Guidance on the Assessment of Tangible

Flood Damages

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1. Guidance on the assessment of flood damages

1.1 Introduction

The impact of flooding on communities is extensive. It typically includes damage to property, community infrastructure, the local economy and the environment, and causes individual and community distress and hardship.

The purpose of this bulletin is to assist applicants to the Regional Flood Mitigation Program to assess tangible flood damages (i.e. those that can be estimated in dollars). The focus is on how to estimate the value of potential[1] physical damage caused to property and infrastructure exposed to flood inundation within an urban environment. The common methods and approaches adopted for estimating flood damages, and the conversion of those estimates to an average annual damage figure necessary for cost/benefit calculations, are explained.

This guidance is consistent with that in broadly accepted methods, including those described in Report 73 of the SCARM Series, *Floodplain Management in Australia: Best Practice Principles and Guidelines* (CSIRO Publishing 2000)

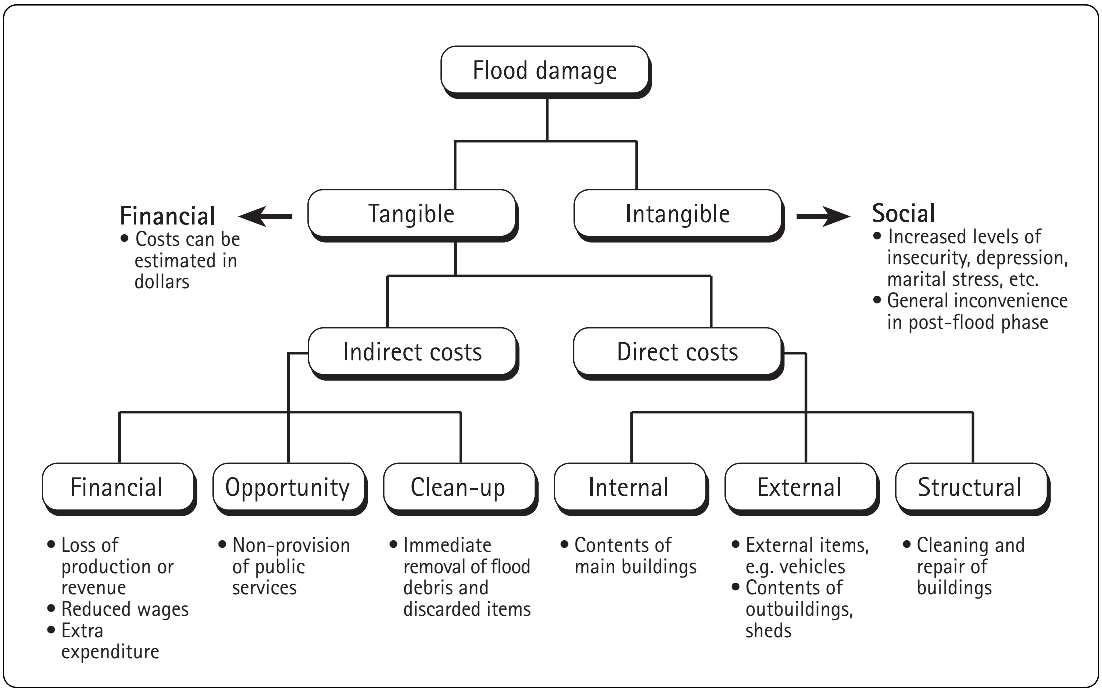
1.2 Types of flood damage

Damage incurred as a result of significant flood events is broadly classified as follows:

- Tangible damages—those that can be estimated directly in dollars.
- Intangible damages—those that cannot be assessed in dollar terms.

The subject of this bulletin is *tangible damages*, which can be further classified as either *direct or indirect*. (See figure 1.)

Figure 1: Types of flood damage



1. Potential damages are discussed further in section 1.3.

Tangible damages are those that can be readily measured in monetary terms. Damage to buildings and contents is considered *tangible* because it can be quantified in terms of replacement or restoration cost. Other damage—such as emotional trauma or loss of life—is considered *intangible* because it cannot be readily expressed in monetary terms.

Direct damages are those that occur immediately and as a direct result of exposure to flood inundation. They include damage to both community infrastructure and private property.

