Determining the benefits of flood mitigation measures in the lower Orange River: A GIS application

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Abstract

When topographical, hydrological, hydraulic and economic information is integrated with the aid of a flood damage simulation model, the total mean annual flood damage can be estimated. With the total mean annual flood damage known, it is possible to ascertain the benefits of several flood mitigation measures. These measures are normally implemented to reduce the physical extent of floods, relieve the effect of a flood on humans and the community and reduce the tendency toward flooding in different areas. It is not economically justified to implement measures to such an extent that they will prevent the total risk of flood losses. The benefits gained from flood mitigation measures should at least exceed the costs involved. Consequently, an optimal package of flood mitigation measures should be compiled where the marginal benefits are equal to the marginal cost.

The purpose of this paper is to identify relevant flood mitigation measures for the research area, discuss their benefits and drawbacks, after which the possibilities for application in the research area are analysed.

Introduction

When one develops a flood damage simulation model, it is possible to integrate flood damage functions, topographical, hydrological, hydraulic and economic databases in order to establish the total direct flood damage. This process can be repeated for various floods with different probabilities of occurrences. With these results it is then possible to calculate the mean annual damage (MAD). With the MAD known, it is possible to calculate the benefits of different flood mitigation measures for any area of investigation. Flood mitigation measures can be implemented to reduce the physical extent of flooding, relieve the effect of a flood on humans and the community and reduce the tendency towards flood damage in different areas. They can also be implemented to reduce the risk of flooding and in this way, income stability can be assured at farm level (Van Zyl and Groenewald, 1984a). Krutilla (1966) points out that, in spite of the disastrous effects of flooding, it is not economically viable to implement measures to such an extent that they will prevent the total risk of flood losses. This is because the cost of the flood mitigation measure will exceed the benefits thereof. Keeping the above-mentioned in mind, an optimal package of flood mitigation measures, can be compiled where marginal benefits are equal to the marginal costs.

Before an optimal set of flood mitigation measures can be established for an area, the different measures which can be implemented should first be identified. After that, it is necessary to indicate for each measure exactly what it entails and what its benefits and costs will be. After the benefits and costs of each measure have been established, suitable packages can be identified for the research area. An optimal flood control and flood damage control measures package can then be compiled.

Against this background, the paper only focuses on the first two steps, namely identifying applicable flood mitigation measures for the research area and estimating the total benefits and cost of the different flood mitigation measures with the aid of a flood damage simulation model (FLODSIM) based on a GIS approach. Due to the fact that the procedures of calculating the different flood damage categories (Du Plessis and Viljoen, 1997; 1998) and also the procedures followed by FLODSIM (Du Plessis, 1999) are already published, no further attention will be given in this paper to the above-mentioned.

Theoretical framework

Flood mitigation measures are divided into three categories (Fig. 1), according to Higgins and Robinson (1981). Handmer (1985) and Viljoen (1979) use the same classification. Although the order is changed, the same basis of classification is used.

The first measure is concerned with the control of flood waters, namely keeping flood water out of developed floodplains. For this purpose, structural measures like flood control dams and levees are usually used. Secondly, damage can be reduced in areas with the greatest flood damage potential by limiting settlement and development in these areas. This usually entails non-structural measures, like land-use regulations. Lastly, measures are associated with the risk actions by the inhabitants of floodplains, in accordance with and overlapping the first two measures. A very important component of this is comprehensive public education and information programmes.

Evaluation of flood mitigation measures

The effect of several flood mitigation measure options on potential disasters and damage is graphically depicted in Fig. 2 by specifically referring to the benefits of different flood control options and disaster potential. The probability of disaster potential can be reduced through some flood mitigation measures or risk-reducing options, while other measures increase the potential for disaster. Apart from the disaster potential, some flood mitigation measures can be advantageous to the local and/ or national community, while others have detrimental effects.

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Received 30 March 1997; accepted in revised form 27 November 1998.

Water control measures	Flood storage Canal improvements Levees and flood ways Catchment area planning
Land-use measures	Planning and building regulations Permanent evacuation Flood barricading
Social measures	Training and information Warning and emergency services Flood insurance

Figure 1
Categories and examples of flood control measures
(Source: Higgins and Robinson, 1981:4)

