Department of Natural Resources, Mines and Energy

Guidelines for the construction or modification of category 2 and 3 levees

Version 2.0

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Queensland Government

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Version history

Version	Date	Comments
1.0	May 2014	New document
2.0	December 2018	Updated department reference. Amendments to be consistent with current water and planning legislation.

Approval

Position	Name	Date
A/Executive Director, Water Policy	Stephenie Hogan	Dec 2018

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1. Purpose

This document provides information to help proponents meet the requirements under the Planning Regulation 2017 (the regulation) for the construction and modification of category 2 and 3 levees. The document also provides general information to help proponents better understand the issues involved in design and management of levees.

The guidelines provide information relating to the following codes:

Code for assessment of development for construction or modification of particular levees (Schedule 10 of the Water Regulation 2016), and State Development Assessment Provisions (SDAP) State code 19: Category 3 levees. These guidelines are designed to be used by:

- landholders interested in constructing a new levee or modifying an existing levee
- suitably qualified persons engaged to design and construct a levee
- assessment managers from local government authorities
- consultants engaged by either proponents or local government authorities.

1.1 Use of the guideline

This guideline does not provide technical standards or detailed methodologies for the design, construction, modification or maintenance of levees. The detailed design and construction or modification of levees is recommended to be undertaken by suitably qualified persons with relevant professional experience and knowledge.

It is important to note that the guideline does not have any legal authority. They are designed to assist in the interpretation of the codes.

Any application to construct or modify a levee is required to comply with the codes listed above which override any information contained in this guideline.

2. Definition of a levee

2.1 Inclusion

The *Water Act 2000* defines a levee as:

> *A levee is an artificial embankment or structure which prevents or reduces the flow of overland flow water onto or from land.*

A levee includes levee-related infrastructure, which is defined as infrastructure that is:

a. connected with the construction or modification of the levee or

b. used in the operation of the levee to prevent or reduce the flow of overland flow water onto or from land.

2.2 Exclusion

The *Water Act 2000* lists a number of activities that are excluded from the definition of a levee, as follows:

a. prescribed farming activities

b. fill that is—

    i. deposited at a place for gardens or landscaping, including, for example, landscaping for the purposes of visual amenity or acoustic screening and

    ii. less than the volume of material prescribed under a regulation (prescribed as $50m^3$ in Section 100 of the Water Regulation 2016)

c. infrastructure used to safeguard life and property from the threat of coastal hazards

d. a structure regulated under another Act including, for example, the following—

    i. a levee constructed as emergency work under the Planning Act

    ii. a structure constructed under an approved plan under the *Soil Conservation Act 1986*

    iii. a structure whose design takes into account the impacts of flooding or flood mitigation but which is not primarily designed for flood mitigation

    Example——a public road within the meaning of the *Transport Infrastructure Act 1994*

    iv. a structure constructed within the bed, or across a bank, of a watercourse, including, for example, a weir or barrage, the construction of which was carried out under this Act and for which a development permit under the Planning Act was given

    v. an embankment or other structure constructed for long-term storage of water under the Water Supply Act

    Examples——a ring tank or dam

e. irrigation infrastructure that is not levee-related infrastructure.

Appendix C provides more information on the activities that are excluded from the definition of levees and where these activities may be captured by other legislation or regulations. Where there is uncertainty around whether an activity or structure is defined as a levee, the proponent should contact the assessment manager.

2.3 Levees that are constructed as emergency works

A levee is exempt from the regulation if it is constructed or modified because of an emergency endangering

(i) the life or health of a person;

(ii) the structural safety of a building; or

(iii) the operation or safety of community infrastructure that is not a building.

The person must give written notice to the assessing authority as soon as practicable after starting the development. This does not apply if the person is required by an enforcement notice or order to stop carrying out the development or use (*Planning Act 2016* section 168).

3. Construction or modification of levee

The guideline applies to the construction of new levees or the modification of existing levees. A new levee is a structure that is built where no pre-existing levees are in place for flood mitigation or other purposes.

An existing levee means a levee:

a) that

- was under construction when section 967 of the *Water Act 2000* commenced and
- has not been modified since the construction of the levee was completed or otherwise came to an end or

b) that was existing on the commencement and has not been modified since.

Modify, for an existing levee, means any or all of the following:

- to raise or lower the height of the levee
- to extend or reduce the length of the levee
- to make another change to the levee that affects the flow of water.

3.1 Calculating off-property impacts

An off-property impact means an impact caused by flooding as a result of the levee being constructed or modified. Off-property impacts are measured in terms of the hydraulic effects of the levee under a range of flood events that may include impacts on people, property or the environment beyond the property.

Level of off-property impacts will determine whether a proposed levee is subject to self-assessment or code/impact assessment. In calculating the off-property impacts requirements, category of levee will determine the type and level of assessment required as shown in table 3.1.

Table 3.1: Calculating off-property impact

Off-property impact	Category	Assessment type	Assessor
A levee in rural area that has no off-property impact	Category 1	Accepted development – self assessment	Applicant
A levee that has an off-property impact and for which the affected population is less than 3	Category 2	Assessable development - code assessment	Local Government
A levee that has an off-property impact and for which the affected population is at least 3 or more	Category 3	Assessable development - impact assessment	Local Government with Queensland Government as referral agency.

When conducting levee assessment for a range of flood events, the following area needs to be considered:

- potential changes to the flow path, flow velocity, flooded area or flood height of floodwaters or overland flow waters
- any incremental flood impacts
- other potential risks such as levee failure and climate change impacts.

Assessment of off-stream impacts of a levee is normally carried out by a suitably qualified person (e.g. Registered Professional Engineer of Queensland).

Refer to *Guidelines for the construction or modification of category 1 levees* for more information on how to calculate off-property impacts and determine whether the levee is subject to accepted development or code/impact assessment.

3.2 Calculating the affected population

For levees that have off-property impacts, the affected population will need to be calculated in order to classify the levee as category 2 or 3. Affected population, for a levee, means the total number of persons occupying all buildings on which the levee has a significant impact. Step 4 in section 5.4 provides more guidance in how to calculate the affected population.

3.3 Difference between category 2 and 3 levee assessment requirements

While both category 2 and 3 levees follow a similar process, the main differences in the assessment requirements are:

- Category 2 levees are code assessable development and need to comply with the performance outcomes 1 and 2 of the Code under Schedule 10 of the Water Regulation 2016..

- Category 3 levees are impact assessable development and need to comply with all performance outcomes of the Code under Schedule 10 of the Water Regulation 2016,as well as satisfy the SDAP State Code 19 and any assessment benchmarks and matters prescribed by the Planning Regulation (section 30 and 31).
- As impact assessable development under the *Planning Act 2016*, category 3 levees will also require public notification and the public has the option to make a properly made submission, which confers appeal rights to the submitter.

3.4 Engagement of a suitably qualified person

It is recommended that for all levees the levee proponent engage a suitably qualified person to assist in assessing off-property impacts, categorising the levee type and meeting the requirements of the codes. This person should be engaged as early as possible in the process.

A suitably qualified person is defined as a person with the necessary qualifications and experience to undertake risk assessments, hydrologic/hydraulic studies and/or the design, construction and management of a levee.

An example is a Registered Professional Engineer of Queensland (RPEQ) under the provisions of the *Professional Engineers Act 2002*, such as a civil engineer who has demonstrated competency and relevant experience in the hydraulic assessment and design and construction of levee banks or other flood infrastructure.

Such a suitably qualified person will have access to relevant Australian and international standards and expertise necessary to meet the code requirements.

4. Roles and responsibilities

There are typically many participants (individuals and organisations) involved in flood risk and levee management who need to interact and communicate in order to perform their relevant roles and responsibilities efficiently and effectively.

These roles may be filled by the same person (in the case of simple levees where the levee proponent, designer and constructor may be the same person) or in the case or larger, more complex levees, many different people or companies.

In this section, the focus is on roles and responsibilities rather than organisations because many variants are possible within individual organisations. For example:

- the organisation which owns the levee may also employ the designers and project managers
- the construction company may take responsibility for the design and the project management as well as for the construction itself.

Clearly defined roles and responsibilities are fundamental for efficient delivery of levee design and construction, and its sound management. The levee proponent or project manager should evaluate project needs, clarify roles and responsibilities and establish effective lines of communication.

It is recognised that these roles and responsibilities will not be applicable to assessments and applications for all levee categories.

4.1. Levee proponent

The levee proponent, landholder or levee owner has the responsibility of funding the impact assessment, design, construction, operation and maintenance of the levee over the design life, and communicating with the assessment manager (local council) and providing detailed information about the levee. It is recommended that a suitably qualified person is engaged to assist in this process. Should the levee asset be required to be maintained beyond the design life, it is the responsibility of the levee proponent to repeat the cycle of levee design and construction in perpetuity. Adequate records of assessments, design, construction and maintenance should form part of any levee asset management plan, and these records should be handed over when there is a change of ownership.

4.2 Applicant

For the purposes of these guidelines, it is assumed that the applicant is the levee proponent, landholder or levee owner. In some cases the applicant can be both the levee proponent and the designer. Also, the levee owner can delegate the application role to another party, but the responsibility of the application rests with the levee proponent.

4.3 Designer

A suitably qualified person (e.g. RPEQ) may be needed to certify the levee design if it is a category 2 or 3 levee. Under Queensland law, penalties apply if a professional engineer certifies a design or flood impact assessment that contains information that the engineer knows is false or misleading and does not disclose this (refer to the *Professional Engineers Act 2002*).

The designer will be responsible for the technical elements of the project, and will work closely with the levee proponent to ensure the relevant code requirements are properly addressed. The designer may also have responsibilities for checking that the constructor is complying with the contractual requirements including adherence to the design drawings and the specifications.

4.4 Project manager

The project manager must have sufficient knowledge and experience to manage a wide variety of disciplines. Good overall project management is crucial to the timely delivery of projects, but all team members must understand their roles and contribute accordingly to achieve success. Project managers should have an understanding of levee construction, risk identification, analysis and management and may have to manage conflicting requirements.

4.5 Constructor

The constructor is responsible for adhering to the design and specifications provided by the levee designer, project manager and levee proponent. The constructor must provide sufficient quality assurance documentation to satisfy the levee proponent and the assessment manager that the levee has been constructed to the technical requirements of the design and specifications. Employment of the levee designer or an independent certifying authority is often a means of achieving construction certification to ensure that the design intent is expressed in the construction methodology, and that the construction complies with the certified design.

4.6 Assessment manager

The assessment manager is responsible for assessing the levee application against the codes and then making a decision on whether to approve, approve with conditions or reject a proposal. Local governments are the assessment manager, although in some cases, the local government may choose to employ an independent expert to assist in the assessment process. The assessment manager has to review the hydrologic/hydraulic assessment, levee impacts and levee design, and has the power to accept, reject or require further review of design information. The assessment manager may require the levee proponent to provide additional information to assist in making the decision. If the assessment manager requires a review of the design, the levee proponent may need to review, correct or complete the design, have it re-certified by a suitably qualified person and re-submit the design to the assessment manager for approval.

If the levee design is accepted and the levee is category 2 or 3, then the assessment manager may impose conditions of approval to ensure that any ongoing safety concerns are addressed. This may take the form of regular inspections, operation and maintenance requirements or emergency management plans.

The assessment manager is also responsible for recording and maintaining the detailed information on levees (including notification forms on category 1 levees) submitted by the proponent.

4.7 Referral agency

Category 3 levees are referred to the Queensland Government for assessment against the SDAP State code 19. The levee proponent must forward a copy of the development application to the Department of State Development, Manufacturing, Infrastructure and Planning (DSDMIP) as the referral agency on behalf of Queensland Government who will assess the levee application and can approve, approve with conditions or reject a proposal based on whether it meets the State code.

5. Meeting the performance outcomes for Category 2 and 3 levees

This section provides guidance on how to address the performance outcomes in the Code under Schedule 10 of the Water Regulation 2016 and the SDAP *State Code 19*.

The performance outcomes of the codes are addressed within a broader step-by-step iterative process outlined here as a guide. The iterative process ensures that as more information is gathered, consultation undertaken and models run, the hydraulic assessments and design options are able to be adjusted. The process also ensures that relevant risks are considered. The series of steps has been provided as a guide for proponents with the statutory code requirements addressed in steps 6 to 9 (sections 5.6 to 5.9). A levee proponent or consultant may follow their own process as long as the code requirements are met.