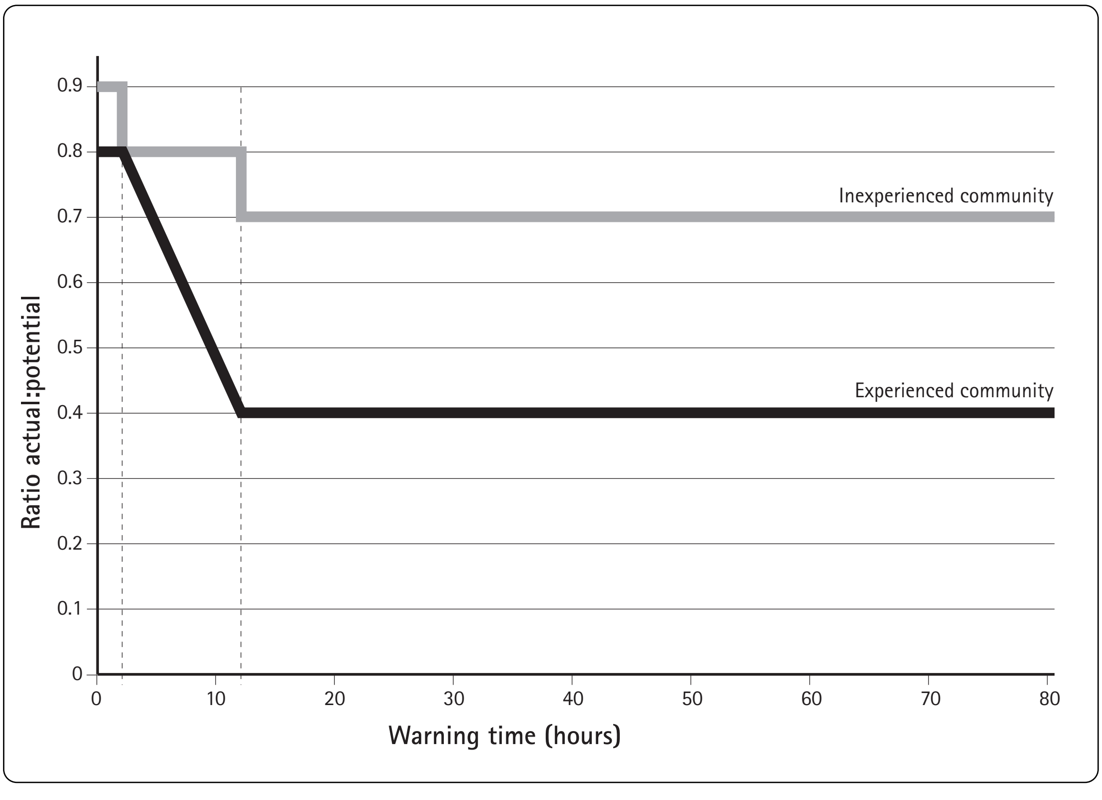
Indirect damages occur as a consequence of direct flood impacts. They include reduced economic activity and individual financial hardship, as well as adverse impacts on the social well-being of a community, and encompass disruptive impacts, including lost trading time and loss of market demand for products.

1.3 Actual and potential damages

The consideration of *potential* versus *actual* damages presents a further complication. Typically, as part of supporting investigations for floodplain management or flood risk reduction measures, damages likely to occur as a result of a given flood are assessed, and particular assumptions are made about what structures and possessions will be affected. Generally, the worst-case assumption is that nothing can or will be done to remove susceptible valuables from the area facing inundation. However, significant reductions in potential damages can be achieved by relocating movable possessions to flood-free areas, where warning times are sufficient (and the affected population is 'flood aware').

When estimating potential flood damages, consider including a reduction based on the possible efforts of residents and volunteers ahead of the flood. Factors such as the warning time, access to flood free refuges and the flood readiness of the community at risk must be taken into account

Figure 2 : The relationship between actual and potential damages



Reproduced from Victorian Department of Natural Resources and Environment 2000, Rapid Appraisal Method (RAM) for Floodplain Management, *prepared by Read Sturgess and Associates, Melbourne.*

As noted earlier, the focus of this bulletin is on the estimation of *tangible direct* and *indirect potential damages* to private and public infrastructure. While not exhaustive, such an assessment is a useful indicator of the level of economic impact.

(It is intended that the assessment of social and environmental impacts will be detailed in other bulletins.)

1.4 Approaches to flood impact assessment

There are a number of approaches that can be used to estimate tangible flood damages. In decreasing order of accuracy they are:

1. Survey of individual properties by a loss assessor to determine potential damages.
2. Application of stage–damage curves to assess potential damages.
3. Adoption of an average damage amount per building.