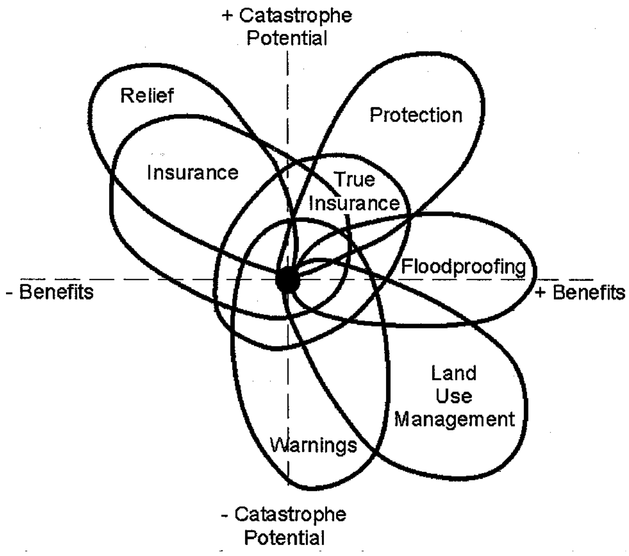

Figure 2
Benefits and disaster potential of alternative flood mitigation measures
(Source: White, G. 1945, quoted by Smith and Greenaway, 1993:23)

Smith and Greenaway (1993:18) discuss this aspect in more detail. Fig. 2 is subsequently explained through a short discussion of relevant factors.

Flood protection

In this case, flood protection refers to the building of levees, which are structural flood control measures. Structural measures built in the floodplain, can counteract flooding of the floodplains in several ways. For instance new catchment dams can reduce flood peaks, levees channel the flow into certain predetermined entry ways and flood ways help to channel excessive flow away. However, building and maintenance costs of this type of measure are high (Smith, 1993).

Structural control measures have two important characteristics, namely:

- They can never provide full protection. The expected flood damage is only reduced, while the risk of settling in the floodplain remains unchanged after structural measures have been built, and
- They create a false feeling of security.

A belief that the building of structural measures reduces the probability of flooding can lead to large-scale development in floodplains and the expected flood damage will increase. The catastrophic consequences of larger floods are increased in this case, because these measures lead to further development behind levees. Further development in floodplains takes place as a result of the false feeling of security created by levees. In effect, this reduces the ability of the community to avoid losses as a result of larger floods. This phenomenon is common in urban areas.

In spite of the fact that structural measures increase the disaster potential, structural measures reduce the mean annual flood damage, especially for smaller floods, and for this reason they have a positive effect on flood control. The use of only structural measures can lead to a sub-optimal development of floodplains because of the very high cost involved implementing it and also because structural measures on their own lead to the escalation of flood damages over time, mainly because of the false feeling of security created. Therefore non-structural measures are also required in order to effect optimal floodplain development.

Land-use planning

Land-use planning in floodplains has the aim of reducing the expected flood damage on the one hand and reducing the risk of development in the floodplain on the other hand, by following less flood-hazardous building practices. In order to fulfil this, the different land-use options within floodplains should be analysed. Dividing the different land-use types into different zones, according to certain river characteristics usually facilitates the analysis of land-use options. Some land-use types are more susceptible to floods than others and the following options can be exercised;

- the most vulnerable land-use activities should be discouraged in floodplains or
- land use can be shifted to less vulnerable zones/areas, for instance where rivers have characteristically less flood damage.

Brown (1972), Krutilla (1966) and Lind (1967), as quoted by Thampapillai and Musgrave (1985), criticise land-use planning as a flood control mechanism. The expected flood damage is reduced at a cost, because of the loss of profit, in that a land use that would have taken place in the floodplain now takes place outside the floodplain where it is less profitable. Higgins and Robinson (1981) link this argument to the one that several alternatives are available to prevent flood losses. The concept of freedom of choice should also be kept in mind; to the agriculturist, this means to produce at free will. Some inhabitants of the floodplains take chances and prefer to produce a high-value flood risk crop, while others prefer a lower expected income, which is more stable over time. To reconcile this the application of land-use regulations is made more difficult. The ultimate purpose of land-use planning is not to harm individuals, but rather to increase public welfare. In some areas, applying land-use regulations can thus reduce the necessity for structural protection. So, agricultural production activities are changed to crops that grow and ripen outside the main flood season.

According to Fig. 2, land-use management/planning (together with flood warnings) has the greatest net benefit of the above-mentioned flood mitigation measures. Reducing the average annual flood damage and disaster potential positively influences flood control. Another method of land-use planning is the development of crop varieties which are resistant to flood water and can be cultivated in floodplains, while less resistant crops can be cultivated on higher-lying areas. The first has already been successfully done with lucerne in New South Wales (Higgins and Robinson, 1981). The average flood damage per year is reduced in this way and so the disaster potential is reduced.

Flood barricading

Flood barricading can be divided into three categories, namely;

- Permanent measures - the choice of building material and flood heights of buildings,
- Unforeseen measures - these are implemented after flood warnings have been issued, for example sealing walls and closing unnecessary openings.
- Emergency measures - this is done during a flood, like the use of sand bags.

