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AGRICULTURAL FLOOD DAMAGE ASSESSMENT: A REVIEW AND INVESTIGATION OF A SIMULATION METHOD

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This paper reviews current methods of estimating agricultural flood damage and proposes a model which is flexible for use in resource allocation problems and is amenable to computer application. The inherent variability of the damage process itself suggests the use of probability measures, and to demonstrate the use of the assessment model, range estimates sampled under rectangular probability assumptions are used to simulate variability. While the problem of unreliable basic data remains, it can be explicitly recognized by variance estimates.

INTRODUCTION

In order to plan flood control projects, it is necessary to have detailed information on the nature of flood damages. Assessment work in agricultural areas is difficult because of the large areas to be covered, the variety of damageable components, and the variability of damage from one flood to the next. Ideally an assessment should be made prior to any construction of control works, and should provide guides to the optimum size and nature of measures used. Currently used methods of assessment are cumbersome and do not provide high quality planning information. Of course any assessment is only as good as the data on which it is based, and this will probably remain one of the greatest obstacles to improve reliability.

Most agricultural flood damage assessments aim to provide data on mean annual damage both before and after the installation of damage reduction measures. For this purpose a number of analytical procedures have been developed which will be discussed briefly. Usually these are "one-shot" attempts applied to a given set of works. More advanced techniques for assisting design of works at an incremental level involve simulation and system models. If the flood damage process in an area can be adequately captured by a set of tables, maps, and equations, much more flexible assessments become possible. The requirements of systematic damage estimates were recognized by Lacewell[12] and Kates[10]. Applications to agricultural areas have been envisaged by Lacewell[12], Maas[14], James[19], and Hufschmidt and Fiering and some of the details have been investigated.

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2 CURRENT METHODS OF DAMAGE ASSESSMENT

2.1 FREQUENCY METHOD

This is the most commonly used method of deriving estimates of damage and it involves a number of linked steps in execution:

- (a) Construction of a curve describing the frequency or recurrence interval of floods of various discharges
- (b) Relating discharge of a series of floods to height on the floodplain to derive a stage-discharge curve
- (c) Measurement of the area of the floodplain at varying elevations to give stage-area or hypsometric curves
- (d) Assessment of the damage sustained by various areas flooded
- (e) Construction of frequency-damage curves from (a) and (d).

In practice the assessment has mainly been carried out as a step in isolation from the remainder of the work. As will be explained further in the final section, a system model approach would make it an integral part.

To assess damage over a given area it is necessary to know:

- (a) What are the damageable components
- (b) How susceptible they are to damage over the varying conditions of a year
- (c) What is the total damageable value at any given time.

From farm surveys, tables are constructed to show the damages resulting from each of a number of floods of varying magnitude. Alternatively tables are compiled which show the percentage of damage to crops and pastures from flooding over a range of flood heights, usually at intervals of one foot. Tolley and Freund[20] suggest that seasonal figures would be equally as useful as monthly, as well as being labour saving. Where drainage is a problem, length of duration in days may be substituted for, or used together with height as a basis for damage estimation, especially on large flat floodplains.

The assessment might be applied to the whole of a floodplain if the area in question is not too extensive. However sample areas or "reaches" are mainly used and the results extrapolated to the whole area of the project. A variant of this procedure, where long narrow floodplains are involved, is used in a study of the Green River Watershed[21] where sample "stream miles" along two representative streams were taken. The reliability of extrapolation obviously depends heavily on the care taken in sampling [5]'[16]. Another simplifying procedure is to construct for the whole floodplain a "composite-acre" describing the proportion of the various crop and pasture components. Total damage is the product of the total area flooded and the composite damageable value per acre. The major difficulty with this method is the assumption of homogenous land use when in fact zones reflecting land use adjustment to flood frequency are likely to be the case[2]. Differential effects of control works will also lead to error.

Nobe and Dill[18] propose the use of airphoto analysis to facilitate evaluation of stage-area and stage-land use relationships for long narrow floodplains. Evaluation of flood damage must then be made by interpreting these relationships in terms of some damage functions based on land use. The method would be very time saving, especially in areas where data is lacking.

Following methods suggested by Berry[1], Sloggett and Cook [19] use a point sampling grid to estimate the total area inundated, damage per acre and hence total flood damage. This method assumes either availability of base maps and accompanying data from which a sample is to be taken, or subsequent field investigation of points thus selected. It is doubtful that the first procedure would improve the speed of assessment over planimetering or the second improve accuracy over farm interviews.

