# 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.

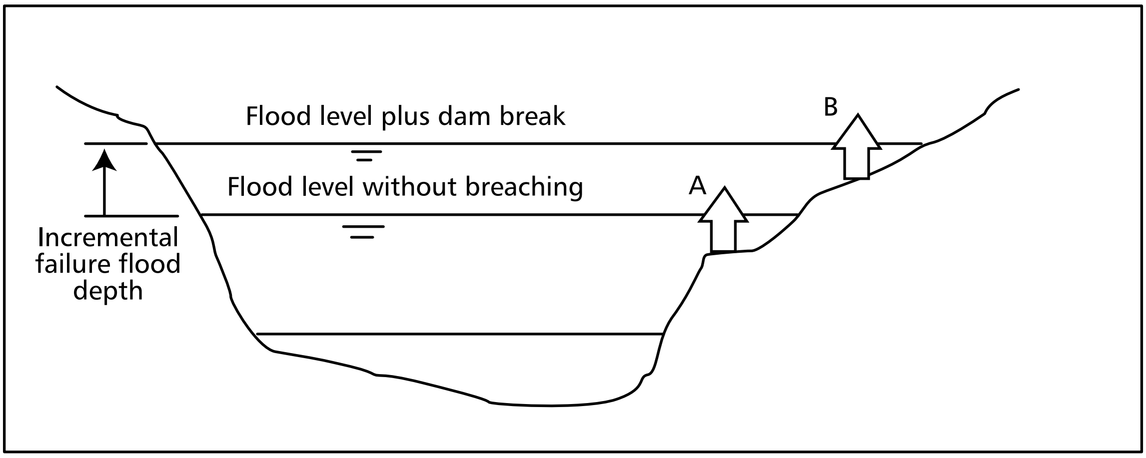
Note: The written assessment must state the nature of the site and justify the populations used for those places of occupation not listed in Appendix A.

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:

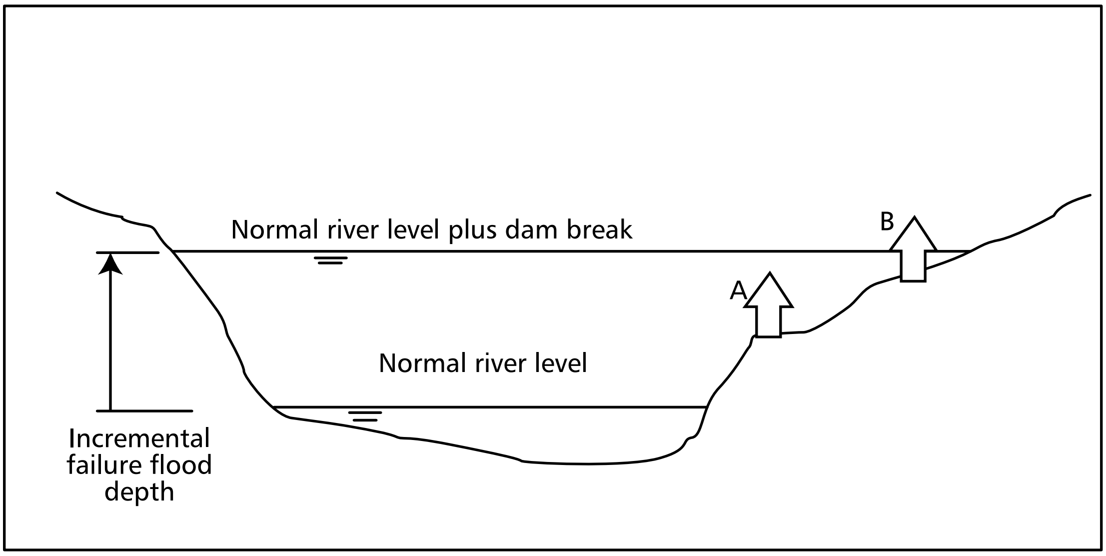
- Dam failure during a flood: 170 people are at risk from a dam failure, and 20 of those people are at risk from the natural flooding even if dam failure does not occur; it follows that 150 people are at risk if the dam fails (ie. 170 people minus 20 people). In the diagram below, house A is not included 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:

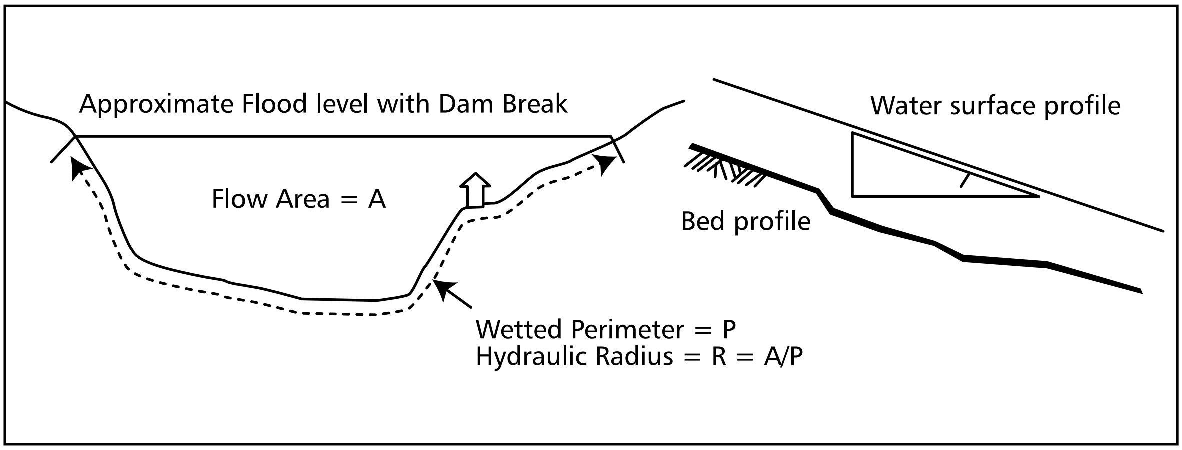
$$Q = \frac{R^{2/3} S^{1/2}}{n} A$$

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:**

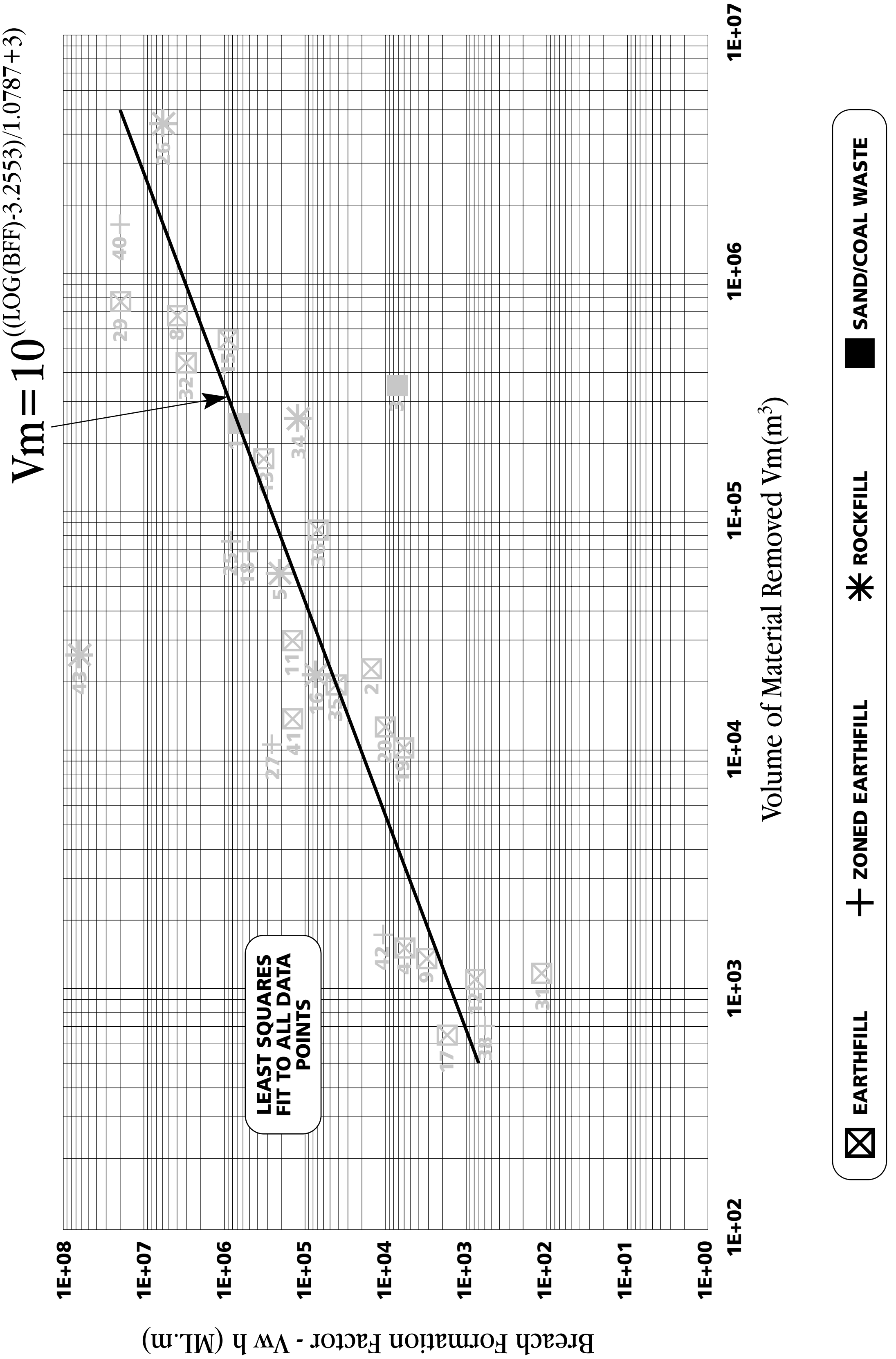
3. Calculate Breach Formation Factor for the assumed failure condition:

   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.

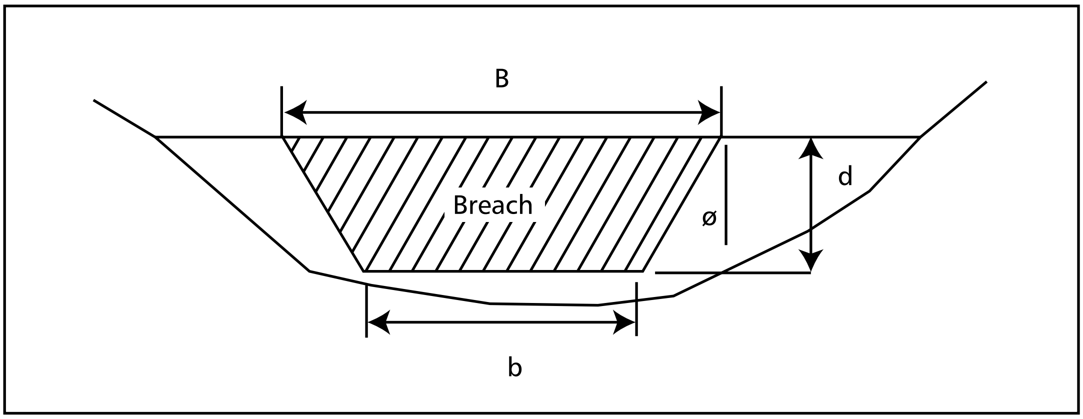
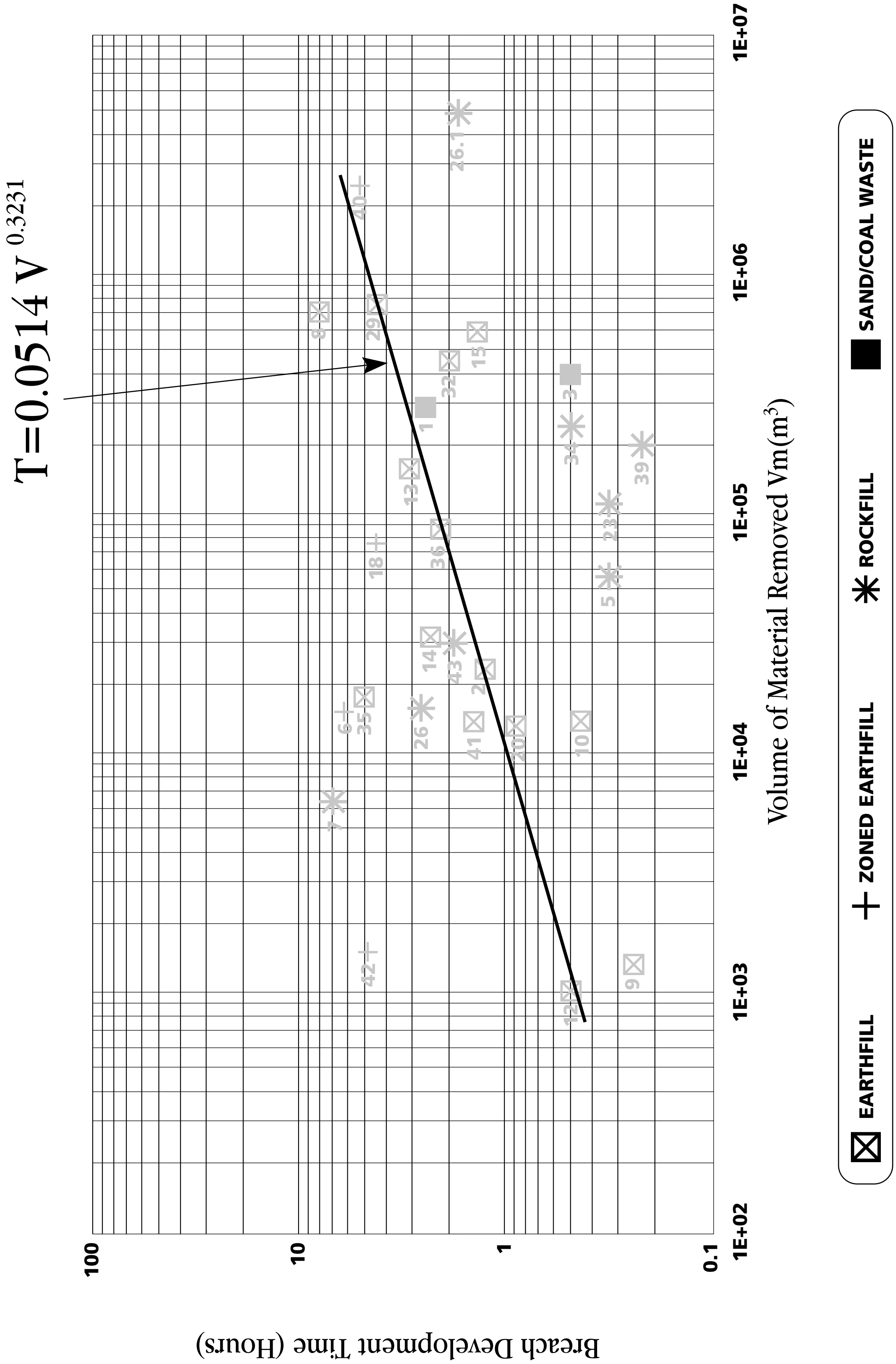