James (1964), quoted by Higgins and Robinson (1981), determined that flood barricading is only economically viable in thinly populated urban areas which are often flooded (at least once every two years). When urbanisation exceeds about 10% of the floodplain, other measures like joint levee protection become more cost-effective. Flood mitigation measures should always be evaluated in terms of costs and benefits. Higgins and Robinson (1981) quote Flack (1978) who emphasises that the decision to provide individual homes with flood barricading rests with the owner himself. For this reason, a cost-benefit analysis for a floodplain as a whole will not necessarily be applicable to an individual's decision or control mechanism.

Flood warning

If floodplain inhabitants can be warned against flood disasters in time, emergency measures like evacuation and the building of temporary flood mitigation measures can be implemented. Most of the time this means that only a part of the property that is exposed to flood damage, is saved. Higgins and Robinson (1981) measure the effectiveness of a flood-warning trellis system according to the following:

- Flood damage when no action is taken;
- Flood damage when all portable items are removed; and
- Expected flood damage.

The ability of floodplain inhabitants to react effectively to flood warnings, will reduce flood losses. An effective flood-warning trellis system is able to protect floodplain inhabitants against any flood and the risk of settling in the floodplain is reduced at a cost equal to the cost involved in a warning trellis system. The different emergency measures taken by floodplain inhabitants, are based on two aspects, namely:

- Flood warnings can be very effective if they reflect both the time of occurrence and extent of a flood. The more accurate the prediction, the greater the expected loss which can be prevented and the smaller the risk taken.
- Secondly, the range of the warning trellis system, in other words the area which is covered by the warning, is important.

It is important to note that flood warning as such cannot reduce damage, but it only provides the opportunity for other activities to start. According to Fig. 2, the same principles as for land-use management are valid here.

Insurance

Flood insurance is not a direct flood damage control measure, but rather a mechanism that transforms a series of stochastic losses into a homogeneous series at a greater total cost (Higgins en Robinson, 1981). De Villiers (1974), quoted by Van Zyl and Groenewald, (1988) mentions four characteristics of flood insurance:

- It reduces uncertainty with the insured
- It transfers the risk from the insured to the insurer
- The economic loss of the insured is compensated fully or partially
- Only two parties are involved.

It is important that authorities are involved when flood insurance is determined for flood-prone areas. The insurance premium can be of value to the policy-maker in order to plan and manage floodplains optimally. Thampapillai and Musgrave (1985) mention four benefits of flood insurance, namely:

- It makes the floodplain inhabitants aware of the risk involved in settling in the floodplain
- It complements structural measures by removing remaining risk
- It is relatively cheaper than structural measures
- It creates environmental benefits by not interfering with nature.

Van Zyl and Groenewald (1984b) calculate a further benefit for floodplain inhabitants from flood insurance, by comparing the average net cash flow for different sized farms with and without flood insurance. In this research, it was found that the net cash flow for each size farm was not only higher, but also more stable when they insured against flood damage.

Figure 2 distinguished between insurance and true insurance. Insurance refers to insurance that is borne by the authorities or paid out, while true insurance refers to insurance borne by the individual himself (individual floodplain inhabitant). Where the owner himself does not pay the premium (in full), but it is paid or subsidised by the authorities, the real risk of settling in floodplains is not realised. Such a trellis system has negative effects on insurance premiums by encouraging the undesirable use of floodplains. When the insurance premium is not subsidised, the floodplain inhabitants will be more aware of the risk involved in settling in floodplains. As a result, it has an advantageous effect on flood control. In both cases, the disaster potential increases because of a false feeling of security which is being created.

As far as can be ascertained, there is no insurance scheme in South Africa at present that covers flood losses specifically. Possible reasons for this are that production on floodplains takes place only on a limited scale in South Africa, a lack of data pertaining to flood records and problems pertaining to determining loss functions for different crops (Van Zyl and Groenewald, 1984a). An important aspect which one should not lose sight of, is that most insurance schemes function on the assumption that the insured do not suffer losses at the same time and thus also will not claim at the same time. The opposite is true with flood insurance. When floodplains flood, all insured persons in the floodplain will claim compensation at the same time. A situation can arise where all claims exceed the pooled premiums. Very few, if any, insurance companies will bear such a risk (Van Zyl and Groenewald, 1988).

In answer to the above, Thampapillai and Musgrave (1985) say that a compulsory national flood damage insurance scheme can be recommended to reduce the risk for insurance companies. A compulsory flood insurance scheme ensures government involvement and absorbs the losses borne by the company. Lind (1967:347), as quoted by Van Zyl and Groenewald, (1988) stated that a compulsory flood insurance scheme is a method of preventing irresponsible utilisation of a floodplain. The fact that the state will not commit itself causes this aspect of policy to be ineffective. Insurance premiums can also be so high that it discourages any development within the floodplain and so, a scheme which could have been profitable, will not be developed (Wiggens, 1974 - quoted by Van Zyl and Groenewald, 1988). A non-compulsory flood insurance scheme was unsuccessful in the USA, in spite of a 90% subsidy by the authorities. The main reasons for this were a lack of awareness by individuals pertaining to the flood losses and the probability of occurrence as well as the availability of insurance.