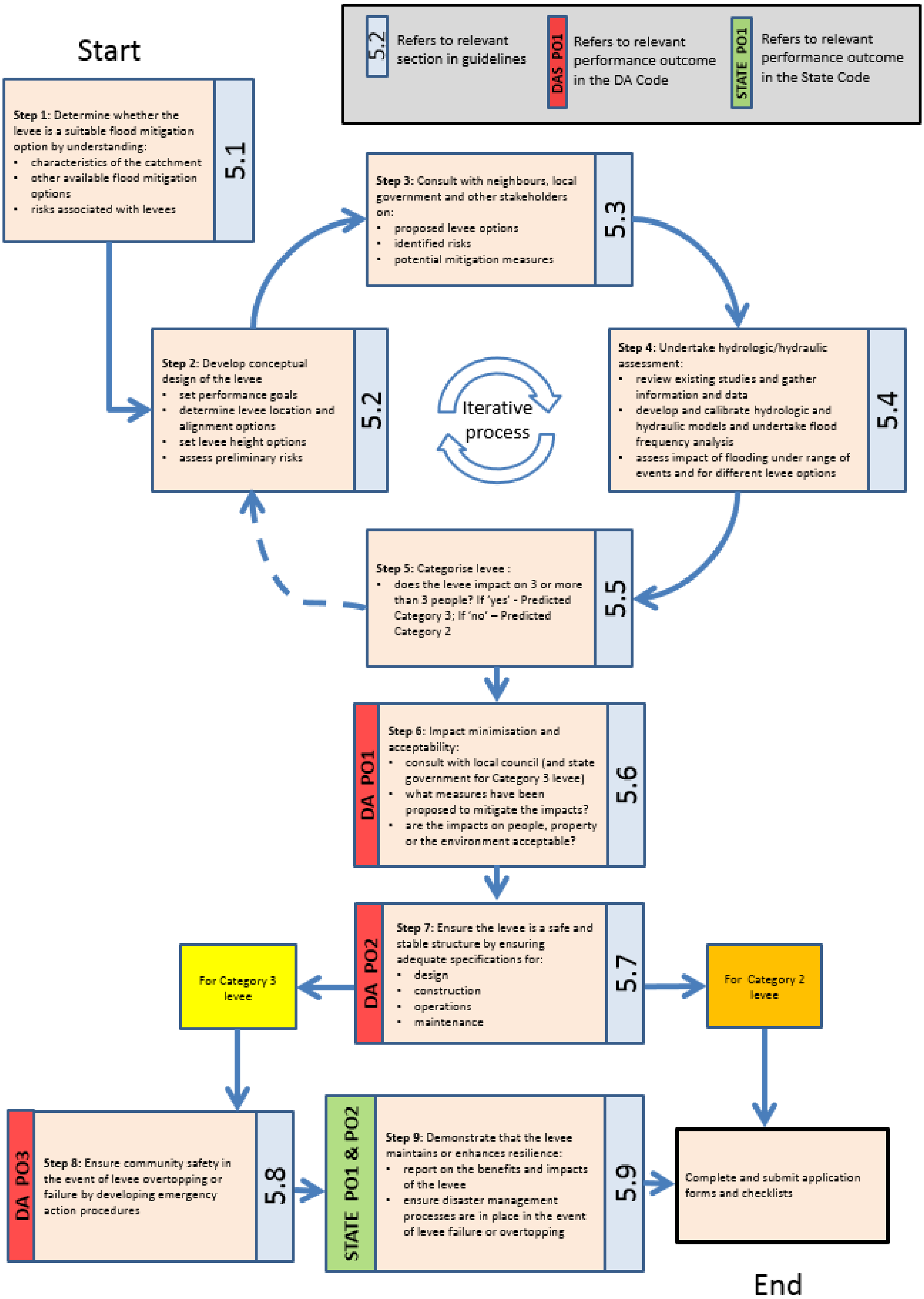
The codes comprise a set of requirements, including performance outcomes and acceptable outcomes. Acceptable outcomes represent ways of meeting the relevant performance outcomes. An application that complies with the applicable acceptable outcomes will satisfy the relevant performance outcome.

If an application does not comply with all acceptable outcomes or no acceptable outcome has been provided, the proposed development must comply with the relevant performance outcome in order to comply with the purpose of the code.

The steps are listed below with a summary provided in Figure 5.1. The performance outcomes of the Code under Schedule 10 of the Water Regulation 2016 and SDAP State code 19 are noted beside the relevant step:

- Step 1: Determine whether the levee is a suitable option for flood mitigation
- Step 2: Conceptual design phase
- Step 3: Consultation
- Step 4: Hydrologic/Hydraulic assessment
- Step 5: Levee categorisation
- Step 6: Impact minimisation and acceptability (Water Regulation code PO1)
- Step 7: Design specification, operations and maintenance (Water Regulation code PO2)
- Step 8: Emergency management (Water Regulation code PO3)
- Step 9: Resilience (SDAP State code 19 PO1 and PO2)

Figure 5.1: Application process for the construction or modification of category 2 and 3 levees



5.1 Step 1. Determine whether the levee is a suitable option for flood mitigation

The objective of step 1 is to ensure that the prospective levee applicant is aware of the implications of building or modifying a levee in the catchment, and in particular whether a levee is a suitable option to mitigate flood impacts. A levee can be an appropriate flood mitigation option, but the applicant should be aware of any negative impacts that may result from the levee and how these may be mitigated. The applicant should also be aware of the costs involved in designing, constructing and maintaining the levee over its design life.

This step involves gathering information on the catchment and understanding the role of levees and how they fit within the range of flood mitigation options. This step will provide the applicant with an understanding of the potential benefits and impacts of a levee and helps determine whether a levee is a suitable option for mitigating the effects of floods.

5.1.1 Understanding the catchment

Gaining an understanding of the catchment in which the levee is to be located is critical to deciding:

1. whether or not a levee is the best option to deal with flood events
2. the size, location and alignment/configuration of the levee.

This step involves gathering information and data on the topography, environment, geomorphology, hydrology and geology related to the site and catchment. The information gathered will also be used in subsequent steps as part of the conceptual design and detailed design of the levee.

The following is a list of site characterisation data that the applicant should gather where available to help determine the suitability of the levee option:

General site and catchment information
Geographical features: watercourses, wetlands, matters of state environmental significance, cropping lands, urban and rural areas
Structural features: dams, weirs, barrages, levees, ring tanks, roads, buildings and other infrastructure
Site constraints
Existing and future planned land uses and current and expected levels of development
Predominant soil types of the site
Typical flood event characteristics in the catchment, i.e. slow moving and long duration or fast rising and short duration
Gradient of the catchment

Flood heights where available, including largest known flood, key historical flood events, Probable Maximum Flood, design floods (e.g. Q100 or historical major floods including 2011 flood event)
Flood hazard level in the area

Sources of information that may assist in collecting catchment information include:

- Available reports and historical flood information.
- Local government floodplain management plans and other related reports.
- Queensland Reconstruction Authority mapping, aerial photography, satellite imagery and other applicable local knowledge (www.qldreconstruction.org.au).
- Consultation with relevant state and local authorities and local residents who have experienced flood events.
- Interim floodplain assessment overlay by Queensland Government.
- Topographic information from aerial imagery or field survey.

5.1.2 Levees as a flood mitigation option

Floodplain management involves a range of measures including land use planning, structural controls, development and building controls and flood emergency measures.

The *Floodplain Development Manual* (NSW State Government, 2005) identifies three categories of flood mitigation measures:

1. Flood modification, for example, structural measures such as flood control dams, levees, retarding basins, diversions and channel improvements
2. Property modification, for example, voluntary house purchase, voluntary house raising, flood proofing buildings and improving flood access
3. Response modification for example, flood warning system, evacuation strategies, recovery plans and community awareness.

The primary objective of structural measures, such as levees, is to provide protection against flood events.

Levees perform a vital role in reducing the flood risk for landholders and many communities in Queensland. Levees can provide protection up to a certain flood height in urban, peri-urban and rural areas. As part of a broader suite of floodplain management measures, levees can provide effective flood protection to urban areas, critical infrastructure, agricultural land and other property and assets.

Levees need to be planned, designed, constructed and maintained to appropriate standards if they are to reliably provide flood protection. Levees are often constructed to reduce the frequency of exposure of vulnerable communities to flooding and the associated impacts. The benefits of a ‘town’ levee can be significant as it can remove or at least significantly reduce the impacts of flooding up to the design event. These types of levees can save a community millions of dollars and the significant emotional and physical impacts of flooding.

Properly designed and constructed levees can also provide effective flood mitigation in rural areas. Levees can protect rural properties and buildings, cropping land and other agricultural areas and assets. These types of levees can be built on one property by a single landowner or across a number of properties in a joint effort by a number of landowners.

There are a number of inherent risks associated with levees. Levees are designed to divert floodwaters and overland flow water elsewhere. The *Queensland Floods Commission of Inquiry Final Report* (QFCoI, 2012) stated that levees influence flood flows and therefore can have the following types of impacts:

- they can concentrate flows leading to higher velocities, erosion of land, loss of crops, damaged irrigation infrastructure and damaged public infrastructure such as roads
- they may cause floods to take new directions and increase the flood risk in other areas
- if levee banks fail, damage may result to the area that they were intended to protect
- levees along a watercourse can create deeper flows and higher velocities in streams which increases the risk of bed and streambank erosion and can increase flooding problems for downstream properties.

Levees are designed to protect against a certain flood height. At some point in time levees will overtop as it is not commonly economically feasible to protect against the probable maximum flood. The result of a levee overtopping during large flood events is often flooding of the protected areas as well as exacerbated flooding of other areas. It is important to note that whilst levees provide a level of flood protection, a 'residual risk' of flooding always remains because it is probable that a flood exceeding the design flood occurs in the future, resulting in overtopping or failure of levees to serve its intended purpose.

The cumulative effects of levees can also be significant where a number of levees are constructed in a floodplain and should be considered. In a number of catchments in Queensland, levees have been built by a large number of property owners. The effect of a large number of levees in a catchment can be considerable upstream and downstream.

The financial and social benefits of a levee, whether it is built to protect one landholder or a community, must be weighed up against any potential environmental and social costs. Potential disadvantages of levees are:

- An increased risk to life and property when levees fail
- The potential to attract development in the area behind the levee without an understanding of the risks involved and sometimes leading to a vicious circle of increasing risk
- Local impacts (hydrologic/hydraulic, social, economic, environmental)
- Upstream and/or downstream impacts.

The management of levees must be seen alongside a broader range of activities such as land use planning and emergency preparedness that may reduce the flood risk. A whole of catchment perspective is recommended as part of any levee application. Since no two catchments are identical, there is no standard recipe of measures and instruments for reducing the flood risk.

5.1.3 Outcomes for category 2 and 3 levees

The information gathered in step 1 can be used in the conceptual design phase of the levee and in any pre-lodgement meetings with the assessment manager or consultation with neighbours. This step should enable the applicant to demonstrate that the levee is a suitable flood mitigation option.

For category 2 levees, the applicant may develop a brief report describing the proposed option for the levee, its benefits as well as risks and impacts.

For category 3 levees, the applicant may provide an appraisal report, signed off by a suitably qualified person. This appraisal report should describe the proposed option/s for the levee that have been considered, its benefits as well as risks and impacts. This report should address the potential social, economic and environmental impacts as well as the technical aspects of the proposed levee. The report should also address the requirements with regards to the community resilience.

5.1.4 Further information

Further information on floodplain management options can be found in the references below:

- *Floodplain Management in Australia. Best Practice Principles and Guidelines* (SCARM, 2000), Appendix B ‘Floodplain management measures’
- *Managing the floodplain: A guide to best practice in flood risk management in Australia* (Emergency Management Australia, 2013)
- *International Levees Handbook*, chapters 2, 3, 5 and 7, (CIRIA, 2013)
- *Floodplain Development Manual* (NSW State Government, 2005)
- *Planning for stronger, more resilient floodplains* (Queensland State Government Queensland Reconstruction Authority, 2011)
- *Emergency Management Practice Guide 3: Managing the Floodplain* (Emergency Management Australia, 1999).

