to identify the level of acceptable change before adaptation options must be implemented. The benefits are:

- a triggered approach allows for actions to be implemented before the threat arises, while also allowing time to improve coastal hazard data and obtain necessary funding, resources and capacity, including additional time for stakeholder consultation where required
- the approach limits community burden, costs and inappropriate adaptation measures should coastal hazard impacts not eventuate as projected.

A threshold for major impact should be identified first whereas the trigger should be a value that occurs prior to a threshold being reached. In some cases, a staged approach could be implemented where multiple triggers can be set for the various stages of implementation of an adaptation action. A reference framework is provided by Fisk and Kay (2010), and illustrated in [Figure 8](#).

Figure 8. Continuum model for adaptation pathways



Note: Terminology used in this figure (i.e. 'acceptable' and 'unacceptable') correspond to the terminology used in this guideline (i.e. 'tolerable' and 'intolerable').

Source: Fisk & Kay, 2010.

Changing risk profile and tolerance

As hazards increase over time the level of potential risk to assets will also change. Understanding individual assets' tolerance of these risks is important in determining fit for purpose adaptation action. Figure 9 and Figure 10 provide examples of how an appreciation of the changing risk profile of two types of assets can influence the consideration of adaptation action.

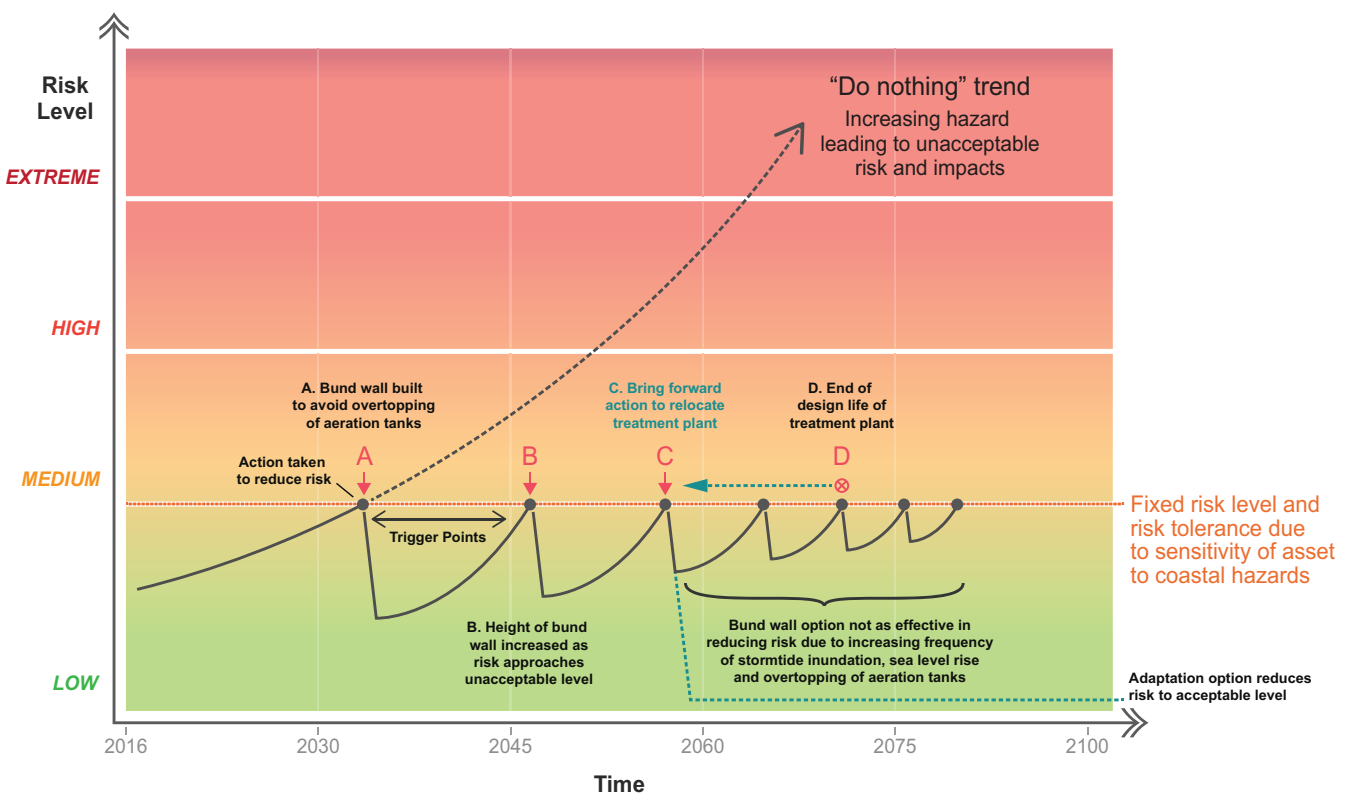
The simplified hypothetical example of the sewage treatment plant (STP) indicates that this sewage treatment plant has a risk tolerance level to coastal hazards fixed at "low". This reflects that the likelihood and consequences of impact on the STP asset is unacceptable and that tolerance to these impacts will not change over time. As hazards increase over time the risks cannot be maintained at a tolerable "low" risk level without repeated investment in adaptation action approaching the trigger points at which the risk tolerance

level would be exceeded. The adaptation action in this example is the progressive increase in the scale of a bund wall to mitigate impacts. This example assumes that this action is feasible whilst there is considerable life remaining in the asset, however as the end of asset life approaches another option emerges which can reduce the exposure of the STP to the hazard and thereby sustain the required risk tolerance level long term.

The example of the inundation of a foreshore park indicates how changing community tolerance to increasing hazard influences adaptation action.