Other measures

Apart from the above measures, the following can also be applied (Higgins and Robinson, 1981);

- Catchment areas can be changed upstream to such an extent that it reduces the flood peak. Possible activities include afforestation and building of contour walls. It is usually only practical in small catchment areas.
- Public schooling and training programmes can inform floodplain inhabitants about the risk involved in settling in floodplains.
- Permanent evacuation or large-scale redevelopment of a floodplain are alternatives which will not be used very often, if at all. Permanent evacuation becomes relevant with old buildings or if the structure is such that flood barricading is difficult. It mostly results in great disruption and the social disruption of evacuation cannot be justified economically.

Empirical results

With the above theoretical background, it is possible to evaluate alternative flood mitigation measures for the research area with the flood damage simulation model (FLODSIM).

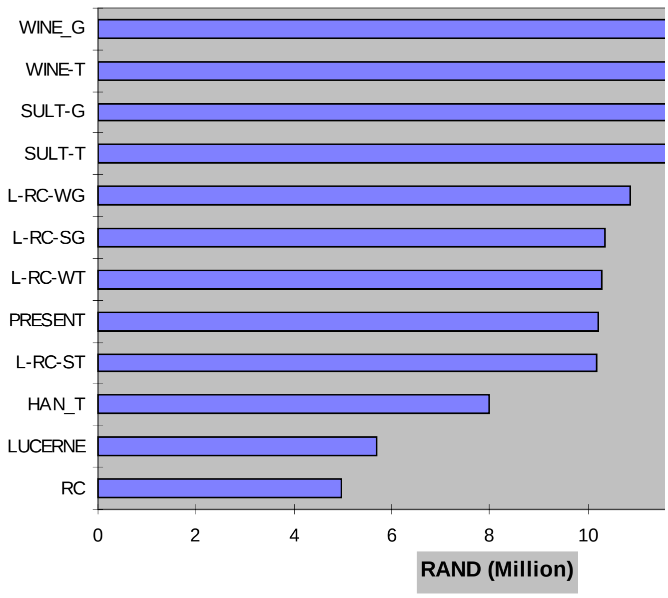

Figure 3

The mean annual flood damage (MAD) for land-use management options in the Lower Orange River floodplain between Gifkloof Weir and the Manie Conradie Bridge, 1992

Key:

Wine_G:	All land uses have been changed to wine-grapes with gable trellis systems in the research area.
Wine_T:	All land uses have been changed to wine-grapes with T trellis systems in the research area.
Sult_G:	All land uses have been changed to sultana with gable trellis systems in the research area
Sult_T:	All land uses have been changed to sultana with T trellis systems in the research area..
L_RC_WG:	All vines have been changed to wine-grapes with a gable trellis system with existing rotational crops and lucerne.
L_RC_WT:	All vines have been changed to wine-grapes with a T trellis system with existing rotational crops and lucerne.
L_RC_SG:	All vines have been changed to sultana with a gable trellis system with existing rotational crops and lucerne.
L_RC_ST:	All vines have been changed to sultana with a T trellis system with existing rotational crops and lucerne.
Present:	Present land-use patterns occurring in the research area.
Han_T:	All land uses have been changed to hanepoot with T trellis systems in the research area.
Lucerne:	All land uses have been changed to lucerne in the research area.
RC:	All land uses have been changed to rotational crops in the research area.

TABLE 1
NET BENEFIT OF DIFFERENT LAND-USE OPTIONS FOR THE RESEARCH AREA BETWEEN GIFKLOOF WEIR AND THE MANIE CONRADIE BRIDGE, 1992

Land use	Net income (R)	Mean annual damage (R)	Net benefit (R)
Rotational crops	5 942 918	4 980 666	962 252
Lucerne	10 139 444	5 704 474	4 434 970
HAN_T	29 036 561	7 984 520	21 052 041
L_RC_ST	19 936 498	10 186 066	9 750 432
L_RC_SG	23 971 851	10 369 402	13 602 449
L_RC_WT	19 643 611	10 302 375	9 341 236
L_RC_WG	30 256 764	10 866 618	19 390 146
SULT_T	30 622 020	12 530 431	18 091 589
SULT_G	38 483 728	13 320 332	25 163 396
WINE_T	30 051 413	15 403 000	14 648 413
WINE_G	50 728 048	15 413 182	35 314 866
PRESENT	19 857 277	10 220 911	9 636 366

Key:
MAD: Average annual flood damage

Land-use management

The effect of different land-use management options is investigated in this section with the aid of the flood damage simulation model. From the many options a number of hypothetical land uses are analysed to illustrate the application of the flood damage simulation model. The flood damage simulation model consists of several output files which are stored in GIS (geographic information trellis system) format. Thus, the land-use pattern in the research area can easily and quickly be changed to ascertain the effect of management options of different land use in this way. As a first round, the land uses have been changed by only cultivating lucerne or applying rotational crops or viticulture in the research area. Secondly, the existing land-use pattern has not been changed but all grape cultivars have been changed to sultana or wine-grapes or hanepoot. The effect of the different trellis systems on the MAD has also been ascertained. Figure 3 represents the results graphically.