5.2 Step 2. Conceptual design of the levee

The conceptual design phase allows options for location, alignment and size to be evaluated and compared, in order to identify the optimal levee solution. The outputs of this phase will feed into the detailed design phase.

The purpose of this step is for the applicant to confirm that the size, location and position are suitable for the purposes of the levee, compared to alternative alignments. This includes testing a number of options to find the solution that provides the necessary flood mitigation while minimising the impacts. This question is about the physical footprint of the levee and associated works, while other impacts, such as the direct and indirect impact on flood risk via the levee's hydraulic performance, are addressed in subsequent steps.

As part of the conceptual design, the applicant should set the performance-related goals of the levee. These will typically encapsulate the benefits that the levee will deliver to the landowner and community and could include:

- reduction of flood risk for the majority of affected parties and/or up to a fixed water level
- integration with local and regional development plans

- managing changes to the protected area, including provision of secondary benefits for recreation and environment.

Issues for consideration in this step include:

1. For new levees:
    a. the design limit and the estimated flood height that the levee will protect against
    b. the extent of the area to be protected
    c. a range of potential levee alignments
    d. the use of discrete elements (such as spillways) and other flood mitigation measures (such as channel diversions or temporary flood storage) at strategic locations
    e. a range of different levee cross-sections (such as distance from waterway, levee geometry and levee crest structures).
2. In addition, for modification of existing levees:
    a. local levee raising or repair, if required to bring a short section of the levee up to the same standard as the rest of the levee system
    b. general levee raising or strengthening, if required to deal with a perceived increased risk of flooding.

This step is often a process of brainstorming and consultation between the applicant and suitably qualified person to determine the options and risks for levee location and size. The final decision on the alignment and size of the levee is a balance or trade-off between the positive and negative aspects of each issue, and between the costs and benefits. The identification of risks will feed into the risk assessment as part of the next steps.

5.2.1 Considerations when setting the levee location and alignment

The first aspect of levee design is often the determination of the location of the levee, as this will determine the characteristics of the environment, including the hydraulic, geomorphic and ground conditions and social and environmental factors upstream and downstream. Careful early thinking about the levee location and alignment may avoid 'locked-in' problems when future adjustments are needed.

When determining the most suitable location, the following should be considered:

- existing development and land use, including existing levees in the catchment
- potential future development and land use
- proximity of the levee to rivers, wetlands and other watercourses
- proximity of the levee to existing high ground
- proximity of the levee to occupied buildings and critical infrastructure
- location of the levee in floodway, flood storage or flood fringe[1] area
- geomorphological processes

[1] These are defined in the glossary and based on the NSW Floodplain Management Manual, 2001

- potential hydraulic impacts
- cumulative impacts of levees and other structures in the catchment
- environmental benefits
- underlying ground conditions
- availability of suitable construction materials
- position or alignment in relation to the predominant flood flow path
- potential locations of spillways and temporary flood storage areas
- location and nature of existing utilities (surface, buried or aerial)
- expected design life of the levee.

It is important that the levee should not worsen the impact of a flood. In many instances, this will mean locating the levee not on river frontage, but setting it back a sufficient distance. Locating levees on frontages may also impact on native vegetation and require removal of trees although in some situations the only option is to build the levee along the river frontage.

5.2.2 Considerations when setting the levee height

The design limit of the levee is typically set early on in the design process because it relates closely to the need for intervention. The design limit does not necessarily correspond to the height of the levee. It is common for an additional freeboard to be added to the levee crest level to compensate for uncertainties in hydrological or hydraulic design, future settlement or to provide an extra margin against overtopping flow.

As a first step, the applicant should contact their local government to check whether a floodplain management plan (FMP) has been developed or whether there are any other plans or policies in place that will influence the height at which the levee can be built. The FMP will include flood levels and a design limit. Advice can be sought from the local government regarding appropriate design limits in relation to the design limits specified in the FMP.

In Queensland, the general standard for land use planning is based on providing protection against a one per cent annual exceedance probability (AEP) flood (or a 1 in 100 year average recurrence interval). This is the common standard for residential buildings for example. For levees, a one per cent AEP is common under normal circumstances, although in some cases a higher (e.g. for remote rural areas) or lower (e.g. for towns or urban areas or critical infrastructure) exceedance probability is used.

While the one per cent AEP may be a useful general guide, it is important that policy makers review this risk level and adopt a suitable flood probability based on an acceptable risk for different locations, land use and infrastructure in the floodplain. This review is particularly important given that new planning policies, design standards and assessment guidelines require potential future climate change impacts to be addressed. For more information, refer to the *Australian Rainfall and Runoff: A Guide to Flood Estimation*, © Commonwealth of Australia (Geoscience Australia), 2016 and *Planning for stronger, more resilient floodplains* (Queensland State Government Queensland Reconstruction Authority, 2011).

Higher standard or lower AEPs may be required for high risk levees, increased level of protection and enhanced resiliency to protect against much rarer and hence extreme events. Levees in relation to mining activities, for example, although exempt from this regulation, can be built to protect against a 1 in 1000 year flood event. This is primarily to protect against the flooding of a mine site and the risk of hazardous materials contaminating watercourses, ecosystems and infrastructure.

If no FMP covers the applicant's property, the applicant is responsible for setting their own design limit. The design limit should be appropriate for the potential consequences of flooding.

When selecting the design limit, the following factors need to be considered:

- safety
- resilience (for example to overtopping)
- required level of service or maintenance for hydraulic performance
- the need to reduce potential flood damage based on a risk assessment process
- regional planning goals
- maintenance requirements
- construction and operating costs
- legal and statutory requirements
- convenience or nuisance reduction requirements
- aesthetics.

Based on the design limit, it is possible to make an early estimate of the crest height and the associated approximate width. It is important to do this early in the design process in order to inform the corridor width. As part of establishing the corridor width for new levees or levee modification projects, where practical, consideration should be given to establishing no-construction zones that extend beyond the levee toes. These zones protect the levee from incursions and damage, make the process of levee inspections easier, provide easier access and working conditions in the case of an emergency or future maintenance and make the levee adaptable in case future developments require an increase to the levee's height and width.

5.2.3 Preliminary risk assessment

As options for size and alignment are considered, the potential impacts can be estimated. At this stage, the preliminary risk assessment can be qualitative. A comprehensive impact assessment will be undertaken as part of the detailed design phase.

The purpose of undertaking an initial impact assessment is to allow the applicant to discuss the implications of the levee construction or modification with local government, neighbours and other impacted parties. Depending on the risk assessment, the design, size and alignment of the levee options can then be adjusted if necessary, prior to starting a detailed design.

5.2.4 Outputs of the conceptual design phase

Recommended outputs for this step include:

- Performance-related goals of the levee
- Site map showing:
    - the location of the proposed works

- options considered including size and alignment
    - existing works that affect the flow of overland flow water and/or floodwaters
    - lot boundaries and descriptions
    - position of any watercourses and water bodies
    - position of any roads
    - position of neighbouring occupied buildings
- Qualitative assessment of the benefits and impacts for the selected levee options.

5.3 Step 3. Consultation

The conceptual design phase will provide information to allow the applicant to consult with neighbours, other potentially impacted parties and the local government. Informing these stakeholders of the intention to build the levee and its location and design options will allow feedback to be obtained before the more resource intensive and costly detailed design and hydraulic assessments are undertaken.

The opportunity for input by neighbours and local government may allow for alterations to the conceptual design that will minimise impacts on others and the environment. This may also avoid disagreement down the track when the application is submitted.

If agreement is not made with the neighbours on the conceptual design, there is an option to engage a mediator at this stage to find a suitable solution.

Consultation at this stage should focus on the outputs of the first two steps:

- the rationale for the levee as a suitable option for mitigating floods
- the levee size and alignment options under consideration
- the estimated extent of impacts from the different options
- any proposed mitigation measures to manage the expected impacts.

5.3.1 Pre-lodgement meeting with the assessment manager and referral agency

The applicant may wish to hold a pre-lodgement meeting with the relevant assessment manager from the local government and if applicable, the referral agency from the Queensland Government to discuss:

- the conceptual design options
- available hydrological and hydraulic models
- review the options and the associated benefits and costs
- the next steps and related expectations and costs.

It may be helpful as part of the pre-lodgement meeting to prepare a justification report describing the height of the flood that the levee will protect against and the benefits that the preferred location and alignment will deliver, such as the size of the area that is protected and the protected assets or property. The report can also describe the alternatives for the size, location and position that have been considered and why the proposed alignment is a suitable solution. Basic maps and details can be used to demonstrate the options and final alignment of the levee.

The results of any consultation undertaken should also be discussed at this stage.

The purpose of this step is to seek early input from the assessment manager on the design and location of the levee. This is to ensure that, where applicable, the following aspects are identified and discussed:

- relevant floodplain management plans, studies and models
- land use planning implications
- preliminary levee size, location and alignment (including the levee category)
- appropriate consultation requirements
- potential impacts and mitigation measures
- emergency response requirements.

A separate pre-lodgement meeting with the Queensland Government via the State Assessment and Referral Agency (SARA) will also identify and discuss:

- additional state assessment referrals required (e.g. clearing native vegetation, waterway barrier works) including fees
- potential considerations for meeting SDAP Code 19: Category 3 levees (where relevant).

Issues that need to be addressed in the detailed design phase will be identified at this stage. The meeting will enable the applicant to discuss options and implications with the assessment manager (and Referral Agency), prior to undertaking the more resource intensive and expensive detailed design phase. This step will provide the applicant with an indication of the suitability of the application and an understanding of their requirements and responsibilities under the Development Assessment System.

It should be noted that this step will not guarantee approval of the application once the detailed design is complete. Preliminary support may be given at this stage by the assessment manager, but the approval of the development application will be subject to the outcomes of the detailed design phase, comprehensive risk assessment, levee categorisation, as well as the requirements under Water Regulation code and the SDAP State code (if applicable).

5.4 Step 4. Hydrologic/Hydraulic assessment

During the detailed design phase the design criteria are finalised and further site assessment and modelling is undertaken to establish the hydraulic and geotechnical conditions for design and to analyse the impacts of the levee.

Similar to the conceptual design phase, this step will be an iterative process between the design options, impact identification and mitigation measures. Consultation with local government, neighbours and other impacted parties should also occur throughout this phase as more information is gathered and the impacts are better understood.

The detailed design phase is comprised of the following elements:

- a hydrological/hydraulic assessment which will be used to help determine the assessable development category

- impact mitigation options to ensure the impacts are minimised and acceptable
- design, construction, operation and maintenance specifications.

The level of complexity of the assessment will be dependent upon the likely risk the levee poses and the data available. These issues could be discussed at the pre-lodgement meeting and possibly at an initial meeting with a suitably qualified person engaged to conduct hydrologic/hydraulic assessment.

This step will involve the use of design standards and codes of practice where necessary, and a list of these is included in the references section in Appendix B. A suitably qualified person will also have access to relevant standards and expertise for levee design and construction.

Sufficient site data is needed, including ground investigation works to establish a conceptual site model and geotechnical parameters for the full detailed design of the levee.

The hydrologic/hydraulic study of the levee, also referred to as a flood study or impact assessment, includes modelling to determine what changes in water level, velocity and flow direction will occur as a result of building the levee. The assessment will help to answer the following questions:

- Does the levee increase flood risk elsewhere.
- Is the increase acceptable.
- Will the increase be mitigated and how.

5.4.1 Contents of a hydrologic/hydraulic assessment

The differences between a hydraulic and hydrologic assessment are as follows:

- A hydrologic assessment is the study of water and its constituents as they move through the natural processes that constitute the hydrological cycle (i.e. rainfall, runoff, evaporation, infiltration).
- A hydraulic assessment is the study of the flow of water in waterways, in particular, the evaluation of flow parameters such as water level, extent and velocity.

The detail and technical complexity of a hydrologic/hydraulic report will be proportional to the scale and potential significance of the levee project. The suitably qualified person will have sufficient experience to judge the detail and complexity of the study.

