# Flood damage estimation - A review of urban stage-damage curves and loss functions

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## Abstract

The estimation of damages is integral to the formulation of flood policy. For the assessment of flood losses this requires the use of stage-damage curves for different classes of buildings. A review is presented of the methods used to construct these. The use of synthetic techniques is stressed and attention given to actual and potential losses and to the susceptibility of buildings to failure in response to floodwater depth and velocity. Recommendations are presented for the construction and use of stage-damage curves for residential and commercial buildings in South Africa.

## Introduction

The Department of Water Affairs and Forestry is currently engaged in formulating a National Flood Policy for South Africa. A key element in such a policy is the assessment of flood damages for both the rural and urban sectors. This is necessary in order to weigh the costs of flood mitigation measures against the benefits of reducing flood damage. This account reviews research on stage-damage curves to evaluate urban losses and presents guidelines for their use in South Africa.

The basic methodology is dependant upon the development and use of stage-damage curves, alternatively called "loss functions". These were outlined by Gilbert White some 50 years ago (White, 1945; 1964). A stage-damage curve normally relates to a specific class of building or crop and presents information on the relationship of flood damage to depth of flooding (or stage). Stage-damage curves are the essential building blocks upon which flood damage assessments are based.

This review considers:

- the development of the concept of stage-damage curves;
- problems in constructing such curves; and
- recommendations for South Africa.

## The development of the concept

Stage-damage curves were developed in order to predict flood losses. The initial response was to gather data from actual flood events and use these as a guide to future events. There are a number of problems with this approach. Extrapolation from place to place poses difficulties due to:

- differences in warning time; and
- differences in building type and contents.

Even at a single location, for floods of comparable magnitude, there are differences. A key reason is the prior flood experience of the community. Compounding the problem is that detailed damage surveys after major floods are uncommon and often rely upon the analysis of relief payments, insurance pay-outs or, worst of all, newspaper accounts of damage.

Extrapolation and prediction of flood losses, as an input into benefit/cost analysis, requires a different approach to the use of actual damages from a past flood event. White (1964) was the first to suggest a new methodology which for the purposes of this account can be termed "synthetic". Synthetic stage-damage curves do not rely on information from an actual flood event but are based on hypothetical analysis. The approach provides stage-damage curves for differing land uses, specifically building types and uses.

The skill in obtaining synthetic loss functions is to decide on the number of building types to be included. This represents a trade-off between time expended and accuracy. An accepted and standardised methodology is required. This is necessary in South Africa as an essential component of a national flood policy.

The first major application of standardised stage-damage curves to buildings was for use with the National Flood Insurance Act (1968) in the USA, administered by the Federal Insurance Agency. This involved the US government in providing financial backing for flood insurance for established residential buildings located in flood-prone areas (below the 1 in 100 year flood line). Houses were divided into insurance classes, each with their own stage-damage curves, based on size, type of building (construction material, number of storeys, presence or absence of a basement), contents etc. The stage-damage data were, however, presented in terms of market value. Examples of the rating tables are given in HUD (1970).

This approach is not recommended as there is a relatively poor relationship between the market price and susceptibility to flood damage. Loss is restricted to the buildings and its contents, land price is extraneous. Although stage-damage curves are internationally accepted as the standard approach to assessing urban flood damage there are relatively few published accounts that give details of the methodology for their construction or their application. Examples in the literature are mainly from North America, the UK and Australia.

Penning-Rowsell and Chatterton (1977) produced a *Manual of Assessment Techniques* which provided detailed synthetic stage-damage curves for both residential and commercial property in the UK. These data are extensively used to assess flood damage there and provide an essential input into computer programs designed to evaluate flood mitigation options. The data have been revised and are available in Parker et al. (1987).