It is important to adopt an assessment approach that is appropriate for both the level of flood risk and the quality of flood hazard information.

The stage–damage curves provided in this bulletin are suitable for use by applicants under the Regional Flood Mitigation Program. However, it is strongly recommended that, where possible, local authorities develop their own data.

2. Estimating damages to residential and commercial properties

The relationship between the level of inundation by floodwaters and the resulting damage to residential and commercial property is influenced by the value of the building structure, the value of its contents, and the susceptibility of each to damage.

In addition, the local velocity of floodwaters, in combination with their depth, can result in significant structural damage to a building if the forces exceed the capacity of the structure to withstand them.

2.1 Stage–damage relationships

The damage to residential properties and household contents can be assessed using stage–damage curves, which describe the relationship between levels of inundation and damage incurred. Surveyed damage estimates for a range of flood levels are essential to their production.

Where velocities are considered high enough to demolish a structure, the replacement value of the structure and contents should be adopted. Such magnitudes of velocity are usually experienced only in extreme flood events—that is, floods of a magnitude greater than a 100-year average recurrence interval (100-year ARI).

It is strongly recommended, where possible, to develop stage–damage curves that represent local conditions and the types of buildings present. Where this is not possible because locally specific data does not exist, use available stage–damage curves produced as a result of previous flood damage studies.

The Department of Natural Resources and Mines recommends adopting the stage–damage curves developed for ANUFLOOD[2]. The curves for this flood damage model were developed for a range of building types and sizes, and include those that represent:

- residential buildings for a range of property sizes
- commercial buildings for a range of sizes and contents.

2.2 Estimating levels of inundation for affected properties

Property inundation levels are calculated using information on ground heights, flood heights and property floor levels.

- **Ground heights** can be measured by a range of survey techniques and are also required for numerical flood modelling exercises (e.g. a flood study). Where this information is not available from flood modelling studies, estimates of ground heights may be made from sources such as topographic maps, sewerage plans and building approvals.
- **Flood heights** are predicted either by numerical flood modelling or from flood extent maps of previous flood events.
- **Floor levels** can be estimated from building approval records or by traditional survey techniques. Less accurate kerbside estimation techniques can also be used, which involve estimating floor heights above ground levels rather than the survey of actual levels. The level of over-floor inundation is the difference between the flood height and the floor height at each property.

Indirect damages (e.g. clean-up costs) for residential and commercial properties are difficult to estimate and are commonly assessed as a proportion of direct damages.

2. A computer model (developed by ANU) designed to assess flood damages to urban buildings.

2.3 Estimating flood damages

The following steps are involved in estimating flood damages:

1. Identify flood-affected properties and the likely height of inundation.
2. Select appropriate stage–damage curves for determining potential direct damages.
3. Apply stage–damage curves to estimate potential direct damages from flooding.
4. Estimate indirect losses.
5. Calculate total (direct and indirect) damages.

2.3.1 Step 1

Flood hazard mapping exercises predict the extent and depth of floodwaters for varying levels of flood severity. These flood maps provide the information on location of affected buildings, ground levels, flood levels and flow velocities required to calculate a damage estimate.

To use the stage–damage curves in later steps, an estimate must be made of the height of inundation (above floor level) at each of the affected properties.

2.3.2 Step 2

The stage–damage curves provided in this bulletin are separated into residential and commercial categories.

Three residential curves have been developed to cover the range of house sizes (small, medium and large). (See table 1 for further illustration.)

The size categories are as follows:

Small house: < 80m^2 and/or 1–2 bedrooms

Medium house: 80–140m^2 and/or 3 bedrooms

Large house: > 140m^2 and/or 3+ bedrooms

Table 1: Stage–damage relationships for residential properties

Depth over floor level	Small house ($)	Medium house ($)	Large house ($)
0 m	905	2 557	5 873
0.1 m	1 881	5 115	11 743
0.6 m	7 370	13 979	25 351
1.5 m	17 379	18 585	32 276
1.8 m	17 643	18 868	32 768

Reproduced from Centre for Resource and Environmental Studies (Australian National University) 1992, ANUFLOOD: A Field Guide, *prepared by D.I. Smith and M.A. Greenaway, Canberra.*

To account for different building sizes and the varying value of any contents, there are several categories of commercial stage–damage curves (see table 2). First, there are three size categories for commercial properties:

Small property: < 186 m^2

Medium property: 186–650 m^2

Large property*: > 650 m^2

**For large properties, damage estimates are per square metre of floor area and must be multiplied by floor area.*

Within each commercial property size category there are classes to account for the value of any contents and how easily they are damaged by floodwaters. They range from one to five in increasing value of potential damage. (See figure 3 for guidance on the selection of an appropriate value class for commercial property contents.)