Attempts have been made to apply linear programming techniques to floodplain development problems, especially in assessing flood damage and agricultural change after the implementation of a project[7]. The method assumes optimization of farm resource allocation to a reduced flood hazard, a restrictive assumption. An even greater obstacle is the requirement that the programming model depict accurately the situation before protection. That is obviously prohibitive unless a more approximate description is acceptable.

2.2 HISTORICAL FLOOD SERIES

This approach is based on the availability of historical data of flood magnitude and flood damage. The various categories of flood damage are estimated by the "damageable value" technique already described or by adjusting assessed values by changes in the value of money. As a result stage damage curves, possibly by season, are derived for the evaluation period. A useful by-product of an historical evaluation series is that some indication of the effect of recurrent flooding is provided. However the distortive effect of differing survey procedures, changed land use and altered damageable values is a severe problem with this method.

The benefit of a project is assessed when the estimated damage after the hydrological conditions change is subtracted from the original damage and the figures converted to a mean annual basis by dividing by the evaluation period.

2.3 SOME PROBLEMS COMMON TO ALL ASSESSMENT METHODS

Recurrent Flooding

When using either the frequency method or an historical series based on damageable value it is necessary to take account of the possibility that more than one flood will occur within a year or growing season. Initial flooding will damage components at the full damageable value but if full value has not been restored, subsequent flooding will cause less damage. It is very difficult to account for such a problem and to gather information from farm surveys. Analysis of a large number of assessments based on

historical series in the United States has led to the derivation of empirical relationships to overcome the incompleteness of any one series[22].

$$\frac{1}{Y} = 0.7706 + 0.2387X$$

where Y is the proportion of total damage for the recorded floods, adjusted for flood intra-seasonal recurrence; X is the sum of areas flooded by all the floods recorded divided by the sum of the areas flooded by the largest flood in each year of the record.

Although apparently practical in the area where it originated, it would possibly be invalid in other areas, and is obviously inappropriate in an area such as Australia where few flood damage surveys have been carried out. A simulation of flood series and flood damage could reduce this problem provided the flood probability process could be approximated.

Yields, Pricing, and Prediction

A problem basic to all assessments of damage is the pricing of inputs, outputs and the consequences of flood on different farm enterprises and entities. Inputs such as seed and fertilizer may have relatively uniform value but costs such as ploughing, planting, maintenance, and use of crops and pastures which depend on labour and capital inputs are variable as a result of scale factors, management efficiency and farm utilization practices. Output in physical terms is also very variable and the money value of particular components will vary between farm units as practices differ. For example maize may be a cash crop on one farm and an input for livestock enterprises on another. The loss sustained in a flood may be much different considering alternative supply, impact of partially damaged crops and the impact on dependent farm activities.

Prediction of land use changes over the life of a project is necessary so that damage after project installation can be estimated. As with most projections, these decrease in reliability the further one moves into the future, and for works having a life period up to 100 years become very dubious. In many cases, damage to the altered land use which is likely to be more intensive, is not included at all.

3 THE EFFECTS OF INUNDATION ON FLOODPLAIN PLANT LIFE

To understand the limitations and uses of damage estimation it is essential to appreciate what happens to plant life under flood conditions. Research on the processes by which floodwater damages plants is at a relatively underdeveloped stage. The best single source is Luthin[13] and then a series of articles by Kramer[11]. Many botanical and soil studies relate to this problem although very few of them have maintained flooded plants to maturity or have used a sufficiently wide range of conditions. General quantitative estimates, then, are not available for most plants.

The most important factors governing amount of damage are the height, length of duration, silt and salt content, temperature and turbulence of the floodwater itself and the species, height and stage of growth of the plants flooded. Variability is apparent in all studies especially those examining only a small number of these factors. For example McKenzie[17] quotes tolerance ranges for pasture species which are of the order of 1-4 weeks. Colman and Wilson[4] make this fact clear in their study which also provides a ranking of the hardness of species.

One of the most relevant studies from the point of view of agricultural flood damage estimation has been carried out by Daugherty[6]. The preliminary results of this study highlight the difficulty of quantifying plant damage factors. Survey data provided the basis for a multiple linear regression analysis of damage and a number of causative factors (table I). But the correlation coefficients were low—maize $R^2 = .419$; tobacco $R^2 = .546$; pasture $R^2 = .144$.

Flood damage to plants is only one section of the extrapolation of hydrologic data into loss estimates. Interacting variability suggests that a systematic simulation approach may show how significant each component is and where further research and greatest care should be taken.