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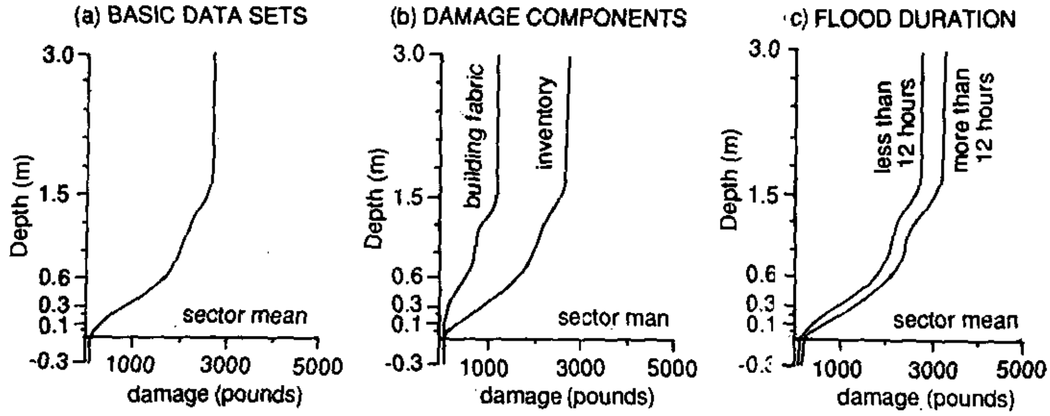


***Figure 1***
*Examples of standard depth/duration/damage curves (Penning-Rowsell and Chatterton, 1977)*

In Australia during the 1970s, a number of urban flood studies were undertaken, all of which used the stage-damage concept. Initially they relied on surveys of damage following major floods, for example the SMEC (1975) study of the 1974 Brisbane flood. The analysis, for the Torrens area of Adelaide (SMEC, 1980) was, however, a synthetic study with the results presented in terms of potential loss. The study by Smith et al. (1979), for the city of Lismore in coastal northern New South Wales (NSW), was the first to combine an analysis of actual flood damage with an assessment of potential damage. A similar approach was presented for Forbes, a small inland town in central NSW, by Higgins and Robinson (1981).

It is necessary at this stage to specify in more detail the differences between varying types of survey methodology used to obtain stage-damage curves.

## Synthetic stage-damage curves

Synthetic stage-damage curves are of 2 types. These are based on:

- existing data bases; and
- surveys by valuers and loss adjusters.

Both require the buildings at risk to be subdivided into a number of classes.

### Existing data bases

This approach was used by Penning-Rowsell and Chatterton (1977) in the UK. The first step is to classify residential buildings into major categories such as detached, semi-detached and terrace construction, all of which are predominantly two-storey as well as bungalows which are single-storey. These categories were also classified by age, i.e. pre-1918, 1918 to 1935, 1935 to 1965 and post-1965. This gave 21 differing types of dwelling. These were further subdivided by social class of the occupants, reported in the British Census and based upon occupation of the head of each household. This extended the number of dwelling types to 84.

The stage-damage information, following normal practice, was divided into "building fabric" and "inventory". The former comprises the building structure, electrical wiring , gas and water, gates and fences. The latter includes furniture and fittings, domestic appliances and personal effects (clothes, books etc.). These 2 categories correspond :o the items usually covered by "building" and "contents" insura:ice policies. Estimates of the damage to building fabric were c btained using existing information on the possible effects of floıding on building material and the like.

The losses to co itents were based upon ownership rates obtained from marketi ıg manuals and consumer research surveys. These relate ownership to social class. Thus, in 1975, 84.7% of social class AB (upper and middle class) households owned washing machines cor.ıpared to 58.2% for class DE (working class and state pensioners). The building and contents data were then allocated by height tı obtain stage-damage curves at 15 depths, from -0.3 m (below floor level) to 2.0 m above floor level. The stage-damage informıtion was presented for durations of flooding of less than 12 h or n ore than 12 h.

The final data th:refore, are available as 168 stage-damage curves for 21 house types, for 4 social class divisions and for 2 durations of floodi ıg. Further details of the methodology and the results are given in Penning-Rowsell and Chatterton (1977). These are updated fo· changes in ownership rates and for inflation in Parker et al. (198˙). A selection of the stage-damage curves is given in Fig. 1; these :ıre the weighted mean values for the complete set of 168 residentia loss functions.

These data, held ɔy the flood hazard research group (FHRC) at the University of Middlesex (formerly Middlesex Polytechnic), are the most comprehensive sets of their kind anywhere. However, it is unlikely that con ıparable sets of synthetic inventory data could be constructed for m any countries, including South Africa. This is because the informıtion on itemised flood damage to building structure, the markt t and consumer ownership statistics and the data on social class are not available.

Penning-Rowsell and Chatterton (1977) also present stage-damage curve infoı mation for building and contents loss to the retail, retail servic:: and office sectors, which for convenience we can term the "cc mmercial sector". This aspect of urban flood damage is often po ɔrly analysed in spite of the fact that commercial sector flood lc sses often far exceed those to the residential sector. There is a so the need to separately analyse damage to large industrial ent:rprises. Loss assessment using stage-damage curves, is inapprcpriate for industrial plants and they should be analysed using questionnaires. It is important to note that a single large indusırial plant can incur direct flood damage that exceeds that for sc veral hundred nearby dwellings subject to the same flood risk.