Example

Property: Jim's Hardware Store

Floor area: 250 m^2

Contents: hardware supplies

In this example of the selection of an appropriate commercial stage–damage curve, the floor area is greater than 186m^2, therefore a medium-sized commercial property curve with value class 2 contents (see table 2) should be selected.

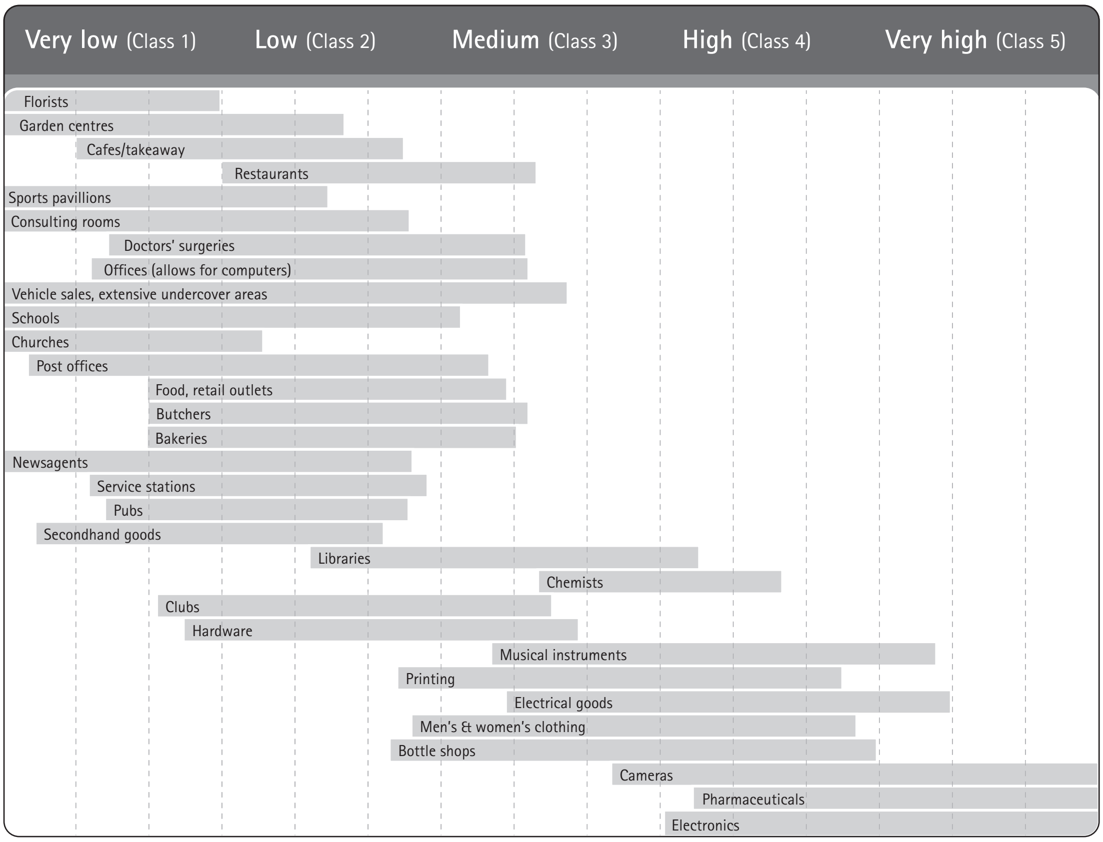
Table 2: Stage–damage relationships for commercial properties

Value class	Small commercial properties (<186m²)					Medium commercial properties (186-650m²)					Large commercial properties (>650m²)*				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
0.25	$2 202	$4 405	$8 809	$17 618	$35 237	$6 975	$13 948	$27 896	$55 791	$111 583	$7	$15	$32	$61	$122
0.75	$5 506	$11 011	$22 023	$44 046	$88 092	$16 884	$33 768	$67 537	$135 074	$270 147	$39	$78	$154	$308	$619
1.25	$8 258	$16 518	$33 034	$66 069	$132 137	$25 693	$51 387	$102 773	$205 574	$411 094	$81	$162	$326	$649	$1297Ł
1.75	$9 176	$18 352	$36 705	$73 410	$146 819	$28 445	$56 893	$113 785	$227 570	$455 140	$132	$267	$533	$1065	$2129
2	$9 726	$19 454	$38 907	$77 814	$155 628	$30 281	$60 564	$121 126	$242 252	$484 504	$159	$318	$636	$1 272	$2 545