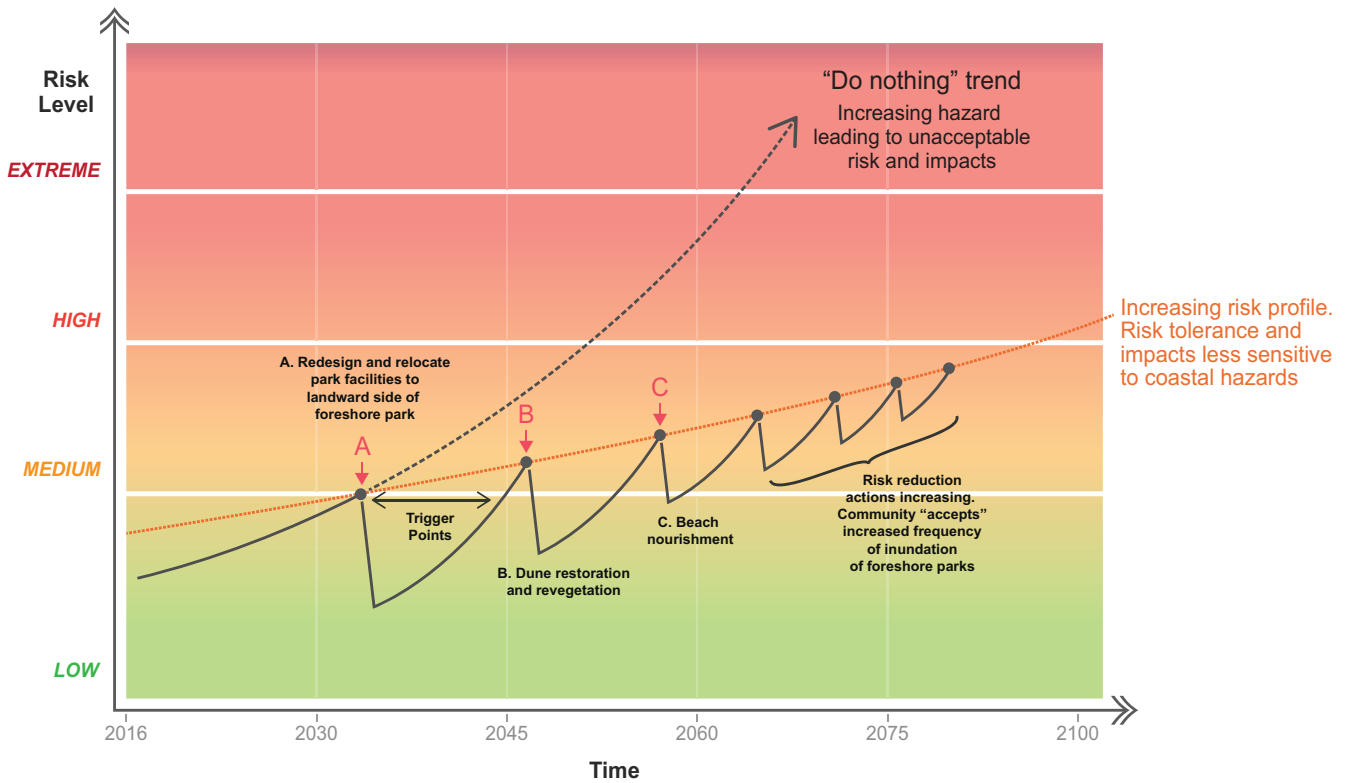
An appreciation that hazard, risk and risk tolerance are dynamic and interrelated elements of adaptation planning, reinforces the importance of adaptive management approaches being integrated into the CHAS development and implementation.

Figure 9. Hypothetical example - Sewage treatment plant with fixed risk level



- 'Fixed' risk tolerance and low acceptability of impacts due to sensitivity of asset.
- Reducing effectiveness of risk reduction actions.
- Increasing frequency of risk reduction actions.

Figure 10. Hypothetical example - Inundation of foreshore parks with changing risk tolerance and risk profile over time



- Risk profile increasing over time.
- Increasing frequency of coastal hazard events.
- Increasing frequency of action to reduce risk.
- Reduction in effectiveness of risk reduction measures.
- Increasing acceptability of impacts and risk tolerance as asset not as sensitive to coastal hazard impacts.

Implementation and monitoring

The Implementation Strategy of the CHAS should draw on all relevant council services, operations and functions and where appropriate, recognise opportunities for integration of community and other stakeholders into its implementation. Internally, it should involve council officers at various levels across the organisation and councillors. This is important to ensure commitment and ownership of the strategy and sharing of its implementation across the organisation. Ideally, coastal hazard adaptation needs to be integrated and embedded into council 'business as usual' activities.

Effective delivery of adaptation actions relies on a range of delivery tools including the planning scheme, asset management plans, disaster management and response plans, environment programs, community awareness plans, corporate plan, operational plan, annual budgets and long term financial planning.

For new land use, infrastructure and development, the planning scheme is an important statutory tool to deliver adaptation actions. The CHAS should inform the planning scheme to ensure new development is appropriate to the level of existing or future coastal hazard risk and that the development incorporates adaptation options consistent with the direction and outcomes intended by the CHAS. Depending on the adaptation options selected, there are a number of ways in which CHAS outcomes and adaptation options can be reflected in planning instruments. Best practice planning for coastal hazard adaptation requires a risk based approach to land use and development. The *State interest guideline for natural hazards, risk and resilience* (April 2016) provides guidance on how to integrate natural hazard and risk assessment outcomes into planning schemes, includes model codes and may provide further guidance in this area.

Effective implementation of the CHAS cannot rely on the planning scheme alone. Adaptation options will also need to be integrated into other relevant plans such as disaster management plans, economic development plans, natural area management plans and assets and infrastructure management plans.

Furthermore, adaptation options do not operate in isolation. Important aspects when considering the feasibility of adaptation options include the application of relevant statutory requirements.