**TABLE 1**
**COMMERCIAL POTENTIAL DIRECT STAGE-DAMAGE CURVES, IN AUSTRALIAN DOLLARS AT 1993 VALUES**

| | Size 1 (<186 m²) | | | | |
|---|---|---|---|---|---|
| | Value class | | | | |
| **Over-floor depth** | **1** | **2** | **3** | **4** | **5** |
| 0.00 m | 0 | 0 | 0 | 0 | 0 |
| 0.25 m | 1 755 | 3 510 | 7 020 | 14 040 | 28 080 |
| 0.75 m | 4 388 | 8 775 | 17 550 | 35 100 | 70 200 |
| 1.25 m | 6 581 | 13 162 | 26 325 | 52 650 | 105 300 |
| 1.75 m | 7 313 | 14 625 | 29 250 | 58 500 | 117 000 |
| 2.00 m | 7 750 | 15 502 | 31 005 | 62 010 | 124 020 |
| | **Size 2 (186 to 650 m²)** | | | | |
| | Value class | | | | |
| **Over-floor depth** | **1** | **2** | **3** | **4** | **5** |
| 0.00 m | 0 | 0 | 0 | 0 | 0 |
| 0.25 m | 5 558 | 11 115 | 22 230 | 44 460 | 88 920 |
| 0.75 m | 13 455 | 26 910 | 53 820 | 107 640 | 215 280 |
| 1.25 m | 20 475 | 40 950 | 81 900 | 163 800 | 327 600 |
| 1.75 m | 22 668 | 45 338 | 90 675 | 181 350 | 362 700 |
| 2.00 m | 24 131 | 47 263 | 96 525 | 193 050 | 386 100 |
| | **Size 3 (A$/m²)** | | | | |
| | Value class | | | | |
| **Over-floor depth** | **1** | **2** | **3** | **4** | **5** |
| 0.00 m | 0 | 0 | 0 | 0 | 0 |
| 0.25 m | 3 | 6 | 13 | 25 | 50 |
| 0.75 m | 16 | 32 | 65 | 126 | 253 |
| 1.25 m | 33 | 66 | 133 | 265 | 530 |
| 1.75 m | 54 | 109 | 218 | 435 | 870 |
| 2.00 m | 65 | 130 | 260 | 520 | 1 040 |

**Valuation surveys**

The alternative approach to the inventory method is to undertake surveys of the different types of dwellings at risk in the flood-prone study area. The inventory method employed by Penning-Rowsell and his co-workers makes the assumption that properties in flood-prone areas are comparable to the whole UK residential data set. There is no reason to doubt the validity of this assumption; but the valuation survey method is normally limited to dwellings in a particular region.

Valuation surveys select a sample of dwellings in each designated dwelling class and a check-list of possible contents, usually by type of room (kitchen, bedrooms etc.), is drawn up. For the selected properties the surveyor (ideally a qualified loss adjuster or valuer) notes all items and their current value based on type, quality and degree of wear. The survey can include information on the height above the floor of each item or the heights can be taken as standard from house to house.

The information for the sample of each dwelling type is then averaged and stage-damage curves constructed. The resulting stage-damage curves are for potential damage, i.e. no allowance is made for actions that would be taken to reduce flood losses. Similar methods can be used to assess losses that occur immediately after a flood, i.e. actual damage surveys. This approach to the construction of residential stage-damage curves has been used in a number of studies undertaken in Australia by the Australian National University (ANU), see for example Smith et al. (1979 and 1990).

The Australian studies have been extended to the production of stage-damage curves for the commercial sector. Commercial enterprises are classified by size and by value class. There are 3 size classes. "Small" (<186 m²) corresponds to the average high street shop, "medium" (186 to 650 m²) to a small supermarket. For larger premises the actual area (in m²) is recorded. Each commercial building is given a value class that indicates the susceptibility of the contents to flood damage. These are in the range of 1 (very low) to 5 (very high). The stage-damage curves form a matrix based on size and value class with average damages for each class given at 5 heights above floor level. Table 1 presents this information for Australian commercial outlets at 1993 prices.