* units of $/m²

Reproduced from the Centre for Resource and Environmental Studies (Australian National University) 1992, ANUFLOOD: A Field Guide, *prepared by D.I. Smith and M.A. Greenaway, Canberra.*

Figure 3: Damage categories for commercial properties



Reproduced from Centre for Resource and Environmental Studies (Australian National University) 1992, ANUFLOOD: A Field Guide, *prepared by D.I. Smith and M.A. Greenaway, Canberra.*

2.3.3 Step 3

An estimate of potential damages can be generated once an appropriate stage–damage curve has been selected for the exposed properties.

The first stage in estimating potential damages is assessing the likelihood of the building structure failing when exposed to flooding. This requires information on flood velocities. If this information is unavailable, an estimate of likely velocities should be used.

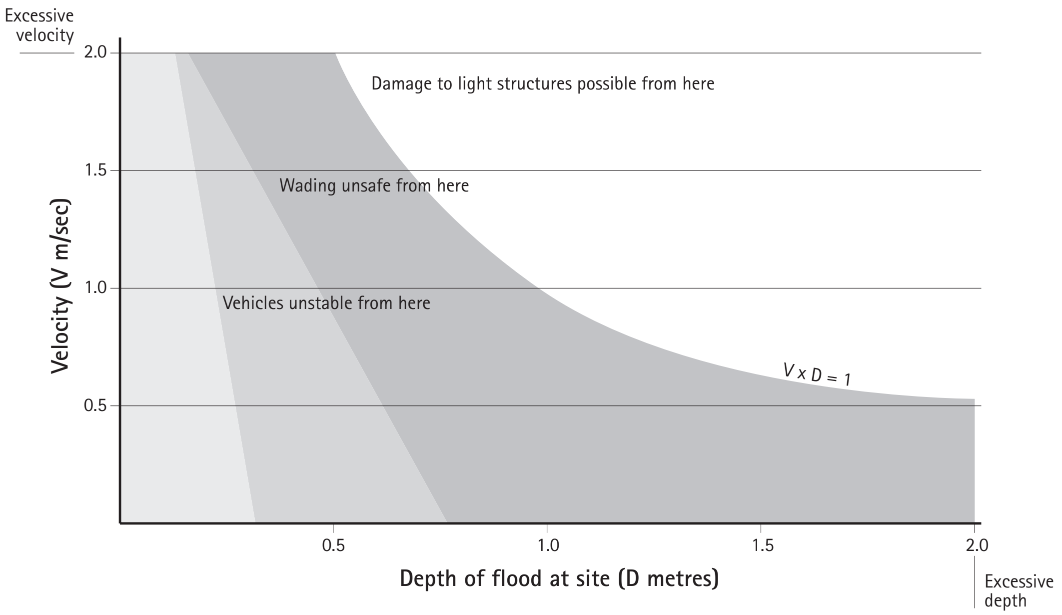
Structural failures can begin at a range of flood depth–velocity combinations. At shallow depths, velocities greater than two metres per second can affect the stability of building foundations through the actions of scour. Even at very low velocities, damage to light-framed buildings from water pressure, flotation and debris loads can be caused by flood inundation depths of greater than two metres. Typically, such damage is considered likely to occur where the product of the depth and velocity is greater than one.

Figure 4 may be used as a guide to assessing whether depth and velocity require consideration in the damage estimate. Where the graph indicates that the depth and velocity experienced by a building are great enough to cause failure, the potential damage estimate should be based on the cost of replacing both the building and its contents.

If depth–velocity figures indicate that structural damage is not likely, the application of stage–damage curves alone is appropriate to estimate potential damage.

