NEW DECISION SUPPORT MANAGEMENT MODELS FOR DISASTER MANAGEMENT

by

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1. INTRODUCTION

The White Paper on Disaster Management, which outlines Government's new policy with regard to disaster management, emphasized a number of aspects which make the research and computer models developed by the flood damage research team at the University of the Free State, extremely topical. Application of the flood damage management aids that were developed in flood areas will contribute substantially to ensuring the practicability of the new policy. The following aspects, quoted from the White Paper (Department of Constitutional Development, 1999), are particularly relevant:

- In line with international trends and our national objectives of efficient and effective management of our nation's resources, priority is given in this new approach to prevention. This is unlike previous policies that focused predominantly on relief and recovery efforts. In short the new policy aims to promote proactive disaster management through risk reduction programmes.

- Disaster management is now seen as a continuous process and disasters are managed as a parallel series of activities rather than a sequence of actions, as in the past.

- Disaster management is not considered to be the exclusive preserve of Government. The private sector and civil society have crucial roles to play. The fostering of partnerships between Government and the private sector is considered to be a prerequisite for sustainable and effective disaster management.

- The establishment of a National Disaster Management Centre is proposed to overcome the current fragmented and poorly coordinated approach to disaster management, the fact that there is no integrated national disaster management strategy or plan that supports local level responses to emergencies and disaster mitigation in the long term, and the absence of comprehensive, coherent and appropriate disaster management training and community awareness strategies and programmes.

- One of the most important functions of the Centre should be its ability to act as a repository and conduit of information on issues pertaining to disaster management. It should serve as an information management and advice centre to all spheres of Government, the private sector and the broader community on risk reduction and disaster management.

- Another key function of the Centre is the preparation of strategies, policies and plans in conjunction with relevant national, provincial and local government agencies, as well as NGOs and broader civil society. The establishment and maintenance of links amongst all relevant role players are very important.

The flood damage management approach and aids developed by the University of the Free State flood damage research team is in line with that proposed in this new policy, as will become clear in the following presentation.

2. METHODOLOGICAL FRAMEWORK

New decision support management tools were developed by the Department of Agricultural Economics. These management aids (computer models and questionnaires) give execution to the new White Paper on Disaster Management, namely to manage disasters continuously, pro-actively as well as in the reactive and post disaster flood phases.

A methodological framework, resulting from more than 25 years of research, is represented in Figure 1. The methodological framework (Figure 1) indicates the possibilities of flood decision support management tools in a continuous disaster management process.

