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Articles in the field of agricultural economics, suitable for publication in the journal, will be welcomed.

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G.P.-S. (L.).

ECONOMIC ASPECTS OF FLOOD DAMAGE PROPENSITY IN AGRICULTURE - A STUDY IN THE LOWER UMFOLOZI FLATS*

by J. VAN ZYL and J.A. GROENEWALD
University of Pretoria

1. FREQUENCY AND DURATION OF FLOODS

The most prominent feature of the Republic of South Africa's water household is a relative scarcity of water. There is, however, also a problem of redundance if there is more water than can be efficiently utilised and dispensed with, and capacities of drainage canals are exceeded to such an extent that the adjacent flood plains are inundated.

Figure 1 presents a schematic exposition of variables and parameters involved in flood damage and flood control. Factors generally beyond human control are shown as exogenous variables, while those that can possibly be controlled are known as parameters (Spies *et, al.,* 1977:4).

If flow records of a river such as the Umfolozi are inadequate to compile flood peak frequency curves, then, according to Weiss (1976), methods as described in the Hydrological Research Unit Design Floods Manual (1972) can be used. Two methods are described namely the Lund and Pitman analyses. The Lund analysis is based on *ex-post* information concerning peak discharges and is used to determine the frequency of a possible future flood peak. The result of such an analysis for the Lower Umfolozi Flats is shown in Figure 2.

In the Pitman analysis, the possible duration and frequency of certain maximum storms in a specific catchment area is determined. Thereafter the effect on a certain stream flow is determined after allowances had been made for losses. Weiss (1976) incorporated this entire procedure of hydrographic synthesis in a computer program. Input to this program comprises essentially the data in Tables 1 and 2. A summary of the results appears in Table 3.

Weiss (1976:7.4) utilised Chow's (1964:8-22) methodology on Pitman and Lund analyses in order to improve the accuracy of values at the high frequency end of the spectrum. These results are shown in Figure 2.

Reasonably acceptable hydrographs over the occurrence time were obtained for the 1957,1963, 1973 and 1975 floods at the railway bridge on the Umfolozi Flats. (See Figure 3.) At all these floods the relationship between flood peak and flood volume was found to be parabolic. According to Weiss (1976:7.2), this relationship can be accepted for all floods on the Umfolozi Flats. This implies that flood damage can be linked directly to flood peak frequency (Figure 2) without separately providing for flood volume.

2. FLOOD DAMAGE

During normal flow a stream utilises only a part of a river valley and the adjacent area can be used by man for economic activity. These low-lying adjacent areas are shown as the flood-plain which is frequently very fertile because of earlier sediment deposits. Nature periodically claims its toll for the utilisation of the flood-plain by way of flood damages (James, 1976:33). Flood damage consists of material and non-material losses suffered by the community because of floods. Material or tangible losses comprise that part to which a monetary value can be attached whereas the non-material or intangible losses consist of the part to which monetary value cannot be attached. Figure 4 gives the flood damage classification of Spies *et. al.,* (1977:19).

Two approaches are used to determine damage curves (Parker and Penning-Rowsell, 1972:5), viz. methods based on reported flood damage and methods based on situation simulation techniques.

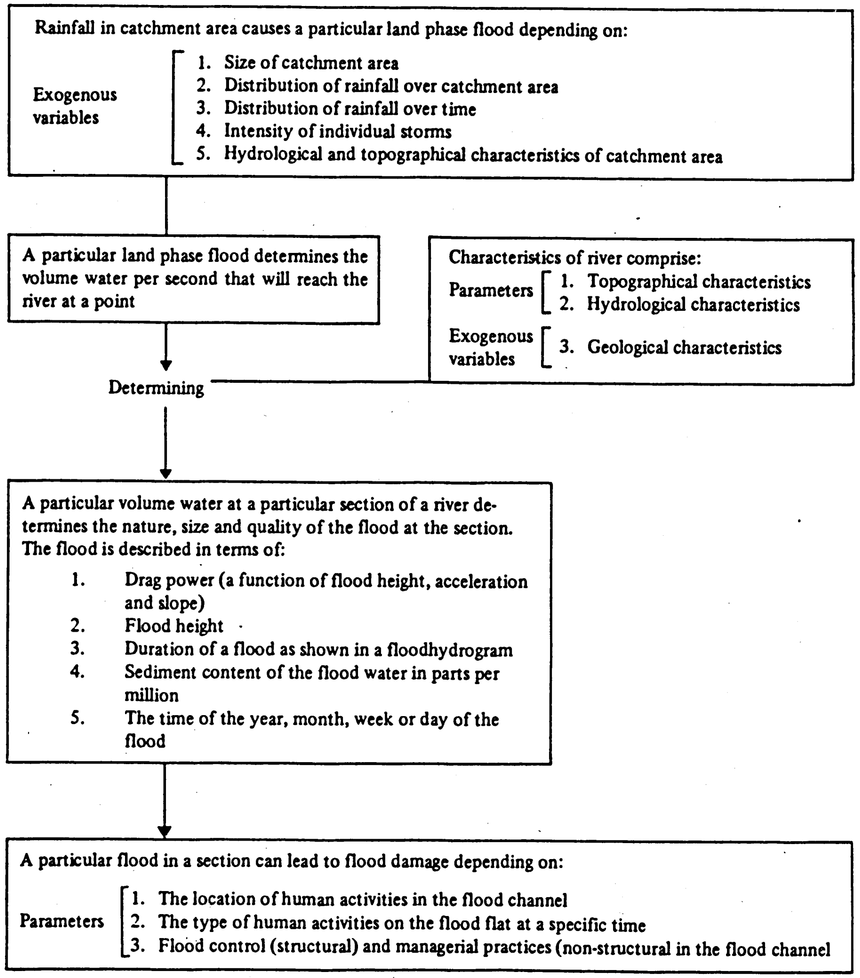
2.1 Methods based on reported flood damage

In these calculations comprehensive surveys, sample surveys or indicator methods are used (Spies *et. al.*, 1977:62-65).

