Guidelines for Failure Impact Assessment of Water Dams

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Queensland
Government
Natural Resources
and **Mines**

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1 Introduction

There is community concern regarding the potential for medium to large dams, including ring tanks and some weirs, to fail and threaten lives. In the past dam safety has been regulated by the *Water Resources Act 1989*, with safety requirements incorporated into the conditions of waterworks licences issued under that Act.

New legislation, the *Water Act 2000*, which supersedes provisions of the *Water Resources Act 1989,* received assent on 13 September 2000. The dam safety provisions of the *Water Act* commenced on 19 April, 2002.

This new legislation changes the way in which referable dams are defined and regulated. Dam owners need to check whether their dam is subject to this legislation. The *Water Act 2000* requires owners of particular dams to assess the impacts of dam failure on the safety of people living downstream of the dam, by way of a 'dam failure impact assessment', to determine whether the dam is a referable dam. The new legislation also provides for regular ongoing assessment of the potential threat to people from unexpected flooding caused by a failure of one of these dams.

1.1 Dam Safety

Under the *Water Act 2000*, the chief executive of the Department of Natural Resources and Mines (NR&M) is responsible for the regulation of referable dams in Queensland.

The chief executive becomes involved in the assessment of applications for development permits that seek approvals to:

- build new referable dams or
- carry out works on existing referable dams that will increase the storage capacity of those dams by more than 10%.

The chief executive has the power under the *Integrated Planning Act 1997* to impose conditions relating to dam safety on development permits which approve the above dams and works. The development permits attach to the land where the referable dam is located and bind the owner, the owner's successors in title (ie future purchasers) and any occupier of the land.

The chief executive also has the power under the *Water Act 2000* to impose safety conditions on referable dams that have already been constructed. The chief executive can modify these conditions if the chief executive believes that the changes are in the interests of dam safety. Safety conditions are taken to form part of a development permit for the dam and can be imposed regardless of whether the dam owner already has a development permit for the dam. They attach to the land where the dam is located and bind the owner, the owner's successors in title (ie future purchasers) and any occupier of the land.

The chief executive can also give directions to take stated action to an owner or operator of a referable dam by issuing a written notice. Such a notice will only be issued if:

- there is a danger of the dam failing and
- action is necessary to prevent or minimise the impact of the failure.

These notices also attach to the land where the referable dam is located, binding the owner of the land at the time it is issued and any future owners.

1.2 Guidelines - Aims

The *'Guidelines for Failure Impact Assessment of Water Dams'* and *'Queensland Dam Safety Management Guidelines for Referable Dams'* have been developed to help owners comply with the *Water Act 2000* and dam safety conditions for referable dams (these include both conditions relating to dam safety imposed on development permits and safety conditions imposed under the *Water Act 2000*).

The *Guidelines for Failure Impact Assessment of Water Dams* provide information about:

- referable dams
- failure impact ratings
- dam failure impact assessment and how it is done
- certification of a dam failure impact assessment
- lodging a dam failure impact assessment for an existing dam
- lodging a dam failure impact assessment for a new or proposed dam
- lodging a dam failure impact assessment for works on an existing dam
- timing requirements for undertaking dam failure impact assessments
- processes for accepting, rejecting or reviewing a dam failure impact assessment
- responsibilities, penalties and provisions for appeals

More information on changes to the legislation and dam safety generally can be found in the *Queensland Dam Safety Management Guidelines*.

For further information on this guideline or the information outlined above, please contact:
Dam Safety (Water Supply)
Water Industry Compliance
Department of Natural Resources and Mines
Ph: (07) 3224 7215

www.nrm.qld.gov.au

2 Overview: Requirements of the legislation

2.1 What is a dam failure?

A dam is considered to have failed when:

- a part or all of the dam physically collapses. For example:
  - when the earth wall slumps
  - when part of the wall erodes when overtopped
  - when foundation weakness removes a section of a concrete dam wall or
- there is an uncontrolled release of any of the contents from the dam. For example:
  - when a gate or valve fails
  - when an outlet pipe breaks.

2.2 What is a dam failure impact assessment?

A dam failure impact assessment is the process used under the *Water Act 2000* to determine the number of people whose safety could be at risk should a dam fail (the "population at risk"). The results of the assessment are used to determine:

- whether a dam is referable and
- the failure impact rating of a dam.

2.3 What is a failure impact rating?

A failure impact rating is a measure of the population at risk should a dam fail. There are two categories:

- **Category 1 - Between 2 - 100 people** at risk by the dam failing.
  All category 1 dams are **referable dams** under the *Water Act 2000*.
- **Category 2 - More than 100 people** at risk by the dam failing.
  All category 2 dams are **referable dams** under the *Water Act 2000*.

If less than 2 people are at risk by the dam failing then the dam is not given a failure impact rating and is **not referable** under the *Water Act 2000*.

The chief executive imposes dam safety conditions on referable dams based partly on the failure impact rating. Dam safety conditions can be imposed either when a development permit relating to a referable dam is granted or, after the dam has been built (as safety conditions under the *Water Act 2000*, which are taken to form part of a development permit for the dam).

2.4 Who certifies a dam failure impact assessment as complete and accurate?

A written dam failure impact assessment must be certified by a registered professional engineer, which is a person, company or unit registered under the *Professional Engineers Act 1988* (Qld). He or she is responsible for certifying, as specified in these guidelines, the:

- accuracy and content of a dam failure impact assessment.
- adequacy and accuracy of the modelling used to calculate the population at risk.
- accuracy of the assessed population at risk and other matters.

An assessment cannot be certified by an engineer who is:

- the owner of the dam being assessed or
- an employee of the owner of the dam or
- the operator of the dam or
- an employee of the operator of the dam.

2.5 How do you do a dam failure impact assessment?

An assessment can be done using one of the following methods:

2.5.1 Two-dimensional flow analysis

This form of assessment is used if the population at risk is situated close to a possible dam breach(es) location(s) and there is a risk that the population will be inundated by water from the dam before it concentrates in downstream channels. This method is likely to be used for ring tanks.

2.5.2 Simplified Assessment

This might typically be used when the flow of water proceeds down well-defined channels and when there is little doubt regarding the level of population at risk. For example, it may be used when:

- the dam is large and located upstream from a major urban population and where it is clear that more than 100 people would suffer the impact of dam failure (ie the dam would have a category 2 failure impact rating) or
- the dam is small and there are no people at risk should the dam fail (ie the dam would not be a referable dam).

2.5.3 Comprehensive Assessment

This may be used when the flow of water proceeds down well-defined channels and when there is some uncertainty in estimates of the population at risk.

This is a detailed assessment and must include a dam break analysis for a range of dam failure scenarios such as overtopping, sabotage, seeping and piping failure.

A dam owner may choose to commission a comprehensive assessment even though a simplified assessment should be acceptable under these guidelines. However, the owner must undertake a comprehensive assessment if the registered professional engineer is:

- uncertain that the dam will have a category 1 or 2 failure impact rating and the owner wishes to justify the lower category 1 failure impact rating or
- uncertain that the dam will have a category 1 failure impact rating, or have no failure impact rating (ie it is not a referable dam), and the owner wishes to justify the dam not being referable.

2.6 Do I need to undertake an initial dam failure impact assessment to obtain a failure impact rating?

See Chart 1 (page 10).

Yes, if you are the owner of a dam which is not deemed to have a failure impact rating under a regulation, and the dam:

- exceeds, or will after its construction, exceed the height and storage criteria specified in the *Water Act 2000* (refer to 2.7) or
- is under notice from the chief executive to undertake a dam failure impact assessment (s.483(2) of the *Water Act 2000*). Notices will only be issued if the chief executive reasonably believes the dam will be given a category 1 or category 2 failure impact rating.

You do not have to undertake an initial dam failure impact assessment if your dam has been deemed to have a failure impact rating under a regulation.

2.7 Does my dam exceed the height and storage criteria specified in the Water Act 2000?

Yes, if your dam is, or after construction will be:

- more than 8 metres in height with a storage capacity of more than 500 megalitres or
- more than 8 metres in height with a storage capacity of more than 250 megalitres and a catchment area more than three times the maximum surface area of the dam at full supply level.

2.8 Do all dams that exceed the height and storage criteria specified in the Water Act 2000 require an initial dam failure impact assessment?

See Chart 1 (page 10).

Yes, unless it is:

- a dam which contains hazardous waste or
- a proposed dam which will contain hazardous waste or
- a weir that does not have a variable flow control structure on it's crest or
- a dam that has been deemed to have a failure impact rating under a regulation.

2.9 Do I need to undertake a dam failure impact assessment if I want to increase the storage capacity of my dam?

Yes, if either:

- you are the owner of an existing referable dam and
- you want to carry out operational work that will increase the storage capacity of that dam by more than 10% and
- your existing development permit for the dam does not authorise the carrying out of those works.

OR if:

- the dam did not previously exceed the height and storage criteria specified in the *Water Act 2000* (refer section 2.7) and the increase in dam size means that the dam will exceed the criteria.

2.10 What if I receive a notice from the chief executive to undertake a dam failure impact assessment?

You must comply with the notice.

The chief executive can issue a notice requiring the owner of an existing dam, or a dam being constructed, to undertake a dam failure impact assessment (s.483(2)). Notices will only be issued if the chief executive reasonably believes the dam will be given a category 1 or category 2 failure impact rating. Notices can be issued for dams that do not meet the height and storage criteria specified in the *Water Act 2000* (refer section 2.7). Notices can be issued for dams that have previously been failure impact assessed.

2.11 Who pays for dam failure impact assessments?

See also Responsibilities 3.1

- The chief executive will pay reasonable costs if a dam failure impact assessment was required because of a s.483(2) notice given by the chief executive, the assessment is accepted by the chief executive and in that assessment the dam is not given a failure impact rating (ie it is not a referable dam). Under such circumstances, the chief executive will pay the reasonable costs of:
  - preparing the assessment
  - certifying the assessment
  - any review of the assessment that occurs under the *Water Act 2000* (s. 489).
- In all other cases, the owner of the dam must pay the costs.

2.12 Who submits the dam failure impact assessment?

- The owner of the dam.

The owner must submit a written dam failure impact assessment certified by a registered professional engineer. The dam failure impact assessment must be carried out in accordance with these guidelines and clearly detail how the assessment was undertaken and justify the conclusion.

2.13 To whom does the owner submit the dam failure impact assessment?

See Charts 1 (page 10) and 2 (page 11)

- The chief executive.

2.14 When do I need to submit my initial dam failure impact assessment for my existing dam if my dam exceeds the specified height and storage criteria?

Unless the chief executive gives you a notice to have a dam failure impact assessment carried out earlier (under s.483(2)), the initial dam failure impact assessment must be done :

If your dam was not licenced under the *Water Resources Act 1989*:

- within 1 year after the commencement of the dam safety provisions of the *Water Act 2000*.

If your dam was licenced under the *Water Resources Act 1989*:

- within 5 years after the commencement of the dam safety provisions of the *Water Act 2000*.

You do not have to undertake an initial dam failure impact assessment if your dam exceeds the height and storage criteria specified in the *Water Act 2000* and your dam has been deemed to have a failure impact rating under a regulation.

2.15 When must I submit my dam failure impact assessment if I plan to construct a new dam that exceeds the height and storage criteria specified in the Water Act 2000?