The following requirements are a guide to what a hydrologic/hydraulic study should include:

- Background site data
    - catchment and sitemaps
    - photographs
    - information on geographical and structural features
- Existing / historic data
    - rainfall and streamflow gauging
    - map with historical flood marks, flood extents and depths of flood events
    - flood information (anecdotal, photographic, survey)
    - recorded data
- Methodologies

  - adopted hydrologic and hydraulic modelling methods
  - appropriate input data, calibrated and validated to observed/recorded data (gauging station levels / historical (epigraphic) flood levels)
  - design river flood flows and/or flow hydrographs
  - joint probability analysis (if appropriate)
  - appropriate sensitivity analysis (e.g. climate change)
- Elements of a hydraulic assessment
  - identification of the source/type of potential flooding
  - assessment of appropriate design flows and levels at the subject site and upstream and downstream of the site
  - plan extent, depth and any flood pathway indicated on a map for appropriate return periods
  - assessment of likely rate of inundation, and associated flooding of specific features
  - plans and description of structures that may influence hydraulics
  - hydraulic information on any culverts or drains (existing or proposed)
  - estimates of climate variability impacts on probabilities, flood depths and extents
  - impact of the levee on flooding elsewhere (upstream, downstream and adjacent areas)
  - contribution of the levee to cumulative impacts on a catchment or sub-catchment scale
  - an assessment of the potential impacts on the environment (ecology, habitat, morphology).
- Conclusions—the report should conclude with a summary of the findings and how, in the applicant's view, these comply with the requirements of the code and the appropriate regulations.

5.4.2 Modelling

The hydraulic model developed for the levee must be capable of accurately determining flood levels, extents, residual time and velocities for given flow conditions. Where possible, the model should be integrated with existing models in the catchment.

There are a range of techniques and assessments that could be carried out by the applicant or, as recommended, by a suitably qualified person.

For hydrological assessment these include:

- Site-specific flood frequency analysis
- Regional flood frequency
- Hydrological (rainfall/runoff) modelling

For hydraulic assessment these include:

- Simple Manning's calculations
- 1D steady state hydraulic modelling (e.g. HEC-RAS)
- 2D fully hydrodynamic modelling (e.g. MIKE-21, TUFLOW, RMA-2)

For levees that pose a significant risk, it is recommended that robust hydrological investigations are carried out including (depending on data availability and quality) a combination of flood frequency analysis and rainfall / runoff modelling and for hydraulic modelling detailed 2D hydrodynamic modelling is carried out to define:

- peak flood water levels
- flow distribution on the floodplain
- velocity distribution on the floodplain and channel(s).

For a detailed review and guidance on the current best-practice flood estimation techniques, reference should be made to Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M, Testoni I, (Editors) Australian Rainfall and Runoff: A Guide to Flood Estimation, © Commonwealth of Australia (Geoscience Australia), 2016.

5.4.3 Hydraulic assessment process

A typical hydraulic assessment process for a levee includes the following requirements:

- develop hydrologic and hydraulic models of the catchment
- assess the range of floods under the pre-levee conditions using the flood models
- assess the flooding associated with identified levee options using the flood models.

The levee proponent should consult relevant methodologies for hydraulic assessments. As an example, the steps that should be undertaken for a category 3 levee proposal are:

1. Review existing flood studies and available models
2. Collect available data
3. Develop and calibrate a hydrologic model for the catchment
4. Undertake a flood frequency analysis (FFA) where suitable data exists
5. Application of the hydrologic model, and reconciliation with the FFA results as appropriate, to derive design flood hydrographs for the 1 in 20, 50, 100, 200, 500, 1000 and 10000 year AEP design flood events, as well as the probable maximum flood design event
6. Develop hydraulic model for the catchment
7. Calibrate the hydraulic model (using same flood events as in hydrologic model)
8. Assess the extent and impact of flooding under existing floodplain conditions (pre-levee) for the range of design events described above
9. Assess the impact of flooding for the identified levee options.

The hydraulic assessment will feed into the next steps associated with impact assessment and detailed design.

5.4.4 Linking with existing models and studies

When undertaking a hydrological / hydraulic study the applicant should make best use of existing data studies and models. If existing studies and findings are relied upon in the application, both the applicant and assessment manager will need to be satisfied that the aims and objectives of the original studies are compatible with that of the required flood impact study for the levee application.

As part of the requirements for the *State Planning Policy* (Queensland State Government Department of Infrastructure, Local Government and Planning, 2017) local governments need to identify and map flood hazard areas. More information on the requirements can be found in the *State Planning Policy* and the accompanying *State Planning Policy – state interest guidance material: Natural hazards, risks and resilience - Flood* (Queensland State Government Department of State Development, Infrastructure, Local Government and Planning, 2017).

5.5 Step 5. Categorising the levee

The modelling and assessment undertaken in the previous step will provide the information necessary to categorise the levee.

The affected population will need to be calculated in order to classify the levee as category 2 or 3. Affected population, for a levee, means the total number of persons occupying all buildings on which the levee has a significant impact.

A significant impact on a building means:

- an increase, caused by the levee, of more than 5cm in the flow height of water over the floorboards of the building or
- an increase, caused by the levee, of more than 0.2m/s in the flow velocity of water over the height of the floorboards of the building.

An occupied building is a building normally occupied by people on a regular basis and with an allocated default population in line with Appendix E.

A levee can have varying levels of impact depending on the type of flood event. The models to determine the impact on occupied buildings should be run against a range of flood scenarios. This sensitivity analysis should be appropriate for the size and location of the levee. The flood events should include a range of floods up to the flood protection height of the levee and a range of events that exceed the levee height and result in overtopping.

The impact on buildings from a structural failure of the levee, such as a breach, does not need to be considered as part of the categorisation. Levee failure should be taken into account as part of the levee design and emergency management.

Because the impacts of a levee may differ across a range of flood events including overtopping, any occupied buildings that are impacted under the range of flood events should be included in the calculation. **This includes buildings within the protected area of the area and outside the protected area.**

The models should show the extent of inundation, flood heights and velocities associated with the different levee options and flood events. The incremental change to flow velocity and height will determine the number of occupied buildings that are affected by the construction or modification of the levee.

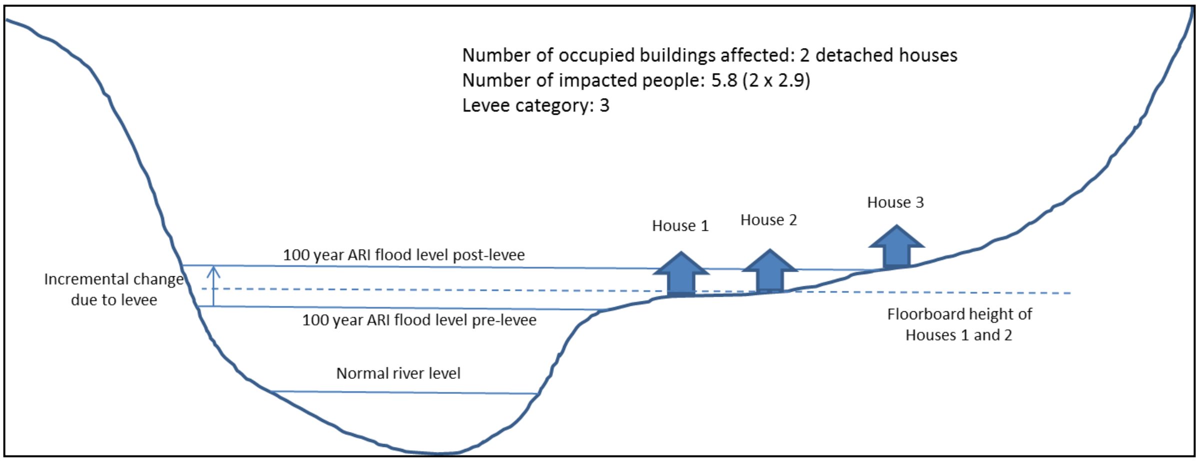
The incremental change is identified by comparing the results of the modelling of the flood extent and impacts under existing pre-levee conditions or before modification of the levee with the flood extent and impacts after the construction or modification of the levee. The number of occupied buildings affected by above floor flooding for pre and post levee will indicate the category of levee. Figure 5.2 shows a simplified illustration of the pre and post-levee impacts.

Using the default populations in Appendix E, if the number of impacted people is less than 3, the levee is a category 2 levee and code assessable. If the number of people is 3 or more, the levee is a category 3 levee and impact assessable. An example of a detached house is provided in the example below.

Detached house example

A detached house has a default population of 2.9 people according to Appendix E. If more than one detached house is impacted by the levee, this will trigger a category 3 levee designation. If there is one detached house and no other occupied buildings impacted by the levee, the levee is a category 2 levee.

Figure 5.2: Simplified illustration showing number of impacted people



5.6 Step 6. Impact minimisation and acceptability (Water Regulation code PO1)

This step addresses the first performance outcome of the development assessment code as shown in the table below.

The levee proponent is advised to seek guidance from their local council as the assessment manager on the specific expectations with regards to the level of analysis and the information to be provided to allow an assessment to be undertaken.

Performance outcome	Acceptable outcome
1 Any off-property impacts from the levee are minimised and acceptable having regard to the following— • the environment in which the levee is located	The levee does not result in— a) an unacceptable change in hydraulic effects that occur off-property and b) an unacceptable impact on people, property or the environment

Performance outcome	Acceptable outcome
• the measures proposed to be taken to mitigate any off-property impacts • any compensation measures for an impact proposed by the applicant	Note: It is recommended that a report by a suitably qualified person (e.g. RPEQ) identifying and assessing the hydraulic effects and impact on people, property and the environment under the proposed levee option/s across a range of flood events is provided.

Whether an impact on people or property or the change in hydraulic effects are acceptable or not depends on many factors. These factors include the context in which the levee is built, the measures put in place to mitigate the impacts, the extent of public consultation and any compensation measures that are put in place. The acceptability of a change will typically rely on a negotiation between the applicant, the assessment manager and any impacted parties.

The decision on the acceptability of the impacts is to be made by the assessment manager. These guidelines do not provide a set of rules that will determine the acceptability for all levees across the state. Instead, the guidelines provide a set of issues that the assessment manager may consider in the decision process.

To address the performance outcome, the levee proponent should consider providing information on the following:

- the benefits that the levee will provide to the landholder and the community
- the impacts of the levee on people, property and the environment, including any cross-jurisdictional impacts
- any mitigation measures to minimise or prevent potential impacts to land outside the property boundaries
- any compensation measures that have been agreed to between the landholder and impacted parties
- the extent of consultation with impacted parties
- the process undertaken to identify and test levee options, identify and minimise risk and why the preferred option was selected.

This performance outcome is about justifying why the levee is where it is, why the benefits outweigh the costs and detrimental impacts, and what measures have been taken to ensure impacts are minimised. The levee proponent should document community consultation processes, and if and how the levee design changed in response to community concerns.

Box 5.1 shows an example of risk assessment output that shows the number of occupied buildings, community infrastructure and environmental assets affected pre and post-levee. This type of output will assist the assessment manager in assessing the acceptability of the impacts in an objective manner. It is important that outputs are produced for a range of flood events to help determine the acceptability of the outcome.

Box 5.1**:** Example of model outputs

One way to demonstrate the benefits and impacts of the proposed levee is to prepare tables that show for each flood mitigation option and at a number of different flood events:

- occupied buildings, community infrastructure or environmental asset that do not flood with or without levee
- occupied buildings, community infrastructure or environmental asset that are saved from flooding by the levee
- occupied buildings, community infrastructure or environmental asset that now flood due to the levee
- occupied buildings, community infrastructure or environmental asset that flood with or without the levee

The risk assessment of the levee, including identification of the risks to people, property and the environment, will form a critical part of the requirement for this performance outcome. Box 5.2 provides a summary of the risk assessment of a levee as defined in the *International Levees Handbook* (CIRIA, 2013).

Box 5.2: Risk assessment of a levee (from *International Levees Handbook*, CIRIA, 2013)

Any risk identification process should consider the following factors:

- Loading conditions (floods and other hydro-meteorological events) and their likelihood/probabilities
- Likelihood of flood inundation without a levee breach (i.e. loading event exceeds levee crest and/or due to hydraulic or non-structural failure)
- Levee condition and its probability of breach under load (i.e. levee reliability) resulting in inundation
- Characteristics of floodplain and inundation (depth, velocity, geographical extent, etc.)
- Nature, extent and vulnerability of receptors (human, environmental, economic) to inundation
- Existing risk control mechanisms and measures and their effectiveness (e.g. emergency response)
- Uncertainty in knowledge about and data on the above factors.