When correctly used, these methods can yield accurate information and also approach flood damage determination from different angles.

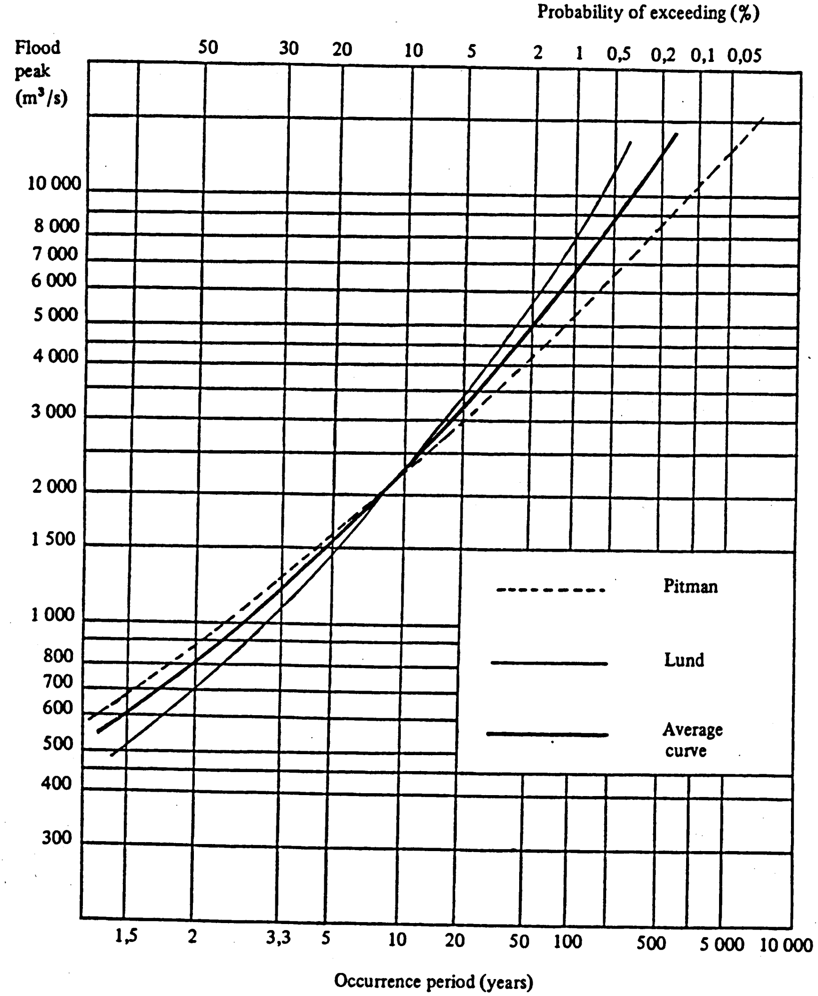
Practical problems, with the human factor one of the most important, often cause the results to be less satisfactory. For example, a person can, because of his direct involvement with the flood, be inclined to overestimate damage shortly after a flood. Surveys done shortly after a flood will not

* Based on an unpublished MSc(Agric) thesis by J van Zyl, University of Pretoria. The research costs were borne by the Department of Agriculture



Source: Spies *et.al.* (1977:4)

FIGURE 1 - Relationships, variables and parameters connected with flood damage in a particular section



Source: Weiss (1976)

FIGURE 2 - Floodpeak to frequency of occurrence relationships, Umfolozi Flats

TABLE 1 - Rainstorms, losses and run off (mm) in the Umfolozi catchment area

Recurrence interval	Item (mm)	Duration of storm (hours)				
		4	8	12	18	24
5 years	Rainfall	39,2	44,4	48,6	52,3	55,4
	Loss	32,8	36,4	39,4	42,0	44,1
	Run off	6,4	8,0	9,2	10,3	11,3
10 years	Rainfall	55,9	63,3	69,3	74,5	79,0
	Loss	44,4	49,4	53,4	56,2	59,3
	Run off	11,5	13,9	15,9	18,3	19,7
20 years	Rainfall	68,2	77,3	84,6	90,9	96,4
	Loss	52,7	58,3	62,5	66,4	69,4
	Run off	15,5	19,0	22,1	24,6	27,0
50 years	Rainfall	84,7	96,0	105,0	112,9	119,7
	Loss	62,4	69,3	74,1	77,7	81,4
	Run off	22,3	26,7	30,9	35,2	38,3
100 years	Rainfall	94,6	107,2	117,3	126,1	133,7
	Loss	68,3	75,6	80,8	84,9	87,6
	Run off	26,3	31,6	36,5	41,2	46,1

Source: Weiss (1976)

TABLE 2 - Area of the Umfolozi catchment area*

Sub-area	Area (km²)
White Umfolozi	5 289
Black Umfolozi	3 639
Lower Umfolozi	425

*The Umfolozi catchment area is divided into three sub-areas viz. the White Umfolozi, Black Umfolozi and the Lower Umfolozi between the confluence of aforementioned two areas and the railway bridge at Riverview
Source: Weiss (1976)

TABLE 3 - Summary of results

Recurrence interval (years)	Critical storm duration (h)	Flood peak (m³/s)
5	24	1 260
10	24	2 200
20	24	3 020
50	24	4 280
100	24	5 170

consider lagged damage effects on long-term crops (e.g. sugar-cane) adequately. Personal interview surveys are subject to several limitations (Warwick and Finnigen, 1975).

Indicator methods refer to short cut methods used to estimate flood damages.

Table 4 shows flood damage estimations for the Lower Umfolozi Flats (Rix, 1982:4).