The average losses per annum due to flood damage are limited to the minimum, if only rotational crops (RC) are planted in the research area. In contrast to this, the MAD is highest for wine-grapes with a gable trellis system (Wine_G) followed by wine-grapes with a T trellis system (Wine_T). If the existing vine production is changed to wine-grapes with a gable trellis system (L_RC_WG), wine-grapes with a T trellis system (L_RC_WT), sultanas with a gable trellis system (L_RC_SG) or sultanas with a T trellis system (L_RC_ST) (while existing rotational crops and lucerne stayed the same) and compared to the existing land-use pattern, there is little variation in the MAD.

To make meaningful recommendations, the MAD of different land uses should be compared to the net income of the different land uses. The net income for individual land-use types specified in Table 1 can be calculated by multiplying the gross margin of the land-use type with the total area under production. The net benefit of the land uses can than be determined by subtracting the MAD from the net income (Table 1). A positive net benefit is present with all of the land uses, which indicates that the average net profit is consistently higher than the average annual flood damage.

Levee analysis

Structural flood mitigation measures for the research area are largely limited to the building of levees. The location of levees, as well as the height above ground level of the different levees, is also stored in an output file. In this way, levees can easily be manipulated by changing the height of individual levees or even changing the location of levees. In order to do a meaningful analysis between the "with" and "without" approach, the total cost of building levees should also be calculated. Costs for the building of levees have been provided by Ekkard (1993). A distinction was made among the three types of levees in the research area, namely soil, gravel and good gravel levees (see Du Plessis, 1994 and also Du Plessis et al., 1995 for more information). The total length of different levees in the area of investigation (three types) has been calculated with the aid of the flood damage simulation model and is as follows:

- Soil levees: 59 560 m
- Gravel levees: 17 705 m
- Good gravel levees: 31 729 m

Levees in the research area, according to Ekkard (1993), have an average top width of 3.5 m, a side slope of 1:1 and an average height of 1.6 m. As a result, levees in the research area consist of on average 8.16 m^3 of building material per 1 m of levee length (Du Plessis, 1994:122). The total cost of building all the levees in the research area, presuming that building material has to be transported for 1 km on average, is summarised in Table 2.

The total cost of building levees in the research area is R3.6 m. (1992 prices). By subtracting the MAD of R7.029 m. from the MAD without the effect of levees being accounted for (R9.305 m.), a benefit of R2.286 m. is found. The shaded area in Figure 4 indicates the benefit of levees. On first glance, it seems

TABLE 2 TOTAL COST OF THREE TYPES OF LEVEES BETWEEN GIFKLOOF WEIR AND THE MANIE CONRADIE BRIDGE AT KANONEILAND, 1992			
Item	**Soil levees**	**Gravel levees**	**Good gravel levees**
Total length (m)	59 560	17 705	31 729
Cost per 1 m length of levee (R)	20.40	32.64	57.12
Total cost (R)	1 215 024	577 891	1 812 360

TABLE 3 BENEFITS GAINED FROM THE BUILDING OF LEVEES FOR THE RESEARCH AREA BETWEEN GIFKLOOF WEIR AND THE MANIE CONRADIE BRIDGE AT KANONEILAND, 1992					
Discounting rate	**Total levee benefit (R)**	**Cost of levee without maintenance cost (R)**	**Cost of levee including maintenance costs (R)**	**Net benefit without cost of maintenance (R)**	**Net benefit with maintenance costs (R)**
NHW 8%	24 297 189	3 338 218	3 906 930	20 958 771	20 390 259
NHW 10%	20 660 532	3 277 523	3 730 811	17 383 009	16 929 721
NHW 12%	17 852 012	3 218 996	3 585 482	14 633 061	14 266 530

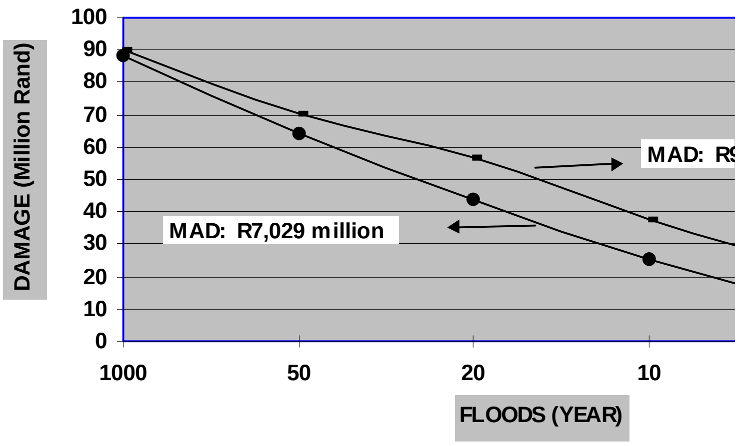

Figure 4
Net benefit caused by the building of levees between Gifkloof Weir and the Manie Conradie Bridge for a 5 March flood, 1992

that R3.6 m. in expenditure is being saved for a benefit of R2.286 m.