- For example, adaptation works or development on a foreshore reserve may conflict with the purpose for which land has been reserved under the *Land Act 1994*.

- Adaptation works may require State approvals under the *Sustainable Planning Act 2009* or other relevant legislation or require State land tenure to be granted. Local government should be aware of potential development or tenures approval requirements.
- Adaptation strategies should consider issues of displaced environmental and cultural values that may be captured under other Queensland legislation (e.g. the *Marine Parks Act 2004*) or Commonwealth legislation such as the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) and may need to refer the proposed works to the Australian Government.

The Compendium has a section dedicated to specific implementation mechanisms which may provide further guidance. Other leading practice examples and discussion on mainstreaming and monitoring progress of adaptation at the local level are provided in Gurrán *et al.* (2013) and Sanò *et al.* (2015)

CHAS review, operational monitoring of actions and reporting

As with other corporate documents and strategies, it is important for systematic reviews of the CHAS to be undertaken, together with operational monitoring of risks, thresholds and impacts to ensure 'on the ground' risk treatment actions are effective or need adjusting.

The implementation and monitoring of the CHAS should be embedded into the organisation's 'business as usual' activities and regularly reported in a similar way that other corporate plans, strategies and tools are monitored and reviewed. Indicators of progress should be identified, monitored and reported periodically following the organisation's best practice. An organisational change management plan can be prepared which provides direction on required changes to organisational culture, documents, procedures and any other governance arrangements necessary to implement the strategy.

This guideline advocates (as leading practice) for the CHAS and supporting action plan to include specific triggers or thresholds to signal or drive specific risk treatment actions. It may be the case that multiple triggers are required with different adaptation responses for each. Monitoring is therefore an essential part of coastal hazard adaptation.

Regular progress reports and strategy reviews are undertaken to:

- identify if data needs to be updated
- review or revise implementation actions
- report on the outcomes of implemented actions.

Adjustment to the CHAS and action plan could be linked to the following:

- if a critical threshold or trigger is reached
- changing risk profile
- periodically, in conjunction with the future review of planning schemes
- if sea level rise or other climate change projections are changed following publication of updated Assessment Reports by the Intergovernmental Panel on Climate Change (IPCC)
- emerging best practice or other adaptation learnings
- changes to community attitudes and risk tolerance
- changes to legislation.

2.8.4 Leading practice

Adaptive Management Framework

Many corporate documents, plans and strategies are static and can be slow to catch up and be amended or refreshed to take account of new data, studies, learnings, changing community attitudes or impacts being experienced.

Figure 11 illustrates a coastal hazard adaptive management framework and provides a continuous improvement cycle of review for the CHAS. Taking an adaptive management approach to the review, implementation and monitoring of the CHAS provides a good framework to address issues of uncertainty associated with climate change impacts. The approach also helps to evaluate the effectiveness of actions to treat risks, and increases the organisation's ability to better respond to rapidly increasing risks or changing risk profiles, and adjusting the strategy and implementation actions accordingly.