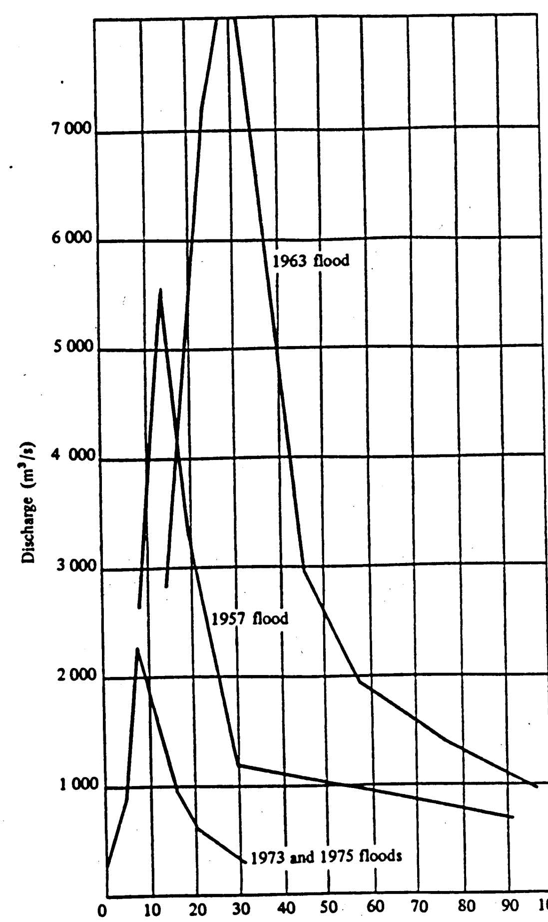
On the other hand, actual damage sustained with the 1977 flood (7 650 m³/s), as obtained from 21 family sized farm units, as well as from the Umfolozi Co-operative Sugar Planters Limited (U.C.S.P.), were estimated on yield losses of 59% and a re-establishment area of 42%.

2.2 Situation simulation techniques

In situation simulation techniques flood

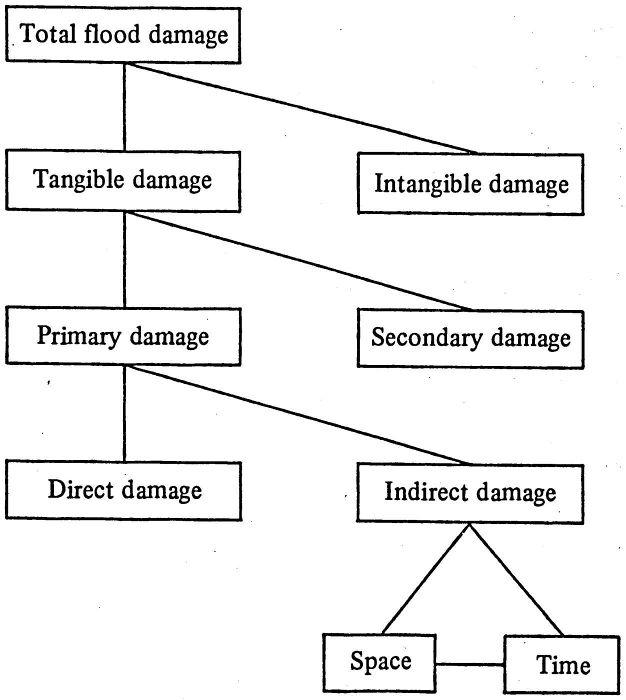
TABLE 4 - Estimated damage caused by floods

Major flood (> 3 000 m³/s)		Minor flood (<3 000 m³/s)	
Yield losses %	Area replanted %	Yield losses %	Area replanted %
70	40	25	15



Source: Weiss (1976)

FIGURE 3 - 1957, 1963, 1973, and 1975 flood hydrographs, Umfolozi Flats



Source: Spies *et.al.* (1977)

FIGURE 4 - A classification of flood damage for measurement purposes

damage is estimated by simulating flood situations by means of different flood damage relationships. These methods, therefore, are directed at projection of possible flood damage within a planning framework (Parker and Penning-Rowsell, 1972), rather than at reporting actual flood. Flood damage relationships are required for this, and a relationship must be determined between flood damage and physical flood parameters, such as depth of inundation, duration of inundation, drag power of water and sediment content and deposits of the water. These relationships or damage functions (Weiss, 1976; Spies *et. al.*, 1979) can be presented graphically in tabular form or mathematically. The deductive approach of White (Parker and Penning Rowsell, 1972) is used to determine flood damage independent of the occurrence of an actual flood.

3. DAMAGE FUNCTIONS

Flood damage to sugar-cane can be both direct and indirect. Direct losses occur in that sugar-cane is dragged along with water, by inundation or by smothering because of sediment depositions. Indirect losses involve establishment costs, time losses and possibly land reclamation where heavy sediment deposit may be.

3.1 Direct losses

Direct yield loss is a function of the height of the sugar-cane during flood. The height of sugar-cane varies largely during the year because of the growth season as well as the harvesting season. On the Umfolozi Flats cane grows all year round, but at rates varying according to the season. Table 5 shows the average monthly growth of sugar-cane on the Umfolozi Flats (Rix, 1982:3).

TABLE 5 - Average monthly growth of sugar-cane on the Umfolozi Flats

Month	Growth (m)
January	0,25
February	0,24
March	0,20
April	0,14
May	0,06
June	0,05
July	0,03
August	0,03
September	0,08
October	0,13
November	0,16
December	0,22

Growth rates during the first growing season are approximately 50% lower than average and this sugar-cane usually requires 20 months instead of 14 months to reach maturity. Mature cane reaches an average height of about 1,8 metres (S.A.S.A., 1982) and is then harvested. The harvesting season usually lasts from May to December.

According to Weiss (1976:6.4), the above-mentioned information can be shown graphically as the height (h) of cane against area under sugar-cane. Figure 5 shows this relationship.

The problem is, however, how to relate height of cane to damage. Direct losses due to inundation, violence and smothering by sediment deposits will now be discussed separately.

(i) Drowning

Little is understood about the processes involved when sugar-cane drowns. All varieties however deteriorate rapidly after periods of complete submergence (Satoris and Belcher, 1949:36-39). The critical period is generally accepted to be about three days (Humbert, 1968:411).

Provided the water moves and can thus supply oxygen, cane can survive for reasonably long periods provided the inundation is only partial (Humbert, 1968:413; Barnes, 1974:120). In running water where cane is only partially inundated, it can take longer than 20 days for the cane to die. High temperatures reduce this period.