See Chart 1 (page 10) and Responsibilities 3.4.

2.16 When must I submit my dam failure impact assessment if I plan to carry out works that will increase the storage capacity of my referable dam by more than 10%?

- You must ensure the dam failure impact assessment is completed, and accepted by the chief executive, before work begins.
- You must also obtain a development permit approving the works before starting work, and supply evidence of the accepted dam failure impact assessment with the application for the development permit.
- In some cases, the *Water Act 2000* will also require the chief executive to give written consent (as the water manager under the *Water Act 2000*) to the development application being made. Consent will be required in cases where a water entitlement is required to operate the dam. The entitlement could be a water allocation, an interim water allocation or a water licence.

2.17 How often do I need to undertake a dam failure impact assessment once I have my initial failure impact rating?

See Chart 1 (page 10).

Every 5 years if your dam:

- has a category 1 failure impact rating or
- is not given a failure impact rating in a dam failure impact assessment accepted by the chief executive, but your dam exceeds the specified height and storage criteria outlined in the *Water Act 2000* (refer to 2.7).

Each five-year period runs from the date the last assessment was accepted by the chief executive.

For dams deemed to have a failure impact rating under a regulation, the first five year period will start on the date of commencement of the dam safety provisions of the *Water Act 2000*.

A further dam failure impact assessment will also be required if your dam is a referable dam and you want to carry out operational work that will increase the storage capacity of the dam by more than 10% and the existing development permit for the dam does not authorise the carrying out of those works. This further assessment is required because of the application for the development permit for the works (ie permission to carry out the works) must be supported by evidence the chief executive has accepted a dam failure impact assessment for the dam.

A further dam failure impact assessment will also be required if you are given a notice to have your dam failure impact assessed by the chief executive (s.483(2)).

Five yearly dam failure impact assessments are not required if:

- your dam has a category 2 failure impact rating as it is considered unlikely that such a dam would be given a lower rating if reassessed
- the chief executive issued you with a notice under s.483(2) to have your dam failure impact assessed, the dam failure impact assessment is accepted by the chief executive, the dam is assessed as not having a category 1 or category 2 failure impact rating (ie it is not a referable dam), and the dam does not meet the specified height and storage criteria outlined in the *Water Act 2000*.

2.18 When must I submit my failure impact assessment if I receive a notice from the chief executive requiring me to undertake a dam failure impact assessment?

The notice you receive will state the date when the dam failure impact assessment must be submitted.

2.19 What details must be included in the written dam failure impact assessment?

See Section 5 on page 35 for a complete list.

However in general the assessment must include:

- general information (eg name of owner, operator, address, geographical location etc)
- catchment area details
- dam description
- data and analysis
- results of failure impact assessment (include detailed discussion)
- registered professional engineer's written certification

2.20 What happens to my dam failure impact assessment once it is submitted?

See Chart 2 (page 11) and Responsibilities 3.3

The chief executive (NR&M) can:

- accept a dam failure impact assessment or
- reject a dam failure impact assessment or
- require a review of a dam failure impact assessment.

A dam failure impact assessment may be rejected or a review of it may be required if it is:

- not completed in accordance with these guidelines
- incomplete in a material particular (eg the assessment is not certified by a registered professional engineer)
- incorrect in a material particular (eg the assessment did not take into account downstream residential development).

The owner of the dam will be given written notice of the chief executive's decision.

Before requiring a review of, or rejecting an assessment, the chief executive can request additional information about the assessment.

If a dam failure impact assessment is not initially accepted and is then reviewed, corrected or completed, it will need to be recertified and resubmitted.

Details of the process for accepting, rejecting or reviewing a dam failure impact assessment are presented in Chart 2 on page 11 (including the appeals process against the chief executive's decision).

2.21 What happens if I don't do a dam failure impact assessment as required?

See Responsibilities 3.1 & 3.2

A dam owner may be prosecuted for failing to comply with the *Water Act 2000* if he or she fails to carry out and submit a dam failure impact assessment as required. Penalties may also apply if a person gives information which is false or misleading to the registered professional engineer certifying the dam failure impact assessment or if the registered professional engineer certifies a dam failure impact assessment the engineer knows is false or misleading.

2.22 What happens to my waterworks licence issued under the Water Resources Act 1989?

For dams which are no longer referable:

Owners may find that their dam, which was referable under the *Water Resources Act 1989* and had a waterworks licence, is not referable under the *Water Act 2000*. However, take note that there may be certain waterworks licence conditions which still apply. For example:

- If your dam was licenced under the *Water Resources Act 1989* and is no longer considered to be a referable dam, conditions on the waterworks licence other than dam safety conditions may still continue to apply (eg conditions dealing with the interference with the flow of water in a watercourse continue to apply).
- If your dam contains hazardous waste it is not covered by the *Water Act 2000*. The Environmental Protection Agency will eventually deal with hazardous waste dams under the *Environmental Protection Act 1994*. However, until this occurs conditions (including dam safety conditions) that applied to your dam as part of the waterworks licence, continue to apply as if the *Water Resources Act 1989* was still in force.

For dams which are still referable:

If your dam was licenced under the *Water Resources Act 1989* and is still a referable dam under the *Water Act 2000*, the licence for that dam will be taken to be a development permit approving the dam. Any safety conditions issued as part of the existing waterworks licence continue to apply and form part of the development permit.

Chart 1:
How to determine if your dam is refereable and when a dam failure impact assessment is required

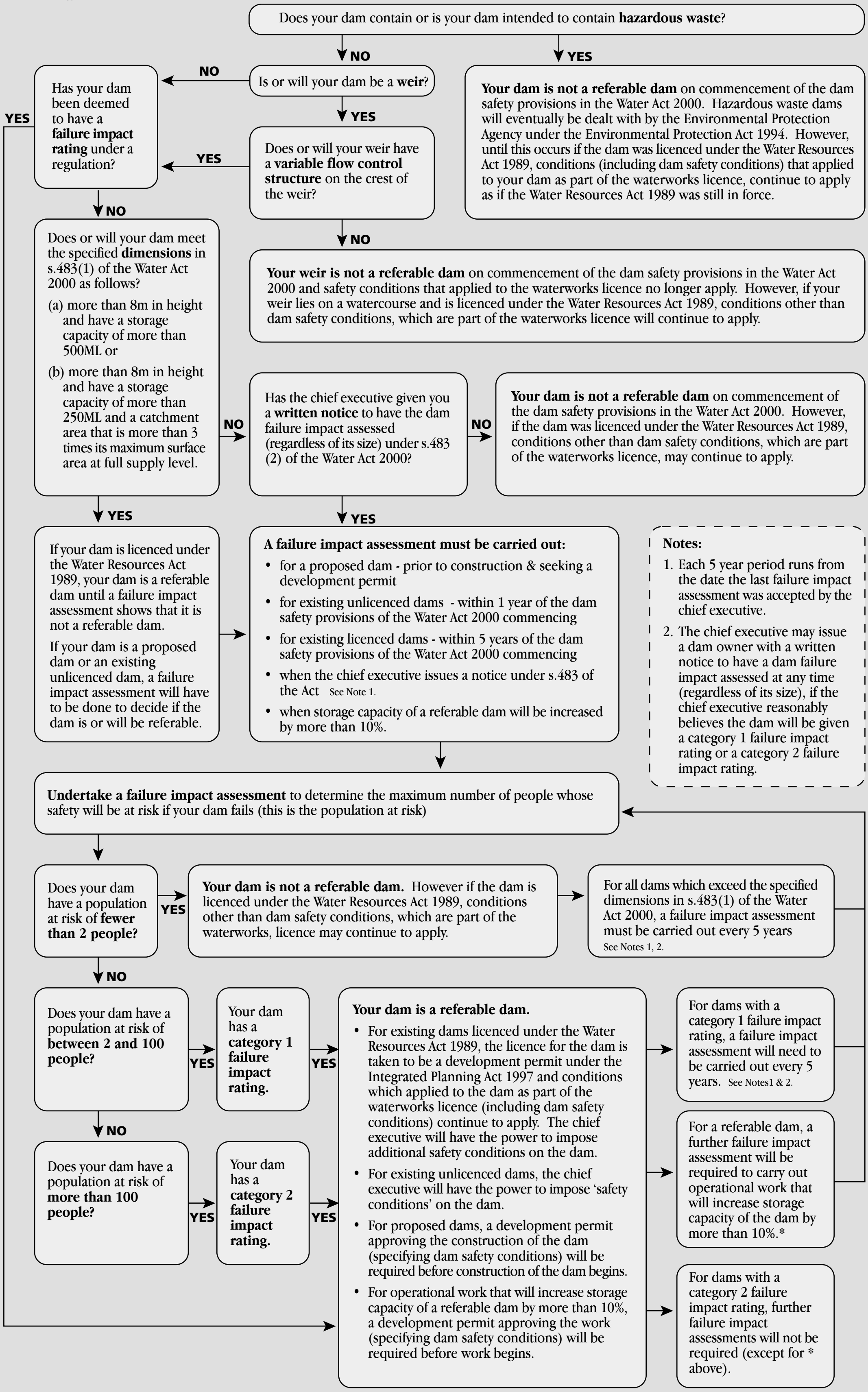

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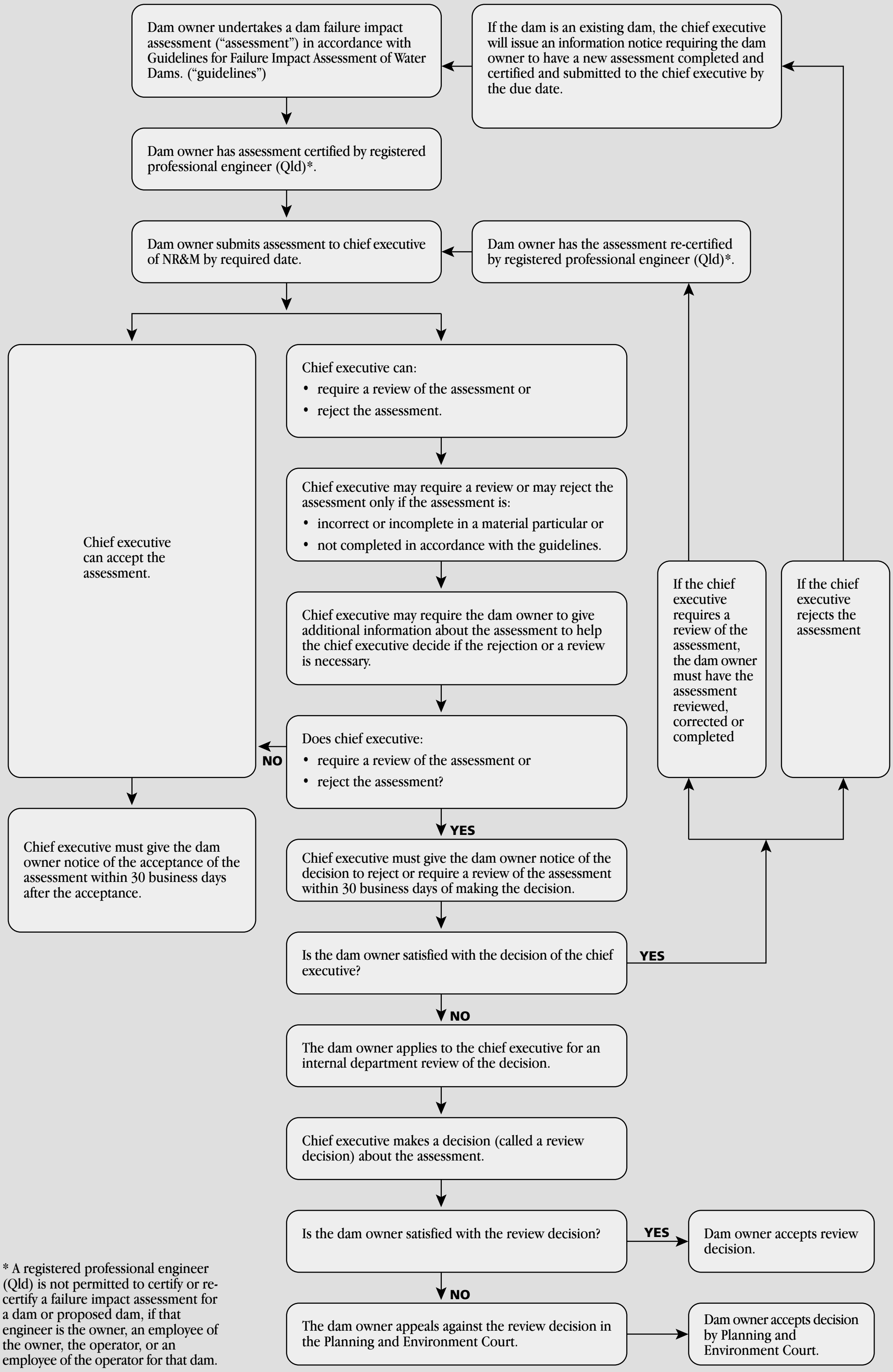
Chart 2:
Process for Accepting, Rejecting or Reviewing Dam Failure Impact Assessments