TABLE I

Simple Correlation Matrix: Maize Damage and Damage Factors in the S.E. United States

	Days planted	Depth	Duration	Velocity	Average drainage area	Gross damage
	1	2	3	4	5	6
1	1.00	0.25	0.20	0.04	0.22	—0.03
2		1.00	0.27	0.28	0.04	0.52
3			1.00	—0.11	0.39	0.26
4				1.00	—0.18	0.39
5					1.00	—0.12
6						1.00

Source: Daugherty, A. B. [6, p. 15]

4 A SYSTEMATIC ASSESSMENT MODEL

There are many difficulties associated with relating damage to any given flood characteristic. Some research already has indicated the benefits of a systematic analysis to decision making in water control[8],[9],[10],[12]. Hufschmidt and Fiering⁽⁸⁾ have outlined a model which was used for evaluating surface water development along the Lehigh Valley. It uses a variety of statistical and analytic formulations to investigate all aspects of water supply and use in a manner which gives optimum construction priorities. The model also allows testing of the sensitivity of the "plan"

to changes in various input variables, especially the critical stream flow variable. Competing users of a river, such as irrigated agriculture, flood susceptible agriculture, hydro electric power, recreation and urban consumption and disposal are all sub-sections of the model through which the water flows. Construction costs are varied by specification of known damsites and river profiles. Agricultural flood damage in this model was estimated by a simple stage-damage function.

Further refinement of the above model was envisaged in assessing flood damage on the Macleay River floodplain in Northern New South Wales[15]. In this situation choice could be made between several alternatives for reducing damage in the area. The choices were:

- (a) Raising the permanent levees to reduce the frequency of overflow
- (b) Increasing the rate at which ponded water could escape
- (c) Preventing overflow from concentrating in narrow, high velocity and high damage channels over agricultural land
- (d) Routing flow through given channels when it had overflowed
- (e) Changing land use.

A simple stage-damage estimation is virtually useless in estimating the efficiency of these alternatives. Hence another approach is necessary. To illustrate the model that was used in the Macleay River study, a simple case will be applied to part of the floodplain.

(a) Physical Components

- (i) Floods of varying discharge in each of the eight growing season months.

- (ii) To calculate flood height on the floodplain, the equation

$$H = 59.6Q^{0.052} \text{ (see figure IV)}$$

is used, when H is height, Q is flood discharge. The two coefficients are derived from statistical analysis of previous floods of various discharges.

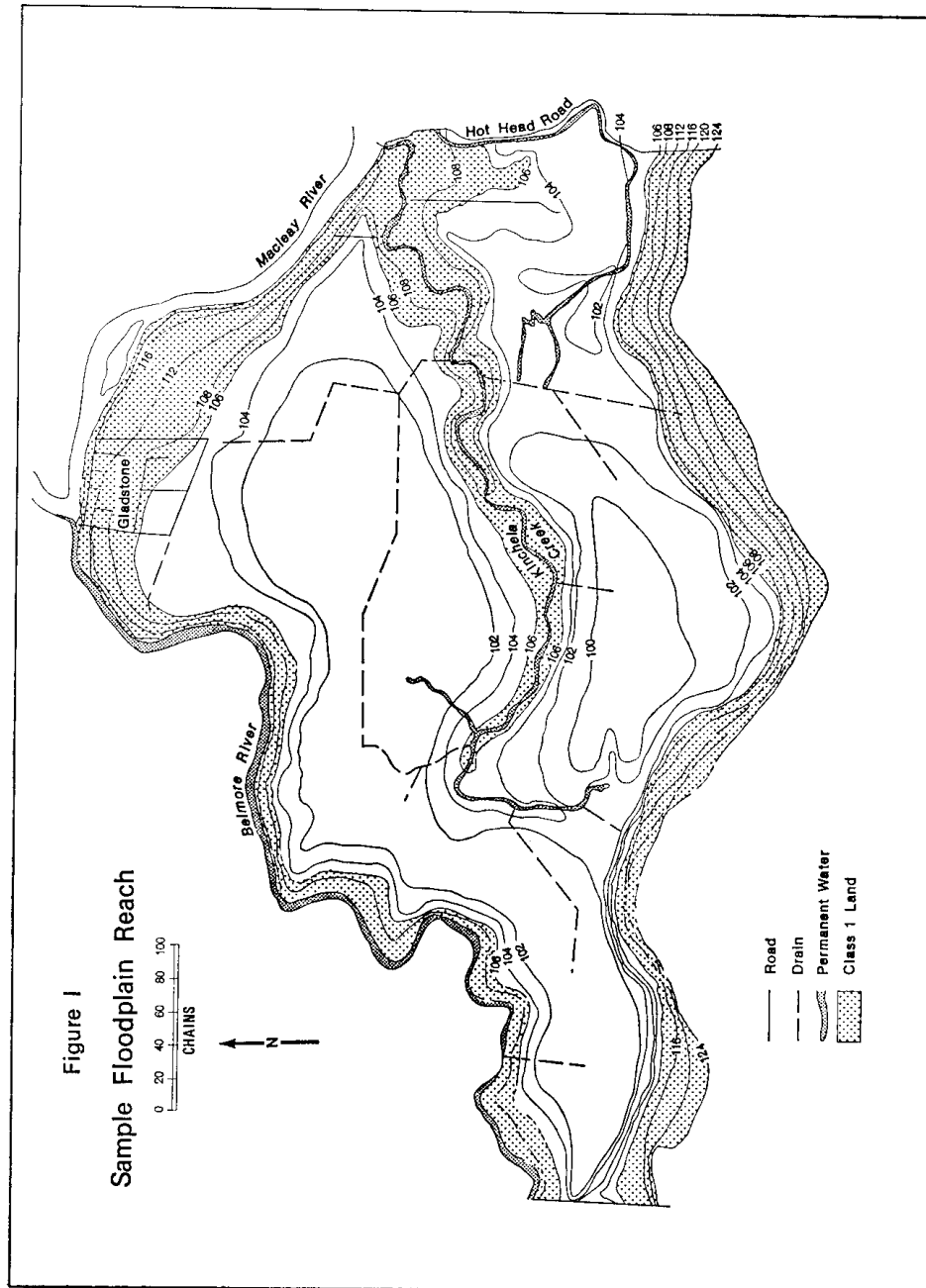
- (iii) Topographic data as shown on figure I. The areas at different elevations can be planimetered from the map contours to give the hypsometric curve in figure II.