Stagnant water smothers sugar-cane. The plants die within a few days. Even if only the roots are covered major damage will occur and the cane will succumb.

(ii) Violence and inundation

Fast-flowing water may damage sugar-cane by

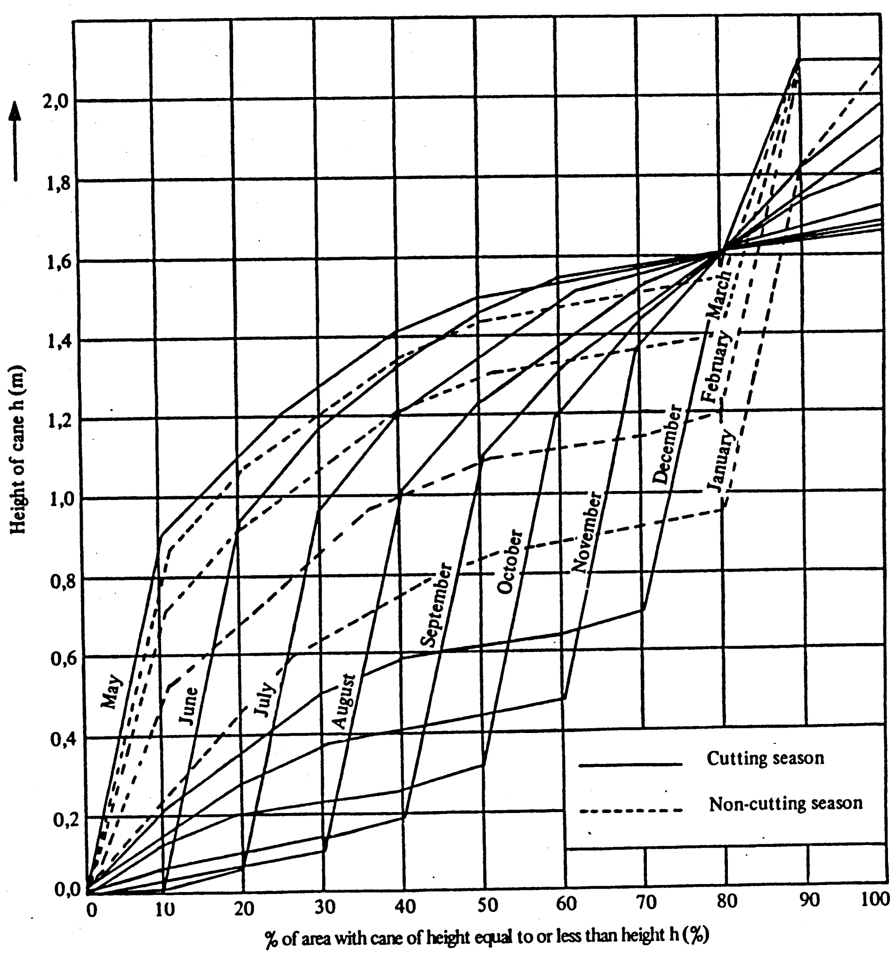


FIGURE 5 - Average height distribution (by months) of sugar-cane, Umfolozi Flats

bending it, thus increasing the susceptibility to drowning. Even should bent cane survive in water, growth is influenced disadvantageously since plants are lying flat. The flood may also drag along cane, thus destroying it completely.

According to Weiss (1976:6.5) fully submerged cane of height h or less will be destroyed at water velocity V if:

$h < 1,8\ [(V - V_{min})/(V_{max} - V_{min})]^n$ .... (1)

in which 1,8 = average height of mature cane (m)

V_{max} = water velocity fatal to mature cane, viz. 2,0 to 2,5 m/s

V_{min} = velocity to which young cane is tolerant, viz. 0,3 to 0,6 m/s

n = exponent to allowing for non-linearity, viz. 0,5 to 1,5

It is difficult to distinguish between extent of damage and for the purpose of these calculations it is assumed that at a given water velocity there will be either zero damage or complete destruction.

Equation 1 implies that the taller the cane, the greater is its resistance to damage. If the resistance capacity is exceeded the financial loss will obviously be considerably higher than with younger sugar-cane.

From the above, it can be concluded that direct damage to cane yield through inundation is a function of cane height. Weiss (1976:6.7) presents this relationship as being linear (Figure 6).

3.2 Indirect damage

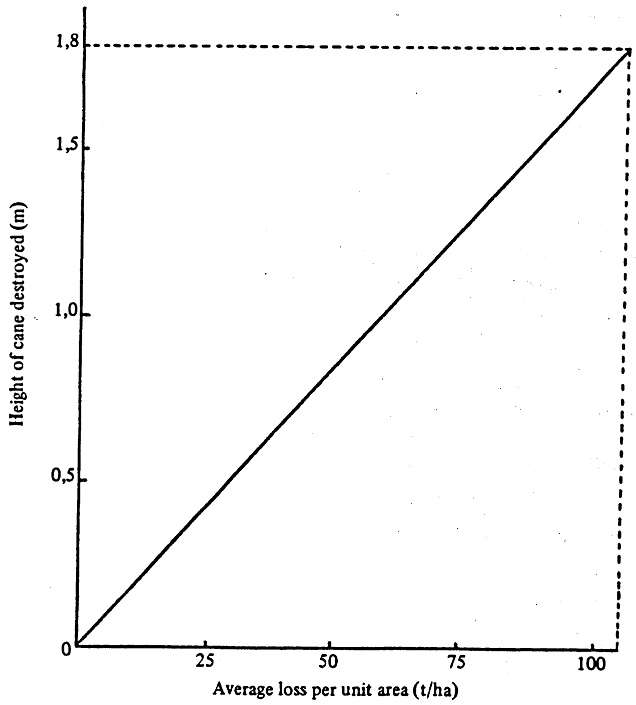
Indirect damage is independent of the height of sugar-cane and includes the following:

(i) Re-establishment costs (R870 per ha)

(ii) Loss of time while re-establishment is in progress (> 3 months)

(iii) Losses because new cane grows 30% slower during the first growth season (6 months)

(iv) Land reclamation costs where sediment deposits occurred



Source: Weiss (1976)

FIGURE 6 - Relationship between height of sugar-cane and yield loss per unit area

TABLE 6 - Reclamation costs of sand covered land, 1980/81

Depth of sand deposits (m)	Cost of reclamation (R/ha)
0,0 - 0,9	525
0,9 - 1,5	2 100
1,5 - 2,1	6 300
> 2,1	Irreparably destroyed

3.3 Other damages

It consists of damage that are not directly felt by the farmer. It includes damage to roads and railways and un-utilised capacity at sugar mills, railways, etc. In this analysis such damage have not been taken into account.

