Loss functions for sugar-cane: Depth and duration of inundation as determinants of extent of flood damage

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Abstract

The paper aims to discuss the methodology used to develop loss functions for sugar-cane, with reference to the treatment of depth and duration of inundation as the main determinants of the extent of damage. The Mfolozi floodplain in Northern KwaZulu-Natal served as the study area. Loss functions for sugar-cane, for *ex ante* estimation of damage to harvests and crops, were developed for inclusion in a flood damage simulation model (FLODSIM) developed by the Department of Agricultural Economics of the University of the Free State in collaboration with the Water Research Commission. Depth of inundation was calculated in relation to the height of inundated sugar-cane in order to establish the extent of damage. Duration of inundation was taken into account by determining the maximum period of complete inundation after which the cane would be destroyed. Loss functions were determined for calculation of damage to harvests and damage to crops respectively.

Introduction

The aim of this paper is to discuss the methodology used to develop loss functions for sugar-cane, with reference to the treatment of depth and duration of inundation as independent variables. The Mfolozi floodplain in the coastal region of Northern KwaZulu-Natal was used as study area. Loss functions for sugar-cane find its application in a flood damage simulation model for irrigation areas in South Africa (FLODSIM) developed by the Department of Agricultural Economics of the University of the Free State in collaboration with the Water Research Commission (Du Plessis et al. (1998). The economic impact of the 1996 floods on the structural flood mitigation measures and the sugar mill in the Mfolozi floodplain is discussed in Berning (1999).

In order to estimate flood damage with a simulation model, it is firstly necessary to identify relationships between characteristics of the flood and the extent of flood damage and secondly to quantify these relationships. The latter is done with the aid of loss functions. Du Plessis and Viljoen (1996) developed loss functions for vineyard, rotation crops and lucerne for *ex ante* flood damage determination in the Lower Orange River. They identified depth of inundation as the most important determinant of the extent of flood damage to the mentioned crops. With regard to sugar-cane, however, it was found that a strong relationship exists between the extent of flood damage and both depth and duration of inundation.

The paper sets out with a discussion of depth and duration of inundation. In the third section definitions of the different damage categories precede an exposition of the steps followed to determine loss functions for each of these categories. This is followed by a short discussion of the results obtained. Conclusions are given in the final section of the paper.

Depth and duration of inundation

When the availability of oxygen to sugar-cane decreases for a sufficiently long period of time, as a result of partial or complete inundation by water or sediment, losses are suffered either because sugar-cane drowns completely (Weiss, 1976), or because of a decrease in sucrose content (Humbert, 1968).

Except when standing in stagnant water for prolonged periods, sugar-cane will not suffocate during periods of inundation provided the meristem and uppermost leaves of the plant extend above the water level (Rege and Mascarenhas 1965, referred to by Humbert 1968). Therefore with regard to sugar-cane, depth of inundation must be viewed in relation to the height of sugar-cane. A characteristic of sugar-cane areas is the great variation in the height of the cane which results from the harvesting season which extends from April till December each year. In order to determine, for every month of the year, the percentage area under cane of a specific height or lower, average monthly growth rates of cane in the floodplain were combined with the time of harvesting (Weiss, 1976).

Information regarding the area where sugar-cane has been completely inundated is, however, not sufficient to estimate flood damage. Even after complete inundation sugar-cane can still survive, given that the period of complete inundation is short enough. Thus it was necessary to determine the critical or maximum period of complete inundation after which the cane would be destroyed. According to cane farmers in the Mfolozi floodplain the minimum period of inundation before sugar-cane is completely destroyed, varies between approximately three days during warm months and six days if the flood occurs during cold months. Damage to sugar-cane increases if flooding occurs during warm conditions because plants have relatively higher water and nutrient requirements than during winter (Humbert, 1968). For purposes of flood damage simulation, sugar-cane which had been completely inundated for longer than three days, was considered destroyed if floods occurred during any month from November until April. From May until October the critical period was taken as six days. Hence the area of sugar-cane of different heights which is totally destroyed during the flood, could be determined. In the case of immature sugar-cane, the productive value was taken as the ratio of the true height of damaged sugar-cane, to the average height of mature sugar-cane (Weiss, 1976).