* A registered professional engineer (Qld) is not permitted to certify or re-certify a failure impact assessment for a dam or proposed dam, if that engineer is the owner, an employee of the owner, the operator, or an employee of the operator for that dam.

3 Responsibilities

3.1 Responsibility of the owner

An initial dam failure impact assessment must be undertaken by a dam owner if the dam is not deemed to have a failure impact rating under a regulation and:

- the dam exceeds the specified height and storage criteria outlined in the *Water Act 2000* (refer to 2.7) or
- the dam owner is issued with a notice by the chief executive (NR&M) under s.483(2) of the *Water Act 2000*.

The *Water Act 2000* sets out timing requirements for initial dam failure impact assessments (see Chart 1, page 10).

The *Water Act 2000* also sets out when further dam failure impact assessments are required (see Chart 1, page 10). Such assessment must be undertaken by a dam owner if:

- the dam is given a category 1 failure impact rating in an assessment accepted by the chief executive, or
- the dam is not given a failure impact rating in an assessment accepted by the chief executive, but the dam exceeds the height and storage criteria specified in the *Water Act 2000* or
- the dam owner is given a notice to have the dam failure impact assessed under s.483(2) or
- the dam is given a category 1 or category 2 failure impact rating in an assessment accepted by the chief executive, and the owner wants to carry out operational work that will increase the storage capacity of the dam by more than 10% and those works are not authorized by the existing development permit for the dam.

The owner of the dam must pay for a dam failure impact assessment, unless the chief executive requires the owner to carry out a dam failure impact assessment (under s.483(2) of the *Water Act 2000*) and subsequently the assessment is accepted by the chief executive and the dam is assessed as not being referable. In these circumstances, the chief executive must pay the reasonable cost of preparing and certifying the dam failure impact assessment.

The dam owner must obtain a development permit after the failure impact assessment is accepted by the chief executive, in certain situations (see 3.4 below).

Please note that the provisions of the *Water Act 2000* relating to referable dams and flood mitigation do not affect the liability of a dam owner or operator for any loss or damage caused by the failure of a dam or the escape of water from a dam.

3.2 Responsibility of the certifying engineer

A registered professional engineer must certify each written dam failure impact assessment. Penalties apply if a registered professional engineer certifies a dam failure impact assessment which contains information in that the registered professional engineer knows is false or misleading and the engineer does not disclose this.

The written certification must state:

- That the assessment has been prepared in accordance with these guidelines and that it is not based on information that the registered professional engineer knows is false or misleading

- That the certifying registered professional engineer is not the owner, an employee of the owner, the operator, or an employee of the operator of the dam being assessed
- That it is an accurate estimate of the population at risk and that the estimate is consistent with:
  - the detail and accuracy of the modelling used
  - the extent of the failure impact zone.
- The certifier's judgment of the appropriateness and accuracy of the information included in the assessment
- The certifier's view of the veracity of the information included in the assessment, as well as specifying the information on which the assessment was made
- That the certifier is satisfied that the inspection of the site has accounted for sufficient points of impact, covering the failure impact zone as a minimum, to justify the failure impact rating.
- That the certifier is satisfied with the locations of cross-sections and the intervals between those cross-sections for each individual numerical model generated for the dam failure impact assessment.

For dam failure impact assessments completed following an initial assessment accepted by the chief executive (ie the second and subsequent assessments), it may be permissible to use the same inundation data used in the previous assessment of the population at risk. However, the registered professional engineer's certification must include justification of this approach in the reassessment (refer to section 4.8 for details).

3.3 Responsibility of the chief executive

See Chart 2 (page 11)

The chief executive may accept, reject, or require a review of a dam failure impact assessment. If a dam failure impact assessment is accepted and the dam is referable (ie it has a category 1 or a category 2 failure impact reting), the chief executive may impose dam safety conditions on the dam. Dam safety conditions can be imposed either when the development permit for the dam or for works proposed to be undertaken on the dam is granted (as development permit conditions), or after the dam has been built (as safety conditions).

The chief executive may reject or require a review of a dam failure impact assessment if the assessment:

- has not been completed in accordance with these guidelines or
- is incomplete in a material particular (eg the assessment is not certified by a registered professional engineer) or
- is incorrect in a material particular (eg the assessment did not take account of downstream residential development). [1]

The chief executive may require the dam owner to supply additional information to assist in the decision to reject or require a review of the assessment.

The owner of the dam will be given written notice within 30 business days of a decision being made to accept, reject or require a review of a dam failure impact assessment.

If the chief executive requires a review of the assessment, the dam owner must review, correct or complete the dam failure impact assessment, have it re-certified by a registered professional engineer and resubmit the assessment by the required date specified.

1 The chief executive reserves the right to check the accuracy of an assessment, although the certifying registered professional engineer retains responsibility for the accuracy of the assessment.

If the chief executive rejects an assessment relating to an existing dam, the dam owner must prepare a new dam failure impact assessment, have it certified by a registered professional engineer and submit the assessment by the required date specified.

If the chief executive rejects an assessment relating to a proposed dam, the dam owner will not be required to complete a new assessment by a specified date. However, if the proposed dam meets the height and storage criterion outlined in the *Water Act 2000* (refer section 2.7), it will still be nesessary for the dam owner to obtain an accepted failure impact assessment before

(a) a properly made application for a development permit is made, and
(b) before construction of the dam begins

A dam owner may apply to the chief executive for an internal departmental review of the decision, if the chief executive requires a review of, or rejects, a dam failure impact assessment. The chief executive will then review the dam failure impact assessment and make a review decision (see Chapter 6 of the *Water Act 2000*).

If a dam owner is not satisfied with the review decision, the appeal provisions of the *Water Act 2000* allow the owner to appeal this decision in the Planning and Environment Court (see Chapter 6 of the *Water Act 2000*).

3.4 Responsibilities under the Integrated Planning Act 1997

A development permit must be obtained if a person wants to carry out operational work that is the construction of a new referable dam or that will increase the storage capacity of a referable dam by more than 10%. A development permit is an approval under the *Integrated Planning Act 1997*, which allows particular development (eg construction of a new referable dam) to occur. A development permit may impose conditions (eg dam safety conditions) on the approveddevelopment.

A development permit is only issued after a development application has been assessed and approved using the Integrated Development Assessment System (IDAS) under the *Integrated Planning Act 1997*.

A development application for the construction of a new referable dam or for carrying out operational work that will increase the storage capacity of a referable dam by more than 10% must be lodged with an assessment manager, who is then responsible for administering the assessment and approval process [2]. The development application must be supported by evidence the chief executive has accepted a dam failure impact assessment for the dam (refer to s.971 of the *Water Act 2000*). Additionally, if a water entitlement is required under the *Water Act 2000* to operate the dam (eg the proposed dam is on a watercourse) the development application must be accompanied by the chief executive's consent (as the water manager under the *Water Act 2000*) to the application being made.

The assessment manager for a development application for construction if a new referable dam or for operational works that will increase the storage capacity of a referable dam by more than 10% will generally be the local government if its planning scheme makes the construction of the new dam, or the carrying out of the operational works, assessable development. If the local government does not make the dams construction, or the operational works assessable development under its planning scheme, a regulation under the *Integrated Planning Act 1997* may make the chief executive the assessment manager. Enev in those cases where the chief executive is not the assessment manager, the chief executive will have the power to require dam safety conditions to be imposed on the development permit.

2 The appeal provisions of *Integrated Planning Act* allow appeals in the Planning and Environment Court against the decision made about the development application.

In some cases, a dam may become referable after it is constructed (eg if the chief executive issues a s.483(2) notice to have the dam failure impact assessed and the dam is assessed as having a category 1 or category 2 failure impact rating). In these cases, the chief executive has the power to impose safety conditions on the dam under the *Water Act 2000* and these are take to be part of a development permit for the dam. However, as the dam was not a referable dam prior to it's construction, there is no need for the dam owner to apply for a new development permit under the *Integrated Planning Act 1997* to construct the dam.

4 Methodology

4.1 Introduction

The owner needs to undertake (possibly in conjunction with a registered professional engineer) the following activities when preparing a dam failure impact assessment. The dam site needs to be inspected at least once; data needs to be collected and its appropriateness and accuracy assessed; the dam failure zone must be identified, and an assessment of the population at risk calculated. Finally, the written dam failure impact assessment needs to be certified by a registered professional engineer and submitted to the chief executive.

4.2 Dam Site Inspection

Site inspections are mandatory. These ensure that the information upon which the dam failure impact assessment is based is correct and up-to-date, and also enable an appreciation of the characteristics of the site. The date(s) and name(s) of the personnel involved in the site inspection must be included in the written dam failure impact assessment.

Site inspections must include areas that could be affected by dam failure both upstream and downstream of the dam. Site inspections are needed to:

- Verify the accuracy of all mapping/aerial photogrammetry that is used in the assessment
- Verify the existence of buildings and other places of occupation to justify the failure impact rating identified in the assessment
- Identify other storages on the same waterway
- Identify buildings and other places of occupation along waterways, which may house population at risk (eg camping facilities)
- Identify catchment modification works (eg diversion drains and levee banks).

The registered professional engineer certifying the failure impact assessment must be satisfied that the inspection of the site has accounted for sufficient points of impact, covering the failure impact zone as a minimum, to justify the failure impact rating. The registered professional engineer must include a statement to this effect in the certification.