4. DAMAGE FORECAST

4.1 Background

A damage forecast model was compiled, based on the damage functions as described above and the flood hydrogram of 1957, 1963, 1973 and 1975. The situation simulation model of Weiss (1976) based on the principles of the Hydrological Research Unit (1972), was used. The general flow chart for flood damage prediction (Weiss, 1976:6.5) is given in Figure 7.

Table 7 shows a comparison between actual damage (U.C.S.P., 1982) and the predicted damage as computed by the model of Weiss (1976). Tables 7 and 8 show that the predicted flood damage, irrespective of the variation in flood peaks of the four years, compares fairly well with actual flood damage. This is sufficient indication that the results of the model are satisfactory (Weiss, 1982).

Because of the similar course and form of the 1957, 1963, 1973 and 1975 floods as shown in Figure 3, it was possible in spite of differences in flood peaks, duration and volume to generalise and to present the information in Figure 8 in the form of flood damage against flood peak relationships, as is shown in Figure 9. Normally, one curve would have to be drawn for each month. The single curve however, refers to an average month (Weiss, 1976).

In the next section the flood damage to flood peak relationship as shown in Figure 9, is used. However, it is important to remember that certain simplifications have been made, namely that it is assumed that floods with the same flood peak will have hydrograms the same course and form, as well as that the flood damage holds for the average month.

4.2 Mean annual damage

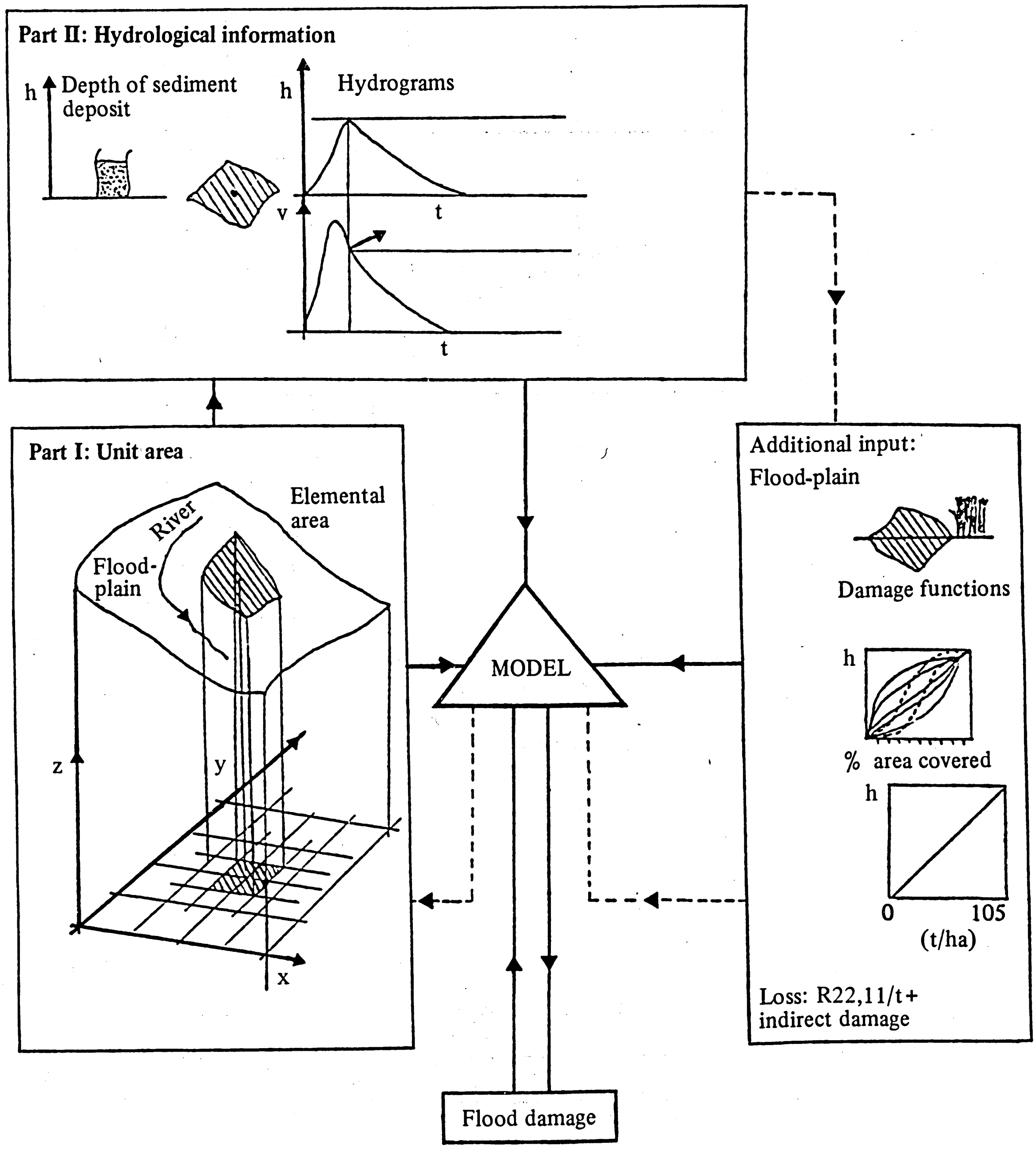
Robinson (1970) and Maas (1962) calculated expected mean annual damage by simulating long time series of rainfall, run off and peak river