The hydraulic simulation model Mike 11 was used to simulate the flow of water through the Mfolozi floodplain and to supply

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water levels at intervals of one hour in order to determine the depth of inundation and the duration of inundation of flooded areas at specific water levels. Hydraulic, topographic and economic (loss function) data were thus combined in order to calculate flood damage to sugar-cane.

Loss functions for sugar-cane

Damage to harvest

According to Viljoen, et al (1981) damage to the harvest is the loss when crops are partially or completely damaged during a flood. Damage to the harvest (DH) is calculated as the decrease in income due to destroyed sugar-cane (D), minus the resultant decrease in cost (B) (harvesting cost saved as a result of the smaller harvest), plus the decrease in income due to lower sucrose content (P):

$$DH = D - B + P \quad (1)$$

The first component of Eq. (1) above, namely the decrease in income due to destroyed sugar-cane (D), was calculated as follows:

$$D = \sum_{L=0.1}^{N} D_L$$

$$D_L = A_L * A * {}^{H_L}\!/_{H} * C * S_h * GI_S$$

where:

D (R)	=	Decrease in income (destroyed cane)
N (m)	=	Depth of inundation
D_L (R)	=	Decrease in income for cane with height L
A_L (%)	=	Percentage area with destroyed sugar-cane of height L
A (ha)	=	Total area under cane
H_L (m)	=	Height of destroyed cane (0.1 m to 2.4 m)
H (m)	=	Average height of mature cane (2.1 m)
C (t/ha)	=	Tons cane per hectare
S_h (%)	=	Percentage sucrose
GI_S (R/t)	=	Gross income per ton sucrose.

The second component of Eq. (1), the decrease in harvesting cost (B), is a function of firstly the amount of ton sugar-cane destroyed and secondly the harvesting and transport cost per ton:

$$B = \frac{D}{GI_C} * M_C$$

where:

B (R)	=	Decrease in harvesting cost
D (R)	=	Decrease in income (destroyed cane)
GI_C (R/t)	=	Gross income per ton cane
M_C (R/t)	=	Harvesting cost per ton cane - Includes transport cost.

The third component of Eq. (1) refers to partially damaged sugar-cane (P), which is cane that can still be harvested after the flood, but whose quality (sucrose content) has deteriorated as a result of an oxygen shortage in the root zone during floods. The decrease in sucrose content is reflected in lower income for farmers since farmers are paid per ton of sucrose delivered and not per ton of cane. An average decrease in sucrose content of 2%, as determined during the survey, was used. The decrease in income caused by partially damaged sugar-cane (P) can be calculated by means of the following formula:

$$P = A_P * (1 - A_D) * A * C * (S_H - S_L) * GI_S$$

where:

A_D	=	$\sum_{L=0.1}^{N} A_L$
P (R)	=	Decrease in income (partially damaged sugar-cane)
A_P (%)	=	Percentage of area not destroyed, where cane has been partially damaged
A_D (%)	=	Percentage area with destroyed cane
A (ha)	=	Total area cane
C (t/ha)	=	Tons sugar-cane per hectare
S_H (%)	=	Normal (higher) sucrose content
S_L (%)	=	Lower sucrose content after flood
GI_S (R/t)	=	Gross income per ton of sucrose
N (m)	=	Depth of inundation
A_L (%)	=	Percentage area with destroyed cane of height L.

The area with partially damaged cane is expressed as a percentage of the area that has not been destroyed by the flood. This percentage is assumed to increase with an increase in depth of inundation, while the area under sugar-cane not damaged, is expected to decrease. The relationship between the total area under cane and areas with destroyed, damaged and undamaged cane respectively after flooding, can be depicted as follows:

$$Area = A_D + A_P*(1 - A_D) + (A_N*(1 - A_D))$$

where:

$A_P + A_N$	=	1
Area (ha)	=	Total area
A_D (%)	=	Percentage area under destroyed cane
A_P (%)	=	Percentage area under partially damaged cane
A_N (%)	=	Percentage area under cane not damaged.