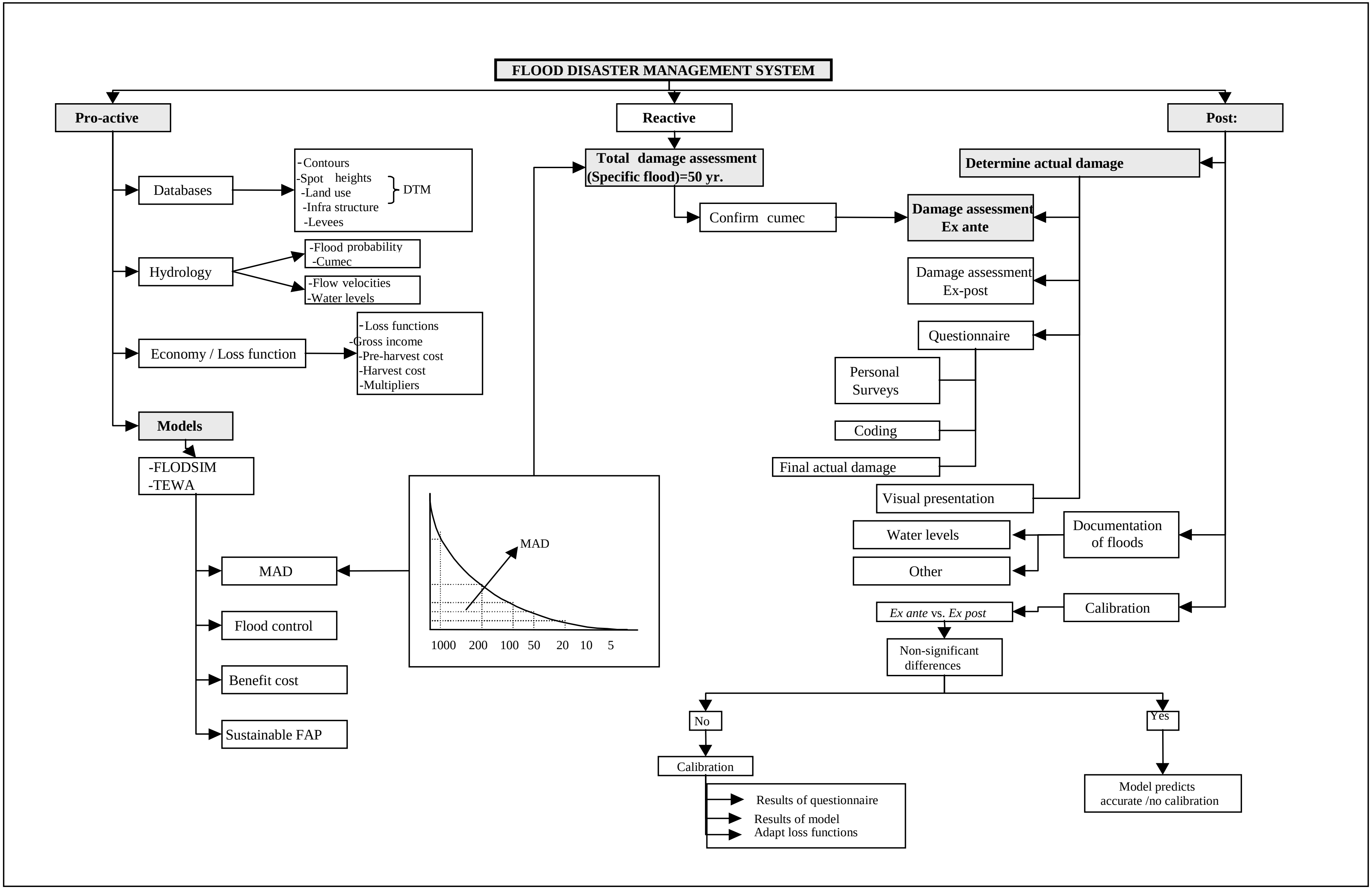


Figure 1: Continuous flood disaster management system

2.1 PRO-ACTIVE DISASTER PHASE

Before any flood occurs it is envisaged that various data bases and simulation models, designed by the Department of Agricultural Economics, will be installed at provincial and local government level. Data bases, such as contour lines, spot-heights, land use patterns, infrastructure, hydrological and hydraulic data as well as economic data will be acquired and stored in GIS format. These data bases are integrated with two simulation models, namely FLODSIM (flood damage simulation model for irrigation areas) and TEWA (flood damage simulation model for urban areas). A very important component of these flood damage simulation models is loss functions. A loss function defines the relationship between direct flood damage and certain flood characteristics such as depth of inundation, duration of inundation, area inundated, silt content and momentum flux of the flood waters for a specific damage category.

Before the application of the two simulation models is demonstrated, a short discussion of FLODSIM and TEWA will be given.

2.1.1 FLODSIM

A typical flood damage simulation process (FLODSIM), based on GIS, is portrayed diagrammatically in Figure 2, will be discussed. As a starting point, various data bases have to be developed. After creating these data bases, the integration and modelling process starts (see Commencement). The dotted lines in Figure 2 indicate that a specific data base must be selected from a data bank, while the black solid lines indicate various inputs to FLODSIM.

A digital terrain model (DTM) is essential for FLODSIM, and can be created in several ways.

