Estimation of total direct flood damage in the lower Orange River area with the aid of a flood simulation model - A GIS approach

LA du Plessis* and MF Viljoen
University of the Free State, Department of Agricultural Economics

Uittreksel

In vorige artikels is prosedures ten opsigte van die konstruering van verliesfunksies en vloedskadesimulasiemodelle bespreek. Met die verliesfunksies en rekenaarmodelle is dit moontlik om die totale impak van vloede (direk en sekondêr) te beraam deurdat topografiese-, hidrologiese-, hidrouliese en ekonomiese inligting in die vloedskadesimulasiemodel geïntegreer word. Vloedskade word eerstens uit die gesigspunt van die individu (plaaslike gesigspunt) beraam, waarna dit uit 'n streek- en nasionale gesigspunt beraam kan word. Omdat die metodologie om vloedskade uit 'n streek- en nasionale gesigspunt (sekondêre skade) te beraam, heelwat verskil van die metodologie om die totale direkte vloedskade uit 'n plaaslike gesigspunt te bepaal, is besluit om met die artikel slegs op die bepaling van die totale direkte vloedskade vanuit 'n plaaslike gesigspunt te fokus. Die vloedvlakte van die Oranjerivier, stroomaf van die Gifkloofstuwal tot by die Manie Conradiebrug by Kanoneiland, is as ondersoekgebied vir die navorsing gebruik.

Abstract

Methodology with regard to construction of stage damage curves and flood damage simulation models was discussed in two previous articles. The integration of topographical, hydrological, hydraulic and economic information in flood damage simulation models makes it possible to determine the total impact of floods (direct and secondary) by means of stage damage curves and computer programs. Flood damage is firstly determined from the viewpoint of the individual (local viewpoint) and secondly from a regional and national viewpoint. Since the methodology to determine flood damage from a regional and national viewpoint (secondary damage) differs considerably from that of determining the total direct flood damage from a local viewpoint, it was decided to focus on the latter in this article. The floodplain of the Orange River, downstream from the Gifkloof Weir to the Manie Conradie Bridge at Kanoneiland, served as research area.

Introduction

After constructing stage damage curves for different land-use types in the research area, a flood damage simulation model was developed. This model is based on a geographic information system (GIS) approach. The main aims of this simulation model are to calculate flood damages caused by various sizes of floods, and to quantify the benefits of various flood damage control measures. Therefore, better flood plain planning can be done to reduce flood damages.

As a starting point it is necessary to determine the total direct damage from a local viewpoint, before the secondary damage of floods from a regional or national viewpoint can be assessed. Topographic, hydrological, hydraulic and economic information must be integrated in the flood damage simulation model, to calculate the total direct and secondary effects of floods. When the total direct impact of floods is known, useful flood-plain management becomes possible. Flood plain management entails amongst other things, the determination of various flood control and flood damage control measures with the flood damage simulation model. The aim with this article is to illustrate from a local viewpoint the direct impact of floods with different probabilities of occurrence. The secondary effects of floods and the benefits of different flood control and flood damage control measures fall outside the scope of this article. The discussion starts with relevant methodological aspects.

*To whom all correspondence should be addressed.
☎ (051) 401-2721; fax (051) 401-2213; e-mail anton@landbou.uovs.ac.za
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Methodological framework

Direct flood damage refers to damage to items which have been in direct contact with flood-waters. The method of determining direct damage will differ, depending on the items which have been damaged. In the current research area, damage on irrigation land has been classified as either harvest, crop or soil damage. Damage to buildings is also calculated (Du Plessis et al., 1995). Loss functions have been developed for different land uses which are susceptible to damage. Enterprise budgets for different crops have been compiled. The gross income and allocated pre-harvest and harvesting cost, obtained from the enterprise budgets, are important economic data required for loss functions.

Besides an economic database, topographic, hydrological and hydraulic databases have been developed. The topographic database consists of one meter contours, spotheights, land-use patterns, location and height of levees and buildings, each of which is stored in a separate coverage. The hydraulic database comprises information such as cross-sections through the river and flood stages for different probabilities of occurrence and frequencies, which are also stored in separate coverages.

After verifying the model, i.e. checking the model for programming errors and determining that the model had indeed estimated flood damage correctly, several iterations were done with the flood damage simulation model. Amongst others, the following iterations were carried out:

- The determination of total and mean annual direct flood damage for the research area for floods occurring at different times of the year, for two situations, namely with and without levees.
- The determination of the composition of mean annual direct flood damage for the research area for floods occurring at different times of the year.

The methodology used for the calculation of total direct flood damage has already been discussed in detail in Du Plessis and Viljoen (1997), Du Plessis et al. (1995) and Du Plessis (1994) and is not repeated here.