5.7 Step 7. Design specification, operations and maintenance (Water Regulation code PO2)

Performance outcome 2 of the development assessment code deals with the design and construction standards to which the levee is to be built or modified, as well as sound operation and maintenance of the levee throughout its life, based on appropriate engineering standards and practices.

Performance outcome	Acceptable outcome
2 The levee is a safe and stable structure	The design, construction, operation and maintenance for the levee is appropriate for the materials used and the levee's intended function Note: It is recommended that a report by a suitably qualified person (e.g. RPEQ) describing the design and construction of the levee, and a levee operations and maintenance manual is provided.

5.7.1 Design specification and standards

The response to this performance outcome requires a demonstration that the proposed levee will provide an appropriate resistance against failure during construction, during flood events up to the design level and during the period immediately after a flood event.

This section lists the general design considerations and failure mechanisms to address this requirement. More detailed information can be found in Appendix D, the International Levees Handbook and other references and standards contained in Appendix B. Suitably qualified persons engaged by the proponent will have access to appropriate standards and manuals for meeting this requirement.

General design considerations include:

- levee alignment, crest level and cross-section
- ground conditions
- materials
- deterioration and serviceability
- transitions and other points of weakness (including potential failures and emergency spillway)
- designing for human-induced impacts
- levee construction method.
- Freeboard
- Factor of safety.

Failure mechanisms include:

- external erosion
- seepage
- internal erosion
- mass instability
- settlement
- burrowing animals
- seismic loading
- under seepage

- slope stability
- drainage
- preferred failure and diversion paths (including planned failure)
- permeability
- strength
- dispersiveness and erodibility
- compressibility
- foundation and batter surface treatments.

5.7.2 Operations and maintenance

Levees need to be properly maintained over their design life to ensure that they function as designed during a flood event. A suitable operations and maintenance manual would be required to achieve Acceptable Outcome 2. The assessment manager may also require as a condition of approval that the manual be updated following the final design and construction of the levee.

Setting the levee design life

The design life of the levee would have been part of the design considerations in the previous steps.

It is suggested that a minimum design life of 50 years is adopted for category 2 levees and a minimum design life of 100 years for category 3 levee. However, in some cases, a higher design life might be required, just like there might be cases where the applicant can justify a shorter design life. The following should be considered when setting the design life of a levee:

- the likelihood of significant land use change and redevelopments of existing urban and rural areas
- potential future changes to the levee's strength and loading in the initial design and construction
- a monitoring / inspection program and the reservation of sufficient space to enable future raising, widening or other adaptations, if required
- the design life of the other structures which form part of the levee, such as pipes and other drainage systems – these should equal or exceed the design life of the levee.

Operations and maintenance manual

An operations and maintenance manual (the manual) should include the following requirements (based on the *Levee Design, Construction and Maintenance manual* (Victoria State Government, 2002)):

- a statement of the original (and current) intended function and purpose of the levee
- the design details, including design flood levels, standard of protection, freeboard allowance, mode of failure and level of failure
- cross-sections
- 'as-built' drawings
- inspection schedule and requirements (periodical, during and after flood events)

- maintenance of vegetation (trees) and grass cover (grazing, mowing), control of fauna (animal burrows, cattle tracks) and vandalism
- consideration of the issue of deterioration (desiccation cracking, settlement, animal burrowing, etc.), including methods for inspecting, controlling, mitigating and/or repairing such deterioration
- details of levee-related structures, such as drainage systems and any temporary pumping that may be required
- a list of contact people and actions to be taken.

The manual should be more detailed in the description and intensity and frequency of levee inspections for higher risk levees. For example, category 3 levees may require 6-monthly periodical inspections and lower risk category 2 levee may require up to 5-yearly inspections.

The manual should be a living document. It should be updated periodically and all changes to the levee should be recorded and documented.

Inspections

Inspections should be conducted regularly and may be conducted relative to a flood event (pre-event, during the event, or immediately after the event). Depending on the category of levee, recommended inspections are given below (based on *International Levees Handbook*, CIRIA, 2013).

- **Initial inspections** should evaluate and document the condition of the entire levee soon after construction. The initial inspection helps to determine the existing system's capability of the existing system to perform satisfactorily under full hydraulic loading. Initial inspections should document all aspects of the levee system to set a baseline understanding for the condition of the overall levee system.
- **Routine inspections** should provide documented evidence that the levee continues to meet minimum acceptable standards for operations and maintenance, which relate to acceptable performance levels. Routine inspections are normally performed on a regular basis, for example once per year.
- **'Inflood' inspections** are performed while the system is loaded and are extremely valuable in identifying weak or susceptible areas that could lead to a potential future failure. These inspections could lead to planning emergency repairs and/or initiating population evacuation. In-flood inspections should only be undertaken if they can be done safely.
- **'Post-flood' inspections** are crucial in observing any damage which may have occurred and in evaluating the levee's ability to withstand a future loading event. This type of inspection is also used to validate, verify and to add to information collected during the flood event, and could identify the need for urgent remedial work.

5.8 Step 8. Emergency management (Water Regulation code PO3)

Performance outcome 3 of the development assessment code deals with emergency management. This requirement is only mandatory for category 3 levees. However, it is recommended that category 2 applicants also consider the applicability of the guidance provided here. It should be noted that all levee owners have the obligation for duty of care under common law. A levee owner's duty of care is their legal duty to take reasonable care so that others are not harmed. In the case where a levee has a reasonably high risk of harm, the levee owner must take reasonable care.

Emergency action procedures will need to be developed for the construction or modification of a category 3 levee. The assessment manager may require as a condition of approval that the procedures be updated following the final design and construction of the levee. These procedures may be incorporated in the operations and maintenance manual prepared in step 7.

The levee proponent will also be required to refer the procedures or plan to the local disaster management group for consideration and information.

Performance outcome	Acceptable outcome
3 Community safety is ensured in the event a category 3 levee fails or overtops	Appropriate emergency action procedures are in place for category 3 levees **Note:** It is recommended that a suitably qualified person (RPEQ) prepare the operations and maintenance manual including appropriate emergency procedures.

As levees create risks to people in the event of overtopping or failure, there is a need for planning around warning and evacuation. The possibility of individuals becoming isolated, stranded or being swept away in the event of breach or a complete levee failure must be considered and planned for. Appropriate emergency action procedures provide information to those with operational responsibilities about what to do and why and provide the detail about how it will be done. These procedures will typically take the form of an emergency action plan.

Emergency action procedures will be dependent on:

- the range of emergency conditions (e.g. overtopping, failure) that need to be considered
- the magnitude and extent of the potential consequences of those emergency conditions
- the measures that could be taken to reduce the risk of those emergency conditions developing
- the communication that is needed with persons whose safety or property may be threatened by emergency conditions.

Emergency action procedures or plan can include:

- scenario planning—impacts of the range of emergency conditions; mapping of different scenarios to show extent and depth of flooding; resources required for response; identification of immediate and secondary actions
- communication and emergency warning protocols with the public and others with responsibilities under the procedures or plan
- identification of key personnel required to execute the procedures or plan, including their roles, delegation of authority, responsibilities and contact details
- evacuation planning including assembly and staging areas, evacuation routes and time required
- levee operation, maintenance and inspection regime

- surveillance during flood events to identify any faults that may be repairable and for ensuring early warning
- health and safety risks for surveillance and emergency services personnel
- supplies and materials that may be needed to support emergency operations
- details regarding training and exercising for the procedures or plan.

Further guidance on emergency management include:

- Emergency Management Queensland, 2012. Queensland Local Disaster Management Guidelines—*Disaster Management Act 2003*
- Emergency Management Australia, 1999*. Emergency Management Practice Guide 3: Managing the Floodplain*
- Relevant local government local disaster management plans and emergency management processes.

5.9 Step 9. Resilience (SDAP State code 19 PO1 and PO2)

Category 3 levees will need to meet the requirements of the Water Regulation code as well as the SDAP State code 19. Applications for Category 3 levees are referred to the Queensland Government for assessment against the State code. The State code requirements are listed below:

Performance outcome	Acceptable outcome
PO1 People and properties impacted by the category 3 levee have been made aware of the benefits and impacts created by the development.	AO1.1 A vulnerability and tolerability assessment report is provided. AND AO1.2 A report identifying the benefits and impacts to people and property under pre and post category 3 levee conditions across a range of flood event scenarios is provided. Note: The range of flood event scenarios addressed in the report should include all the following: 1. 10, 20, 30, 40, 50 and 100 year average recurrence interval (ARI) design events 2. design flood event 3. an overtopping scenario that will result in the largest impact on people and properties as a result of the category 3 levee's construction.
PO2 Appropriate disaster management processes are in place to maintain or enhance the resilience of the community in the event of levee failure or overtopping.	AO2.1 A levee operations and maintenance manual is provided. Note: It is recommended that a Registered Professional Engineer of Queensland (RPEQ) prepare the operations and maintenance manual.

	AND AO2.2 The emergency action plan in the Local Government's Local Disaster Management Plan is updated to reflect changes as a result of the category 3 levee.

The matter of interest to the state is whether the category 3 levee will maintain or enhance community resilience. Resilience means the ability to adapt to changing conditions and to prepare, withstand and recover from disruption. For levees, the disruption refers to major flood events that result in overtopping of the levee or failure of the levee. The characteristics of a resilient community as defined in Planning for stronger, more resilient floodplains (Queensland State Government Queensland Reconstruction Authority, 2011) and the National Strategy for Disaster Resilience (NEMC, 2009) are:

- functioning well while under stress
- successful adaptation
- self-reliance
- social capacity.

The purpose of the SDAP state code is to ensure that the community's resilience to the impacts of flood events is maintained or enhanced by the category 3 levee. This includes an understanding of the flood risk prior to and after the construction or modification of a levee, integration of the levee into existing emergency and disaster management processes, appropriate planning for a flood event that overtops the levee or when the levee fails, an appropriate level of community consultation and awareness regarding the levee risks, and an evaluation and inspection process following major events.

By being prepared and ensuring the community is aware of the risks and what to do in a major flood event will help to avoid the common tendency for the public and responsible authorities to develop a false sense of security over time and to become complacent to flood risk due to the levee.

For the vulnerability and tolerability assessments, more information can be found in the *Planning for stronger, more resilient floodplains* publication, which refers to the key elements of assessing the consequence of a flood event, as follows:

Consequence = exposure + vulnerability – tolerability

For the purposes of this SDAP State code, these elements can be considered in relation to the consequence of the proposed levee construction or modification. Criteria associated with assessing the level of exposure of the community to the levee, particularly in the case of overtopping or failure, include the severity of the hazard, the size of the impacted population and the settlement pattern, land use and networks.

Vulnerability is defined as the degree of susceptibility of individual persons, the community and the environment to natural hazards, such as floods. To assess a community's resilience, it is imperative to understand the vulnerabilities inherent in the population at risk (Australian Government, 2012). A vulnerability assessment of a community impacted by a levee includes the following criteria:

- personal safety of those potentially impacted

- vulnerable persons
- property impact/built form
- isolation
- transport linkages
- critical infrastructure (e.g. hospitals, emergency services)
- other infrastructure and community services.

Assessment of the tolerability of the community to a flood hazard includes these key criteria:

- community awareness and education
- community attitudes and experience of flood
- insurance levels
- social networks and capacity
- socioeconomic status
- emergency plans and services, including evacuation routes and procedures
- emergency volunteers
- private and public business continuity.

The *Planning for stronger, more resilient floodplains* publication (Queensland State Government Queensland Reconstruction Authority, 2011) provides more information on considerations related to community resilience and floodplain management.

Appendix A: Glossary

Affected population: for a levee means the total number of persons occupying all buildings on which the levee has a significant impact.

Annual exceedance probability (AEP): probability of exceeding a specified flow or level in any one year (CIRIA, 2013).

Average recurrence interval (ARI): the average period in years between the occurrence of a flood of a given size or larger (SCARM, 2000).

Category 1 levee: a levee that has no off-property impact.

Category 2 levee: a levee—

a) that has an off-property impact

b) for which the affected population is less than three.

Category 3 levee: a levee—

a) that has an off-property impact

b) for which the affected population is at least three.