After an appropriate DTM has been constructed, loss functions are selected from the data bank to determine the damage caused by floods. Loss functions for vineyards, rotational crops, lucerne and sugar cane, as well as infrastructure, such as roads, bridges and tramways are available. Modules were recently extended to accommodate additional loss functions as well as providing for a more dynamic loss function approach, such as taking the duration of inundation into account as well.

The next step is to develop a topographical data base, which consists of a land-use patterns, contour lines, spot heights, location and height of levees as well as the location and height of buildings in the area of investigation. The land-use pattern can be determined by using an *in situ* or a remote sensing approach. The *in situ* approach refers to a survey where researchers are in physical contact with the area of investigation. In contrast to this, the remote sensing approach refers to surveys where sensors are not in physical contact with the data. Therefore, data can be acquired by means of various sensors that can be mounted on aeroplanes or satellites. Contour lines and spot heights are essential data to create DTMs.

In order to use FLODSIM for effective flood planning in flood-prone areas in South Africa, it is essential that both flood simulation models and GIS techniques are used (Muller & Rungoe, 1996). To achieve this, appropriate interfaces between MIKE 11 and FLODSIM had to be developed. Therefore a unique module was added to FLODSIM in such a way that it became possible to obtain hydraulic data from MIKE 11, with reference to specific scenarios, that were drawn up with FLODSIM.