Empirical results

The results of the aforementioned iterations will subsequently be discussed. Floods can occur at different times of the year. Since the highest probability for any flood to occur at any time, is the first half of a year (historical records), it was decided to develop the flood damage model to handle any flood which may occur from 1 February to 30 March. For purposes of this article flood damage for three different floods were compared (1 February, 5 March and 30 March). Each time flood damage was estimated for each occurrence with and without the effect of levees. Where damage with levees was estimated, two approaches were applied, namely:

- accepting (as advised by a consultant) that levees in the research area will at least prevent the one-in-five-year flood (Approach 1) (Chunnett, Fourie and Partners, 1993); and
- estimating the mean annual damage with an average levee height of 1.6 m (Ekkard, 1993; Smith, 1993) (Approach 2).

The latter entails the creation of a new water surface for floods with different probability of occurrence with the flood damage simulation model, in order to estimate the damage. Although an average flood bank height is taken as 1.6 m, the individual levees can be adjusted in the flood damage simulation model to make the relevant scenarios more realistic.

Total mean annual direct flood damage without levees

Table 1 gives a summary of the total mean annual direct flood damage (MAD) for the research area, without accounting for the effect of levees and damage to buildings for floods which may occur during different times of the year.

It appears that damage from floods occurring at different times during the year (1 February to 30 March) do not differ significantly from each other. The different damage categories (harvest, crop and soil damage) indicate that damage to the harvest changes most, since the harvest on the land decreases with time. The MAD for the research area, calculated without the effect of levees and buildings, varies between R8 745 and R10 220 m. according to the time of year when the flood occurs.

Besides damage on irrigation farms, damage in urban settlements of the Upington municipal area also occur and should be taken into account. Flood damage to buildings includes damage to the content of houses, as well as damage to the structure. Loss functions to buildings were developed by Booysen (1994) and Booysen and Viljoen (1995) and can also be consulted in this matter. Table 2 gives a summary of the total damage for floods with different probabilities of occurrence to buildings only (including buildings in Upington that will be inundated), as well as damage to the irrigation land and all the buildings combined. The mean annual damage to all the buildings in the research area amounted to R405 541. If the damage to all buildings in the research area is taken into account, the total mean annual damage varies between R9 150 and R10 626 m., dependent on the time that the flood occurs. The buildings next to the flood-plain of the research area are inundated only during a regional maximum flood and it explains the small effect of buildings on the MAD.

Total mean annual direct flood damage with levees

The effect of levees was determined according to two approaches. Table 3 gives a summary of the total mean annual direct flood damage when the effect of levees in the research area is taken into account. In this case the damage to building structures is also considered.

It appears that there is a substantial difference between damage values when the results of the two approaches are compared in Table 3. The total mean annual damage with the first approach for a flood occurring 1 February amounts to R10 015 m., while damage estimated with the second approach is 20% lower and amounts to R7 986 m. The advantage of the second approach is that a new damage value for floods with different probabilities of occurrence can be estimated. As opposed to approach one, the effect of the levees on floods with different probabilities of occurrence can be pointed out with the second approach. Damage to all buildings is taken into account and a more reliable estimation of damage to reflect the benefits obtained from levees, can be obtained with the second approach. Flood damage for the research area with Approach 2 is estimated at between R6.926 and R7.986 m. and amounts to between R1 577 and R1 818/ha.

According to the Department of Water Affairs and Forestry at Upington, the area from the Gifkloof Weir up to the Manie Conradie Bridge at Kanoneiland is representative of the area Boegoeberg Dam to Augrabies; an area of approximately 27 000 ha. The mean annual damage for this larger area will thus vary between R42.488 and R48.981 m.

The composition of total mean annual damage

The contributions of different damage categories (harvest, crop and soil damage, as well as the damage to all the buildings in the research area) to the MAD, are presented in Fig. 1. Approximately half (48.34%) of the total mean damage per annum, can be ascribed to perennial crops (sultana, wine-grapes and hanepoot), while buildings contribute only 6.36% to MAD. Soil and perennial crop damage contribute 32.69 and 12.58% respectively to MAD. It implies that the total MAD could be decreased by half if the vineyard could be removed from the flood plain. This option is, however, not necessarily economically justified, since other factors such as income from alternative land uses must also be taken into account. Since the true benefit of land-use management falls outside the scope of this article, no further attention will be given to it.

TABLE 1
THE TOTAL MEAN ANNUAL DIRECT FLOOD DAMAGE (R) WITHOUT THE EFFECT OF LEVEES AND BUILDINGS FOR THE IRRIGATION LAND BETWEEN GIFKLOOF WEIR AND THE MANIE CONRADIE BRIDGE, 1992

Flood size	1 Feb. flood	5 March flood	30 March flood
One-in-five-year flood	23 824 810	20 173 709	19 719 044
One-in-ten-year flood	41 837 063	36 246 337	35 574 802
One-in-twenty-year flood	62 413 006	54 757 980	53 851 204
One-in-fifty -year flood	75 843 478	66 953 241	65 983 416
Regional maximum flood (one-in-thousand-year)	89 674 729	79 822 493	78 815 529
MAD *	10 220 911	8 900 313	8 745 243
MAD/ha	2 327	2 026	1 991