Less rigour will be required for a dam failure impact assessment where a dam obviously has a category 2 failure impact rating (as this is the highest rating applicable) than if a dam is either on the border of not being referable or on the border of having a category 1 failure impact rating[3] and the owner wishes to justify the adoption of the lower failure impact rating.

4.3 Data Collection

The registered professional engineer certifying the failure impact assessment must judge the appropriateness and accuracy of the information included in the assessment and indicate in the certification, the engineer's views on the assessment information.

3 Note: A detailed inundation map may still have to be produced as part of the preparation of an Emergency Action Plan for the dam.

A wide array of information needs to be collected to determine the effects of a dam failure. These include:

4.3.1 General Information

Floods due to dam failure are generally significantly larger than natural floods. They can rise very rapidly, form steep wave fronts and carry large amounts of debris and sediment.

Flood information can be used in the assessment including:

- available historic flood levels
- hydrographic data
- rainfall/runoff model results
- dam break flood model results under "sunny day" and "incremental" conditions.

4.3.2 Dam and storage information

Information should be gathered which outlines the dam's physical dimensions used to determine potential breach characteristics and incremental flooding effects (for example, stability of slopes, earthquake effects, condition of components, materials and spillway capacity). Such information should include:

- type of dam and location (including latitude and longitude)
- spillway type and adequacy (including flood control facilities such as gates and secondary spillways)
- dimensions such as height and length of embankments and the width of the crest
- storage capacity to full supply level and to the crest of the dam (stage capacity curve)
- use of dam including contents of the storage area
- possible causes and modes of failure
- comments on design, foundations and any unusual conditions
- design studies or reports.

4.3.3 Topographic information

Topographic information can be sourced from a number of areas, with the decision as to which data is used being based on issues such as the availability, relevancy and accuracy of the information. Sufficient topographic information must be obtained to accurately determine:

- the shape and slope of the valley downstream of all potential failure locations
- controls on the downstream flow, such as culverts, vegetation, weirs, bridges, embankments, surface roughness and temporary storage on the flood plains
- location of major downstream tributaries.

If regional maps do not provide sufficient detail for a failure impact assessment, further information may need to be obtained from sources such as:

- road maps
- orthographic, topographic, military and cadastral plans
- surveyed cross-sections
- aerial photographs
- satellite imagery
- local residents.

Orthographic maps, if they exist, are generally very useful for failure impact assessments as they combine contour information with images of buildings, roads etc. Contours can be used as flood level indicators.

It is important to note that mapping or aerial photogrammetry may not contain recent developments eg houses or other places of occupation (refer to Appendix A). Information contained in photogrammetry that plays an integral role in the assessment must be verified by site inspections.

For dam break models where the need for precision is not great, model cross-sections may be based on existing survey information such as stream strips, cross sections, and the most reliable topographic maps available. It may also be possible to extend survey cross sections by using contours from maps etc.

Cross sections may need to be taken at locations where there are buildings or other places of occupation as well as at sufficient other locations, including hydraulic controls such as bridges, weirs, waterfalls, etc, to allow reasonable dam break models to be established.

As a guide to cover the inundation area, the cross sections should extend for at least half the vertical height of the dam above the stream bed at each location. This height of the cross-sections may be able to be decreased at greater distances downstream of the dam.

Where extreme precision is required, extensive, detailed surveys of the downstream valley may be necessary. In such circumstances, surveys may also be required to locate and determine natural surface levels at all buildings or other places of occupation that are thought to be at risk.

4.3.4 Hydrographic data

The inflow hydrograph into a storage during a flood event can affect the results of a dam break analysis. Its impact will depend on a number of parameters such as:

- the size of the available flood storage
- the height of the dam
- the size and capacity of its spillway
- the shape of the valley downstream of the dam.

For lower accuracy analyses, only one roughness coefficient might be sufficient in representing the whole floodplain at each cross-section. In such analyses, it might also be appropriate to adjust roughness coefficients using 'text book' allowances.

To obtain an indication of model sensitivity to variation of the assumed roughness the model must be run with values of Manning's 'n'[4] varying either side of the adopted roughness coefficient.

Some of the potential errors in hydrographic data include:

- extrapolation of existing flood data to predict a much larger, deeper and faster flood
- short circuiting of the much higher flows at loops in a watercourse resulting in a shorter effective flow length
- selecting channel cross-sections that do not accurately represent a watercourse channel
- excluding the effects of the flood wave on the storage in the tributary creeks and other near stream storages
- excluding distributory flows.

Where previous flood records exist in the river or stream reach under consideration, the hydraulic

4 Manning 'n' is a roughness parameter used to model energy losses in streams. Unless reasonable discharge and water level calibration is available, reference should be made to standard hydraulic engineering texts for appropriate values of Manning's 'n'.

model should be calibrated to match the available flood inundation data so that the numerical dam break model can be demonstrated to approximate actual flow conditions. If these records are not available, or are available for a limited range of flows, some assessment must be made of the potential impact on the accuracy of the modelled results. All modelling must be subjected to sensitivity analyses to test sensitivity to model assumptions.

Hydrographic characteristics of each study reach must be assessed and validated using aerial photography (where available) and site inspections.

4.3.5 Hydrologic data

Downstream tributary inflows may impact on the dam break flood, particularly if population centres are some distance downstream of the dam. Simpler analyses on smaller dams would not normally consider inflows from tributaries downstream of the dams. Concurrent rainfall to produce downstream tributary flows should be based on the lesser of the following rainfalls over the tributary catchments (see Table 1 below).

Table 1

Annual Exceedance Probability (AEP) of Dam Break Flood Rainfall	Annual Exceedance Probability of Concurrent Rainfall
1.0 e^{-3} or greater	Nil
1.0 e^{-3} to 1.0 e^{-5}	AEP of Dam Break Flood Rainfall multiplied by 1000.
1.0 e^{-5} or less	0.01

4.3.6 Downstream community information

Downstream community information must include the location, number and nature of buildings and other places of occupation (for details see Appendix A) and approved camping and recreational areas in the failure impact zone.

This information may be obtained from maps, persons with local knowledge and emergency action plans for the dam. Recent aerial photogrammetry also provides useful information on the location of downstream structures. As stated above, site inspections must be undertaken to verify downstream community information (for example, to ensure the information is up to date and identifies buildings and other places of occupation obscured by trees).

4.4 Determination of failure impact zone (see also analytical techniques)

The failure impact zone is the area affected by flooding as a result of the failure of the dam. The magnitute of the flood impact is determined by the difference between the flood impacts associated with a particular event with dam failure and the same event without dam failure. Failure impact zones must be determined for all:

- failure events specified within the analytical technique used for the failure impact assessment (refer to Box 1) and
- for all other failure events relevant to the dam.

The failure impact zone ends when the:

- flood caused by a dam failure is retained within the bed and banks and no more people (including people on boats) are at risk downstream or upstream or
- difference between the flooding effect with dam failure and the flooding effect without dam failure (that is the incremental effect of the dam failure on the impacted zone) is less than 300 millimetres.

It should be noted that:

- while the dam failure impact zone is generally located downstream, areas upstream can also be affected and should be included where relevant (eg an upstream area may be affected by the abnormal operation of discharge control devices such as gates or inflatable bags).
- in some circumstances (eg during a ring tank failure) a dam breach may discharge onto a flood plain before the flow concentrates into a downstream channel. In such a situation there may be areas where the incremental flooding is more than 300 mm, separated by areas where the incremental flooding is less than 300 mm. When determining the failure impact zone, all areas where the incremental effect is 300 mm or higher must be included.
- where a dam has multiple segments such as a main embankment and one or more saddle dams, failure of each of these segments must be considered for its effect on the failure impact zone. The case producing the maximum population at risk must be used to determine the failure impact rating.

A map showing the extent of the failure impact zones must be included in the written assessment.

4.5 Population at risk

People are considered part of the population at risk if:

- buildings or other places of occupation they occupy lie within the failure impact zone and
- any part of the ground where these buildings or other places of occupation are located would be covered by 300 mm or more of water.

When the failure impact zone is being determined, the number, location and nature of buildings and other places of occupation must be identified. A particular population at risk is determined by allocating default populations to each such site depending on its nature. (See Appendix A for default populations). For example, a detached house has a default population of 2.9 people. If 10 detached houses were inundated by 300mm or more of water (and there was no natural flooding at the time) and these were the only buildings or other places of occupation located in the failure impact zone, the population at risk for that dam failure event is 29 people.

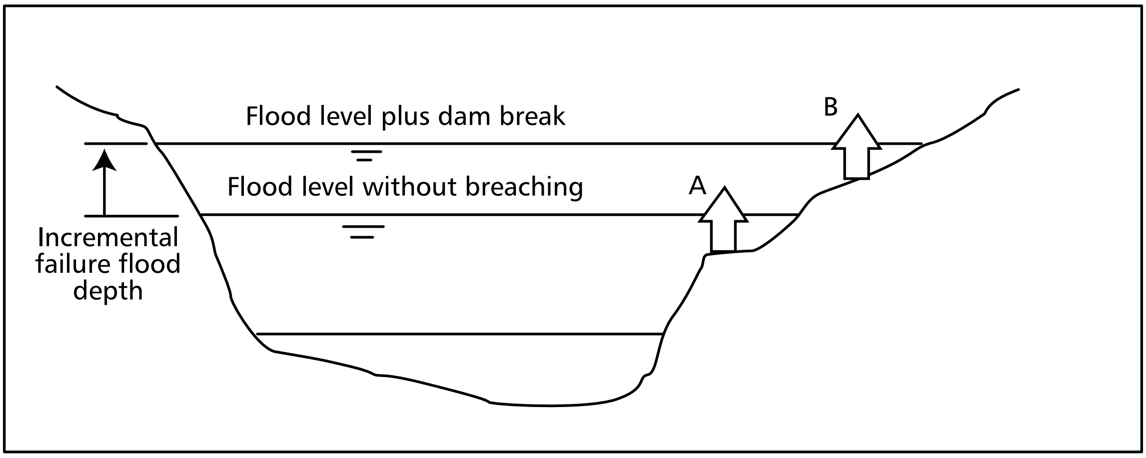
Note: The written assessment must state the nature of the site and justify the populations used for those places of occupation not listed in Appendix A.

The population at risk is the difference between the population at risk for a specific dam failure and the population at risk for the same flood had dam failure not occurred (that is the incremental population at risk). The failure impact rating is determined using the highest incremental population at risk from a range of failure events relevant to the dam.