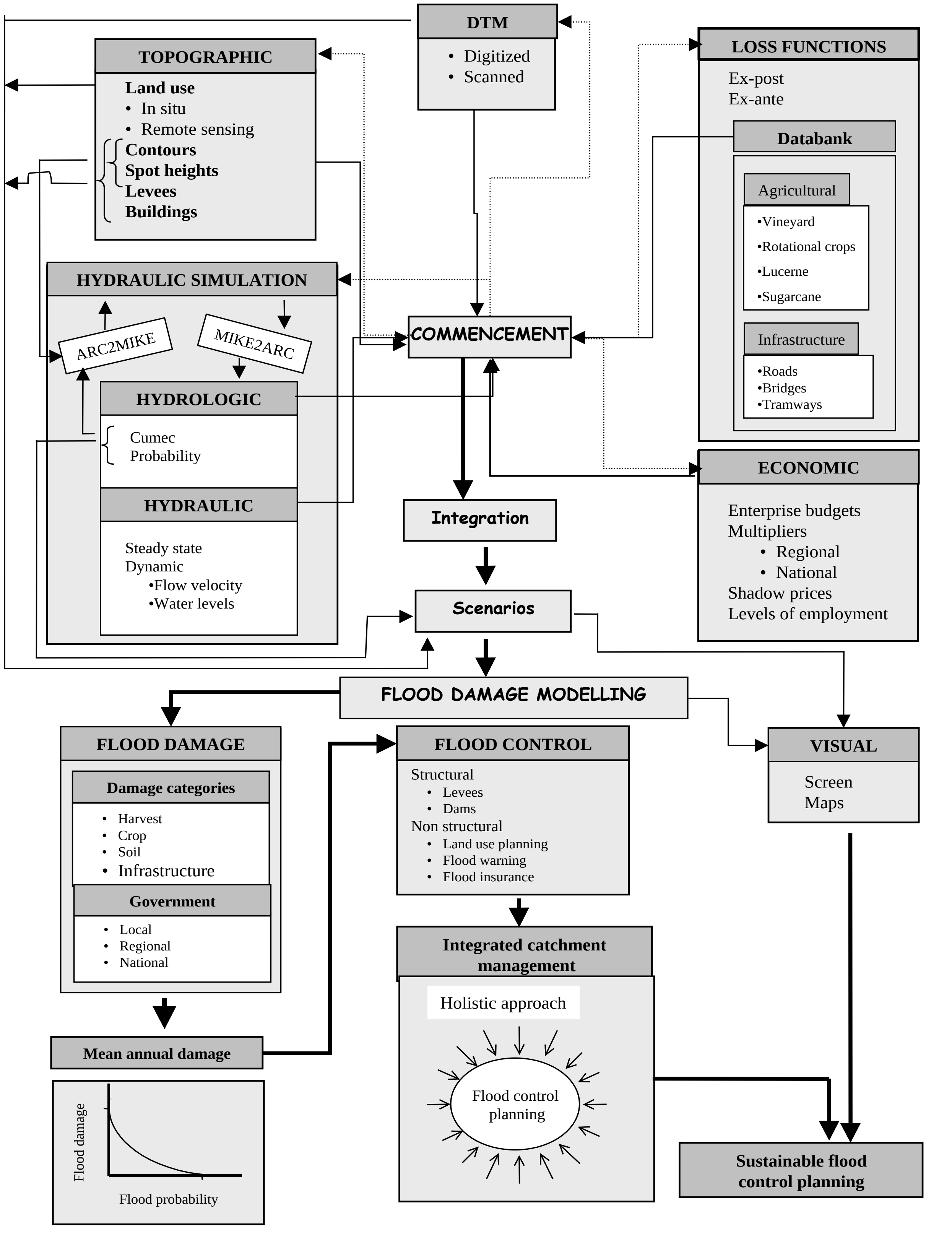


Figure 2: **A Typical FLODSIM-simulation**
Source: *Du Plessis, 1998*

After developing a topographical database, the economic data base is selected. The economic data base consists of enterprise budgets, multipliers (regional and national), shadow prices and employment rates. Information from enterprise budgets is used to calculate the total direct flood damage. With the total direct flood damage known, it is possible to calculate the secondary results of floods through the use of suitable multipliers.

When the data base has been specified in FLODSIM, it is possible to generate several scenarios by manipulating the topographical, hydrological, hydraulic and economic data. Flood damage can then be calculated for a specific scenario from a local, regional and national point of view. Scenarios can also be shown visually on the screen or on maps. Maps are essential for flood plain planning, and the depth and duration of inundation as well as flood lines and flood areas are indicated. After the flood damage has been determined for floods with different probabilities of occurrence, it is possible to calculate the mean annual damage (MAD).

Structural and non-structural flood control measures can only be evaluated adequately if the MAD is known. Traditionally, flood damage modelling is calculated only for structural and non-structural control measures. This gave rise to the escalation of flood damage and the non-optimal utilisation of flood plains. Additional aspects also have to be considered, so that local authorities in particular can be in the position to formulate sustainable flood management plans. For this purpose, a holistic approach to integrated catchment management is necessary. The discussion of this approach is not part of this paper, and therefore, will not receive further attention.

2.1.2 TEWA

TEWA is the acronym for a computer model for Tangible Economical flood Water damage Assessment, and is thus a computer model that calculates tangible flood damages. Furthermore the model can evaluate different flood damage mitigation options. Like EAD[1] (U.S. Army Corps of Engineers, 1988), TEWA is based on the principle that flood damage to an individual structure/property, groups of properties or flood plain zone is determined by the monetary value of flood damage for different magnitudes of flooding. Damage caused to a property or a number of properties by a single flood event is calculated directly from flood damage functions/loss functions.

All geographical and attributed data are stored in a GIS format which makes it relatively easy to combine the data from different sources to analyse and represent the results in different formats (e.g. tables, graphics, maps).

[1] **This program was developed to assist in economic evaluation of flood plain management plans (US Army Corps of Engineers, 1988). EAD computed inundation reduction benefits.**

Figure 3 gives an overview of where TEWA fits into the process of calculating flood damage.