Figure 11. CHAS adaptive management framework for continuous improvement

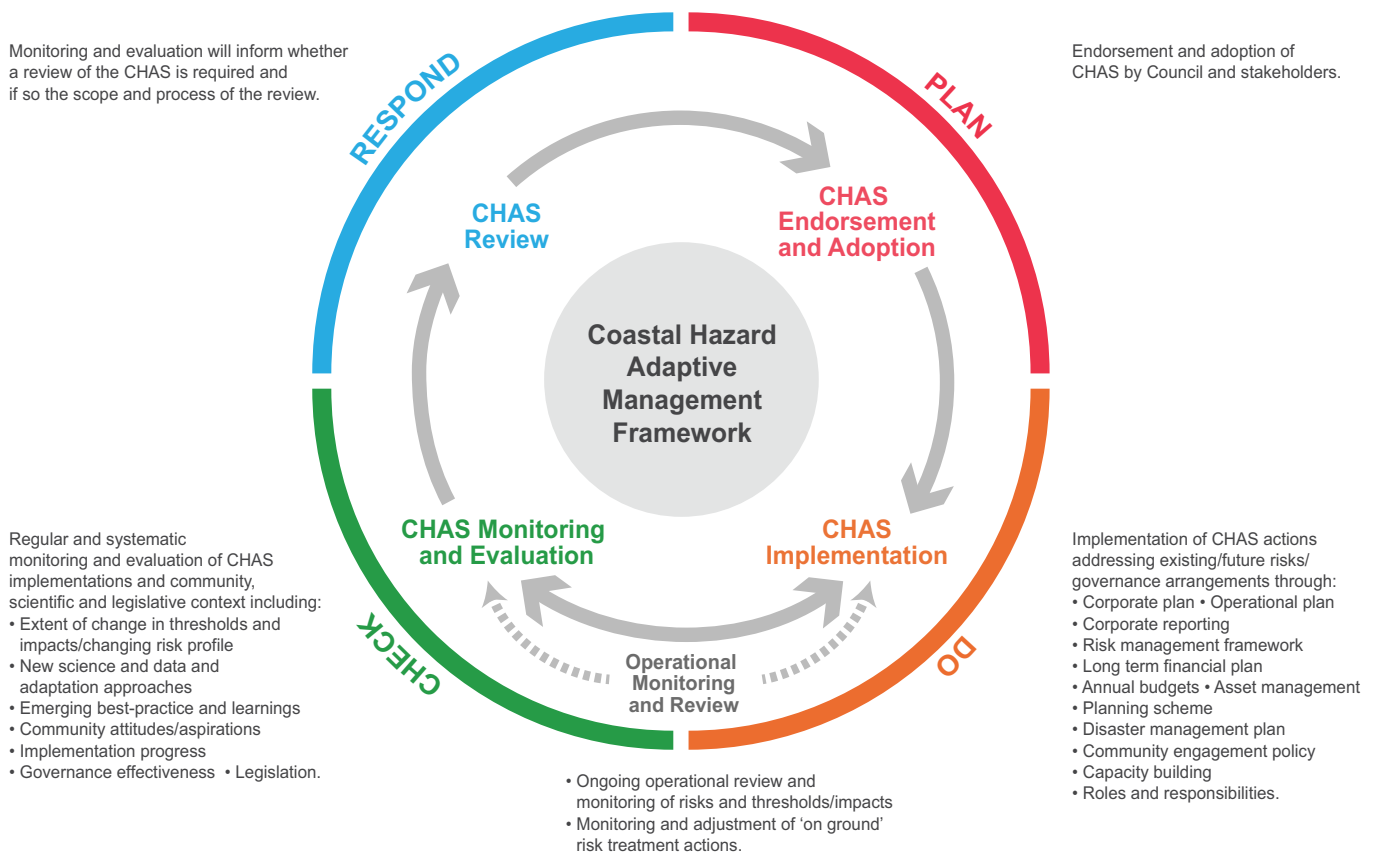




Photo: Tannum Sands, Gladstone Region. © Buckley Vann Planning + Development, 2012

More guidance on the adaptive management framework to strategic planning in a local government context can be found in this article from the International Journal of Climate Change Strategies and Management (<http://www.emeraldinsight.com/doi/abs/10.1108/17568690910955612>)

2.8.5 Leading Practice

Organisational Change Management Plan

An organisational change management plan is important to support a CHAS implementation. The hallmarks of what makes a successful organisational change management plan include the following characteristics:

- ensure there is 'buy-in' from senior management. If senior management are not prepared to lead by example, then the whole change process is very likely to fail quickly
- change needs to be inspired, not mandated. Therefore, organisational change needs to be supported by clear rationale and justification
- establish change champions throughout the organisation. These people need to be respected within the organisation and can be inspiring for others to follow. They need to understand the 'softer' side of communications, negotiations and selling the need for a CHAS
- Ensure there are some quick wins in the organisational change management plan. Building momentum in the change process is important. It will also show potential doubters that it is not as overwhelming or scary as they may think
- It is often easier to introduce small and adaptive change rather than just big new initiatives and major shifts in objectives/policies. People can become sceptical of new initiatives being launched all the time, without follow-through
- participative management will help to overcome resistance in the organisation. Involve relevant staff across the organisation to contribute to and characterise what change is necessary in order to achieve the overall change needs.

Funding

When considering how best to implement the CHAS, councils should identify how the nominated adaptation options will be funded to deliver effective implementation. This includes funding and resources required for monitoring and evaluation to determine whether new risks have arisen, the likelihood or consequence that risks have changed, and to identify when trigger points have been reached.

The Compendium (Griffith Centre for Coastal Management 2012) includes a preliminary identification of revenue-raising mechanisms available to councils for financing the adaptation options and identify measures to ensure the adaptation strategy can be integrated into local, state and national government planning and program areas. These may include council rates, loans, grants, special purpose levies, public private partnerships, etc. Other funding sources may be available to local governments such as infrastructure funds by the state and federal government, land care programs, community groups' grants or community resilience funds/green bonds. Ware *et al.* (2015) provides an overview and analysis of funding mechanisms in Australia, with a focus on public-private partnerships.

In addition to council implementing the CHAS, delivery of adaptation actions will also involve other partners and stakeholders such as state agencies, infrastructure and utility providers, other asset owners and private landholders.

Leading practice would expand the Action Plan component of the CHAS to include other key stakeholders. The CHAS provides a framework to align adaptation actions and works by other stakeholders with the long term intent, priorities and outcomes sought for the local government area, creating a document that is a single point of truth for adaptation activities in a defined area.

2.8.6 References and further reading material

Australia Government Grants and Financial Assistance <http://www.australia.gov.au/information-and-services/business-and-industry/grants-and-financial-assistance>

Australian Government Dept of Infrastructure and Regional Development <http://investment.infrastructure.gov.au/funding/>

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LGAQ Grants and Funding <http://lgaq.asn.au/grants>

Parliament of Australia Community Grants http://www.aph.gov.au/About_Parliament/Parliamentary_Departments/Parliamentary_Library/pubs/rp/rp1516/Quick_Guides/ComGrants

Queensland Government Dept of Infrastructure, Local Government and Planning <http://www.dilgp.qld.gov.au/local-government/grants.html>
<http://www.dilgp.qld.gov.au/local-government/grants.html>

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Photo: Near Mer (Murray) Island, Torres Strait. © Buckley Vann Planning + Development, 2014

Annexes

Annex I Case study: Townsville Coastal Hazard Adaptation Strategy Pilot Project

The LGAQ, Townsville City Council and the Queensland Government have prepared a pilot coastal hazard adaptation strategy for Townsville in 2012. This strategy provides very useful guidance to other coastal councils who are considering how to address coastal hazard risks in their own communities.

The project focused on parts of Townsville City projected to be at risk from coastal hazards (sea level rise, storm tide and erosion) as identified by the Queensland Government coastal hazard area maps.

The project piloted key steps in the development of a coastal hazard adaptation strategy, including:

- identify areas at risk from current and future coastal hazards using the Queensland Coastal Hazard Maps, Townsville City Council's storm tide mapping study and high resolution Digital Elevation Data
- identify current and future assets at risk (private, commercial, community, government)
- using a combination of multi-criteria analysis and benefit-cost analysis methodologies to test the viability of potential adaptation options that weighed effectiveness against future costs of actions or inaction
- identify timeframes and trigger points for decision-making and implementation of adaptation actions
- identify measures to ensure the adaptation strategy can be integrated into existing local, state and national government planning and program areas.