One of the difficulties with standardised synthetic stage-damage curves is that premises within one classification can exhibit large variations. For instance, a women's dress shop can vary from a fashion house with a small number of highly priced items to an outlet with many hundreds of dresses. The damage to the latter, per $m^2$, would be much higher. The allocation of value class during the field survey goes some way to overcome this problem. The ANU field booking sheets also use the Australian standard industrial classification (ASIC, 1983) code for all buildings in the commercial sector. This classification is based on an internationally agreed 4-digit land-use classification. The equivalent South African code is given in the standard industrial classification (SIC) of all economic activities, see DOS (1993).

In addition to such detailed studies, reconnaissance questionnaires for the commercial sector based on information of the total value of stock and equipment provide a useful check. The total value can be apportioned by height using information on the vertical distribution of retail stock. Data for this are given in Penning-Rowsell and Chatterton (1977). Similar surveys in Australia confirm these values and the information can be extrapolated for use for other countries.

The FHRC and ANU research into stage-damage curves for the commercial sector are the only recently published studies available. It is again stressed that special attention should be paid to this sector as damages frequently far outweigh those to residential property.

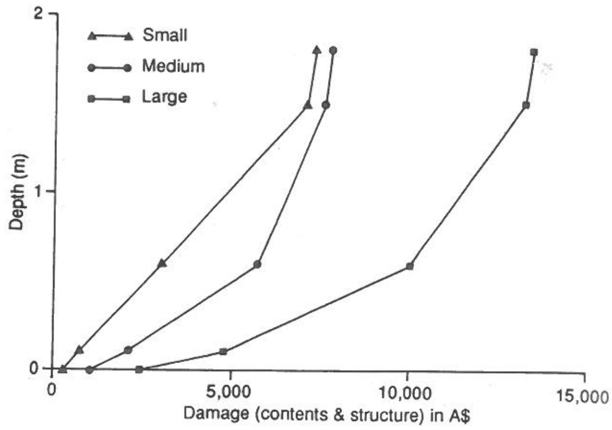


**Figure 2**
*Actual direct damage residential stage-damage curves (contents and structure) for differing residential classes, Sydney 1986 (from Smith et al., 1990)*

## Problems in constructing stage-damage curves

The recommended procedure for the construction of stage-damage curves is that they should be based on synthetic studies. However, the construction of either synthetic or actual damages stage-damage curves poses a number of problems. These can be classified as:

- what to include
- what values should be allocated to items
- how many building types should be used
- scatter and error
- interpolation and extrapolation.

### What to include?

The basic components are damage to building and contents. There is, however, a decision to be made on whether to include vehicles and boats, damage to gardens and whether clean-up costs should be incorporated into the curves.

Vehicles (including caravans) and boats are nearly always excluded. This is because they can readily be moved at times of flood and are often separately insured for flood damage. However, losses to vehicles and boats stored at residential or commercial premises can be substantial, especially for extreme flash floods. The normal procedure is not to incorporate such losses into building stage-damage curves.

Gardens present a different problem. Normally garden equipment, e.g. lawnmowers and tools, and fences are included. Often such items are located below the floor level of the dwelling and the residential stage-damage curves used by the FHRC and ANU allow for such damage by extending the stage-damage curves to below floor level (Fig. 1). However, the loss of the plants or lawns is difficult to assess and, for keen gardeners, becomes an intangible loss. These are excluded from flood loss.

The most difficult category to assess is the cost of clean-up. It is usual practice to incorporate these into the overall stage-damage curves for residential property. There is considerable variation both in the estimates of the time required and in how the time should be costed. Penning-Rowsell and Chatterton (1977) suggest 15 to 20 h per house; Higgins and Robinson (1981) 50 to 60 h for the 1974 Forbes event and the 1974 flood for Lismore averaged 5 person-days per dwelling (Smith et al., 1979). SMEC (1975) for the Brisbane floods of 1974 suggests 62 person-days for flooding 0.30 m over the floor rising to 91 person-days at 1.80 m. Even more problematic is how to convert time to monetary values. The overall approach is to use average hourly wage rates. For the commercial sector it is common practice for the majority of staff to be employed in clean-up operations after a flood. In such cases clean-up costs are excluded; this is to avoid double counting when indirect losses are incorporated.