However, the above saving is an average annual saving and for the purpose of comparison, the saving should be discounted over the life-span of the levee. The life-span of a levee was estimated at 25 years (Ekkard, 1993), consequently a saving of R20.660 m. (1992) is effected. By subtracting the cost involved in building levees from this saving, the net benefit gained from the levees, is obtained. The above approach does not make provision for the annual cost of maintenance for levees, as well as repairs to levees because of damage by flood waters. To compensate for this, the net benefit of levees is estimated by using 0.5% annually of the construction cost as maintenance to levees, as well as 15 and 20% of the construction cost in Years 10 and 20 for repairs to levees as a result of flood damage. Table 3 summarises the results.

The net benefit which can be gained from levees, is estimated for a 5 March flood. From Table 3, a net benefit of R17.383 m. is gained (discounted at 10%) if no maintenance and repair costs are taken into account. If maintenance and repair costs are taken into account, a net benefit of R16.930 m. is gained through levees. A greater benefit is gained if a smaller discounting rate (8%) is used, while about a 15% smaller benefit is gained with a 12% discounting rate. The net benefit gained through levees, is not sensitive to the percentage of maintenance and repair costs. After increasing maintenance to 5% and cost of repairs to 30 and 60% of the cost of maintenance in Years 10 and 20, a net benefit of R15.268 m. was still gained. With the above percentages, floods that had occurred on 1 February and 30 March were taken and net benefits of R18.571 m. and R14.793 m. were still obtained.

TABLE 4 THE REDUCTION IN AVERAGE ANNUAL FLOOD DAMAGE WHEN THE PROBABILITY OF THE OCCURRENCE OF FLOODING IN ANY YEAR HAS BEEN REDUCED THROUGH DAM MANAGEMENT, 1992	
Flooding probabilities (Case)	**Mad (R)**
Present flooding probabilities	7 029 753
I	6 390 685
II	5 858 128
III	4 327 795
IV	3 849 861

Key:
MAD: Mean annual flood damage
I: 10% reduction in flood probabilities.
II: 20% reduction in flooding probabilities.
III: The once-every-four-years flood becomes the once-every-five-years flood, once-every-five-years becomes the once-every-ten-years flood, once-every-ten-years flood becomes the once-every-twenty-years flood, once-every-twenty-years flood becomes the once-every-fifty-years flood, the once-every-fifty-years flood remains the once-every-fifty-years flood and the regional maximum flood remains a once-every-thousand-years flood.
IV: The once-every-four-years flood becomes the once-every-five-years flood, once-every-five-years flood becomes the once-every-ten-years flood, once-every-twenty-years flood becomes the once-every-fifty-years flood, the once-every-fifty-years flood becomes the once-every-hundred-years flood and the regional maximum flood remains a once-every-thousand-years flood.

Dam management

Apart from structural flood damage measures, like levees, floods can also be controlled through dam management. In effect, river hydraulics is influenced by changing the water levels at different places in the river. This implies that increasing or reducing the probability of occurring in a specific year changes the risk of floods. The building of an additional dam or raising the height of an existing dam wall, can reduce the probability of flooding in any year. The effect of this on the MAD can be determined through the use of the flood damage simulation model. Two approaches have been followed:

- changing the probability of occurrence of the different floods,
- reducing water levels by 1%.

When the water level is reduced because of a new dam or the raise of an existing dam wall, the probability of the occurrence of floods is reduced. A few hypothetical probabilities of flooding occurring in any year have been adapted, mainly to show the sensitivity of flood probability in the MAD (Table 4).

When the risk of flooding is reduced by 10%, the MAD is R6.391 m. This is a 9% reduction in flood damage. A 20% reduction in flood damage causes a 17% reduction in the MAD. Although a less than 20% reduction in the MAD does occur, the benefit should be compared to the cost involved in the flood control measure. A drastic change in the probabilities of flooding, cases III and IV, causes a 38 and 45% reduction in the MAD and the MAD amounts to R4.328 and R3.850 m. respectively. Further investigation on the cost implication of the above-mentioned scenarios is necessary before real decisions can be made.