TABLE 7 - Comparison between recorded and predicted flood damage, Umfolozi Flats

Date of flood	Cane damaged or destroyed R/ha	Re-establishment costs R/ha	Land reclamation costs R/ha	Total damage R/ha
Recorded:				
October 1957	563	Not available	75	638
July 1963	1 163		75	1 238
September 1973	91	21	15	127
February 1975	56	9	1	66
Predicted:				
October 1957	525	88	50	663
July 1963	1 088	125	88	1 301
September 1973	109	24	13	146
February 1975	44	14	5	63

TABLE 8 - Percentage difference between recorded and predicted flood damage, Umfolozi Flats

Date of flood	Difference between recorded and predicted total damage (%)
October 1957	3,9
July 1963	5,1
September 1973	15,0
February 1975	4,8



Source: Weiss (1976)

FIGURE 7 - General damage prediction model

discharge in a model. This approach could not be applied at the Umfolozi River because only limited data is available with respect to rainfall in the catchment areas.

Another method is to determine the probability of exceeding a given damage (Hydrological Research Unit, 1972). This is done by combining the flood peak probability (Figure 2) with the damage to flood peak relationship (Figure 7).

The mean annual damage, D_m, is then presented by the area supported by the solid line Figure 10, i.e.:

$$D_m = \int_1^0 D_i \; dp \quad \ldots\ldots\ldots\ldots (2)$$

where D_i = annual damage with a probability P_i of bigger damage

and the standard deviation, σ_D, is given by:

$$\sigma_D = \sqrt{\int_1^0 (D_i - D_m)^2 \; dp} \quad \ldots\ldots (3)$$

The values of D_m and σ_D for the Umfolozi Flats, as calculated using the above-mentioned method are R56,25 and R156,25 per ha respectively.

In another method proposed by Weiss (1976),

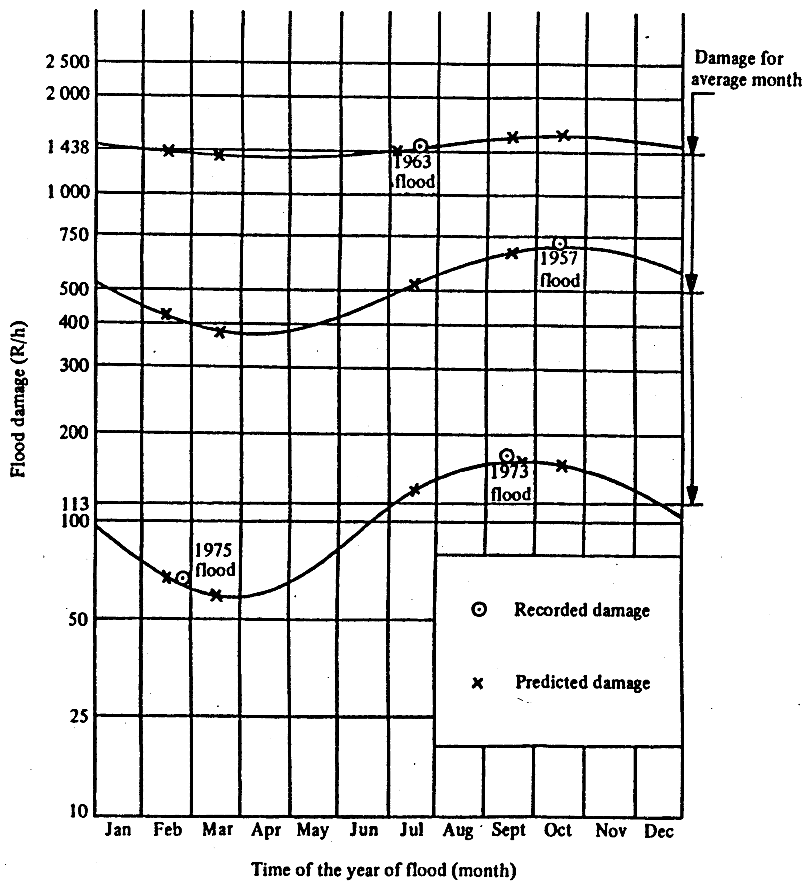


FIGURE 8 - Comparison of recorded and predicted flood damage taking into account seasonal variations, Umfolozi Flats