Damage to crops

In the case of perennial crops such as sugar-cane, damage to crops can occur in addition to damage to the harvest. The effect of damage to the crop is usually spread over a number of years and can be reflected by lower than normal yields for a few years following the flood (Viljoen, 1979). From the questionnaires it became apparent that cane yields are generally lower than normal only during the first two years following the flood. On average yields decreased by 20% and 10% during the first and second year, respectively.

After a flood the farmer has two options and his decision depends largely on the extent of damage. It was assumed that when less than 30% of the sugar-cane has been destroyed, farmers will not re-establish and production will continue with less than optimal yields in the following two years, but that farmers will re-establish sugar-cane when more than 30% of the sugar-cane has been destroyed. If a farmer decides to continue production with damaged crops, the damage to the crop is calculated as the discounted value of the decrease in income minus the saving in harvesting cost for the period during which a lower yield is obtained (Viljoen, 1979). In the case of re-establishment the damage is the discounted value of additional expenses such as the cost of establishment, plus the total loss in income due to the flood, for as long as it deviates from the normal production pattern. The cost of establishing sugar-cane is not regarded as flood damage when a field would have been established during the first year after the flood in the normal course of production. Several farmers indicated that they generally re-established 10% of the farm annually in the absence of floods and this percentage was taken as the norm. Thus for the calculation of damage to crops, a period of ten years was considered.

In order to calculate the value of the loss in income due to damage to the crop, the gross margins of future yields were discounted to present values (PV) and added to get the net present value of the gross margin (NPV_{GM}). *[A discount rate of 10% was used]*. The damage to the crop was calculated as the difference between the NPV_{GM} without a flood and the NPV_{GM} with a flood. Formulae used in the calculation of the damage to the crop are the following:

Damage to the crop if the farmer does not re-establish cane (IC):

$IC = NPV_1 - NPV_2$

Damage to the crop if the farmer does re-establish cane (IE):

$IE = NPV_1 - NPV_3$

Net present value of the gross margin

$= NPV_{IJK}$

where:

I = 1 ... 3
- 1 = normal production pattern
- 2 = production with damaged cane
- 3 = re-establish cane

J = 1 ... 10 year of cane establishment

K = 1 ... 10 year

$NPV_{1.1} = PV_{1.1.1} + PV_{1.1.2} + ... + PV_{1.1.10}$

$NPV_{1.2} = PV_{1.2.1} + PV_{1.2.2} + ... + PV_{1.2.10}$

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$NPV_{1.10} = PV_{1.10.1} + PV_{1.10.2} + ... + PV_{1.10.10}$

Hence:

$NPV_1 = (0.1*NPV_{1.1}) + (0.1*NPV_{1.2}) + ... + (0.1*NPV_{1.10})$

Similarly:

$NPV_2 = (0.1*NPV_{2.1}) + (0.1*NPV_{2.2}) + ... + (0.1*NPV_{2.10})$

$NPV_3 = (0.1*NPV_{3.1}) + (0.1*NPV_{3.2}) + ... + (0.1*NPV_{3.10})$

In the case of re-establishment (I = 3), it was assumed that the whole area was re-established in the first year after the flood. The formula for NPV_3 thus reduces to the following:

$NPV_3 = NPV_{3.1} = PV_{3.1.1} + PV_{3.1.2} + ... + PV_{3.1.10}$

Results

Figure 1 shows the loss functions for sugar-cane in the Mfolozi floodplain to determine the damage to harvests that occurs at various depths of inundation. Duration of inundation was taken into account by determining the maximum period of complete inundation after which the cane will be destroyed. A different curve has been constructed for each month of the year since the area: cane height relationship varies greatly between months. In order to keep the graph simple only six months have been presented in the graph.