The pilot project has delivered the following publications:

- a coastal hazard adaptation strategy for Townsville
- a compendium cataloguing a suite of innovative adaptation options relevant to Queensland, assessing their feasibility, costs and effectiveness in the short and longer terms
- an economic analysis report
- a learnings report (including pitfalls to avoid), which have been incorporated into this document where relevant.

While the pilot project provides Townsville-specific detail of the risk and potential mitigation to coastal hazards, the overall adaptation strategy process can be used to inform other Queensland coastal councils in undertaking their own strategies.

The pilot coastal hazard adaptation strategy for Townsville is available on the Council's website <https://www.townsville.qld.gov.au/building-planning-and-projects/council-projects/townsville-coastal-hazard-adaptation-strategy>.

Annex II Compliance with state policies

State Planning Policy

The Government has adopted the State Planning Policy (SPP) as a key component of Queensland's statutory land use planning system. The SPP identifies state interests that must be considered when preparing or amending local planning schemes and, in some cases, assessing development applications.

Any CHAS should be consistent with the SPP and relevant State interest policies. Guidance on implementation of the State interest policies should be sought from the State Planning Policy Guidance material at <http://dilgp.qld.gov.au/planning/state-planning-instruments/state-planning-policy-guidance-material.html>

Coastal hazard adaptation may also need to consider other state regulatory controls outside of the SPP, the principal one being the Marine Park Zoning Plans.

State interests directly related to coastal hazard adaptation are provided below:

1. Natural hazards, risk and resilience

The state interest policy for natural hazards, risk and resilience requires:

"The risks associated with natural hazards are avoided or mitigated to protect people and property and enhance the community's resilience to natural hazards".

The state interest can be met by:

For all natural hazards:

1. identifying natural hazard areas for flood, bushfire, landslide and coastal hazards based on a fit for purpose natural hazard study
2. including provisions that seek to achieve an acceptable or tolerable level of risk, based on a fit for purpose risk assessment consistent with AS/NZS ISO 31000:2009 Risk Management
3. including provisions that require development to:
 - (a) avoid natural hazard areas or mitigate the risks of the natural hazard to an acceptable or tolerable level
 - (b) support, and not unduly burden, disaster management response or recovery capacity and capabilities
 - (c) directly, indirectly and cumulatively avoid an increase in the severity of the natural hazard and the potential for damage on the site or to other properties

- (d) maintain or enhance natural processes and the protective function of landforms and vegetation that can mitigate risks associated with the natural hazard
- (e) facilitate the location and design of community infrastructure to maintain the required level of functionality during and immediately after a natural hazard event.

For coastal hazards—erosion prone areas:

4. maintaining erosion prone areas within a coastal management district as development-free buffer zones unless:
 - (a) the development cannot be feasibly located elsewhere
 - (b) it is coastal-dependent development, or is temporary, readily relocatable or able to be abandoned
5. requiring the redevelopment of existing permanent buildings or structures in an erosion prone area to, in order of priority:
 - (a) avoid coastal erosion risks
 - (b) manage coastal erosion risks through a strategy of planned retreat
 - (c) mitigate coastal erosion risks.

2. Coastal environment

The state interest policy for coastal environment requires:

"The coastal environment is protected and enhanced, while supporting opportunities for coastal-dependent development, compatible urban form, and safe public access along the coast".

The state interest can be met by:

1. facilitating the protection of coastal processes and coastal resources
2. maintaining or enhancing the scenic amenity of important natural coastal landscapes, views and vistas
3. facilitating consolidation of coastal settlements by:
 - (a) Concentrating future development in existing urban areas through infill and redevelopment
 - (b) Conserving the natural state of coastal areas outside existing urban areas

4. facilitating coastal-dependent development in areas adjoining the foreshore in preference to other types of development, where there is competition for available land on the coast
5. maintaining or enhancing opportunities for public access and use of the foreshore in a way that protects public safety and coastal resources.

3. Biodiversity

The state interest policy for biodiversity requires:

“Matters of environmental significance are valued and protected, and the health and resilience of biodiversity is maintained or enhanced to support ecological integrity.”

The state interest can be met by:

For national environmental significance:

1. considering matters of national environmental significance in the local government area, and the requirements of the *Environment Protection and Biodiversity Conservation Act 1999*

For state environmental significance:

2. identifying matters of state environmental significance
3. locating development in areas that avoids significant adverse impacts on matters of state environmental significance
4. facilitating the protection and enhancement of matters of state environmental significance
5. maintaining or enhancing ecological connectivity
6. facilitating a net gain in koala bushland habitat in the SEQ region

For local environmental significance:

7. considering the protection of matters of local environmental significance, which may involve provisions for environmental offsets, provided those provisions are consistent with the *Environmental Offsets Act 2014*.

Other state interests may relate to adaptation strategies depending on the projects proposed and these include:

- agriculture (protecting fisheries resources from development that compromises long-term fisheries productivity and accessibility)
- liveable communities
- development and construction
- tourism
- cultural heritage

- water quality
- energy and water supply
- state transport infrastructure.

Further guidance on how state interests may be considered in any proposed adaptation works is provided in the:

- State Development Assessment Provisions (SDAP) which guide assessment by the state of development proposals triggered under the *Sustainable Planning Regulation 2009*
- interim development assessment requirements in the State Planning Policy, which ensure that state interests are appropriately considered by council when assessing development applications where the local government planning scheme has not yet appropriately integrated state interests
- local government planning schemes, where these have incorporated the SPP state interests.

Other legislation and policies

For new adaptation works proposed in the future regard should be given to relevant policy and regulatory material and in particular, whether the works constitute development under relevant Queensland planning legislation and are consistent with the planning scheme. However, planning schemes, policy, legislation and development assessment rules change over time. Future sea level rise and accelerated coastal erosion will adversely impact communities in a way that may not be fully considered in present day policies. Hence projects, which are inconsistent with current policy or regulatory measures, should clearly identify this inconsistency for further consideration.