### What values should be allocated to items?

This is of major significance to overall total direct damage. The normal methodology, followed by both the FHRC and ANU, is to use the concept of average remaining value. This is defined as the average pre-flood value of the item. Care must be taken to allow for the residual value of items after they have been flooded; in some cases the damage can be taken as the repair charge to restore to pre-flood condition. Traditionally average remaining value was used by insurance companies. In those cases where insurance policies replace damaged items with new goods, the assessment of flood losses should remain with the average remaining value concept. For convenience, flood damage surveys often assume that the average remaining value is 50% of a comparable new item. For the commercial sector stock is relatively easy to value and losses to equipment should be costed as average remaining value as described above.

### How many building types?

This is of particular importance for the residential sector. There is no clear-cut answer; the number depends on time available and the variations in the area under study. The synthetic method used by the FHRC is the most comprehensive and presents residential stage-damage curves that cover all types of dwelling in the UK.

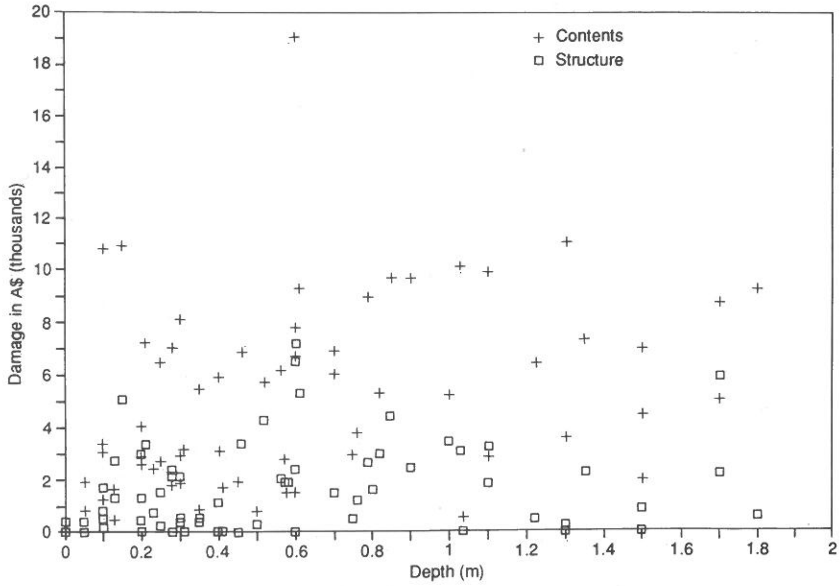


***Figure 3***
*Scatter plot of actual direct contents and structural damage for dwellings, Sydney flood of 1986 (Smith and Greenaway, 1988)*

The valuer-based approach is normally restricted to the study area. In the Sydney flood study only 3 sets of stage-damage curves were used, essentially based on dwelling size. The 3 curves are illustrated in Fig. 2, from Smith et al. (1990). The ANUFLOOD field manual (Greenaway and Smith, 1993a) for coding buildings recommends that surveys to obtain residential stage-damage curves, in terms of direct damage, are undertaken for the area under study. However, it is clear that many other Australian studies use the residential stage-damage curves published by ANU. While this is not ideal, there are broad similarities between house types and average contents throughout much of Australia. This is not true of the UK where dwelling types vary markedly, many are two-storey, or of countries with wide variations in household income. Within countries the problem is less acute for commercial stage-damage curves which, if the ANU matrix approach is used, can be extrapolated from region to region.

Although direct comparisons with differing countries are not recommended, Smith (1981) showed that the potential stage-damage curves for single-storey buildings in Lismore, in northern NSW, were similar to the values given by Penning-Rowsell and Chatterton (1977) for single-storey dwellings (bungalows) in the UK.

### Scatter and error

Direct flood damage for individual properties differ markedly even when they are in a single class. This is especially the case for surveys of actual damage. Figure 3 presents damage estimates from the loss adjuster survey of residential properties undertaken after the 1986 floods in Sydney. Separate values are plotted for contents and building damage, in relation to the depth of overfloor inundation for 71 dwellings. Such information forms the basis for the construction of stage-damage curves. It is clear that published stage-damage curves (see Figs. 1 and 2), involve considerable smoothing of the raw data, i.e. the scatter is large.

### Interpolation and extrapolation

Having estimated the loss for a series of heights there remains the problem of interpolating between the data points. There is no correct solution to this dilemma; common practice is to join the damage points with straight lines. It is, however, important to recognise the critical "step" which corresponds to floor level (Fig. 2).