- (iv) The normal and projected recession of floodwater in days from given peak levels (shown on figure III). Drainage will not be a factor in this illustrative example; however its integral part in the larger study can be indicated. Given a flood of known discharge then it is possible to determine what area is flooded and at what depth over a continuous range. (Time inundated can also be determined.)

(b) Economic Components

- (i) The simplified land use categories in figure 1 show two types which are in direct correspondence with elevation—class I land (dotted) is above 106 ft: class II land (blank) is below. While

this is not an unreasonable assumption in the area in question, it is a simplifying one which could be replaced by location on a two dimensional grid. This would involve greater quantities of data, but would provide greater accuracy.



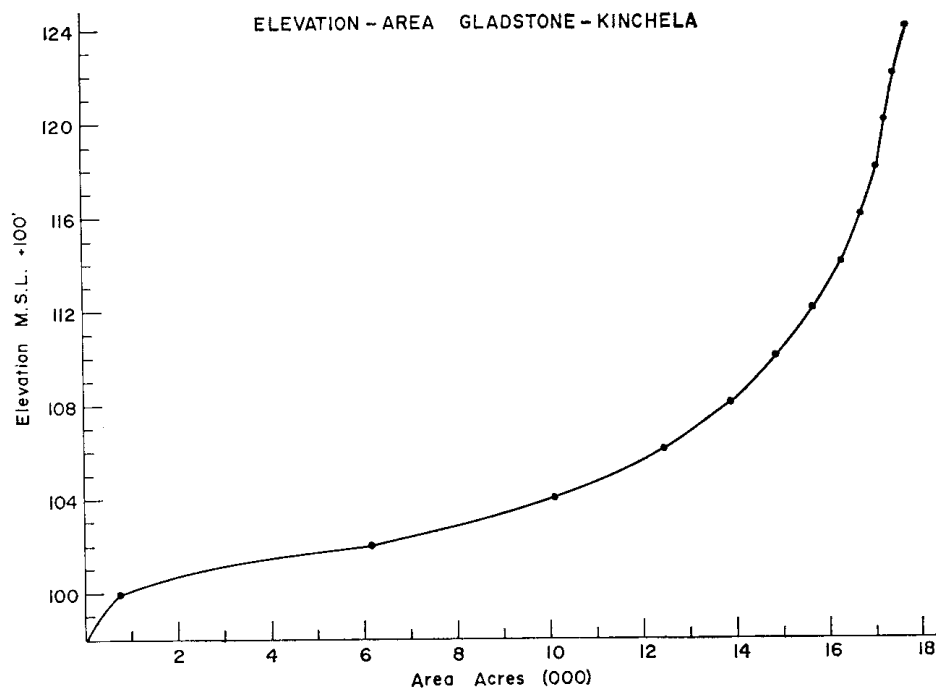


FIGURE 11

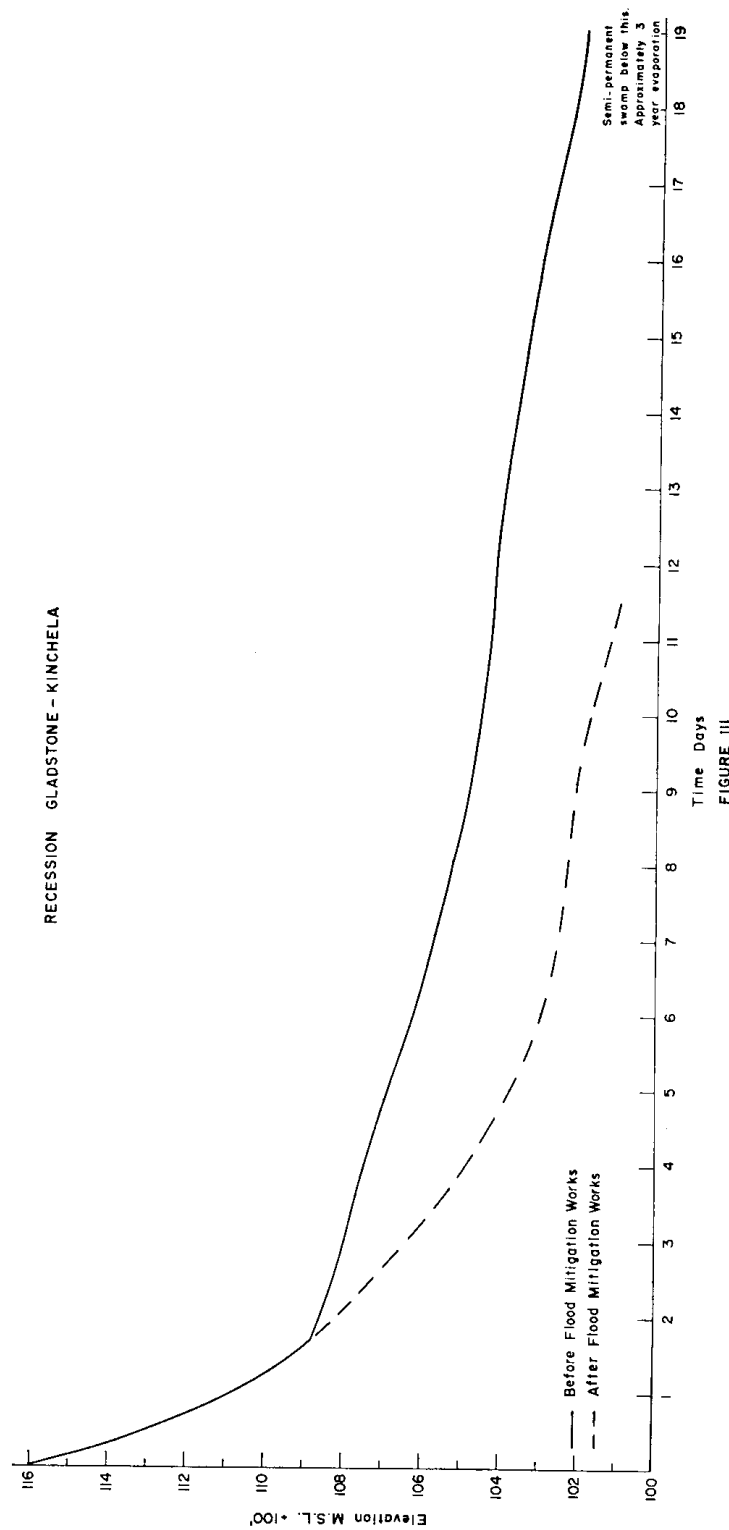


FIGURE III

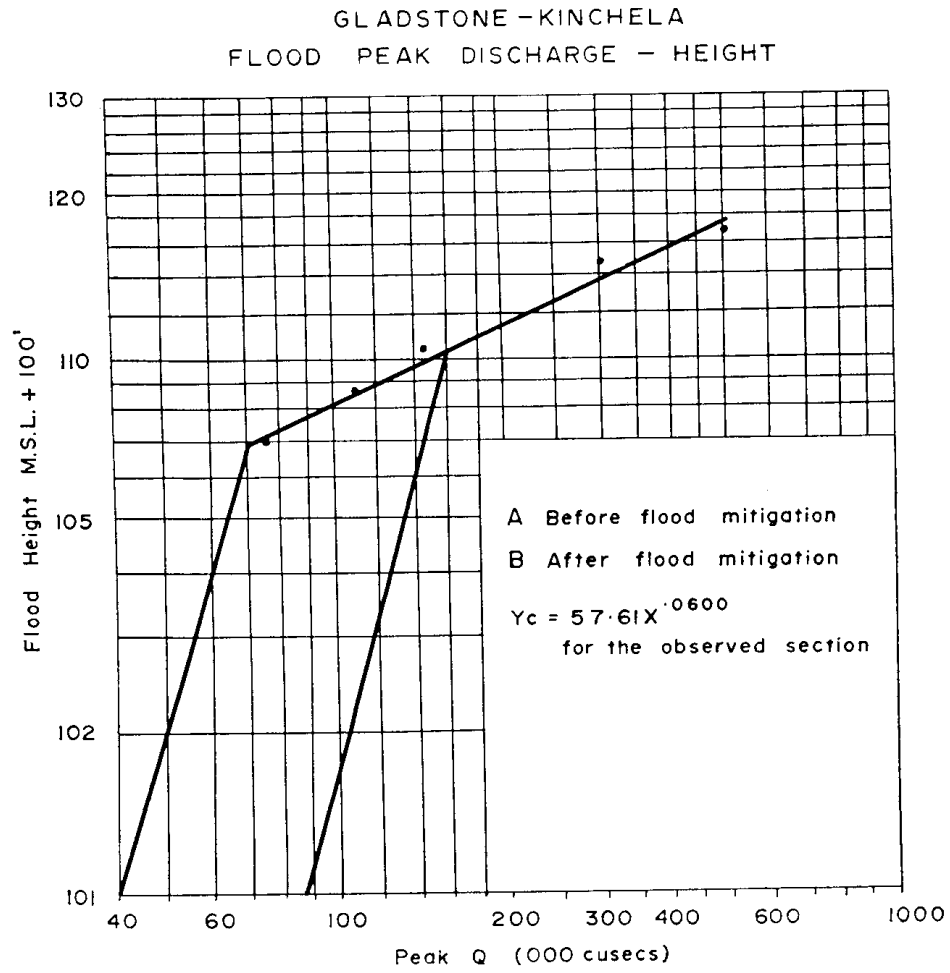


FIGURE IV

FLOW CHART OF A SIMPLE DAMAGE
ASSESSMENT MODEL
(*Italicize entries for simulation of damage variability*)