All projects must have regard to the following regulatory materials:

Table A1. Additional relevant Queensland legislation

State Planning Policy	2014	DILGP
State Development Assessment Provisions - specifically module 10 and any other relevant module	2015	DILGP
Marine Parks (Great Barrier Reef Coast) Zoning Plan	2015	DEHP
Marine Parks (Great Sandy) Zoning Plan	2015	DEHP
Marine Parks (Moreton Bay) Zoning Plan	2015	DEHP
Assessable coastal development	2012	DEHP
Approval requirements for local government works in coastal management district	2013	DEHP
Operational work on State coastal land	2013	DEHP
Development on land under tidal water	2013	DEHP
Management of Declared Fish Habitat Areas	2015	NPSR

Annex III Assets data types, classification and storage

Type of assets

The following is a list of possible physical, natural, economic, social and cultural assets which might be found within coastal hazard areas. These include both tangible (e.g. buildings and parks) and non-tangible assets (e.g. services or cultural values).

Council assets

Council assets may include those currently subject to asset and asset life cycle management policies such as:

- foreshore and beaches
- buildings
- roads, bridges, pathways, boat ramps, car parks, jetties
- flood mitigation and stormwater infrastructure
- water and sewerage infrastructure
- natural assets, including local biodiversity.

Council services (non tangible assets) within areas at risk may include, for instance:

- public transport
- lifeguard services
- disaster management
- waste management and recycling
- water and sewerage management.

Council policies, strategies or plans related with the coastal hazard area should be treated as non-tangible assets. These may include:

- visions and strategies
- management policies
- planning schemes
- shoreline management plans
- economic development plans.

External stakeholder assets

External stakeholders may be responsible for managing natural assets or other physical assets such as:

- ports, major road and rail infrastructure, and airports
- waterways, marinas, jetties, and boat ramps
- water, electricity, telecommunication and energy
- national and marine parks, with special emphasis on local biodiversity
- indigenous land.

External stakeholders can be the owner or leaseholder of parcels of land and buildings such as:

- homes
- businesses
- tourism and recreation facilities
- farm land.

External stakeholders may also provide specific services that can be disrupted by coastal hazards:

- navigation (e.g. ferries)
- asset maintenance
- surf life saving
- recreational services (e.g. surf schools, diving, sailing)
- businesses and other economic activities (e.g. shops or taxis).

Community values and practices (social and cultural assets) can be disrupted by coastal hazards (or by adaptation options intended to address them). These may include:

- public foreshore recreational use and access
- surfing and other water sports
- recreational fishing
- indigenous traditions and places.

Data storage and classification

Most councils use geographical information systems (GIS) and associated metadata to store spatial information. Some of the above assets might have already been identified and classified as part of the council GIS database.

Additional fields might be required to classify assets which are already catalogued in the council spatial datasets or cadastre. Other assets might have to be spatially identified and classified for the CHAS.

This document does not provide specific guidance on the data requirements for the identification and classification of assets, however, some of the fields may include the type of assets, custodianship/responsibility, locality, value, related stakeholders, a short description, notes, etc. The risk on the asset should be assessed separately in Phase 5.

In general, metadata storage should follow international standards adopted by the Queensland Government such as the ISO19115.

Annex IV Storm tide inundation modelling

Table A2. First Pass Storm Tide Project Scoring Criteria

First Pass Storm Tide Project Scoring Criteria		Score		
		1	2	3
1	Climatological Analysis			
1.01	Are the relevant storm surge producing events identified?	No	Yes	Comprehensive
1.02	Are all datasets clearly defined and referenced?	No	Yes	Fully disclosed
1.03	Has Bureau of Meteorology advice been obtained?	Not stated	Yes	Done In conjunction
1.04	Have temporal and spatial distributions of storm populations been determined?	No	Basic	Comprehensive
1.05	Have scale and speed distributions of storm populations been determined?	No	Basic	Comprehensive
1.06	Has the intensity of storm populations been determined?	No	Basic	Comprehensive
1.07	Have synoptic scale interactions been considered?	No	Basic	Comprehensive
1.08	Is parameterisation of the storm set explained and justified?	No	Basic	Comprehensive
1.09	Has any base data been adjusted or corrected with justification?	No	Yes	Comprehensive
1.10	Are inter-annual or inter-decadal variabilities discussed or considered?	No	Yes	Comprehensive
1.11	Is potential enhanced Greenhouse climate change considered?	No	MSL only	MSL, track, intensity, freq
2	Numerical Modelling - Atmospheric			
2.01	Are the atmospheric models adequately disclosed and described?	No	Basic	Comprehensive
2.02	Are critical coefficients and assumptions relevant to this study disclosed?	No	Yes	Comprehensive
2.03	Are example modelled storm systems provided and explained?	No	Basic	Comprehensive
2.04	Are the models shown to be calibrated and/or verified in similar contexts	No	Yes	Insitu
2.05	Does the model consider overland decay or land interactions where relevant?	No	Basic	Comprehensive
3	Numerical Modelling - Oceanic / Hydrodynamic			
3.01	Has suitably accurate bathymetric data been obtained?	No	Yes	Collected or enhanced
3.02	Has suitably accurate land elevation data been obtained?	No	Yes	Collected or enhanced
3.03	Do model extents and resolutions satisfy QCC recommendations?	No	Yes	Exceed
3.04	Are the hydrodynamic models adequately disclosed and described?	No	Basic	Comprehensive