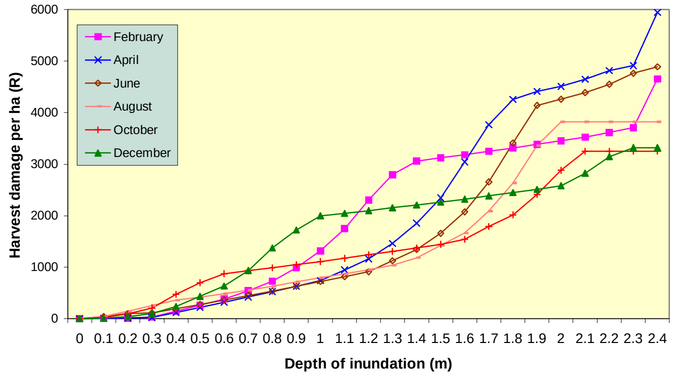

Figure 1
Loss functions to determine damage to the sugar-cane harvest in the Mfolozi floodplain (1996 values)

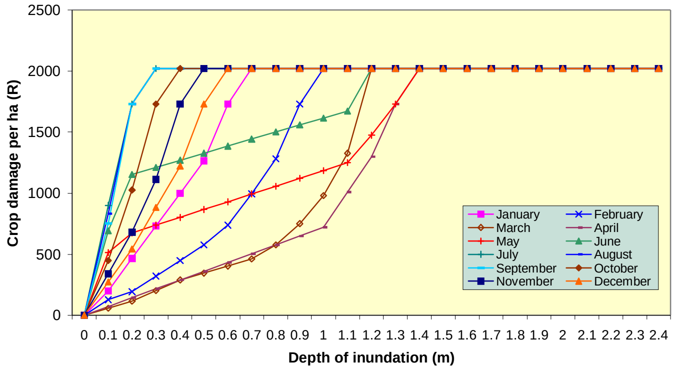

Figure 2
Loss functions to determine crop damage to sugar-cane in the Mfolozi floodplain (1996 values)

Figure 2 shows the loss functions for sugar-cane in the Mfolozi floodplain to determine the damage to crops that occurs at various depths of inundation. A discount rate of 10% was used. The graph illustrates the effect of the assumption that farmers will re-establish sugar-cane when more than 30% of the sugar-cane has been destroyed. It can be noted that for each month the maximum crop damage is reached at a depth of inundation that causes 30% or more of the area of sugar-cane to be destroyed.

Figure 3 shows loss functions for sugar-cane in the Mfolozi floodplain to determine the total flood damage (harvest and crop) that occurs at various depths of inundation. In order to keep the graph simple only six months have been presented in the graph.

Conclusion

Loss functions for sugar-cane were developed for inclusion in a flood damage simulation model (FLODSIM) for *ex ante* estimation of damage to harvests and crops (vegetative part of the sugar-cane

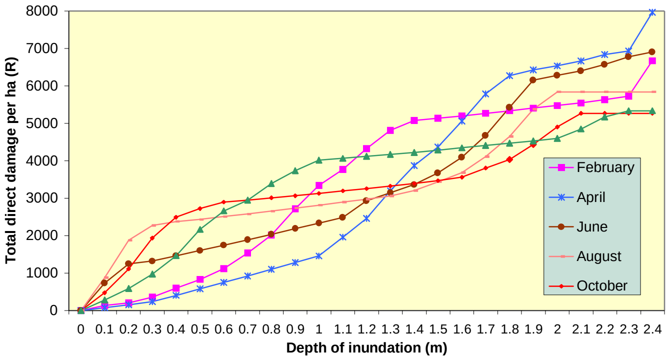

Figure 3
Loss functions to determine total flood damage to sugar-cane in the Mfolozi floodplain (1996 values)

plant). Depth and duration of inundation were identified as the main determinants of the percentage of the total area of cane that will be destroyed during a flood and hence the extent of damage. Depth of inundation was calculated in relation to the height of inundated cane in order to establish the extent of damage to cane. Duration of inundation was taken into account by determining the maximum period of complete inundation after which the cane will be destroyed.

Damage to the harvest includes both damage to destroyed and partially damaged sugar-cane, while taking the saving in terms of a decrease in harvesting and marketing cost into account. When crops are damaged, potential future yields are adversely affected. The difference between the net present value of the gross margin without a flood and the net present value of the gross margin with a flood served as measure of the extent of damage to the crop.

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