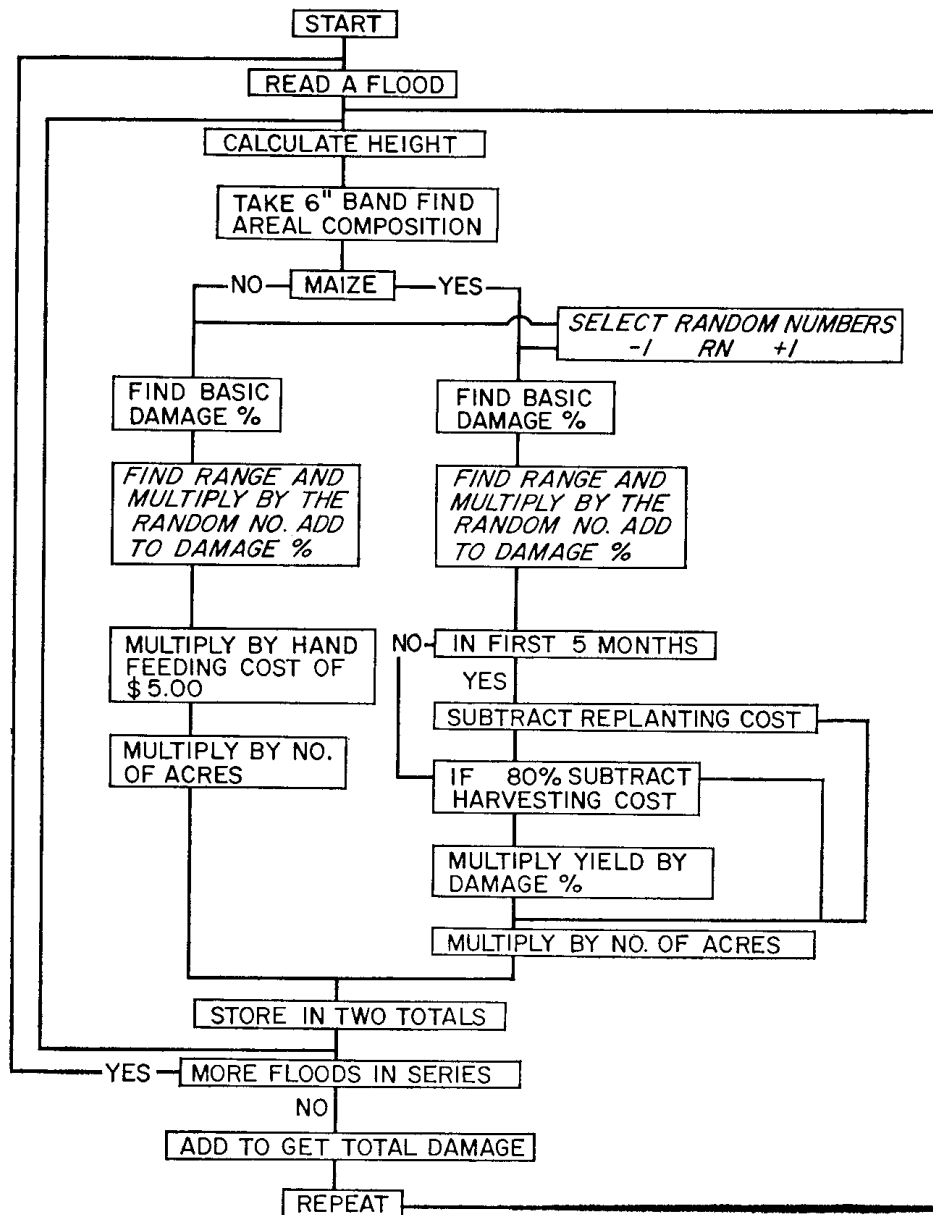


FIGURE V

- (ii) In the two land use types, maize comprises twenty per cent of the class I land, and class II land is entirely pasture. Damageability of the two elements has been investigated along the lines suggested by the U.S. Soil Conservation Service[22] and published in a study by Ian Burton[2]. These are presented in tables 2 and 3.

TABLE II

Percentage Damage Estimates for Maize [19] and Range Estimates (parenthesized)

Stage feet	J	F	M	A	M	J	J	A	S	O	N	D
1	—	100 (10)	100 (10)	100 (10)	75 (30)	100 (10)	70 (30)	50 (20)	40 (20)	40 (20)	40 (20)	—
2	—	100 (5)	100 (5)	100 (5)	100 (10)	100 (5)	80 (15)	60 (30)	50 (20)	50 (20)	50 (20)	—
3	—	100 (0)	100 (0)	100 (0)	100 (5)	100 (0)	95 (15)	85 (15)	80 (15)	80 (15)	80 (15)	—
4	—	100 (0)	100 (0)	100 (0)	100 (0)	100 (0)	100 (10)	100 (10)	95 (15)	95 (15)	95 (15)	—
5	—	100 (0)	100 (0)	100 (0)	100 (0)	100 (0)	100 (5)	100 (5)	100 (10)	100 (10)	100 (10)	—
6	—	100 (0)	100 (0)	100 (0)	100 (0)	100 (0)	100 (0)	100 (0)	100 (5)	100 (5)	100 (5)	—

TABLE III

Percentage Damage Estimates for Pasture [19] and Range Estimates (Parenthesized)

Stage feet	J	F	M	A	M	J	J	A	S	O	N	D
1	40 (20)	40 (20)	40 (20)	40 (20)	40 (20)	40 (20)	50 (20)	50 (20)	50 (20)	50 (20)	50 (20)	40 (20)