First Pass Storm Tide Project Scoring Criteria		Score		
		1	2	3
3.05	Are critical coefficients and assumptions relevant to the study disclosed?	No	Yes	Comprehensive
3.06	Are example model outputs provided and explained?	No	Basic	Comprehensive
3.07	Are the models shown to be calibrated and/or verified in similar contexts?	No	Yes	Insitu
3.08	Is surge-tide interaction considered?	No	Yes	Modelled
3.09	Is storm tide coincident with surface waves modelled?	No	Yes	Comprehensive
3.10	Is surge-wave interaction considered?	No	Yes	Comprehensive
3.11	Is overland flow explicitly modelled?	No	Yes	Comprehensive
3.12	Is potential enhanced Greenhouse climate change considered?	No	MSL only	Interactions
3.13	Is freshwater river inflow considered?	No	N/A	Yes
3.14	Is morphological modification considered?	No	N/A	Yes
4	Statistical Modelling			
4.01	What is the basis of the statistical method?	Bayesian	MCM/JPM	EST or similar
4.02	Are statistics derived from parameterised or full model representations?	Interpolated	Parametric	Full models
4.03	Does the simulation period adequately cover the required ARI estimates?	No	Extrapolation	Yes
4.04	How are the various storm population risks considered?	Separate	Envelope	Comprehensive
4.05	Is coupled tide, surge and wave modelling represented?	Uncoupled	Surge + tide	Surge + tide + waves
4.06	Is freshwater river inflow considered?	No	N/A	Yes
4.07	Is there sensitivity testing of model assumptions?	No	Yes	Comprehensive
5	Risk Assessment			
5.01	Does the study provide storm tide estimates on an ARI basis?	No	Yes	Additional
5.02	Is wave setup or runup included in the estimates?	No	Setup	Setup and runup
6	Documentation and Presentation			
6.01	Does the study provide mapping?	No	Static	Dynamic
6.02	Does the study provide an electronic dataset and/or analysis tools?	No	Yes	Tools

Source: DSITI 2012, Table 2.

Table A3. Summary of model types, their outputs and performance. Single stars represent lowest performance with 5 stars being the highest performance

Model Type	Model Outputs	Ability to Replicate Processes	Ability to predict Horizontal Extent of Inundation	Ability to predict water level	Ability to model flow pathways, temporal changes and velocity	Ability to simulate foreshore evolution/erosion
OD	Horizontal extent of inundation and water depth.	★	★★★	★★	NA	NA
1D Inc WHAFIS	Horizontal extent of inundation, water depth and flow velocity.	★★	★★★	★★★	NA	★★★
quasi 2D	Horizontal extent of inundation, water depth and flow velocity.	★★	★★★	★★★	NA	NA
Raster Routing	Horizontal extent of inundation, water depth and flow velocity.	★★★	★★★	★★★	★★★	★
2D Finite-difference	Horizontal extent of inundation, water depth, flow velocity, flow pathways and time of inundation.	★★★ ★★	★★★ ★★	★★★ ★★	★★★ ★★	★
2D Finite-element	Horizontal extent of inundation, water depth, flow velocity, flow pathways and time of inundation.	★★★ ★★	★★★ ★★	★★★ ★★	★★★ ★★	★
2D Finite-volume	Horizontal extent of inundation, water depth, flow velocity, flow pathways and time of inundation.	★★★ ★★	★★★ ★★	★★★ ★★	★★★ ★★	★
3D Finite-difference	Horizontal extent of inundation, water depth, flow velocity, flow pathways and time of inundation.	★★★ ★★	★★★ ★★	★★★ ★★	★★★ ★★	★
3D Finite-element	Horizontal extent of inundation, water depth, flow velocity, flow pathways and time of inundation.	★★★ ★★	★★★ ★★	★★★ ★★	★★★ ★★	★
3D Finite-volume	Horizontal extent of inundation, water depth, flow velocity, flow pathways and time of inundation.	★★★ ★★	★★★ ★★	★★★ ★★	★★★ ★★	★

Model Type	Computational Efficiency	Financial Cost	Setup Time	User Expertise	Weaknesses
OD	★★★ ★★	★	★	★	Does not model flow pathways, temporal water level variations, or flow velocity.
1D Inc WHAFIS	★★★ ★★	★★★	★★★★	★★★ ★★	Cannot simulate inundation between 1D shore normal transects. Expertise required to select transects.
quasi 2D	★★★ ★★	★★★	★★★ ★★	★★★ ★★	Does not predict flow pathways. Expertise required to select transects.
Raster Routing	★★★★	★★★	★★★	★★★	Velocity flow data is typically not well reproduced.
2D Finite-difference	★★★	★★★★	★★★ ★★	★★★ ★★	Grid systems are not as flexible as irregular grids and must be expertly constructed in order to replicate complex coastal environments while maintaining computational efficiency.
2D Finite-element	★★★	★★★★	★★★ ★★	★★★ ★★	Flexible grid enabling detailed representation of complex environments while maintaining computational efficiency must be expertly constructed.
2D Finite-volume	★★★	★★★★	★★★ ★★	★★★ ★★	Flexible grid enabling detailed representation of complex environments while maintaining computational efficiency must be expertly constructed.
3D Finite-difference	★	★★★ ★★	★★★ ★★	★★★ ★★	These models are over-specified for the inundation problem.
3D Finite-element	★	★★★ ★★	★★★ ★★	★★★ ★★	These models are over-specified for the inundation problem.
3D Finite-volume	★	★★★ ★★	★★★ ★★	★★★ ★★	These models are over-specified for the inundation problem.

Source: Lee et al 2013, Table 2.