Insurance premiums

Insurance premiums can be determined for different flood damage control options, by making the annual flood damage premium equal to the expected average annual flood damage (Krutilla, 1966). Additional administrative costs are ignored in this case, but an additional 10% levy as recommended by Kuiper (1971), quoted by Van Zyl and Groenewald (1988), is added to the premium. Table 5 gives a summary of insurance premiums for a

TABLE 5
EXAMPLES OF INSURANCE PREMIUMS FOR DIFFERENT FLOOD DAMAGE CONTROL OPTIONS FOR THE UPINGTON IRRIGATION AREA, 1992

Flood damage control option	MAD (R)	Insurance premium* per year (R/ha)	Insurance premiums per month (R/ha)
Present land use	10 220 911	2 559	213.26
Land use was changed to wine-grapes with gable trellis system	15 413 182	3 859	321.60
Land use was changed to rotational crops	4 980 666	1 247	103.92
Present land use with the effect of levees taken into account	7 029 753	1 760	146.68
10% probability reduction in the occurrence of flooding	6 390 685	1 600	133.34

Key:
MAD: Mean annual flood damage
* 10% levy added to the premium

few options for the Upington irrigation area. The total irrigation area was calculated from the flood damage simulation model and comprises approximately 3 994 ha.

First the current land-use pattern in Upington was taken as a starting point. For the current situation the MAD is equal to R10.220 m. (Table 5) and when divided by the total area under irrigation (3 994 ha) the insurance premium is R2 559/ha. When the effect of levees is taken into account within the current land-use type the insurance premium is R1 760/ha. With a 10% reduction in the probability of flood occurrence, the premium falls by 9% and is R1 600/ha·yr. Where only wine-grapes with a gable trellis system are cultivated, the premium is 34% higher than with the present land-use pattern (without the effect of levees being taken into account) and amounts to R3 859/ha·yr.

Conclusion and recommendations

One can draw important conclusions from the land-use management options investigated. When the MADs for the different vine cultivars, as well as the different trellis systems are compared to one another, it seems that there are no significant differences (see L_RC_WG, L_RC_WT, L_RC_SG and L_RC_ST). This implies that one does not have to distinguish between different vine cultivars and trellis systems for future flood damage analyses.

Although rotational crops (RCs) have the lowest average flood damage per year, it is not the most profitable way to practice only crop rotation in the floodplain. According to Table 1, rotational crops have a net benefit of R962 252 (1992), while the greatest net benefit is gained by cultivating wine-grapes on a gable trellis system (Wine_G). Next to rotational crops, lucerne has the lowest net benefit. The average annual saving on flood damage by cultivating only rotational crops instead of the present vine cultivars, is about R10.432 m. (1992). If this is compared to the loss of income, about R44.758 m. in loss of income will be cancelled by practising rotational crops instead of cultivating vine cultivars.

Brown (1972), Krutilla (1966) and Lind (1967), quoted by Thampapillai and Musgrave (1985), justly comment that the expected flood damage is reduced, but at a cost if a crop which yields a greater than expected net income in floodplains than outside, is no longer cultivated in the floodplain. Other factors like the suitability of soil for different crops, the financial skills and expertise of farmers to cultivate other crops, the availability of labour, implements and processing capacity and the ability to market the products, should also be ascertained before an optimal land-use pattern can be determined.

From the levee analyses, it emerges that levees can be financially justified in the research area. However, with the present hydraulic information (constant flow), water levels remain constant as levees are manipulated. To make provision for this, refined hydraulic information should also be used to perform further analyses using the flood damage simulation model, in order to obtain a better answer.

It is possible to illustrate the benefits of dam management with the flood damage simulation model. Hypothetical examples were used during this research. As new dams are built, a complete cost analysis should be done among others, in order to be able to come to meaningful conclusions. For this purpose, the real costs involved in the building of a new dam should also be known. However, this type of analysis falls outside this research.

It was also possible to indicate the real risk of settling in floodplains with the aid of the flood damage simulation model (Table 5). Premiums for the present land-use options are high and not at all affordable. Affordable premiums can be calculated by varying land use to such an extent that more flood-resistant crops are cultivated in the floodplain. It is only when producers have to pay the premium themselves, that undesirable cultivation practices in floodplains can be eliminated. The above aspects will have to be researched more fully before meaningful recommendations can be made pertaining to flood insurance premiums.

Summary

In this paper flood mitigation measures were discussed under three categories of damage. The first category is related to measures which control flood-waters, namely keeping flood-waters out of developed floodplains. For this purpose, structural measures like levees are usually used. Secondly, damage can be reduced in areas with the greatest flood damage potential by limiting settlement and development in these areas. This usually includes non-structural measures, like land-use regulations. Lastly, flood mitigation measures can be categorised into measures, which can be regarded as community service. A very important component of this is extensive public education and information programmes.