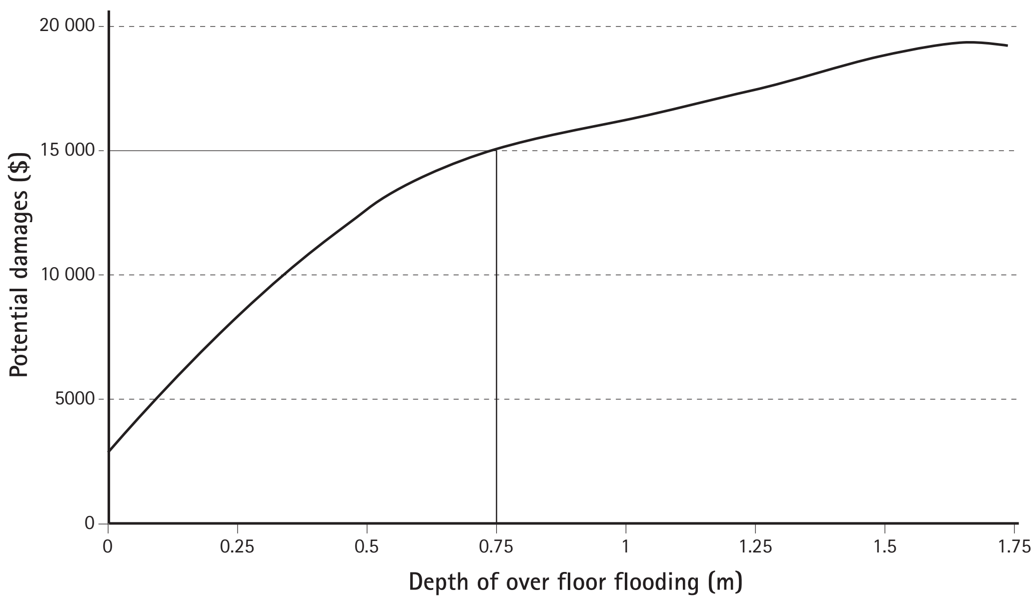
An example of a typical stage–damage curve for a large residential property is provided at figure 5.

Figure 4: Critical depth–velocity relationship



Reproduced from the New South Wales Government 2001, Floodplain Management Manual: the management of flood liable land, *Sydney.*

Figure 5: Residential stage–damage curve for a medium-sized house



Entering this graph on the horizontal axis (height of inundation), a vertical line is drawn to the curve. The value displayed on the *y*-intercept is the potential damage.

As some residential properties may be raised, with storage provided underneath for items such as mowers and washing machines, allowances can be made for damage caused to these items. ANUFLOOD has a maximum under-house damage allowance of $1225. Where the flood height is lower than the habitable floor height, a proportion of this allowance can be included in the damage estimate:

$$\text{Damage} = \frac{\text{Inundation above ground level}}{\text{Habitable floor height above ground}} \times \text{Maximum under-house damages}$$

The total damage for a residential property is the sum of under-house damages and internal damage estimates for over-floor flooding (generated from stage–damage curves), plus structural damage, if applicable.

An example of this process is provided below:

Property: 3-bedroom residential

Flood height: 26.5 m

Ground level: 24.95 m

First floor height: 0.8 m above ground level

Velocity of flow: 0.65 m/s

Depth of over-floor inundation

= 26.5m - 24.95m - 0.8 m

= 0.75 m

Check for structural failure

Depth x Velocity

= 0.75 x 0.65

= 0.49

Therefore, structural failure is not likely. (Refer figure 4.)

Calculate under-house damages

Flood height – ground height is greater than first floor level

Therefore, damage is the allowable maximum of $1225.

Stage–damage curve estimate

Inundation above floor = 0.75 m

Therefore, damage = $14 747*

(Interpolated from figure 4: Residential stage–damage curve for medium-sized house.)*

Calculate total damages

Total damage = under-house damage + stage damage

= $1225 + $14 747

= $15 972

These calculations are then repeated for each affected property.

2.3.4 Step 4

Once an assessment of the potential direct damages to exposed properties has been made, indirect damages are estimated. Commonly, for residential and commercial properties, indirect damages are estimated as a percentage of direct damage.

The following percentages are recommended in the ANUFLOOD model:

Indirect residential damages = 15% of direct residential damages

Indirect commercial damages = 55% of direct commercial damages

2.3.5 Step 5

The total damage cost is the sum of all direct and indirect damages.

Total damages = direct damages + indirect damages

3. Estimating damage to other infrastructure

Other than privately owned property, there are a number of assets that may be exposed to flood damage. For example, direct and indirect damages may be caused to:

- roads and transport infrastructure
- parks and recreational facilities
- hospitals, schools, police and fire stations, and other government buildings
- water, sewerage and drainage systems
- communications networks.