For example:

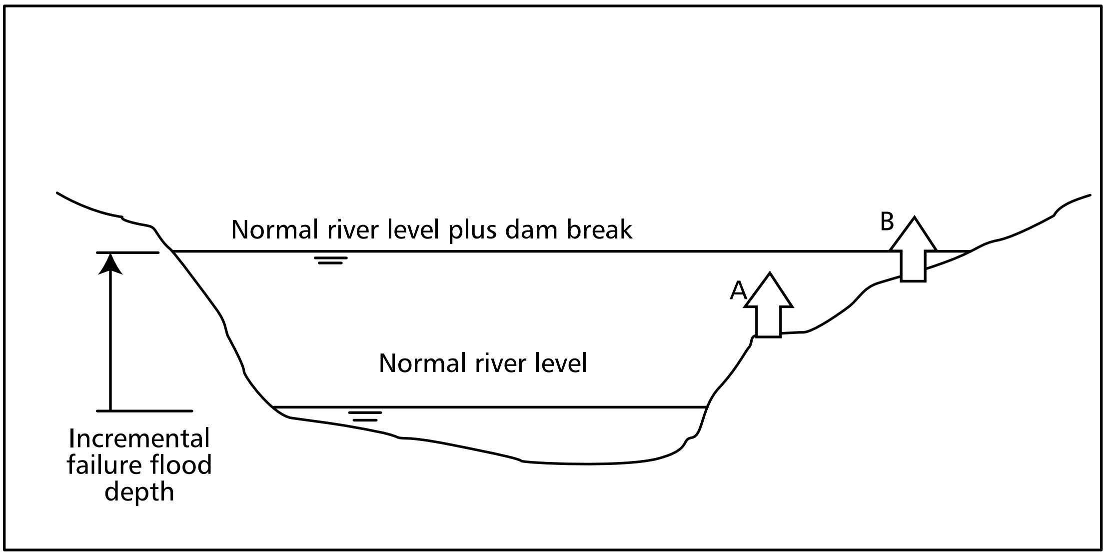
- Dam failure during a flood: 170 people are at risk from a dam failure, and 20 of those people are at risk from the natural flooding even if dam failure does not occur; it follows that 150 people are at risk if the dam fails (ie. 170 people minus 20 people). In the diagram below, house A is not included in the population at risk assessment as it is inundated by natural floodwater. House B is included in the assessment of population at risk if the ground on which the house is located is inundated by at least 300 mm.

Figure 1 - Dam failure during a flood



- A 'sunny day' dam failure (when flooding is due to dam failure only): if 40 people are at risk from a dam failure, the population at risk is 40 people as nobody is at risk if the dam does not fail. In the diagram below, houses A and B are included in the assessment of population at risk if any part of the ground on which the houses are located is inundated by at least 300 mm.

Figure 2 - Sunny day dam failure



4.6 Accuracy of population at risk calculations

A variety of factors may affect the accuracy of population at risk calculations. These must be considered to ensure the reliability of population at risk calculations. Factors include:

- the accuracy of cross-sections used in the analysis
- the locations of cross-sections used in the analysis
- the accuracy of the hydraulic modelling
- availability and accuracy/reliability of calibration data and the degree of extrapolation required to model dam break flows
- assumed hydraulic roughness parameters
- assumed breach development times
- locations, numbers and elevations of buildings and other places of occupation.

Sensitivity analyses or sensitivity tests assess the potential impact of some factors on the size of the population at risk and are normal practice for dam failure impact assessments. For example:

- What if the elevations of buildings or other places of occupation are at the lower bounds of the accuracy of the available survey information (eg the accuracy of contours used to assess flood inundation is 2 metres)?
- What is the population at risk if all buildings or other places of occupation were 2 metres lower than assumed in the analysis?
- Does the population at risk change if conservatively short breach formation times are used?
- Does the population at risk change if conservatively high stream channel roughness parameters are used?

The degree of conservativeness should reflect the amount of calibration data available to determine stream channel roughness for the watercourse reaches in question.

The written dam failure impact assessment should include a statement on the range of the estimate of population at risk for the critical case. Such an assessment should indicate values for the upper limit of population at risk that could reasonably be expected as a result of the analysis and a similarly derived lower limit of population at risk.

4.7 Analytical Techniques

4.7.1 Introduction

Three analytical techniques may be used in preparing dam failure impact assessments. These are two-dimensional flow analysis, simplified assessment techniques and comprehensive assessment techniques. These techniques may be used alone or in combination. Certifying registered professional engineers need to be satisfied that the techniques selected and the accuracy of the models developed are reasonable for the situations under consideration (see Box 1 and refer to section 2.5).

4.7.2 Two-dimensional flow analysis

This analysis will typically need to be used downstream of ring tanks and gully dams where embankments are close to buildings or other places of occupations that may be inundated by dam failure. This analysis calculates the extent of inundation on a local scale prior to the flow entering the main watercourse. This typically occurs on flood plains where there are few or no defined gullies for dam break floodwater to follow. Additionally this technique may be used close to gully dam abutments where failure may inundate buildings and other places of occupation immediately downstream of the dam.

Two-dimensional flow analysis takes curvilinear flow paths into account as flow discharges from the breach and spreads out downstream. Models used in such analyses need to be able to simulate the dynamic behaviour of overland flow over complex geometries. There are a number of models that are capable of being used to determine these local effects. These include those based on the shallow water wave equations such as those discussed in Wang et al (2000) and Zoppou and Roberts (1999). A number of standard commercial software packages are also capable of determining inundated areas for two-dimensional flow (eg MIKE21 - Danish Hydraulic Institute, DELFT-FLS - Delft Hydraulics).

Details on dam breach mechanisms for two-dimensional flow analyses are detailed in section 4.7.5.

Box 1: Minimum failure events which must be considered in the dam failure impact assessment

Two dimensional flow analysis and comprehensive analysis

- "Sunny day" dam failure where the failure occurs at the full supply level and there is no concurrent flooding.
- If the probable maximum flood (or lesser flood event) overtops the dam, assume the dam fails with the water level at the crest of the non—overflow section of the dam embankment.
- If the probable maximum flood does not overtop the dam, assume the dam fails with the water at the level of the probable maximum flood.
- If the dam is filled through pumping, assume failure at the crest level occurs (from pumping alone) when the pumps fail to stop pumping.
- Failure due to the maloperation or malfunction of flow control structures. If the dam has the capability to significantly vary flood discharges through crest gates, sluices or some other type of variable flow control structures, the possibility of either failure or malfunction of these structures must be considered.
- Where there are premises between the "Sunny Day" impact zone and the highest natural flood levels, intermediate flood events are to be considered when the "no failure" flood levels falls just below buildings and other places of occupation that would be inundated with dam failure.

Simplified assessment

- "Sunny day" dam failure where the failure flood occurs with the storage at full supply level and there is no other concurrent flooding.
- Dam crest flood when failure occurs during a flood event or during pump filling with the water level at the crest of the non—overflow section of the dam embankment.
- Where there are premises between the "sunny day" impact zone and the highest natural flood level, intermediate events are to be considered when the "no failure flood" levels fall just below buildings and other places of occupation that would then be inundated with dam failure.

4.7.3 Simplified assessment

A simplified dam failure impact assessment technique may be justified where there is little doubt as to the population at risk and the cost of a comprehensive assessment is anticipated to be high relative to the potential benefits. It involves the conservative use of topographic and hydrographic data and an empirically determined breach discharge.

This is an approximate technique, which uses the 'normal' depth at a section to estimate maximum flood levels at a point for a given discharge. As such this technique does not take any backwater effects into account. It must not be used where backwater effects are expected to be significant in terms of the affected population at risk. Aside from the backwater effects, the principal areas of uncertainty are the accuracy of the stream slopes, the cross-sections, and the locations and levels of the impacted buildings.

Unless more accurate techniques are used which result in the breach size indicated in section 4.7.5, the maximum breach discharge from a dam during a breaching event, Q_{BREACH}, must be determined using Equation 1. The empirical discharge relationship is based on the failure of a typical homogeneous earthfill embankment.

$Q_{BREACH} = 2.5\ F\ V^{0.76}\ H^{0.1}\ m^3/sec$ Equation 1

where:

F = 1.3 = a factor to account for the simplified nature of the assessment
V = total volume of water released (in megalitres)
H = maximum depth of water in the storage (in metres)

Where a case for assessing population at risk includes flow through dam spillways or other discharge points, an additional flow Q_{DCF} must be added to the breach discharge. This additional flow will include the total discharge through any dam spillways with the appropriate storage level for the failure event.

If alternative techniques are applied to determining the dam discharge, the factor 'F' must still be applied to the breach discharge.

For embankments exceeding 12 metres in height or embankments made up of non-cohesive materials such as gravels or ash, the breach characteristics may differ and the expected peak discharge must be adjusted accordingly.

A survey of the cross-sections at buildings or other places of occupation that could be affected is normally required. Survey data may be relative to the creek bed at the cross section under consideration. The distance of the sections downstream of the dam should also be determined using aerial photography or available maps.

The water level at any particular cross-section resulting from the discharge from a dam breach should be consistent with the 'normal depth' for the section using the maximum breach discharge and Equation 2:

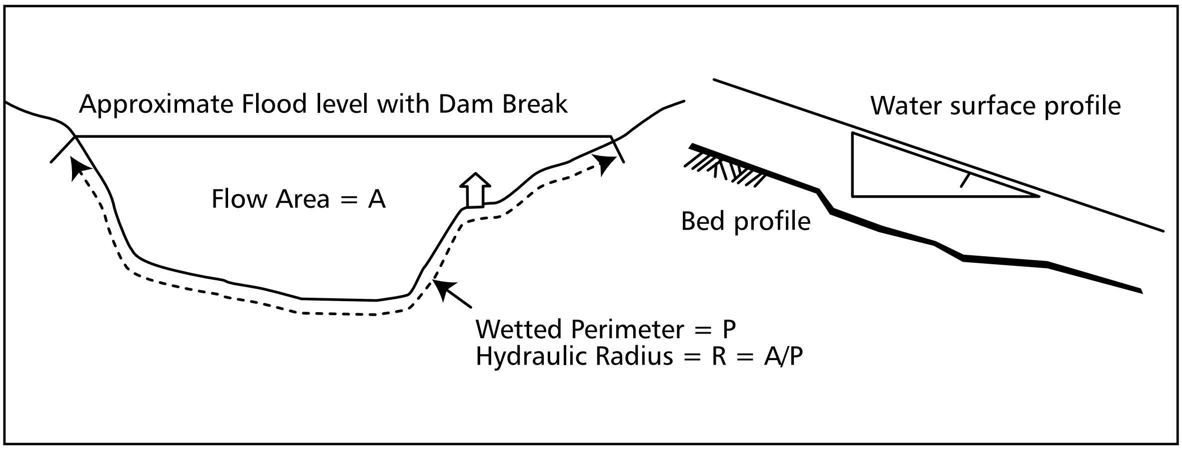
$$Q = \frac{R^{2/3} S^{1/2}}{n} A$$

Equation 2

where:

R = hydraulic radius = A/P (metres)
S = stream slope (metres/metre)
A = flow cross-sectional area (square metres)
P = wetted perimeter of cross-section (metres)
n = Manning's number[5]

Figure 3 - Parameters for water level determinations for simplified assessment



When sufficient depths at downstream sections have been determined the results should be plotted on a map. Interpolation between "calculated points" should be based on the accuracy of prevailing topography and contours.

4.7.4 Comprehensive assessment

If a simplified assessment is not accurate enough to adequately calculate the population at risk, then a comprehensive dam break analysis may be required. A comprehensive assessment is a detailed assessment of the failure impact zone and the population at risk if the dam fails. Dam break analyses must be undertaken for a range of dam failure scenarios (refer to Box 1) and use current hydraulic modelling practice and suitably documented and validated numerical models. Software capable of being used to carry out dam break analysis includes:

- BOSS FLOODWAV - International NWS DAMBRK (Version 3.0).
- Danish Hydraulics Institute - MIKE 11.
- RUBICON.

Some estimate of the accuracy of each model must be made and this accuracy must be taken into account in assessing potential population at risk as indicated in section 4.6. The impact on population at risk will be greatest in areas with higher populations (eg towns), and it may be justified to selectively improve accuracy in these areas.