Defined flood event (DFE): the flood event selected for the management of flood hazard to new development. This is generally determined in floodplain management studies and incorporated in floodplain management plans. Selection of DFEs should be based on an understanding of flood behaviour, and the associated likelihood and consequences of flooding. It should also take into account the social, economic, environmental and cultural consequences associated with floods of different severities (SPP: State interest guideline: natural hazards, risk and resilience)..

Existing levee: means a levee—

a) that

   i. was under construction when section 967 of the *Water Act 2000* commenced

   ii. has not been modified since the construction of the levee was completed or otherwise came to an end

b) that was existing on the commencement and has not been modified since.

Flood: relatively high water levels caused by excessive rainfall, storm surge, dam break or a tsunami that overtop the natural or artificial banks of a stream, creek, river, estuary, lake or dam (SCARM, 2000).

Flood hazard area: refer to State Planning Policy 2017.

Flood protection height: the height of the maximum flood the levee is designed to protect against. The flood protection height should not include the freeboard.

Floodways: areas where a significant volume of water flows during floods and are often aligned with obvious natural channels. They are areas that, even if only partially blocked, would cause a significant redistribution of flood flow, which may in turn adversely affect other areas. They are often, but not necessarily, areas with deeper flow or areas where higher velocities occur (adopted from NSW Floodplain Management Manual, 2001).

Flood storage areas: the area of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood (adopted from NSW Floodplain Management Manual, 2001).

Flood fringe: the remaining area of land affected by flooding after floodway and flood storage areas have been defined. Development in flood fringe areas would not have any significant effect on the pattern of flood flows and/or flood levels (adopted from NSW Floodplain Management Manual, 2001).

Freeboard: the height above a defined flood level, typically used to provide a factor of safety. Freeboard compensates for effects such as wave action, localised hydraulic behaviour and settlement of levees, which increase flood levels or reduce the level of protection provided by levees. Freeboard should not be relied upon to provide protection for flood events larger that the DFE (SCARM, 2000).

Hydraulic assessment: the study of the flow of water in waterways, in particular, the evaluation of flow parameters such as water level, extent and velocity (SCARM, 2000).

Hydrologic assessment: the study of water and its constituents as they move through the natural processes that constitute the hydrological cycle (i.e. rainfall, runoff, evaporation, infiltration) (SCARM, 2000).

Irrigation infrastructure: water infrastructure or other infrastructure constructed, erected or installed for the supply of water or the storage and distribution of water for the irrigation of crops or pastures.

Examples of irrigation infrastructure—a supply channel, head ditch or tailwater drain

Landholder: includes owners or lessees of the land on which the levee is proposed to be constructed or modified. Also referred to as levee proponent.

Levee: an artificial embankment or structure which prevents or reduces the flow of overland flow water onto or from land. A levee includes levee-related infrastructure.

Levee property: (a) means the lot or parcel of land on which a levee is situated; and (b) includes another lot or parcel of land that is contiguous with the lot or parcel mentioned in (a) and owned by the same entity.

Levee-related infrastructure: means infrastructure, including irrigation infrastructure, that is—

a. connected with the construction or modification of the levee
b. used in the operation of the levee to prevent or reduce the flow of overland water onto or from land.

Examples of infrastructure for paragraph (b)—a channel, drain, outfall or pipe

Modify, for an existing levee, means any or all of the following:

- to raise or lower the height of the levee
- to extend or reduce the length of the levee
- to make another change to the levee that affects the flow of water.

Off-property impact: for a levee, means an impact the levee has on a people, property or the environment outside the levee property.

Overland flow water: Refer to Schedule 4 of the *Water Act 2000.*

Overtopping: passing of water over the top of a structure as a result of a water level higher than the crest of the structure (CIRIA, 2013).

Prescribed farming activities means—

a. cultivating soil

    Examples——clearing, replanting and broadacre ploughing

b. disturbing soil to establish non-indigenous grasses, legumes or forage cultivars

c. using land for horticulture or viticulture

d. laser levelling or contouring soil.

Probable Maximum Flood (PMF): the largest flood that could conceivably occur at a particular location. The PMF defines the extent of flood-prone land.

Property: refer to levee property definition

Registered Professional Engineer Queensland (RPEQ): means a person registered as a registered professional engineer under the *Professional Engineers Act 2002.*

Resilience: the ability to adapt to changing conditions and prepare for, withstand and rapidly recover from disruption.

Rural zone: refers to a zone in a local government planning scheme, see Schedule 2 of the Planning Regulation 2017

Significant impact, of a levee on a building, means each of the following:

a. an increase, caused by the levee, of more than 5cm in the flow height of water over the floorboards of the building

b. an increase, caused by the levee, of more than 0.2m/s in the flow velocity of water over the floorboards of the building.

Suitably qualified person: refer to section 4.4 of this guideline.

Watercourse: refer to the *Water Act 2000* section 5.

Vulnerability: the degree of susceptibility of individual persons, the community and the environment to natural hazards, such as floods.

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Appendix C: Activities excluded from the definition of levees

Activity	Definition	How activity is currently managed
1. Prescribed farming activities	a. cultivating soil or *Examples—* clearing, replanting and broadacre ploughing b. disturbing soil to establish non-indigenous grasses, legumes or forage cultivars or c. using land for horticulture or viticulture or d. laser levelling or contouring soil. Common or Dictionary definition applies to laser levelling.	• Prescribed farming activities are managed as in accordance with best practice guidelines. • Check with the relevant codes and best practices applicable in your Local Government area. Refer to the planning scheme of your council for further details.
2. Fill that is used in landscaping /visual amenity / acoustic screening.	Fill is not considered as a levee, if it uses less than a volume of 50m3 of fill material.	Cut and fill is often used to improve access, to provide useable outdoor spaces, to improve visual amenity and provide acoustic screening as in accordance with the best practice guidelines. For example 'Landscape Design requirements for Education Queensland School grounds'. Check with the relevant codes and best practices applicable in your Local Government area. Refer to the Planning Scheme of your Council for further details.
3. Infrastructure used to safeguard life and property from the threat of coastal hazards.	The infrastructure used to safeguard life and property from the threat of coastal hazards within coastal management district, includes coastal protection structures like seawalls and groynes. Dictionary definition applies for seawalls and groynes in *Coastal Protection and Management Act 1995*.	The primary purpose of such infrastructure is to prevent bank or beach erosion. Such infrastructure is assessed under Prescribed Tidal Works Code for development applications as assessable development. SDAP State Code 8: Coastal development and tidal works, or Code for accepted development, for tidal works or work completely or partly in a coastal management district of the Department of Environment and Science also applies here for the assessment of applications on such infrastructure construction.

Activity	Definition	How activity is currently managed
4. Structures constructed for emergency work.	(1) Levees or levee like structures could be constructed as emergency work by an applicant because of an emergency endangering: (i) the life or health of a person; or (ii) the structural safety of a building; or (iii) the operation or safety of community infrastructure that is not a building; and notify (written) the assessing authority as soon as practicable after starting the construction. (2) However, above provisions do not apply if the applicant is required by an enforcement notice or order to stop carrying out the development or use.	The primary purpose of the constructed structures (levees or levee-like) as emergency work is to protect life and property under emergency situations. Levees or levee like structures may be constructed as emergency work as in accordance with the best available engineering standards. An applicant undertaking an emergency development or use, would only be required to give written notice to the assessing authority as soon as practicable after starting the development or use (refer s.166 of the *Planning Act 2016*). An enforcement notice or order to stop carrying out the levee construction could be applied by the assessing authority, if a levee constructed under an emergency is not up to the engineering standards or non-complying with the code provisions.
5. A structure constructed under *Soil Conservation Act 1986 (*SC Act*).*	Structures under the SC Act are designed for the purpose of controlling erosion. Structures include contour banks, diversion banks and waterways.	A property plan details soil conservation works/measures required for an individual landholding. A property plan may be approved by delegated officers. A project plan consists of several properties within a defined catchment and coordinates runoff control works across land within a catchment including road/rail infrastructure. Chief Executive advertises a proposed project plan, review objections and make recommendations to the Governor-in-Council who then may approve the plan. Appeal provisions are available for both project and property plans.
6. A structure whose design takes into account the impacts of flooding or flood mitigation but which is not primarily designed for flood mitigation such as public roads	Roads and associated engineering structures designed and constructed under *Transport Infrastructure Act 1994* and Planning schemes of the local government.	The roads designed and constructed under *Transport Infrastructure Act 1994*, are being assessed under chapter 1 of the Department of Main Roads and Transport's Road Drainage Manual (RDM) for flood impacts. Council roads are assessed under the relevant codes of the Planning schemes, for flood impacts.

Activity	Definition	How activity is currently managed
		The provisions of the Queensland Urban Drainage Manual (QUDM) are also being applied to assess the flood impacts of these roads.
7. Structure regulated under *Environmental Protection Act 1994* (EP Act).	Dams or levees relating to resources operations are regulated structures constructed as part of environmentally relevant activities. Protecting human life and the environment requires that the standards used for the design, construction, operation, modification and decommissioning of regulated structures mitigate the consequences arising from potential failure or collapse of those structures. **Notes:** The term regulated structures includes land-based containment structures, levees, bunds and voids, but not a tank or container designed and constructed to an Australian Standard that deals with strength and structural integrity.	An environmental impact statement (EIS) is required for an environmentally relevant activity. Generic terms of reference for EIS provides for the description of current flood risk for a range of annual exceedance probabilities up to the probable maximum flood, for potentially affected waterways, and the assessment of (through flood modelling) how the project may potentially change flooding characteristics. The assessment should consider all infrastructure associated with the project including levees, roads and linear infrastructure and all proposed measures to avoid or minimise impacts. (Ref-section 8.6 of ToR). EIS lists and describe all dams or levees proposed on the project site and undertake an assessment to determine the hazard category of each dam or levee (low, significant, or high), according to the criteria in the EHP 'Manual for Assessing Hazard Categories and Hydraulic Performance of Dams'. Further, the potential risks to people and property that may be associated with the project in the form of a preliminary risk assessment for all components of the project under section 8.13 – 'Hazard and Safety 'in the ToR of EIS.
8. Structures constructed within the bed, or across a bank of a water course under *Water Act 2000*	Construction of weirs, barrages and dams across a water course that hinder or obstruct the flow of water in the watercourse. **Notes:** A watercourse is a river, creek or other stream, including a stream in the form of an anabranch or a tributary, in	The construction of weirs, barrages and dams are code assessed (SDAP State Code 10: Taking or interfering with Water) unless operations are mentioned as accepted development in a Water Plan or Water Management Protocol. It may be an exempt activities under the Riverine

Activity	Definition	How activity is currently managed
	which water flows permanently or intermittently, regardless of the frequency of flow events (Ref: Chapter 1 Part 2). The bed and banks of the watercourse typically consist of bedrock and very coarse material, including boulders, cobbles and gravel (Water Regulation 2016 Schedule 1). Weir means a barrier constructed across a watercourse below the outer banks of the watercourse that hinders or obstructs the flow of water in the watercourse weir means a barrier constructed across a watercourse below the outer banks of the watercourse that hinders or obstructs the flow of water in the watercourse.	Protection Permit Exemption Requirements.
9. Waterway barrier works	Waterway includes a river, creek, stream, watercourse or inlet of the sea. Waterway barrier works means a dam, weir or other barrier across a waterway if the barrier limits fish stock access and movement along a waterway (Ref-*Fisheries Act* 1994).	Operational work that is the construction or raising of waterway barrier works are code assessed (SDAP State Code 18: Constructing or raising waterway barrier works in fish habitats), other than operational work that is accepted development. (Accepted development requirements for operational work that is constructing or raising waterway barrier works).
10. A structure constructed for long term storage of water under the Water Supply Act	*Water Supply (Safety and Reliability) Act 2008* (WSA) provides for the regulation of referable dams constructed and maintained for the safety and reliability of water supply. Under section 341 of this Act: A dam is, or a proposed dam after its construction will be, a referable dam (dam is considered referable if it would threaten life if it failed.) if— (a) a failure impact assessment of the dam, or the proposed dam, is required to be carried out under this part; and (b) the assessment states the dam has, or the proposed dam after its construction will	Construction of a dam is subject to a development permit under the *Planning Act 2016*. The Water Supply Act provides for a determination of whether the proposed dam is referable or not. The failure assessment must be undertaken by a Registered Professional Engineer and is required for all dams exceeding the following criteria: • more than ten metres high, and • a storage capacity exceeding 1500 megalitres OR • more than ten metres high, and

Activity	Definition	How activity is currently managed
	have, a category 1 or category 2 failure impact rating; and (c) the chief executive has, under section 349, accepted the assessment	• a storage capacity exceeding 750 megalitres, and • a catchment area which is more than three times the reservoir surface area at full supply level.
11.Irrigation Infrastructure that is not levee-related infrastructure	Irrigation infrastructure means water infrastructure or other infrastructure constructed, erected or installed for the supply of water or the storage, distribution and application of water for the irrigation of crops or pastures. Examples of irrigation infrastructure— a supply channel, head ditch or tail water drain Irrigation channel means an artificial channel in which there is only water that is intended to be used for irrigation (Ref: Chemical Usage (Agricultural and Veterinary) Control Regulation 2017- Div 3 Sub Div 1 –Interpretation)	Irrigation infrastructure is managed at property level and the responsibility being on a landholder to carry out works and measures for flood mitigation. More information on certification of irrigation professionals is available on Irrigation Australia website

Appendix D: Levee design and failure mechanisms

This appendix provides more information on design and failure considerations. For more detailed information, consult the International Levees Handbook (CIRIA, 2013) or other relevant standards. A suitably qualified person should be engaged by the levee proponent for the levee design and construction.