2	60 (30)	60 (30)	60 (30)	60 (30)	60 (30)	60 (30)	85 (30)	85 (30)	85 (30)	85 (30)	85 (30)	60 (30)
3	80 (30)	80 (30)	80 (30)	80 (30)	80 (30)	80 (30)	120 (30)	120 (30)	120 (30)	120 (30)	120 (30)	80 (30)
4	95 (30)	95 (30)	95 (30)	95 (30)	95 (30)	95 (30)	145 (15)	145 (15)	145 (15)	145 (15)	145 (15)	95 (30)
5	110 (15)	110 (15)	110 (15)	110 (15)	110 (15)	110 (15)	170 (15)	170 (15)	170 (15)	170 (15)	170 (15)	110 (15)
6	125 (15)	125 (15)	125 (15)	125 (15)	125 (15)	125 (15)	195 (10)	195 (10)	195 (10)	195 (10)	195 (10)	125 (15)

(c) Damage

By adjusting the monthly damages by the appropriate flood frequency for the month, a discharge-damage curve as shown on table 4 was calculated. The steps in the procedure are shown by the flow chart in figure V.

When changes are proposed in the hydrologic conditions of flooding (in this case height), the benefits can be calculated by rerunning the assessment using the new height function shown on figure IV. Changes in drainage conditions or the land use pattern can similarly be incorporated (see figure III). Alternatively, given the flood conditions, an optimal distribution of various uses in the area can be estimated by maximizing farm income net of flood damage.