5 Manning 'n' is a roughness parameter used to model energy losses in streams. Unless reasonable discharge and water level calibration is available, reference should be made to standard hydraulic engineering texts for appropriate values of Manning's 'n'.

Initially, cross-sections should be taken at or near the intervals shown in Table 2. However, the registered professional engineer certifying the assessment must be satisfied with the locations of cross-sections and the intervals between these cross-sections for each individual numerical model generated for the failure impact assessment.

Table 2

Storage (megalitres)	Indicative intervals between cross-sections	Indicative total distance downstream
20000	1 kilometre	Up to 60 kilometres
2000	0.5 to 1 kilometre	Up to 20 kilometres
200	Not greater than 0.5 kilometre	Up to 5 kilometres

The total distances downstream in Table 2 are based on actual dam break studies indicating the distances downstream where the incremental effects of the dam break flood become relatively small.

Care should be taken to treat each case as site specific, particularly where the downstream valley is confined and narrow for great distances. In these cases, the dam break flood may not dissipate quickly and greater distances downstream may need to be considered, especially where there are buildings and other places of occupation at risk.

When carrying out dam break studies, other factors that must be included are:

- downstream hydraulic roughness.
- other significant downstream hydraulic coefficients such as expansion and contraction coefficients.
- dam break characteristics including breach base width, breach side slopes, breach depth, time for completion of breach.
- spillway discharge rating curve.
- storage versus height curves.
- inflow hydrograph.
- downstream tributary inflows.

The output from a dam break analysis must include:

- hydrograph at each section (flow versus time).
- depths at each section at appropriate time intervals.
- velocities at each section at time intervals.
- flood peak arrival times at each section.
- the first rise in water level at each section.
- recession time of the dam break flood.

This information needs to be summarised in tables and plotted on a map. The preferred map scale is 1 in 5000 with contours at maximum 2 metre intervals. However this can be varied depending on the scale of the inundated area.

It is expected that a detailed dam break analysis will provide results that are at best accurate to +/- 1m vertically. However, it should be noted that most dam break models are based on two-dimensional cross sections. "Real life" effects such as run-up around bends, the effects of rolling wave fronts and the effects of debris building up into secondary dams and then breaking may not be catered for in such models.

Details on dam breach mechanisms for comprehensive assessments are described in section 4.7.5.

4.7.5 Dam breach mechanisms for two-dimensional flow analyses and comprehensive assessments

Assumptions made of dam breach parameters can significantly affect the results of dam break analyses. The most significant parameters are the dimensions of the fully developed breach and the time it takes for the breach to develop.

Breach analyses must include sensitivity tests using assumed breach parameters to gauge their impact on the overall analysis.

The following procedure must be used for determining the magnitude of any potential dam breaches (Allen 1994). The same procedure is to be used for determining the ultimate size of the breach for both overtopping failures and for "Sunny Day" failures. In piping failures, it is to be assumed that the breach is initiated at the level which produces the maximum discharge from the breach. Unless special provisions are made, overtopping failures should be initiated as soon as the embankment is overtopped.

1. Examine the structure, or proposed structure, of the dam and obtain any available service histories, design reports or design reviews which may indicate likely modes and/or locations of breaches for that type of structure;

2. Consider all possible breach mechanisms, with a view to selecting the critical mechanism after running dam break inundation models for each alternative breach:

Then for Embankment dams:

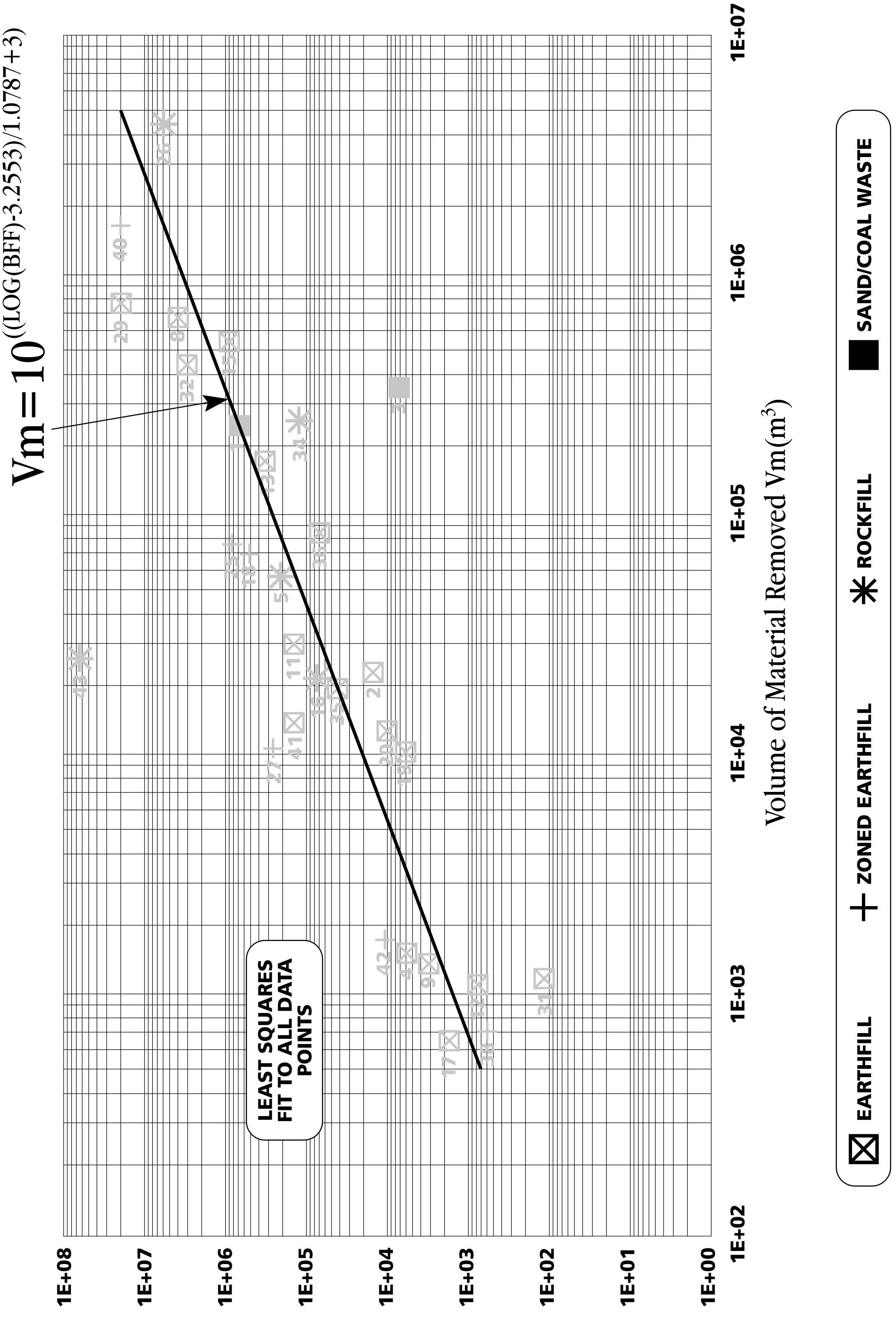
3. Calculate Breach Formation Factor for the assumed failure condition:

   BFF = Vw * h

   where
   BFF = Breach Formation Factor
   Vw = Total volume of water to flow through the breach (megalitres)
   h = Height differential between headwater and tailwater levels (metres)

4. Use Figure 4 to determine the volume of material expected to be removed during the formation of the breach Vm (cubic metres).

Figure 4:
Outflow characteristics as a function of breach size



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5. Determine the size of breach that corresponds to Vm assuming a trapezoidal breach with side slopes of between IH: IV and IH:2V.
   Note: If Vm is more than the volume of material available in the embankment, assume the embankment is effectively removed and replace Vm with this volume.

6. Unless special circumstances previal (such as a very high embankment being required to store a relatively small volume of water), check to see that the breach size is within the following range of parameters (refer to Figure 5 below). ie
   1.06 < B/b < 1.74 with a mean of 1.29 and a standard deviation of 0.18
   0.84 < B/d < 10. 93 with a mean of 3 and a standard deviation of 2.62
   side slope ø in the range 10° to 50° off vertical.

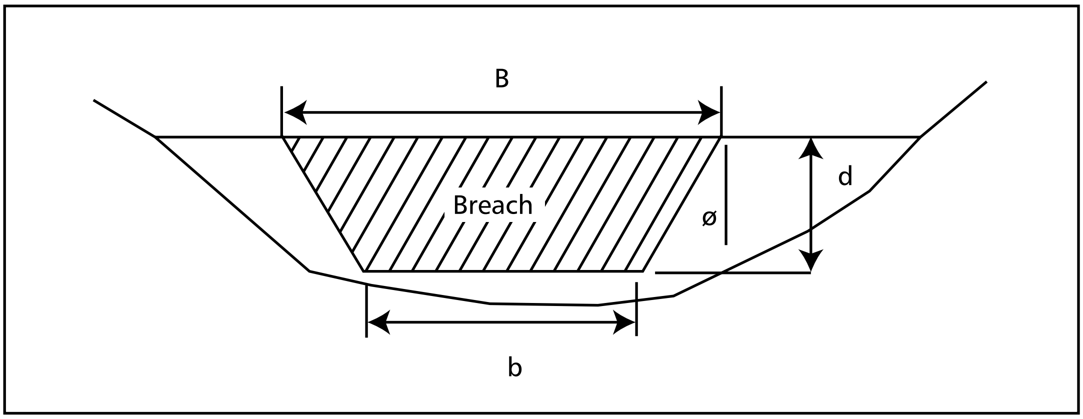
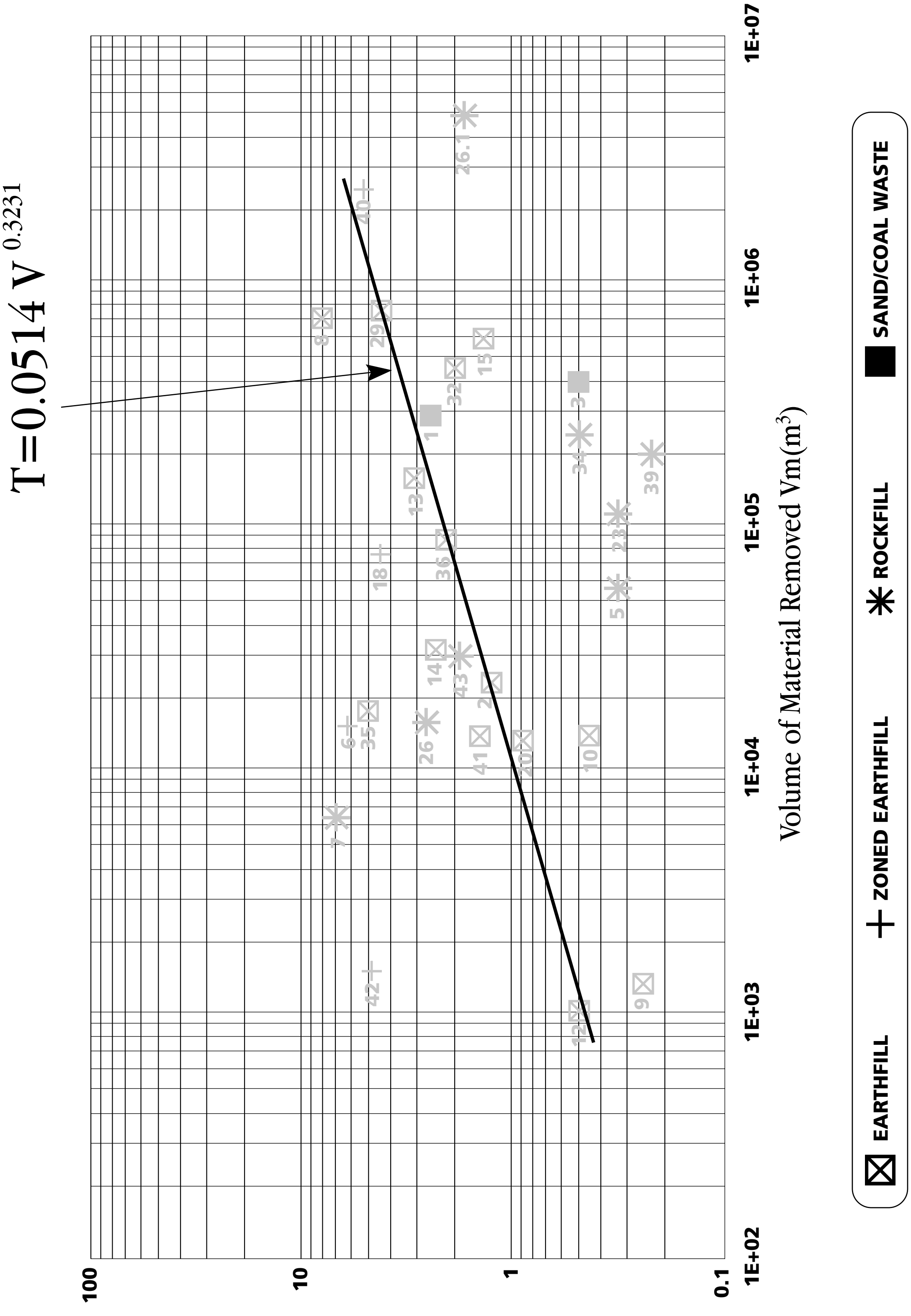