Extrapolation is also problematic. Many surveys of actual damage contain only a relatively small number of overfloor depths in excess of 1.0 m. Thus, there is a need to extrapolate the survey information in order to obtain estimates for more extreme floods. The usual procedure in such cases is to extrapolate the data following the pattern of synthetic stage-damage curves. For single-storey dwellings the increase in damage for overfloor depths in excess of 1.5 m is relatively small.

## Ratio of actual to potential damage

Synthetic stage-damage curves are the preferred option. These present losses in terms of potential damage, i.e. worse case scenarios that make no allowance for actions to reduce flood damage. It is, therefore, important to consider how to modify potential loss to give the best estimate of actual loss. This requires information for both actual and potential loss; data that are rarely available.

Penning-Rowsell and Chatterton (1977) and Chatterton et al. (1979) provide information on the effects on contents damage for warnings of 0.5, 2 and 4 h. The results for a single-storey (bungalow) dwelling are presented in Fig. 4. In this case it is stated that "... in single-storey buildings no damage reduction is possible with a half-hour warning time". They recognise that the contents savings "... should be halved to account for failure to react to warnings".

It is clear that the effectiveness of flood warning systems is a function of the length of the warning time and the prior flood experience of those at risk. For example, Smith (1981) estimated the actual to potential ratios for the 1974 Lismore flood. For this community the warning time was about 12 h and they had had frequent and recent experience of similar floods. The ratio for the residential sector was about 0.5 and for the commercial sector 0.24, i.e. the reduction in commercial contents damage was some 76%. This work was extended (Smith and Handmer, 1986), and tentative relationships were drawn for the ratios of actual to potential damage for the residential sector. The ratios were related to warning time and to the preparedness (prior flood experience) of the community. These are given here as Fig. 5.

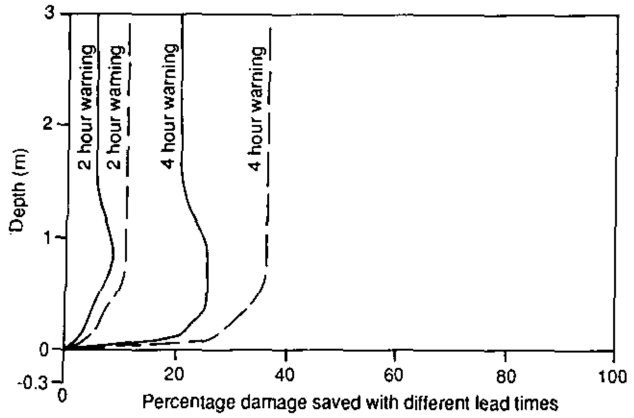


*Figure 4*
*Length of warning and damage reduction for one-storey residence - UK data (Chatterton et al., 1979)*

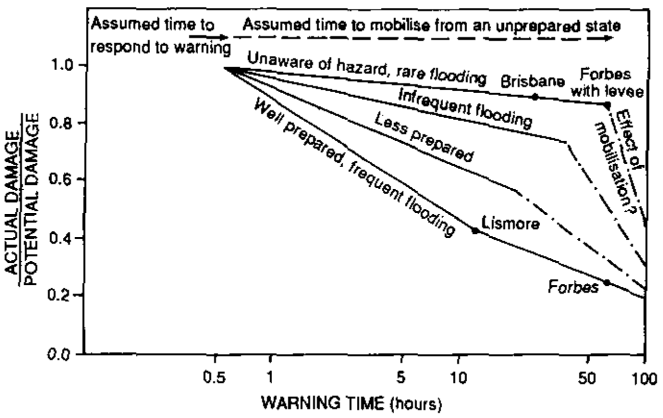


*Figure 5*
*Relationship of actual/potential ratio to preparedness and warning time for residential contents damage (Smith and Handmer, 1986)*

Later work (Smith et al., 1990), based on the Sydney floods of 1986 refined this approach and analysed the actual to potential ratios for differing depths of overfloor flooding. The results are presented in Fig. 6. For the Sydney floods the effective warning time, i.e. how long the residents had before water encroached over floor level, was extremely short. In many cases occupants only realised the risk when water came over the doorstep and few of the residents had any prior experience of flooding. Despite these problems the average saving to contents, of those in the survey, was close to 25% of the total value of household contents. This was attained by lifting high value small electrical items such as videos, and TVs above the flood level.