D1 Design specifications

Levee geometry

Levee geometry can be controlled by many factors: stability during construction, performance during and after extreme events and by the minimum safe operational requirements for emergency access, maintenance and rehabilitation activities such as grass cutting. The critical geometrical features are crest level (or height above the surrounding land), crest width, side slopes (both water-side and landward side), and the dimensions of any berms.

The determination of the levee cross-section is the result of an optimisation process which starts with the geometry required by operational considerations and modifies the arrangement until a stable and serviceable configuration is achieved. Amongst other things, the cross sectional geometry will be affected by the available space (footprint of the levee) and factors related to the resistance to failure mechanisms.

Availability and suitability of materials

As part of the design process, it is necessary to check that the selected fill materials meet the performance requirements. Earthworks materials for levee construction are usually selected through a consideration of the characteristics of the on-site materials and those from potential borrow sources. Whilst the use of selected (idealised) imported materials for levee construction may offer the best engineering performance, cost and environmental constraints may require the use of locally available materials with lower performance levels. In this case the levee design will need to be adapted to suit the available materials. This may lead, for example, to a more conservative design geometry. It is good practice to identify approved primary material sources as well as secondary sources before the commencement of construction.

The results determined from preliminary investigations should be sufficient for design, but should be verified as required during the construction process through construction field data testing analysis and verification bores.

Material availability and the identification, management and operation of suitable borrow areas is an important part of the levee design process and requires consideration of impacts on the environment and on land values. In addition, the effect on levee performance (erosion, under-seepage, uplift pressures, overall levee stability, etc.) of any borrow pits located in the immediate vicinity of the levees should be evaluated.

It is advised that a suitably experienced construction contractor is involved in the selection of a suitable borrow area at as early a stage as is possible.

Intended function of the levee

The function of the levee is to provide an impermeable barrier to the passage of water (up to a design water level) and to channel the flow of water along the existing watercourse. To fulfil this function acceptably over the design life, the levee must be appropriately stable (against every potential failure mechanism, particularly at transitions), impermeable and durable.

D2 Failure mechanisms

External erosion

External erosion is the wearing away of a surface (bank, streambed, embankment, or other surface) by floods, waves, wind, or any other natural process (*Federal Guidelines for Dam Safety Glossary of Terms*, FEMA, 2004). External erosion is initiated by hydrodynamic forces acting on soil particles at the surface of a levee. It occurs when the surface material of the levee is not sufficiently resistant to erosion. That is, when the shear stress induced by flows, exceeds the critical value associated with the nature of the materials of the levee. This problem can arise over time because of the aging of surface materials, but it can also be due to an increasing effect of the environment on the levee (during floods, for instance).

The following mechanisms can result in external erosion:

- Overtopping leading to erosion of crest and landward slope.
- Hydraulic actions such as waves, currents and turbulence leading to erosion of waterward slope and toe.
- Human and animal damage such as cattle (tracks), vandalism, construction, collision (e.g. vessels and vehicles) leading to external erosion of the crest, side slopes and toe of levee.

Key considerations for overtopping to be addressed by the designer, include:

- levee crest level against design water surface profiles
- overtopping flow rate (q)
- landward slope steepness, top soil material and revetment properties
- maintenance regime employed.

An alternative local solution to reduce the effects of overtopping can be to include a ‘low point’ or spillway, to help control extreme situations in which a levee is overtopped by ensuring that the water overtops in the least vulnerable area, combined with sufficient drainage systems to get rid of the overtopped water.

The crest level of a levee is typically set by calculating the water level in the design limit event, and adding a certain additional height (termed ‘freeboard’) to take account of uncertainty. In setting the minimum crest level the following aspects need to be taken into account:

- design life
- future development (land use planning)
- settlement of subsoil and levee-related structures
- hydrological changes
- extreme flood events up to probable maximum flood (PMF).

Internal erosion

Internal erosion is initiated by hydrodynamic forces acting on soil particles inside or through the body of a levee. Internal erosion occurs when soil particles within a levee or its foundation, are carried downstream by seepage flow (CIGB-ICOLD, 2012). In this process, the migration of material particles is induced by elevated pore pressures and the flow of water through interstices in the soil or along channels opened by hydraulic separation. As a result, suffusion, backwards erosion and/or piping can occur, forming channels through the levee or through the foundation soils. These pipes can undermine the structure of the levee leading to crest settlement (and hence increased risk of overtopping) or to instability of the landward side of the levee (and hence possible failure and a breach.

The following mechanisms result in internal erosion:

- seepage
- suffusion
- hydraulic separation
- backwards erosion
- piping.

These mechanisms can be triggered by layers of permeable material within the levee or the levee foundation or by hydraulic separation (hydraulic fracture) along interfaces between soils and structural materials or different material types. Deterioration of the levee caused by animal burrows, desiccation cracks and tree or shrub roots, etc. can also trigger seepage and internal erosion.

Instability

Instability occurs when forces resisting failure (such as shear strength of the soils and the weight of any berm) are exceeded by the applied forces (the applied hydraulic actions, crest loads, the mass of the levee itself etc.). Excessive external loading on a levee (such as that due to a flood) and weak physical properties of the levee materials or the foundation soils, can generate sliding along a shear surface within the levee embankment and/or foundation soils. These processes are related to mechanisms such as rotational or translational sliding of the whole of the levee or part of the levee.

Particular levee failure mechanisms can include:

- levee failure during construction
- land side slope instability, particularly during a flood
- uplift of landward toe during a flood event leading to instability
- water side slope instability, particularly rapid drawdown after a flood
- liquefaction during a seismic event.

Deterioration and failure modes related to transitions

Earthen levees can be relatively flexible structures. This brings advantages in that they are able to settle and potentially distort as the underlying ground consolidates under their weight over time. However, this process of settlement will result in a lowering of the crest level and hence a reduced standard of defence. Particular problems can occur if the settlement is localised; this will result in differential settlement which could initiate cracking. The localised settlement will create a ‘low spot’ which will be vulnerable to the preferential overtopping which would occur at this location.

It is the role of the designer to determine the magnitude and location of settlement resulting from consolidation and compaction of the ground, to identify the possibility of differential settlement and to control these aspects of performance through appropriate design measures.

Performance problems can also be created if rigid structures such as crest walls, pipes and spillways are incorporated into the levee.

Problems that can be triggered by incorporating non-earthwork structures into levees include:

- differential settlement
- external erosion
- instability
- hydraulic separation.

Hydraulic separation is the potentially dangerous process by which a flow path is created (sometimes suddenly) between a rigid structure and poorly compacted or low strength fill material by the action of the pressure of the flood water. It is not straightforward to address, and thus the number of interfaces between rigid elements and fill should be minimised. Again, it is the designer's role to anticipate and address these issues as part of the design process.

D3 Modifications of existing levees

It has to be noted that some modifications that have a positive effect on one of the mechanisms, might have a negative influence on another mechanism. For example, when raising the crest level to reduce overtopping, the following has to be considered:

- The additional weight of the fill used for levee raising may have a destabilising effect on the existing levee, which could result in sliding of the land or waterward slope.
- The greatest thickness of fill material placed is often to the landward side of the original crest and this is the location where short term undrained failure mechanisms may initiate, e.g. during or shortly after construction.
- The magnitude of the settlement caused by the levee raising should be assessed and any anticipated differential settlement controlled by appropriate measures, such as careful control of the landward slope or the use of geofabrics.

A good connection between the existing levee and the new fill material is necessary to ensure that the new fill does not slide down the existing landward slope, and the interface between the old and the new fill does not create a path for seepage. One way to achieve this is to remove the existing topsoil and vegetation from the crest and the landward slope and then create a series of steps on which the new fill is deposited and compacted.

D4 Assessment considerations for failure mechanisms

This section describes specific assessment considerations for seven mechanisms and characteristics. Potential failure mechanisms, deterioration mechanisms and certain levee-related structures need to be recognised and managed by a combination of experience and calculation.

Responsibility of any levee remains with the levee applicant or designer and the constructor regardless of the levee category.

For high risk levees (Category 3) the assessments of the failure mode should always be signed off by a suitably qualified person.

Overflow and overtopping

The following issues should be considered in setting the crest level:

- design water level
- allowance for uncertainty ('freeboard')
- settlement for the design life
- changes in hydraulic and physical loads for the design life (e.g. with regards to climate variability and land use planning)
- overtopping flow rate in relation to landward slope erosion and discharge capacity.

Allowances for freeboard and settlement should be added to the target crest level.

The following activities should be used to confirm the required freeboard:

- detailed assessment of water level uncertainty to confirm that the likelihood of steady overflow in design conditions is acceptably small
- detailed assessment of wave run-up / overtopping, also in relation to the erosion resistance of crest and landward slope.

Slope Stability

Slope stability is dependent on many factors, including:

- types of material
- arrangement of material
- state of compaction of the materials
- nature of the foundation soils
- width of the levee
- hydraulic conditions during a flood.

The assessment of the slope stability always requires stability calculations. Different types of methods can be used to verify the stability, depending on the complexity of the levee and the perceived level of risk:

- Stability charts can be used to estimate the factor of safety of simple geometries and ground conditions.
- Hand calculations can be used to establish the stability of slopes against shallow slips.
- Limit equilibrium slope stability programs are widely used and recommended for category 2 and 3 levees. They allow the user to determine the factor of safety of complex geometrical arrangements, and extensive combinations of soil types, soil characteristics and ground water conditions. A critical slip surface is identified by determining the factor of safety for a large number of potential failure mechanisms and establishing the lowest one.

- Finite Element methods are based on a numerical continuum, which have the benefit of finding their own failure mechanisms. They can be highly sophisticated models but this can make them expensive to run and difficult to check.

The following questions should be considered:

- Has the stability during construction and after a flood event (rapid drawdown of the water level) been considered, besides the stability during the design flood.
- Is the schematisation of the subsurface based on (adequate) ground investigation (borings, in situ tests such as cone penetration tests, sampling, laboratory testing, etc.).
- Are the material properties (volume weight, cohesion and angle of internal fraction) based on soil testing, or have conservative properties been applied.
- Are the calculations based on appropriate water levels and pressures
- Are loads related to potential traffic and maintenance and emergency vehicles considered.
- Has construction material (cranes, trucks) been taken into account for calculating the stability during construction.

When all questions have been considered in the stability calculations, the calculated stability factors have to meet certain minimum safety factors. **Table D1** shows factors of safety based on the 'Global Factor Approach' from the *International Levees Handbook* (CIRIA, 2013) covering the factors used in the US. These factors are used in combination with moderately conservative parameters. Roads and Maritime Services in NSW uses safety factors 1.2 for construction and 1.5 for design events, but these are based on average (mean) parameters.

Table D1 Minimum safety factors for stability calculations

	Minimum factor of safety (FOS)		
	Stability during construction	Stability during design flood event	Stability following a flood (rapid drawdown)
Landward slope	1.3	1.4	n/a
Waterward slope	1.3	n/a	1.0–1.2

The stability calculations always should be carried out by a suitably qualified person.