Figure 5 - Notation for breach paramters

7. Use Figure 6 to determine the breach development time.

Figure 6:
Breach development time as a function of material removed



8. Run the dam break model and examine the hydraulic conditions occurring in the breach throughout the discharge and qualitatively modify the parameters accordingly. For example, if the breach outflow is heavily affected by tailwater, increase the breach development time or reduce the size of the breach to reflect the reduced erosive capacity of the flow. If the discharge continues at high levels long after the breach has been fully developed, increase the size of the breach.

Note: Saddle dams are likely to fail relatively quicker and more completely than main embankment dams because they store more water for a given embankment volume.

9. Conduct a sensitivity analysis on the adopted parameters with due regard to the composition of the embankment.

And for Concrete dams:

10. Determine the storage level at which failure is likely to occur. If no design information is available, assume removal of the top of the non-overflow section above the change of section and the dam foundation. However, this assumption should be checked during model analysis, and, if a more critical case is identified, this should be adopted.

11. Assume that at least 30% of the monoliths in the main section of a mass gravity structure are 'instantaneously' removed at either the change of section or the dam foundation (refer to Figure 7 below).

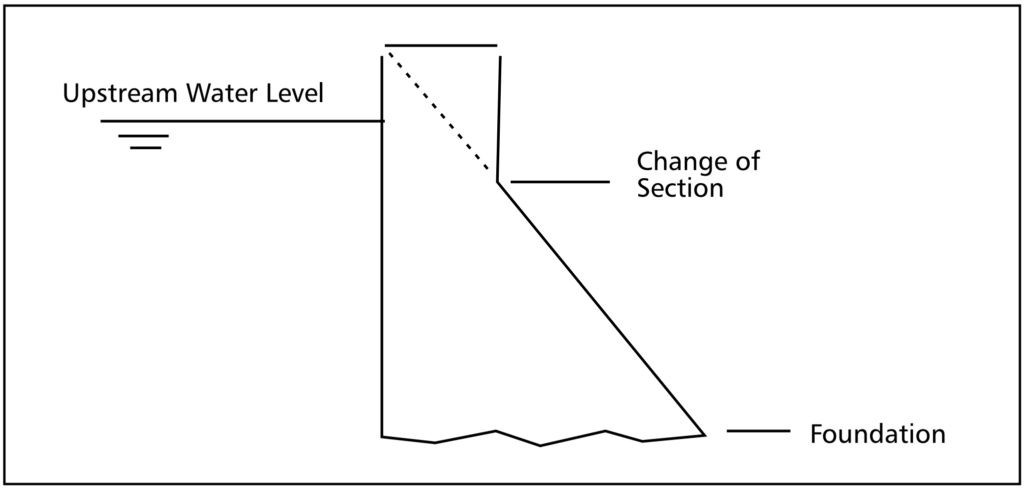


Figure 7 - Typical Mass Concrete Dam Cross-section

12. Assume complete removal of any arch dam or multiple arch dam as rapidly as the model will allow.

13. Conduct a sensitivity analysis on the adopted parameters.

4.7.6 Two or more dams on the same watercourse

Sometimes, two or more dams occur on the same watercourse. In such circumstances, it must be assumed that the failure of an upstream dam may trigger the failure of downstream dams. If the downstream dam cannot store the contents of the upstream dam without failure, the combined effect of multiple dam failures must be considered when determining the incremental population at risk for the upper dam for failure events. Similarly, if failure of a downstream dam could contribute to the failure of an upstream dam (such as through a rapid drawdown failure if headwaters of the downstream dam back up against the upstream dam), the potential failure of the upper dam must be considered when determining the incremental population at risk of the lower dam for failure events. The dam failure case producing the highest incremental population at risk must be used to determine the failure impact rating for the dam.

4.7.7 Other failure events

If the registered professional engineer considers that other failure events could result in a higher incremental population at risk, these failure conditions must be considered and described in the written dam failure impact assessment. These failures may include:

- storage rim instability.
- factors such as deterioration, old age, design or construction faults and poor maintenance.
- damage due to fire, wind (for example, causing beaching leading to a breach) and escape of water into mining tunnels/shafts beneath reservoirs.
- vandalism.

4.8 Periodic Re-Assessment Of Failure Impact Rating

Provided that:

- the records of the previous failure impact assessment still exist and
- there have not been substantial changes in:
  - the stream channel cross-sections and roughness
  - the embankment and spillway geometry and
  - the magnitude of the design floods

it is permissible for each consequential re-assessment of a failure impact rating (after the last failure impact rating has been accepted by the chief executive) to use the same inundation data as used in the previous analysis for assessment of the population at risk.

However, the population at risk must be re-calculated as part of each re-assessment of the failure impact rating.

In all other cases, reassessment will require a complete analysis following procedures outlined in these guidelines.

The registered professional engineer's certification must include justification of the approach adopted in the re-assessment.

5 Summary of written Dam Failure Impact Assessment requirements

The following information is to be included in a written Dam Failure Impact Assessment

Executive Summary/Introduction

A general description of the dam and a summary of the results of the failure impact assessment including:

- Type of dam
- General location of the dam
- Height and storage capacity of the dam
- The maximum population at risk
- A description of the critical failure event producing the maximum population at risk
- The recommended failure impact assessment category for the dam.

General Information

- Name of dam.
- Owner of dam (ie individual or company).
- Dam owner contact details (ie postal address, street address, phone number, facsimile, email).
- Status of dam (ie existing or proposed dam or proposed work).
- Property description of dam (for main part of dam wall including portion, parish, county and locality).
- Location of dam (ie longitude and latitude).
- Date dam construction completed to current arrangement.
- Licence or development permit number (if any).
- Date last failure impact assessment accepted by the chief executive.
- Date last failure impact assessment submitted to the chief executive.
- Attach relevant maps (including map number, scale, map date and height accuracy). Copies of inundation maps in electronic format are also desirable.
- Attach copies of relevant aerial photographs (if any) (including photographic series name, film number, run number, approximate scale, date flown, photograph number(s)).
- Attach other topographic or cadastral source data (eg detailed survey plans, orthographic maps, property boundary details).
- Name of watercourse or offstream storage (including adopted middle thread distance (AMTD) measured in kilometres).

Catchment details

- Catchment area (hectares).
- Catchment general description.
- Percentage of catchment which has:
  - bare ground, rock, pavements, roofs, city areas (fully built)
  - rocky, clayey or non-absorbent soil with scanty herbage
  - open forest or grassed land, cereal crops
  - average grassed timberland of medium soil texture
  - heavily timbered country, closely cultivated land and pasture
  - sand.
- Average catchment slope.

Dam description

- Type (ie homogenous earthfill dam, zoned earth and rockfill dam, concrete dam or other).
- Height (ie the measurement of the difference in level between the natural bed of the watercourse at the downstream toe of the dam or, if the dam is not across a watercourse, between the lowest elevation of the outside limit of the dam and the top of the dam).
- Total length of main dam (ie metres from end of left abutment to end of right abutment).
- Total length and brief description of other dam components (eg saddle dams).
- Saddle dam details
- Purpose of storage (eg water supply for irrigation).
- Dam capacity to full supply level (in megalitres).

- Dam surface area at Full Supply Level
- Details of the storace capacity curve used in the analysis

Spillway description

- Type of spillway.
- Dimensions of spillway.

Data

- Summary of the data collected for the analysis and an assessment of the appropriateness and accuracy of the data.
- Summary of the findings/verification of the site including details of who undertook the inspection and inspection date(s).
- Spillway rating curve used in the analysis
- Details of the critical flood used in the analysis and a summary of the methodology used to derive it.

Results and discussion

- Analytical technique used (ie two-dimensional flow analysis, simplified assessment or comprehensive assessment or a combination of these) and justification for use.
- Details of modelling used including:
  - model or models used in the analysis
  - breach parameters adopted and the basis for their adoption
  - hydrological inputs used
  - statement of calibration data used to validate the models generated
  - degree of extrapolation adopted
  - cross-sections used and roughness parameters adopted
  - predicted accuracy of the modelling, both in terms of flood levels and the population at risk
  - statement on the sensitivity of the model results to the various adopted parameters with supporting evidence drawn from the modelling undertaken.
- Failure events considered.
- Reasonable upper and lower limits of population at risk as a result of the analysis.
- Recommended failure impact rating (i.e. category 1 or 2 failure impact rating or not referable) and the critical dam failure condition determining this rating.
- Failure impact zone accounting for sufficient points of impact for all relevant failure events including map showing the extent of the failure impact zones (hard copy mandatory and electronic format desirable).
- Incremental population at risk for all relevant failure events (including the nature of the site and justification for the populations used for places of occupation not listed in Appendix A).
  Statement on the range of population at risk that can be reasonably expected for the critical case as a result of the analyses.
- Detailed summary of the buildings and other places of occupation containing population at risk, and the location of this population.
- Details of dam break analyses.
- Commentary on sensitivity analyses.

Certifying Registered Professional Engineer

- Name.
- Registration number.
- Contact details (including postal address, street address, telephone number, facsimile, email as appropriate).
- Statement that he or she is not the owner or operator, an employee of the owner or operator
- Statement of certification (refer to section 3.2 for details of what is required in this statement).
- Signature.
- Date.