TABLE IV
Discharge Damage Curve from Raw Data
(monthly frequency adjusted)

Discharge	Damage
(000 cusecs)	\$
50	1,300
100	8,308
150	9,531
200	10,059
250	10,608
300	10,894
350	11,107
400	11,134

Even with much more complicated land use patterns, damage costs and physical variations it is possible to obtain a simply programmed estimation model based on a much reduced amount of data collection about unique events. The flexibility of the application would seem most desirable provided that some confidence could be placed in the results. As far as it is possible to validate any flood damage estimate, it would appear that the model as used in the Macleay River study gave results that were comparable with those achieved by more conventional methods[15].

5 SIMULATION OF DAMAGE VARIABILITY

As suggested in section 3, damage is inherently variable for reasons which cannot be explained on a physical basis at the present time. While much of this variability may be neutralized over an entire floodplain, it is interesting to investigate the possible magnitude of this variation. Tolley and Freund[20] have suggested that probability measures could be used in describing flood damage.

The above damage model lends itself to the estimation of this variation. Ranges over which damage may vary are specified in tables 2 and 3 under the established mean levels. The ranges were estimated subjectively according to the principles:

- (a) At the mid range of damage percentage estimates there is greatest scope for variation because there is the possibility of factors varying damage in either direction
- (b) At damage levels where 100 per cent is estimated for lower order flooding the variation is slight because only a reduction is possible and even an equivalent of one foot will still cause total damage
- (c) The range of estimates are similar to those established by Daugherty[6] but could be established more accurately by field trials e.g.[17].

The ranges were repeatedly sampled at random (on a rectangular distribution) and damage calculated. For this kind of simulation it is not justifiable to rely on a small number of trials[8] and the model was rerun fifty times for a given discharge (80,000 cubic feet per second) for each month of the growing season. A sample is presented in table 5.

Briefly the results from this hypothetical application indicate the expected contrast between maize and pasture damage, the low variability of the individual estimates but the large range between minimum and maximum estimate, as much as 60 per cent of the mean (see table 6).

TABLE V

*Sample of Simulation Runs for November
(discharge 80,000 cusecs)*

Run No.	Maize damage	Pasture damage	Total
1	2,088	11,109	13,197
2	2,746	11,176	13,923
3	1,984	10,356	12,340
4	3,164	11,449	14,613
5	2,623	10,326	12,949
6	2,773	11,688	14,461
7	2,781	11,957	14,738
8	2,484	11,981	14,466
9	1,761	11,196	12,957
10	1,762	12,394	14,156

TABLE VI

Summary of Simulation Statistics

	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
Maize—								
\bar{x}	2,669	2,728	2,519	5,714	17,290	15,205	13,362	12,754
σ	481	570	554	3,823	595	1,252	1,866	1,790
Min.	1,596	1,138	1,332	1,823	16,059	12,919	10,116	9,673
Max.	3,500	3,809	3,604	13,535	18,739	18,057	16,437	15,259
Range	1,904	2,670	2,271	11,712	2,680	5,138	6,321	5,586
σ/\bar{x}	0.18	0.21	0.22	0.66	0.03	0.08	0.14	0.14
Pasture—								
\bar{x}	11,238	11,204	11,287	11,221	11,236	17,248	17,193	17,322
σ	597	600	628	578	633	468	452	429
Min.	10,008	10,051	10,174	10,116	10,253	16,326	16,362	16,549
Max.	12,410	12,358	12,426	12,695	12,319	18,290	18,088	18,228
Range	2,410	2,305	2,252	2,579	2,066	1,964	1,725	1,679
σ/\bar{x}	0.15	0.05	0.05	0.05	0.06	0.03	0.03	0.02
Total—								
\bar{x}	13,908	13,932	13,807	16,836	28,527	32,453	30,555	30,076
σ	727	863	866	3,763	834	1,277	1,901	1,858
Min.	12,413	12,107	11,643	12,788	26,658	30,095	26,515	27,240
Max.	15,422	15,549	15,319	24,822	30,050	35,221	33,335	32,804
Range	3,279	3,441	3,676	12,033	3,392	5,125	6,819	5,564
σ/\bar{x}	0.05	0.06	0.06	0.22	0.03	0.04	0.06	0.06

6 CONCLUSION

Considering the large amount of investment in flood damage prevention in rural areas, it would appear that the basic data and methods of analysis are relatively poorly developed. More refined decision making aids such as system models will make the estimates much more flexible. Some consideration of the indefinite nature of an estimate by simulation should allow more confidence to be placed in benefit-cost figures. To be able to say there is a given probability that costs will be exceeded by benefits would be useful and more realistic. The capability of damage assessment work to play a significant part in development decisions, *at the margin*, is the most important contribution of any model study.

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