Table A4. Summary of Strengths and Weaknesses of Storm Tide Inundation Modelling Approaches

Model Type	Strengths	Weaknesses
OD	<ul style="list-style-type: none"> • Low cost. • Low computation time. • Simulates horizontal extent of Storm Tide Inundation. 	<ul style="list-style-type: none"> • No temporal data e.g. time of surge arrival or period of inundation. • Flow pathways are not stimulated. • No velocity data provided. • Horizontal Storm Tide Extent is typically over-estimated. • Overland wind-valves are not simulated.
ID Hydraulic	<ul style="list-style-type: none"> • Low cost. • Low computation time. • Can simulate inundation along fixed pathways. • Able to provide time series water level and velocity data a locations along the fixed pathways. 	<ul style="list-style-type: none"> • Typically employed for rivers, estuaries or harbours, not open coast surge inundation. • 1D transects unable to reflect 2-D terrain. • Manual interpolation of 1D results in 2D is subjective. • Overland wind waves are not modelled, excepting in the WHAFIS model (next row).
1D Wave	<ul style="list-style-type: none"> • Low cost. • Low computation time. • Simulates inundation water depths along shore normal transects. • Simulates overland wind waves. • Simulates horizontal extent of Storm Tide Inundation along shore normal transects. • Simulates the impact of vegetation and coastal structures on surge/wave propagation. • Can simulate dune erosion. • Model outputs include wave height analysis and wave runup. 	<ul style="list-style-type: none"> • Retraction, diffraction and bottom dissipation effects are not accounted for in initial wave height calculation. • Storm surge and wave behaviour are modelled independently, thus Base Flood Elevations may be over-or under-estimated. The approach for wave dissipation by vegetation, buildings, and levees has not been validated. • 1D transects cannot represent flow pathways as they do not reflect 2-D terrain. • Transect selection is subjective requiring detailed understanding of the site which may not be available. • Areas between cross-sections are not explicitly represented. • Manual interpolation of 1D results to two dimensions is subjective. • The erosion threshold for dune stability (50.2m2) has not been validated.

Model Type	Strengths	Weaknesses
Quasi 2D	<ul style="list-style-type: none"> • Low cost. • Low computation time. • Simulates horizontal extent of Storm Tide Inundation associated with storm tides propagating up coastal rivers or other water bodies with well-defined flow pathways. • Can be used to produce water level time series and velocity time series. 	<ul style="list-style-type: none"> • Poor representation of complex topographies and urban flood-prone areas. • Modelling of velocity is limited. • No studies available simulating propagation of storm surge overland along open coasts. • Considerable skill is required to select appropriate cross-sections. • Flood inundation extent is simulated either by extracting the values of water depth at each cross-section overlaying them into DEM or by linearly interpolating inundation extents at each cross section. • The action of wind waves overland is not accounted for.
Raster Routing	<ul style="list-style-type: none"> • Models require relatively little modelling experience. • Simple to set up and run. • Computationally efficient. • Readily integrated with commercial Geographic Information Systems. • Resolutions can be applied with capture important hydraulic and topographic features. • Can be used in steady-state or dynamic mode. 	<ul style="list-style-type: none"> • Accuracy dependent upon grid cell size and time step. • It is difficult to get the depth and inundation extent as well as travel time correct. • Velocity is not modelled. • Wind waves overland are not modelled. • Potentially long run times, depending upon grid cell size and time step.
2D regular grid	<ul style="list-style-type: none"> • Simulates 2D flow overland due to surge, tides and waves. • Can employ irregular boundary conditions. • Straight forward to apply a regular grid given a DEM. • Can model riverine flooding in concert with coastal inundation. • Numerically stable. • Stimulates spatial and temporal water level and velocity variations. • Able to simulate moving water boundaries. • Nested grid systems can be employed. 	<ul style="list-style-type: none"> • The coastline of a body of water can only be represented as a staircase in orthogonal coordinates. • Potentially long run times. • If using a curvilinear-orthogonal grid, model set up requires more time and a degree of expertise. • Higher monetary cost compared to simpler approaches.

Model Type	Strengths	Weaknesses
3D regular grid	<ul style="list-style-type: none"> • Simulates 3D flow overland due to storm surge, tides and waves. • Straight forward to apply a regular grid given a DEM and bathymetry data. 	<ul style="list-style-type: none"> • Over specified for coastal inundation problems. • Long computational times. • 3D modelling is financially the most expensive option. • The coastline of a body of water can only be represented as a staircase in orthogonal coordinates. • If using a curvilinear-orthogonal grid, model set up requires more time and a high degree of expense.
3D irregular grid	<ul style="list-style-type: none"> • Stimulates 3D flow overland due to storm surge, tides and waves. • Able to replicate complex coastal bathymetries/topographies. 	<ul style="list-style-type: none"> • Long computational times. • 3D modelling is financially the most expensive option. • 3D finite-element models can become unstable with simulating storm surge inundation. • Requires more time and a high degree of sophistication for grid generation and model setup than simpler approaches.
2D irregular grid	<ul style="list-style-type: none"> • Able to replicate complex coastlines, bathymetries and topographies. • Flexible mesh allows coarse resolutions offshore and fine resolutions nearshore/overland. • Can simulate 2D overland flow due to surge, tides and waves. • Can employ irregular boundary conditions. • Can model riverine flooding in concert with coastal inundation. • Simulates spatial and temporal water level and velocity variations. • Able to simulate moving water boundaries. 	<ul style="list-style-type: none"> • Requires more time and a high degree of sophistication for grid generation and model setup than simpler approaches. • Higher monetary cost compared to simpler approaches. • Potentially longer run times.
2D + 1D	<ul style="list-style-type: none"> • Able to simulate coastal inundation, riverine flooding, local overland flooding as well as inputs from sewer and stormwater networks. • Easy to apply regular grid for 2D domain. • Computationally efficient given the numerous processes modelled. • Able to simulate moving water boundaries. 	<ul style="list-style-type: none"> • Work involved in defining the link between 1D and 2D elements. • Potentially longer run times. • Higher monetary cost compared to simpler approaches. • No examples of 2D/1D models accounting for waves at present.

Source: Lee et al 2013, Table 1.

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