With this theoretical framework as background, several flood mitigation measures were researched for the research area. The benefit to be gained from several measures for the research area, was calculated with the aid of a flood damage simulation model. Several land-use management options were first researched. A positive net benefit is obtained with all of the land uses. Although rotational crops have the lowest average flood damage per year, it is not beneficial to only practice crop rotation in the floodplain. The greatest net benefit is gained by cultivating wine-grapes with a gable trellis system in the research area.

Next, levees were researched. This has a net benefit in the research area, even if building, maintenance and repair costs are taken into account.

The manipulation of dams for the purpose of flood control was also analysed. Dams can be manipulated to reduce the flood peak. As a result, the risk of flooding is reduced by reducing the probability of occurrence. It was found that when the risk of flooding is reduced by 10%, the MAD is reduced by 9%.

The involvement of authorities in flood-prone areas during the institution of flood insurance premiums is important. The insurance premium can be very valuable to the policy-maker in order to optimally plan and manage floodplains. For different flood damage control options, the insurance premiums can be calculated by making the annual flood damage premium equal to the expected average annual flood damage. Additional administrative costs were ignored in this case, but an additional 10% levy was added to the premium. It was indicated that premiums vary per year from R1 250 to R3 800/ha, depending on the flood damage option chosen.

From the above, it seems that the flood damage simulation model developed is able to produce useful information as input towards the planning of flood control and flood mitigation measures.

References

DU PLESSIS LA (1999) New flood damage simulation model for irrigation areas of South Africa: A GIS approach. *Agric. Eng. in S. Afr.* **30** (1).

DU PLESSIS LA (1994) Die Ontwikkeling van Verliesfunksies en 'n Rekenaarmodel vir die Bepaling van Vloedskade en Vloedbeheerbeplanning in die Benede-Oranjeriviergebied. B.Sc. (Agric.) Thesis, Univ. of the Orange Free State, Bloemfontein.

DU PLESSIS LA and VILJOEN MF (1998) Estimation of total flood damage in the lower Orange River area with the aid of a flood simulation model: A GIS apporach. *Water SA* **24** (3) 201-204.

DU PLESSIS LA en VILJOEN MF (1997) Die ontwikkeling van vloedskadefunksies vir die landbousektor in die Benede-Oranjerivier. *Water SA* **23** (3) 209-216.

DU PLESSIS LA, VILJOEN MF en BOOYSEN HJ (1995) Die Ontwikkeling van Vloedskadefunksies en 'n Rekenaarprogram om die Voordele van Vloedbeheer- en Vloedskadebeheermaatreëls te Bepaal. Deel 2: Besproeiingsgebied. Dept. of Agric. Econ., Univ. of the Orange Free State, Bloemfontein (WRC Report No. 490/2/96).

EKKARD F (1993) Personal communication. Region Engineer, Dept. of Agric., Upington.

HANDMER JW (1985) *Anuflood in New Zealand, Part 2: Background to Flood Loss Measurement*. Hamilton: Univ. of Waikato, Dept. of Geography. (CRES Working Paper 1986/3).

HIGGINS RJ AND ROBINSON DJ (1981) An Economic Comparison of Different Flood Mitigation Strategies in Australia: A Case Study. Canberra: Australian Government Publishing Service, Dept. of Natl. Development and Energy, Australian Water Resources Council, Research Project No. 78/114.

KRUTILLA JV (1966) An economic approach to coping with flood damage. *Water Resour. Res.* **2** (2) 183-190.

VAN ZYL J en GROENEWALD JA (1984a) Ekonomiese aspekte van vloedskadegeneigdheid in die landbou: 'n Studie in die Laer-Umfolozivlakte. *Agrekon* **23** (1) 32-42.

VAN ZYL J en GROENEWALD JA (1984b) Plaasgrootte en vloedskadegeneigdheid: Gesamentlike effekte op kontantvloei. *Agrekon* **23** (1) 28-33.

VAN ZYL J en GROENEWALD JA (1988) Vloedskadeversekering: 'n Studie op die Benede-Umfolozivlakte. *Agrekon* **27** (3) 16-20.

VILJOEN MF (1979) Die Ekonomie van Waterbenutting met Besondere Verwysing na die Bepaling van Vloedskade in Sekere Riviertrajekte van die Republiek van Suid-Afrika. Inst. for Social en Econ. Res., Univ. of the Orange Free State, Bloemfontein.

SMITH DI (1993) Personal communication. Centre for Resource and Environmental Studies, The Australian Natl. Univ., Australia.

SMITH DI and GREENAWAY MA (1993) An Introduction to Urban Flood Damage Assessment. Johannesburg. Paper presented to the Department of Water Affairs.

SWIEGERS C (1993) Personal communication. Deputy Director: Strategic Management, Dept. of Water Affairs and Forestry, Pretoria.

THAMPAPILLAI DJ and MUSGRAVE WF (1985) Flood damage mitigation: A review of structural and nonstructural measures and alternative decision frameworks. *Water Resour. Res.* **21** (4) 411-424.