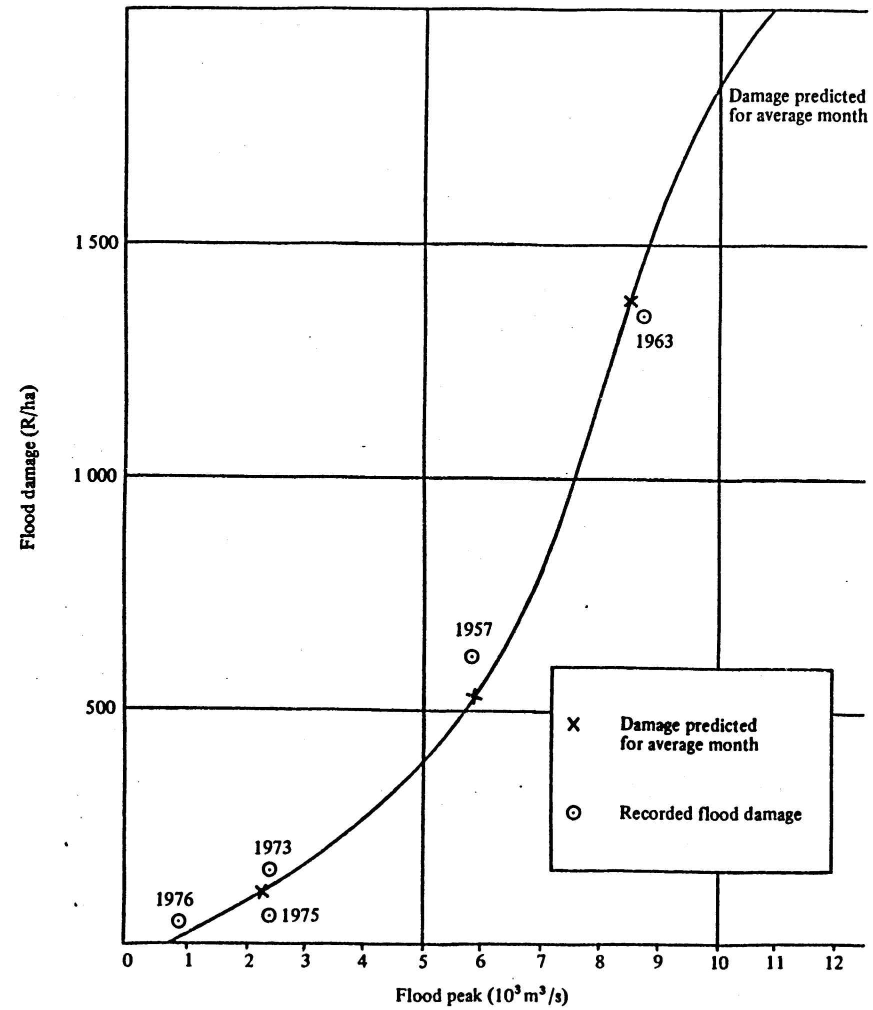


FIGURE 9 - Flood damage to flood peak relationship, Umfolozi Flats

twenty thousand values of the probability (p) were generated as a uniformly distributed random number sequence. Damage values associated with these probabilities were then read from Figure 10.

The mean annual damage (D_m) and the standard deviation (σ_D) is defined for simulation purposes as:

$$D_m = (\sum_{i=1}^{n} D_i) / n \quad \ldots\ldots\ldots\ldots\ldots (4)$$

$$\text{and } \sigma_D = \sqrt{\left[\sum_{i=1}^{n} (D_i - D_m)^2\right] / n} \quad \ldots\ldots\ldots (5)$$

where n = 20 000 (length in years of simulation period) and D_i = annual damage for year i

The values of D_m and σ_D thus computed are R58,75 and R187,50 per ha respectively.

The differences in values can be attributed to differences in determining averages. Averages were used in the first method, while the second method made use of the distribution of values around the mean.

The simulation method (Weiss, 1976), can also be used to illustrate the differences in damage from year to year. Figure 11 shows the flood damage for a 125 year time series that was randomly selected.

4.3 Uncertainty

Using Figure 11, it can be concluded that the average flood damage of every 25 year period will differ from the expected average annual flood damage as calculated in Equation 4. This causes large uncertainty with planners about which values to use. Weiss (1976) therefore simulated a frequency analysis of 800 sequences, ranging in duration from 10 to 50 years (with an average of 25 years) of Umfolozi Flats flood damages. The results are shown in Figure 12.

It can be deducted that there is a probability of 0,4 that the mean annual flood damage of R58,75 per ha will be exceeded.