* MAD: Mean annual damage

TABLE 2
THE TOTAL MEAN ANNUAL DIRECT FLOOD DAMAGE (R) FOR THE IRRIGATION LAND WITH DAMAGE TO ALL THE BUILDINGS IN THE RESEARCH AREA TAKEN INTO ACCOUNT WITHOUT THE EFFECT OF LEVEES BETWEEN GIFKLOOF WEIR AND THE MANIE CONRADIE BRIDGE, 1992

Flood size	Building structures	Agricultural plus building structures		
		1 Feb. flood	5 March flood	30 March flood
One-in-five-year flood	622 317	24 447 127	20 796 026	20 341 361
One-in-ten-year flood	1 198 654	43 035 717	37 444 991	36 776 456
One-in-twenty-year flood	1 984 312	64 397 318	56 742 292	55 835 516
One-in-fifty-year flood	3 333 082	79 176 560	70 286 323	69 316 498
Regional maximum flood	10 279 567	99 954 296	90 102 060	89 095 096
MAD	405 541	10 626 452	9 305 854	9 150 185

TABLE 3
THE TOTAL MEAN ANNUAL DIRECT FLOOD DAMAGE (R) FOR THE IRRIGATION LAND WITH DAMAGE TO ALL THE BUILDINGS IN THE RESEARCH AND LEVEES ARE TAKEN INTO ACCOUNT BETWEEN THE GIFKLOOF WEIR AND THE MANIE-CONRADIE BRIDGE, 1992

Flood size	1 Feb flood Approach 1	1 Feb flood Approach 2	5 March flood Approach 1	5 March flood Approach 2	30 March flood Approach 1	30 March flood Approach 2
One-in-five-year flood	24 447 127	13 539 428	20 796 026	11 341 129	20 341 361	11 137 025
One-in-ten-year flood	43 035 717	29 019 449	37 444 991	25 575 308	36 776 456	25 504 120
One-in-twenty-year flood	64 397 318	50 072 171	56 742 292	44 081 089	55 835 516	43 369 835
One-in-fifty-year flood	79 176 560	71 916 878	70 286 323	64 115 247	69 316 4986	3 249 335
Regional maximum flood	99 954 296	98 065 757	90 102 060	88 281 296	89 095 096	87 277 138
MAD	10 015 274	7 986 457	8 785 953	7 029 753	8 642 251	6 926 398
MAD/HA	2 271	1 818	2 000	1 600	1 968	1 577

* MAD: Mean annual damage

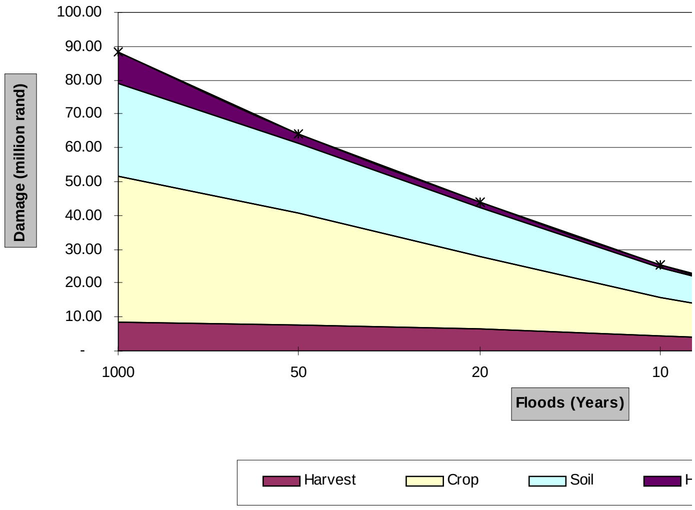

Figure 1
Contributions of different damage categories to mean annual damage

Summary

Various databases were integrated with the flood damage simulation model to estimate the total direct flood damage from the viewpoint of the local community. Different scenarios were studied with the model in order to illustrate various answers that could be obtained. The effect of buildings and levees in the determination of the total direct flood damage can be included or excluded. Two approaches were used to determine the effect of levees on the total mean flood damage, namely:

- where it is assumed that the levees in the research area will at least prevent a one-in-five-year flood (Approach 1) and
- by determining the total mean annual flood damage with a mean flood bank height of 1.6 m (Approach 2).

Approach 2 is more accurate to calculate the effect of levees and with this approach, the total direct flood damage varies between R6.9 and R10 m. for the research area for floods occurring different times of the year. Perennial crops (sultana, wine-grapes and hanepoot) contribute 48.34% to the total MAD, while buildings contribute only 6.36%. The total MAD can be decreased by half if vineyards could be moved out of the flood plains. This option may, however, not be well-founded. Other factors, for example potential damage and income of alternative land uses must also be considered before an ideal land use management plan can be compiled.

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