6 Bibliography

6.1 Papers

Allen, P.H. (1994) "Dam Break Breach Mechanisms", ANCOLD Bulletin No.97, August.

Wang, J.S., Ni., H.G. and He, Y.S. (2000), "Finite Difference TVD Scheme for Computation of Dam Break Problems" , Journal of Hydraulics Division ASCE, Volume 126 (4), April.

Zoppou, C and Roberts, S., (1999), "Catastrophic Collapse of Water Supply Reservoirs in Urban Areas" 1999, Journal of Hydraulics Division ASCE, Volume 125 (7), July.

6.2 Software

Standard commercial packages capable of determining inundated areas for two-dimensional flow include:

- MIKE21 - Danish Hydraulic Institute
- DELFT-FLS - Delft Hydraulics.

Standard commercial packages useful for dam break analysis include:

- BOSS FLOODWAV, NWS DAMBRK (Version 3.0) - International
- MIKE 11 - Danish Hydraulics Institute
- RUBICON.

7 Appendices

7.1 Appendix A - Default Populations

Nature of Buildings or Other Places of Occupation	Equivalent Population
Detached housing [1]	2.9 per house
Semi-detached, row or terrace housing [1]	2.0 per house
Multi-unit buildings [1]	1.7 per unit
Blocks of flats [1]	1.7 per flat
House or flat attached to a shop, office, etc. [1]	2.5 per house or flat
Approved caravan parks [1,16]	1.8 per caravan site
Approved camping grounds [2,16]	0.45 per camping site
Hotel/motel accommodation [3]	1.0 per bedroom
Child-care centres [4]	0.4 per child and staff member
Kindergartens; Pre-schools [5]	0.25 per student and staff member
Primary schools (day) [5]	0.25 per student and staff member
High schools (day) [6]	0.3 per student and staff member
Tertiary education centres [7] 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 [8]	0.4 per employee
Restaurants [9]	0.3 per member of staff and diner's places
Medical centres [10]	1.7 per member of staff
Tavern/hotel bars [11]	0.15 per m^2 of patrons' area
Shops; Shopping centres [12]	2.0 per 100 m^2 of gross area
Hospitals [13]	1.0 per bed plus 0.33 times the total number of staff
Institutional accommodation [14]	1.0 per bed plus 0.33 times the total number of staff
Service stations [15]	0.4 times the total number of staff
Industrial buildings and other non-residential sites	0.4 times the total number of staff
Department of Transport Moorings	2.0 per mooring

Notes:

1. The occupancies for these dwellings are derived from the overall Queensland figures for "persons, by dwelling structure" and occupied "dwelling structures, by tenure type (private dwellings)" in the 1996 census.
2. This occupancy comes from an analysis of 1999 figures for the number of permits issued, the numbers of campers per permit and the duration of each permit for 20 camping grounds under the control of the Department. The average number of campers per permit was 3.0 and the average site occupancy rate was 14.5%. Therefore an average occupancy value of 0.45 campers per site has been adopted.
3. This occupancy assumes that a hotel/motel bedroom will typically accommodate 2 people, who will be present for half of any one day, and that number of staff will compensate for the fact that generally not all rooms will be (fully) occupied.
4. This occupancy is based on a typical 9.5 hour day (8:00-5:30).
5. These occupancies are based on a typical 6 hour day (9:00-3:00).
6. This occupancy is based on a typical 7 hour day (8:30-3:30).
7. These occupancies are based on a typical 8 hour day (9:00-5:00) for day lectures and a typical 3 hour day (6:00-9:00) for evening lectures.
8. This occupancy is based on a typical 9 hour day (8:30-5:30).
9. This occupancy is based on the following assumed patronage:
   a. 10% full-9:00 am - noon, 2:00 pm - 6:30 pm
   b. full-noon - 2:00 pm, 6:30 pm - 10:30 pm
   c. staff numbers are 10% of number of places.
10. This occupancy is based on a 10 hour day (8:00-6:00) and assumes 3 patients at the location for each doctor and other staff member.
11. This occupancy is based on the following assumed breakdown of daily patronage:
   a. 10% of daily peak-10:00 am - noon
   b. daily peak-noon - 2:00 pm
   c. 15% of daily peak-2:00 pm - 5:00 pm
   d. daily peak-5:00 pm - 7:00 pm
   e. 50% of daily peak-7:00 pm - 8:00 pm
   f. 25% of daily peak-8:00 pm - 10:00 pm.

The Liquor Licensing Division of the Department of Tourism and Racing cited maximum numbers of patrons as $2/m^2$ standing and $1/m^2$ dining. The occupancy rate is therefore based on an assumed annual average for the daily peak patronage of 0.6/m2 plus a 10% allowance to cover staff.

12. This occupancy rate is an estimate based on Appendix B of Volume 1 of the Department of Natural Resource Guidelines for Planning and Design of Sewerage Schemes.
13. The occupancy rate of 1.0 per bed assumes that the number of visitors will compensate for the fact that generally not all beds will be occupied. The staff factor applies to the sum of the numbers of staff on different shifts.
14. These occupancies are identical to those for hospitals. It has been assumed that lower visitor numbers will offset the higher "bed" occupancy ratio for institutions.
15. This occupancy rate applies to the sum of the numbers of staff on different shifts. It contains a 20% allowance to cover customers.
16. Only camping areas and caravan parks approved by government agencies (local, state or federal) or included in local authority planning schemes should be included. Because of the difficulties associated with determining the number of sites, and their permanence, of non-approved camping grounds and caravan parks, they are excluded from assessment.

7.2 Appendix B - Definitions

Annual exceedance probability is the probability that a particular flood value will be exceeded in any one year.

Bed and banks for a watercourse or lake is the land over which the water within the watercourse or lake normally flows or the land normally covered by that water, whether permanently or intermittently. This does not include land adjoining or adjacent to the bed or banks that is from time to time covered by floodwater.

Dam means:

1. (a) works that include a barrier, whether permanent or temporary, that does or could or would impound water; and
   (b) the storage area created by the works.
2. The term includes an embankment or other structure that controls the flow of water and is incidental to works mentioned in item 1(a).
3. The term does not include the following-
   (a) a rainwater tank;
   (b) a water tank constructed of steel or concrete or a combination of steel and concrete;
   (c) a water tank constructed of fibreglass, plastic or similar material.

Dam break flood is the flood event produced by a dam failure.

Dam crest flood is the flood event which, when routed through the storage with the storage initially at full supply level, results in a still water level in the storage, excluding wind and wave effects which:

- for an embankment dam, is the lowest point of the embankment crest.
- for a concrete dam, is the level of the non-overflow section of the dam, excluding handrails and parapets if they do not store water against them.
- for a concrete faced rockfill dam, is the lowest point of the crest structure.

Dam failure is the physical collapse of all or part of a dam or the uncontrolled release of any of its contents.

Dam failure impact assessment is an assessment about the safety of a dam or proposed dam certified:

(a) by a registered professional engineer who is not, for the dam, or the proposed dam -
   (i) the owner or
   (ii) an employee of the owner or
   (iii) the operator or
   (iv) an employee of the operator and
(b) in accordance with the guidelines for failure impact assessment of water dams issued by the chief executive.

Development has the meaning given by the *Integrated Planning Act 1997*, section 1.3.2.

Development permit is a development permit as defined under the *Integrated Planning Act 1997.*

Failure impact zone is the area affected by the failure of the dam. The zone is limited to the area where the incremental effect of a dam break flood is 300 mm or higher.

Full supply level is the level of the water surface when the water storage is at maximum operating level when not affected by flood.

Hazardous waste is any substance, whether liquid, solid or gaseous, derived by, or resulting from, the processing of minerals that tends to destroy life or impair or endanger health.

Height for a weir, barrage or dam, means the measurement of the difference in level between the natural bed of the watercourse at the downstream toe of the barrier or, if the barrier is not across a watercourse, between the lowest elevation of the outside limit of the barrier and the top of the barrier.

Incremental effect is the difference between flood impact that what would occur under a given set of conditions with no dam break and the flood impact under the same set of conditions with a dam failure.

Information notice for a decision under the *Water Act 2000*, means a notice stating the following:

(a) the decision
(b) the reasons for the decision
(c) that the person given the notice may appeal against the decision, or apply for arbitration within 30 business days after the day the notice is given and how the person may appeal or apply.

Owner of land means any of the following, and includes the occupier of the land:

(a) the registered proprietor of the land
(b) the lessee or licensee under the *Land Act 1994* of the land
(c) the holder of a mineral development licence or mining lease under the *Mineral Resources Act 1989*
(d) the person or body of persons who, for the time being, has lawful control of the land, on trust or otherwise
(e) the person who is entitled to receive the rents and profits of the land.

Owner of a referable dam means the owner of land on which the referable dam is constructed, or is to be constructed.

Population at risk is the number of persons, calculated using these guidelines, whose safety will be at risk if the dam, or the proposed dam after its construction, fails. For the purposes of this guideline, persons are considered to be at risk if they are within the failure impact zone.

Probable maximum flood is the flood resulting from probable maximum precipitation, and where applicable snow melt, coupled with the worst conditions that can be realistically expected in the prevailing meteorological conditions.

Probable maximum precipitation is the theoretical greatest depth of precipitation for a given duration that is physically possible over a particular catchment area, based on generalised methods.

Referable dam is a dam or a proposed dam:

(a) which must have a dam failure impact assessment carried out under the *Water Act 2000*; and
(b) the assessment states that the dam, or the proposed dam after its construction will have a category 1 or category 2 failure impact rating; and
(c) the chief executive has, under section 487, accepted the assessment.

The following are not referable dams:

(a) a dam containing, or a proposed dam that after its construction will contain, hazardous waste.
(b) a weir, unless the weir has a variable flow control structure on the crest of the weir.

The following are not dams are cannot therefore be referable dams:

(a) a rainwater tank;
(b) a water tank constructed of steel or concrete or a combination of steel and concrete;
(c) a water tank constructed of fibreglass, plastic or similar material.

Registered professional engineer is a registered professional engineer, a registered professional engineering company or a registered professional engineering unit as defined under the *Professional Engineers Act 1988* (Qld).

Ring tank is a dam that has a catchment area that is less than 3 times its maximum surface area at full supply.

Storage capacity means the capacity of water ordinarily stored in a thing.

Top of the barrier for a weir, barrage or dam, means the level of the top of the barrier exclusive of any parapet or ancillary structure or, if the barrier includes a spillway, the level of the top of the abutment walls adjoining the spillway exclusive of any parapet or ancillary structure.

Water means -

(a) water in a watercourse, lake or spring; or
(b) underground water; or
(c) overland flow water; or
(d) water that has been collected in a dam

and includes any other liquid or a mixture that includes water or any other liquid or suspended solid[6].
Weir means a barrier constructed across a watercourse below the banks of the watercourse that hinders or obstructs the flow of water in the watercourse.

6 Refer to s.480 which contains a definition for water for the division dealing with referable dams and flood mitigation.

Queensland Government
Natural Resources and Mines

DEPARTMENT OF NATURAL RESOURCES AND MINES

GUIDELINES FOR FAILURE IMPACT ASSESSMENT OF WATER DAMS

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