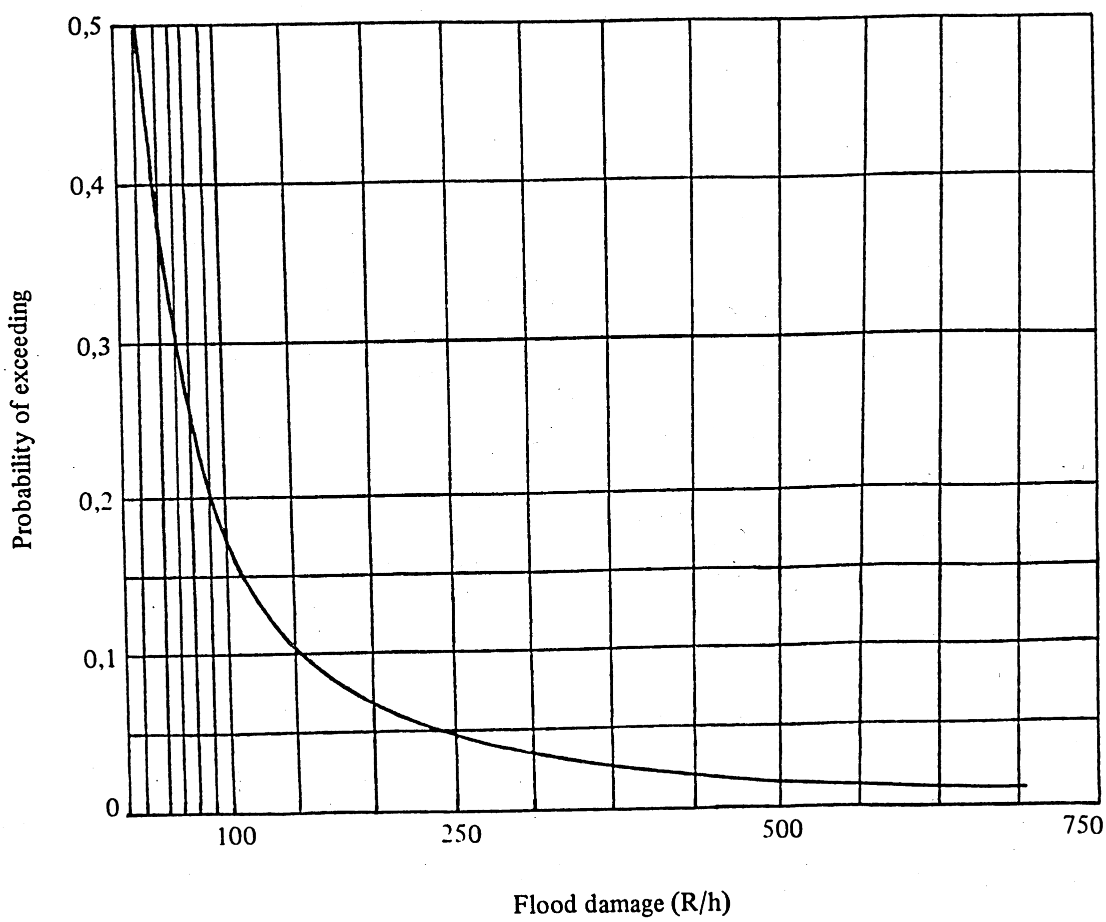


FIGURE 10 - Flood damage to frequency relationship, Umfolozi Flats

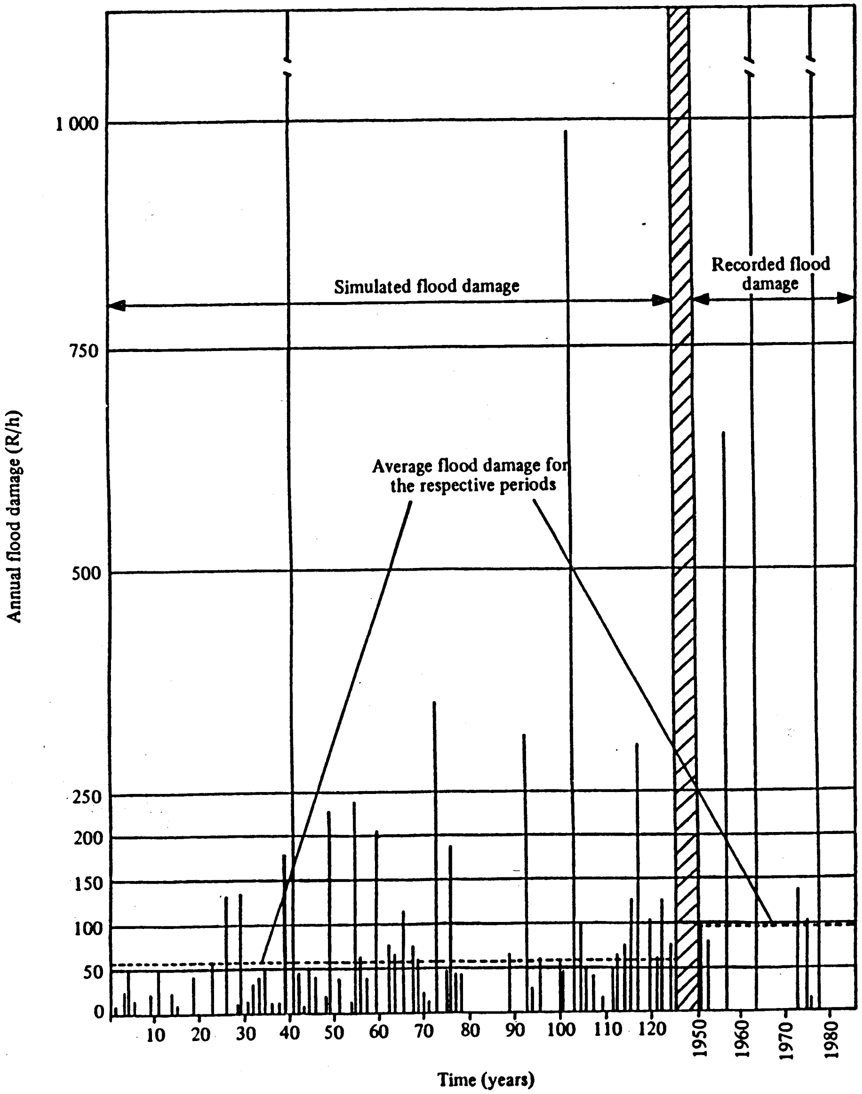


FIGURE 11 - Time series showing simulated and recorded flood damage, Umfolozi Flats

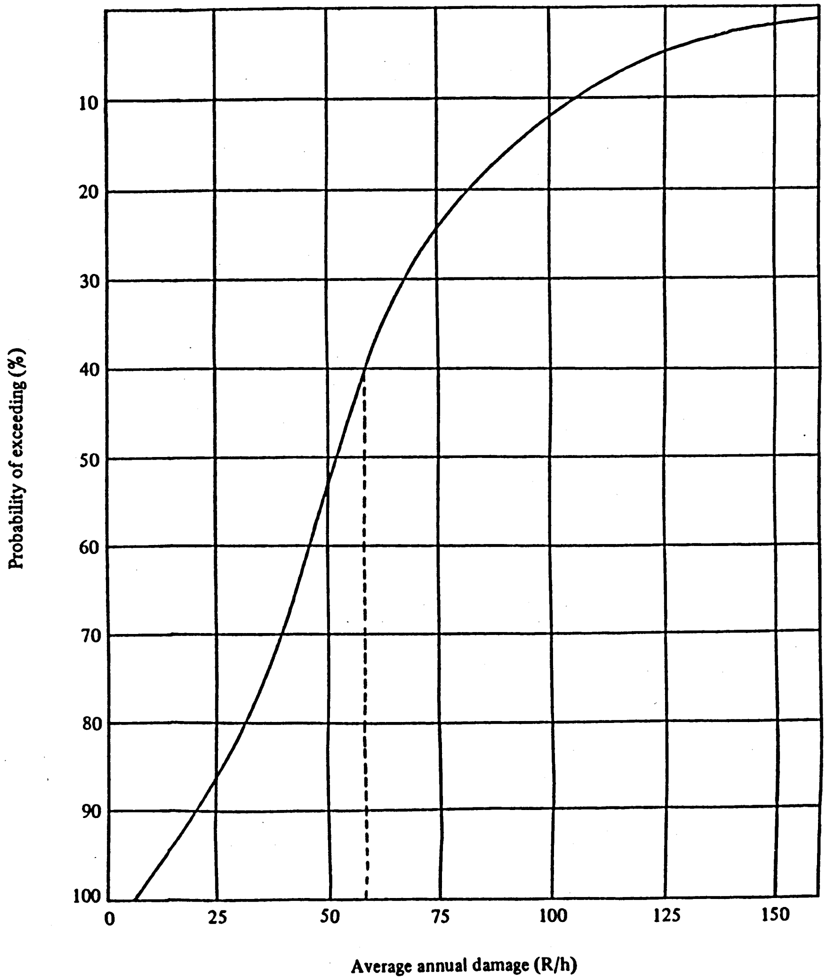


FIGURE 12 - Frequency distributions of simulated mean annual flood damage over long-term planning periods, Umfolozi Flats

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