Seismic loading and liquefaction

Earthquakes are not very common in Queensland, but they do occur (McCue, 1999). When the levee is proposed in an area where the ground peak acceleration (GPA)is smaller than 0.1g, the levee does not have to be further assessed for earthquakes.

One exception is when the levee height is bigger than 6m and/or the levee material of foundation soil has a cone penetration resistance (q_c) of smaller than 30 kPa, i.e. loose material such as sand. Loose cohesionless material could lead to liquefaction and may cause uncontrolled settlement or lateral displacement. In that case the GPA should be less than 0.05g to comply. Note: a levee should never be built out of loose granular material.

For guidance on how to define the PGA, refer to the *International Levee Handbook* (CIRIA, 2013).

The following should be considered when assessing the levee for the possible consequences of earthquakes:

- earthquakes are unlikely to occur at the same time as a flood
- main issue is extent of damage and speed of repair
- levee should not be built on liquefiable soils
- does the proposed levee material (partly) consist of loose granular material or is the levee founded on loose cohesionless material.

An analysis should be undertaken by a suitably qualified person to demonstrate that the levee is appropriately designed to withstand relevant earthquake loading.

Scour and fluvial erosion of waterward slope

The following issues should be considered as a minimum:

- Hydraulic actions such as waves, currents and turbulence can lead to erosion of the waterward slope and toe. Is the water body (e.g. river) on the water side of the levee narrow enough, so that hydraulic action can be neglected.
- If not, are the waterward toe and slope appropriately resistant against hydraulic action.
- Are wave attenuating measures proposed in front of the levee, such as emergent and submerged breakwaters, to limit wave run-up and overtopping.
- Are any hydraulic obstructions on the water side present (planned), such as trees, bridge piers, walls and pipes that could worsen local erosion or scour.

The potential for surface erosion or scour of a levee is determined by:

- calculating current velocities and/or wave action on the waterward levee face and overflow velocities or wave overtopping characteristics on the landward face
- comparing these values to allowable limits for the materials. Movement (erosion) can be expected if calculated values exceed allowable limits for the levee material or protection system.

Once it has been determined that erosion and/or scour is a concern for levee safety, it is necessary to consider measures that can reduce or mitigate the effects. Suitable references (e.g. CIRIA/CUR/CETMEF, 2007) should be consulted for further information on possible surface protection measures.

Seepage, internal erosion and piping

If there are no permeable layers (e.g. sand, gravel and peat) under the levee that could be in hydraulic connection with the source of water (on the waterward side), and the proposed levee material is not permeable, the risk of seepage and piping is negligible.

If permeable layers are present, a simple assessment method that could lead to compliance is the Method of Bligh (or Lane) (RWS, 2006).

The method depends on the material structure of the levee and its foundation soil. The following types can be used:

- Type 1: an embankment built out of clay or consisting of sand on poorly permeable subsoil (clay and peat layers).
- Type 2: an embankment built out of clay on permeable subsoil and the layers directly beneath the embankment's base / sole are permeable cover layers.

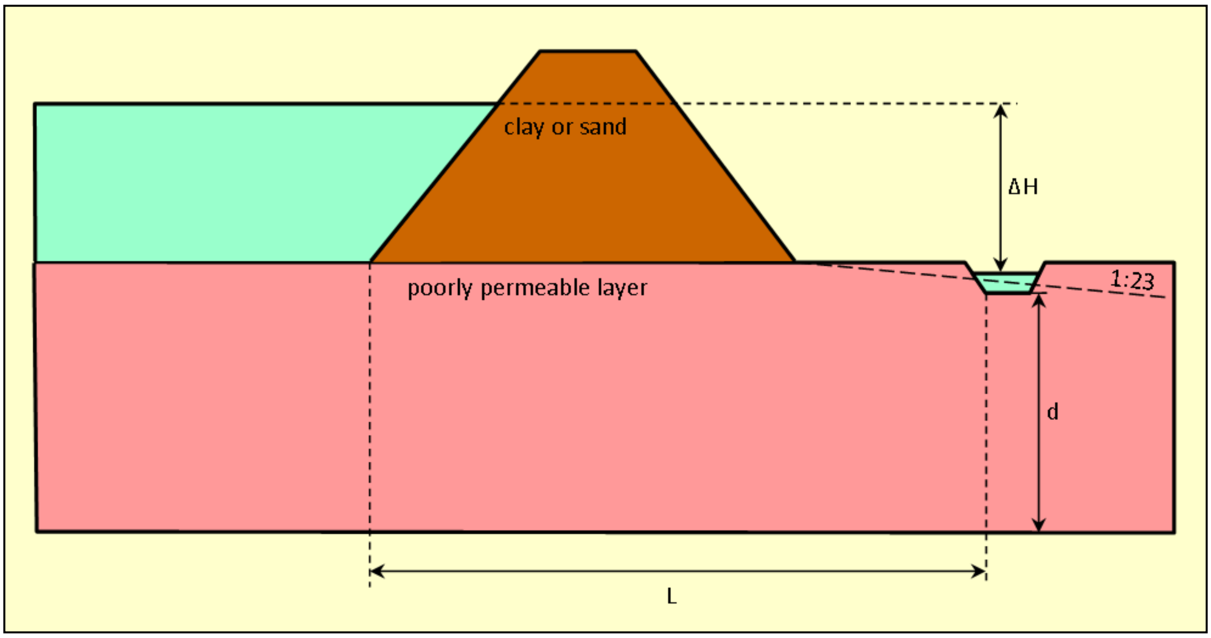
Type 1—**Figure D1** shows a schematic of the relevant dimensions for this type of embankment for the simple assessment. If the assessed embankment has such dimensions that it meets one of the requirements mentioned below, the probability of piping occurrence is negligible and the levee complies for this failure mode.

- Upward pressure safety (σ_g / σ_w) > 1.0
- $(L / 18) > \Delta H - (0.3*d)$

Where:

- $\sigma_g = \gamma_{ground} * d$ [kN/m^2 or kPa]
- $\sigma_w = \gamma_{water} * \Delta H$ [kN/m^2 or kPa]
- γ = specific or unit weight [kN/m^3]
- L = length of seepage path [m]
- ΔH = height difference between the assessment water level and the water level behind the levee (or ground level if there is no drainage ditch behind the levee) [m]
- d = thickness of low permeability layer near the 'water exit point' [m]

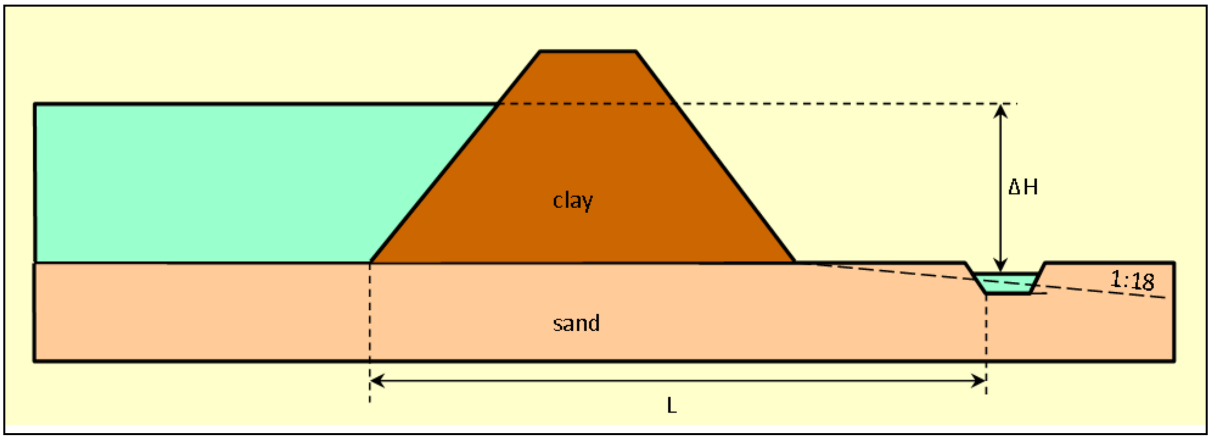
Figure D1: Simple assessment of piping for clay and sand embankments on poorly permeable subsoil with a drainage ditch



Type 2—**Figure D2** shows a schematic of the relevant dimensions for this group of embankments for simple assessment. This criterion for this type only considers the length of horizontal seepage path:

- $(L / 18) > \Delta H$

Figure D2: Simple assessment of piping for clay embankments on a permeable subsoil with a drainage ditch



A detailed assessment based on data collection may consist of:

- determining the embankment's subsoil configuration. The subsoil configuration is especially important in the case of uncertainty regarding the presence of layers sensitive to piping failure
- determining the thickness and permeability (or in combination: the hydraulic resistance) of the top layer on the water side of the levee
- determining the thickness and the weight of the top layer on the landward side of the levee
- determining the particle size distribution and the thickness of the aquifer
- model calibration based on response measurements.

Based on these methods, either a new simple assessment can be carried out or the calculation model has to be refined.

For the analysis of piping and 'heave', some situations may require the use of advanced groundwater flow models, such as:

- non steady-state groundwater flow models in situations with a relatively short period of high water (e.g. embankments in a tidal area, levees subject to infrequent floods of short duration (hours or days rather than weeks or months), etc.)
- spatial groundwater flow models (3D or quasi 3D) in situations for which geometry or layer configuration is not uniform in the direction of or perpendicular to the flood defence.

These methods require input from a suitably qualified person.

Composite levees

Has the interaction between soil (earthen levee) and the crest structure (e.g. asphalt paths and concrete revetment) been considered in terms of stability and durability over the design life. In particular, have the issues and impacts of differential settlement, differential displacement and hydraulic separation been considered, particularly in flood conditions.

Transitions

Has the following been considered:

- Have transitions of the levee with for example higher ground been considered.
- Have transitions of the levee with non-earthwork structures (e.g. spillways, pipes, drainage systems) been considered.

Note that failures of levees often happen around local irregularities and transitions. This is often caused by poor detailing of crest structures or transitions. These become points of weakness.

Pipes – The preferred solution is to carry the pipe or conduit over the levee and avoid disturbance of the levee body, even though this could still lead to external erosion. If this is not the case in the proposed design, the following issues should be considered:

- erosion due to increased turbulence
- leakage due to seepage and hydraulic separation
- differential settlement between levee and pipe
- seepage and internal erosion.

Crest walls and embedded walls—the following key issues should be considered:

- stability of both the composite structure and the crest structure itself, against overturning, sliding and rotational failure and seismic action
- differential settlements and movements, particularly during a flood which could lead to failure of the crest structure
- performance of the structure if overtopped, including external erosion of the levee body (this can remove the passive resistance of the crest structure leading to failure)
- external erosion of the levee body to landward or waterward leading to loss of support for the wall.

Appendix E: Default populations for occupied buildings[2]

Nature of buildings or other places of occupation	Equivalent population
Detached housing	2.9 per house
Semi-detached, row or terrace housing	2.0 per house
Multi-unit buildings	1.7 per unit
Blocks of flats	1.7 per flat
House or flat attached to a shop, office, etc.	2.5 per house or flat
Approved caravan parks	1.8 per caravan site
Approved camping grounds	0.45 per camping site
Hotel/motel accommodation	1.0 per bedroom
Child care centres	0.4 per child and staff member
Kindergartens, pre-schools	0.25 per student and staff member
Primary schools (day)	0.25 per student and staff member
High schools (day)	0.3 per student and staff member
Tertiary education centres Lectures—day Lectures—evening	 0.35 per student and staff member attending during the day 0.15 per student and staff member attending during the night
Offices	0.4 per employee
Restaurants	0.3 per member of staff and diners' places
Medical centres	1.7 per member of staff
Mines Total of all personnel working in inundated area where the path to escape the inundation will be cut-off by the incoming flows.	
Tavern/hotel bars	0.15 per m2 of patrons' area
Shops, shopping centres	2.0 per 100 m2 of gross area
Hospitals	1.0 per bed plus 0.33 times the total number of staff
Institutional accommodation	1.0 per bed plus 0.33 times the total number of staff
Service stations	0.4 times the total number of staff
Industrial buildings and other non-residential sites	0.4 times the total number of staff

[2] This is modified from the **Guidelines for Failure Impact Assessment of Water Dams**, Queensland Government Department of Natural Resources, Mines and Energy, 2018