Traditionally, most of these assets were publicly owned; however, the increasing trend towards privatisation of services (e.g. communications) has influenced the costing methodology used to assess damages. This issue will be discussed further in this section.

3.1 Direct damages

Commonly, the repair and replacement of roads and bridges is the largest component of damages to public assets. The amount of damage caused is a result of flood-related factors and the ability of the road to withstand flood conditions. Relevant factors include both the initial repair costs incurred after a flood event and the possibility of a significant reduction in the overall life of the road surface.

Annual maintenance expenditure figures and other documented historical costs can be used to develop locally specific damage costs. Where this information is not available, data from other studies may be used. See table 3 below.

Table 3: Unit damages for roads and bridges (per kilometre of road inundated)

	Initial road repair ($)	Subsequent accelarated deterioration of roads ($)	Initial bridge repair and subsequent increased maintenance ($)	Total cost to be applied per km of road inundated ($)
Major sealed roads	34 860	17 430	11 985	64 275
Minor sealed roads	10 895	5 450	3 815	20 160
Unsealed roads	4 900	2 450	1 740	9 090

Reproduced from the Victorian Department of Natural Resources and Environment 2000, Rapid Appraisal Method (RAM) for Floodplain Management, *prepared by Read Sturgess and Associates, Melbourne.*

The damage estimates presented above are based on studies completed following floods in Victoria and include the following components:

- initial repairs to roads
- subsequent accelerated deterioration of roads (i.e. reduced pavement life)
- initial repairs to bridges (based on one-third of road damages)
- subsequent additional maintenance required by bridges.

Where possible, direct damages to any other affected infrastructure should be included in the overall damage estimate. Information on the magnitude of such damages may be sourced from data collected after historical flood events and extrapolated to the size of flood event being investigated.

Direct damages to publicly owned buildings (e.g. local government offices) must also be considered and can be evaluated using the stage–damage curves for commercial buildings discussed earlier.

3.2 Indirect damages

The indirect damages to services provided by government or community agencies should be based on the lost wages from downtime and disruption to operations. This may be calculated by multiplying lost working hours by wages.

Businesses or activities not provided by government or community agencies are profit driven. Accordingly, the calculation of their damages needs to be based on different assumptions. These indirect losses should be calculated only as the lost profit component.

4. Economic assessment of flood mitigation projects

The purpose of this section is to provide guidance on the economic assessment of flood mitigation projects based on their costs and benefits.

4.1 Average annual damages

The annual average damage (AAD) cost from flooding (expressed in units of dollars per year) is a common performance indicator used to measure the level of potential flood damages. It expresses the costs of flood damage as a uniform annual amount based on the potential damages inflicted by a range of flood magnitudes.

The calculation of an AAD estimate requires potential damage bills for a number of flood sizes—the more, the better. As a bare minimum, an estimate is needed of:

- the size of flood event where damage to property begins
- potential damage for the design event
- potential damages caused from the probable maximum flood (the largest probable flood event, e.g. 10 000-year-average recurrence interval).

As a general rule, the greater the range of flood events investigated, the more accurate the estimate.

To calculate AADs:

1. Estimate potential damage costs from a range of flood sizes.
2. Plot graph of potential damages versus annual exceedance probability.
3. Calculate annual average damage costs from flooding.
4. Calculate potential reduction in annual average damage from flood mitigation activities.

4.1.2 Step 1

To complete this step, it is necessary to have estimates of potential damages for a range of flood sizes.

Following is a simple example of damage costs that illustrates the process used to calculate AADs.

Event where damages begin:

10-year average recurrence interval (ARI)

Potential damages from 100-year ARI flood event:

Total residential damages		$120 000
Total commercial damages	+	$195 000
Total damages	=	$315 000

Damages from probable maximum flood event:

Total residential damages		$200 000
Total commercial damages	+	$320 000
Total damages	=	$520 000

4.1.3 Step 2

Next, a graph of potential damages estimates versus annual exceedance probability (AEP) is plotted.

Potential damages in dollars are plotted on the vertical axis, while annual exceedance probability is plotted horizontally. Like an average recurrence interval, the annual exceedance probability is a measure of the likelihood of a given flood occurring. The chance of a flood event of a given size (or larger) occurring in any one year is measured as a percentage value between zero and one. (Zero indicates that the event is extremely unlikely, while one indicates that it is certain to occur.)