The use of ratios of the kind shown in Fig. 5, is of critical importance in estimating actual damage. Where warning times are long, say in excess of 24 h, it should be possible to remove virtually all house contents. Damage in such cases would then consist solely of building damage. There are fewer data available for the commercial sector but the indications are that, proportionately, savings to contents can often exceed those in the residential sector.

Studies of actual to potential ratios are also of value in assessing the benefits of flood warning systems. These increase the length of the warning time and should result in increased loss reduction. However, it should be noted that even greater savings can be obtained if flood awareness campaigns can act as a substitute for prior flood experience (Fig. 5). There is little evidence to date of this effect, mainly because of the poor expenditure of monies and expertise in flood awareness campaigns compared to that spent on structural flood measures. The preparation of flood action plans by commercial and industrial concerns could be expected to considerably reduce the actual to potential ratios.

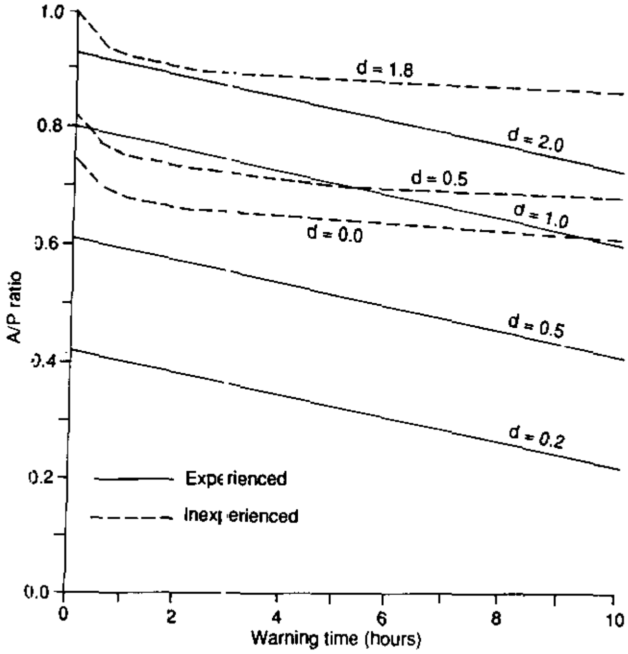


*Figure 6*
*Relationship of actual/potential ratio to overfloor depth and flood experience - Sydney flood 1986 (Smith et al., 1990)*

Further discussion of flood relief, insurance and the role of warning systems is given in Smith and Handmer (1989).

**Structural damage from extreme floods**

Buildings are liable to structural failure if subjected to the combined effects of deep flooding and high velocity flood waters. Such cases are rare but can occur with extreme floods either under natural conditions or as a result of dam failure inundation. The liability to failure is related to the construction material and type of building. Critical combinations of depth and velocity for residential buildings are given in Fig. 7, from Black (1975). If the combination of depth and velocity is above the critical line the probability is that the building will fail.

The effects of structural failure on flood damage to the residential and commercial sector have been little discussed in the literature. They are reviewed in Smith (1991) and the special case of dam failure is presented in Smith (1990). The paucity of earlier discussion of this subject was, in part, due to the lack of data for over-floodplain flood-water velocities. A number of recent computer programs that analyse flood flows can now produce such information and it is important that this is incorporated into flood damage studies. For some regions even the most extreme floods do not produce the critical combination of velocity and depth needed to cause building failure. Elsewhere, floods with a recurrence

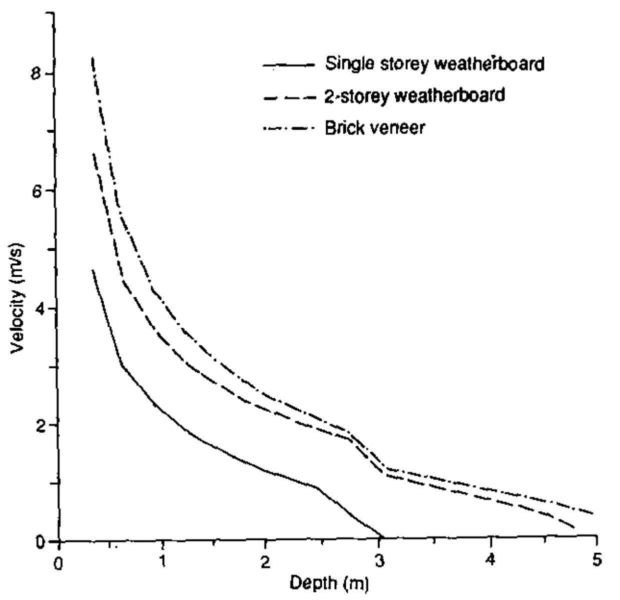


*Figure 7*
*Critical velocity and depth for building failure for differing depths of inundation and residential building types (Black, 1975)*

interval of less than 1 in 100 years can cause such effects.