Figure 5 - Notation for breach paramters

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).

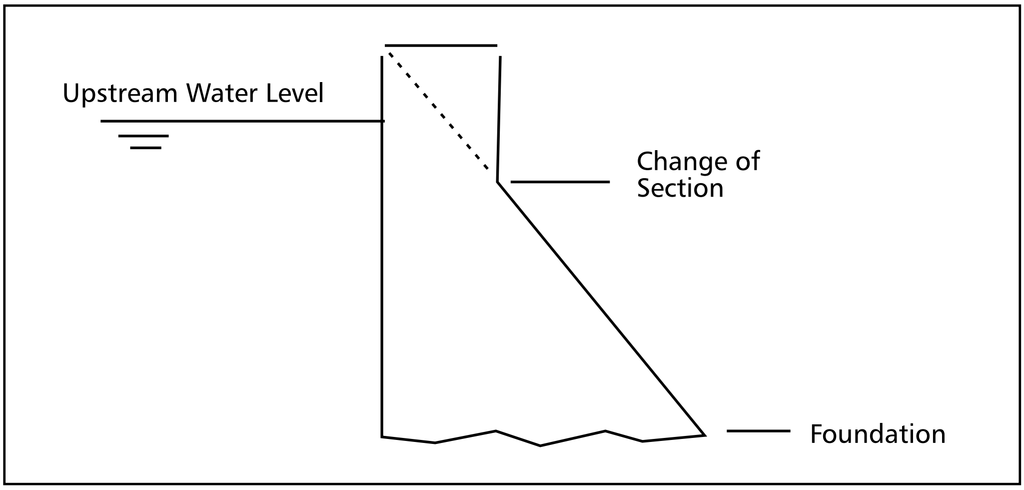



Figure 7 - Typical Mass Concrete Dam Cross-section

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.