The annual exceedance probability for a given flood event is the inverse of the average recurrence interval:

$$\text{Annual exceedance probability} = \frac{1}{\text{Average recurrence interval}}$$

Using the example damage costs from before:

10-year ARI = 10%, AEP = 0.1

100-year ARI = 1%, AEP = 0.01

For rarer flood events, like the probable maximum flood, the annual exceedance probability (AEP) approaches zero.

For the purpose of the example, the probable maximum flood will be assumed to be a 10 000-year average recurrence interval event, or a 0.01 per cent annual exceedance probability event.

Next, potential damage estimates are plotted against annual exceedance probability.

Table 4. Annual exceedance probability

Average recurrence interval	Annual exceedance probability	Total potential damages
10 year	10%	$0
100 year	1%	$315 000
10 000 year	0.01%	$520 000

4.1.4 Step 3

The annual average damage cost is the area under the line of the graph plotted above. It is expressed in units of dollars per year.

Using the previous examples of flood damages (see figure 6), the area under the plotted line is calculated as follows:

Area total = Area triangle + Area Parallelogram

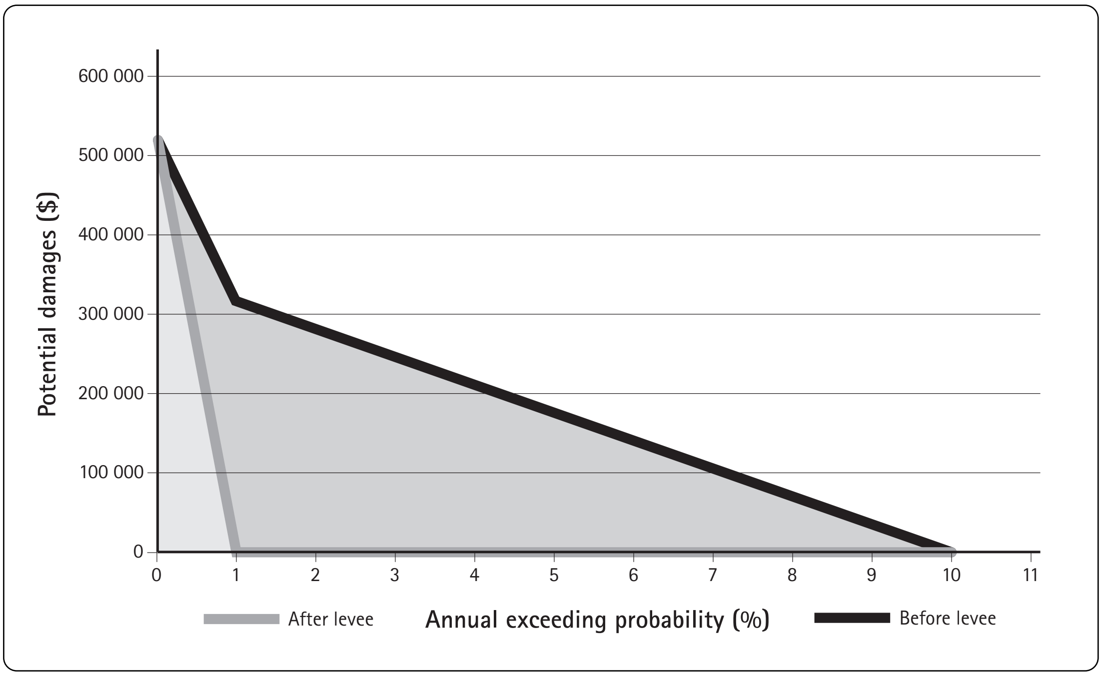
Area = 0.5 x [(0.1-0.01) x 315 000] + 0.5 x [0.5 x (520 000+315 000) x (0.010-0.0001)]

= $ 14 175 + $ 2067

= $ 16 242

Therefore, annual average damage = $16 242.

Figure 6: Plot of potential damages versus annual exceedance probability



4.1.4 Step 4

The reduction in annual average damages (AAD) that can be realised through flood mitigation projects is calculated as:

Reduction in AAD = AAD without project – AAD with project

For example, if a levee bank is proposed to be constructed to provide 100-year average recurrence interval immunity (see figure 6):

Reduction in AAD = AAD without levee – AAD with levee

= $16 242 - $2600

= $13 642

4.2 Future Regional Flood Mitigation Program bulletins

This is the first in a series of bulletins that are currently being developed by the Department of Natural Resources and Mines to provide guidance to Regional Flood Mitigation Program applicants. It is intended that the topics of social and environmental assessment will be covered in future bulletins.

Notes