The effects of building failure on all forms of flood damage are dramatic. There is not only the loss of the building itself but all contents, a considerable risk to life and a major increase in indirect and intangible losses.

## Recommendations for South Africa

An essential element of a national flood policy is the ability to predict flood damages, both as event damages and as average annual damage. This is needed to assess the benefits of the available range of flood mitigation measures from levees to the use of insurance. Basic to such assessment is the need to develop agreed and consistent methodologies to predict flood losses. For rural and urban areas this requires the formulation of stage-damage curves, or loss functions.

Ericksen (1986) stressed the need for similar information in an excellent review of flooding in New Zealand, a study funded by the government as a background to a new national flood policy. He states that "...what is needed in addition to the post-disaster approach [surveys of actual damage] is the use of synthetic pre-disaster estimates of flood damages".

Stage-damage curves are an essential step but are only the first stage in assessing flood losses. They are combined with field surveys of property at risk and with hydrological information (probability and extent of flooding, velocity and the like) to give predictions of event damages from which average annual damage can be calculated. This is normally undertaken by the use of computer programs. A widely used and commercially available example is ANUFLOOD (Greenaway and Smith 1993b, first published 1983, revised 1993; and Smith and Greenaway, 1988). Similar programs could be designed and used for rural (crop) losses. These too, require stage-damage curves as essential inputs. Consistent methodologies are necessary in order that decision makers can compare, on a systematic and rational basis, estimates of flood damage from one location to another.

What then should be the approach to obtaining such stage-damage curves in South Africa?

In the urban sector the aim should be to use the experience from the FHRC and ANU methodologies to produce synthetic stage-damage curves applicable to South African conditions. Throughout most of the Republic dwelling types are similar in construction; they are of brick and mainly of single-storey construction. This simplifies the task of producing stage-damage curves that could be applied at the national scale. The complications of basements (common in North America) or the variations between single and multi-storey dwellings (as in the United Kingdom) are less significant. However, there are clearly large variations in the size, quality and contents of dwellings between various sections of the community.

Surveys of synthetic damage of a range of commonly occurring house types would form a national data base. Ideally, such surveys should be undertaken by experienced valuers or loss adjusters. Initially these would be for larger flood-prone urban communities and then extended to other areas. Additional dwelling types would be included where necessary, for example flats and apartments are uncommon in most rural communities. To simplify the work it is suggested that the variations in direct damage to buildings and contents due to variations in the duration of inundation are omitted. Experience elsewhere has shown that such effects are limited (Fig. 1).

The use of synthetic data, however, requires that information is available on how to convert these to reliable estimates of actual damage. This requires surveys, some of which already exist, of actual damage. The study by Smith and Viljoen (1981) provided guidelines for flood damage assessment in South Africa but, at that time, were only able to present building stage-damage curves for actual losses for single-storey rural residences. Suitably updated these could provide a starting point for estimates of actual damage.

The opportunity afforded by the formulation of a national flood policy should incorporate:

- the effects of severe floods on building failure; and
- the prioritisation of warning systems on the basis of cost-effectiveness.

This account has focused upon stage-damage curves based on potential or actual **direct damage**. This is only one component of tangible flood damage. The other is **indirect** loss. Traditionally indirect losses, essentially due to disruption caused by the flooding rather than the "direct" effects of floodwaters, have been estimated as a fixed proportion of direct damages. That is they too, rely on stage-damage curves of direct damage. The study by Parker et al. (1987) provides a detailed review of methods and new insights for estimating indirect losses. Essentially the argument is that indirect losses, in the commercial and industrial sectors, have been greatly over-estimated. Formerly the emphasis was upon financial loss, broadly items that could be covered by insurance, especially premiums and payments for "business interruption". The recommended procedure is that such indirect losses should be related to overall economic loss at regional or national level. Thus, losses to a retail outlet disrupted by flood would be made up by increased sales at similar flood-free outlets. In such cases there would be no nett economic loss. In the United Kingdom this approach is favoured by Treasury officials; they require that benefit-cost analyses should be on a national basis. In formulating a new flood policy, it is essential that the economic ground rules are clearly expressed.

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