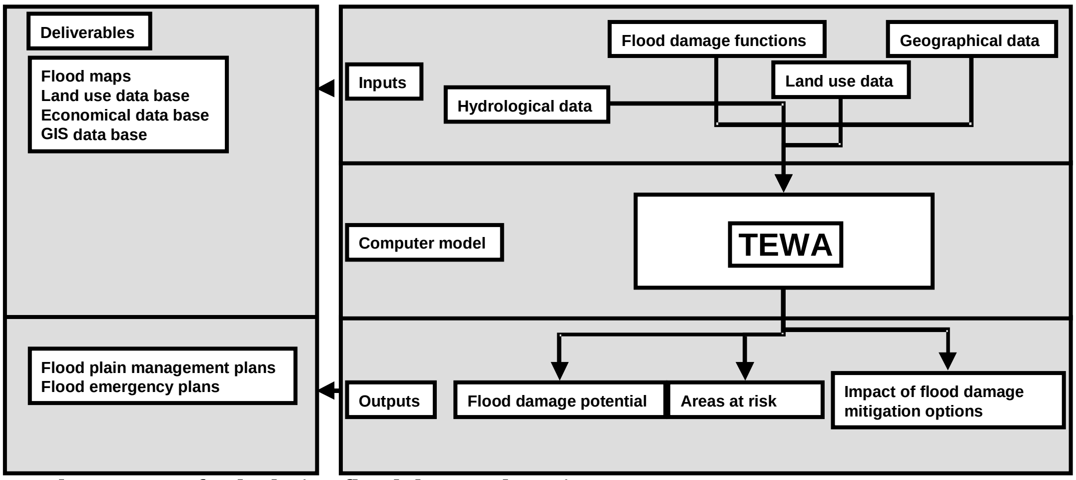


Figure 3 **The process of calculating flood damage by using TEWA**
Source: *Booysen & Viljoen, 1998*

The process starts with the inputs TEWA requires to calculate flood damage, which are similar to the data needed by FLODSIM. With this input certain deliverables are also stipulated.

Output of TEWA includes flood damage potential, area under risk and the impact of different flood damage mitigation options. The deliverables of these outputs are flood plain management, emergency and sustainable flood action plans. To obtain the correct results TEWA must be used in conjunction with GIS software. In this case ArcView is used, see Figure 4.

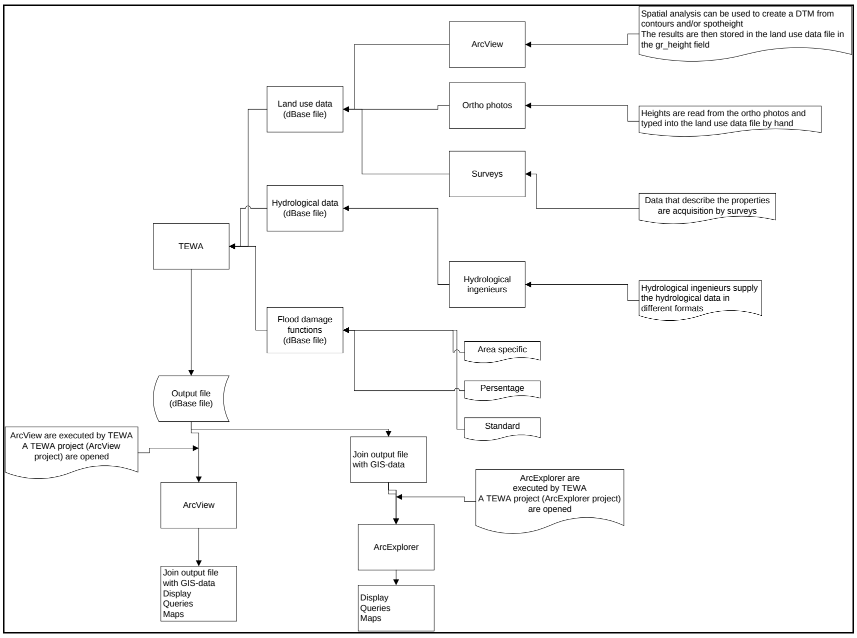


Figure 4 **The methodology of TEWA to calculate flood damage**
Source: *Booysen, 1999*

The land use, hydrological and loss function data bases are integrated with TEWA to calculate the total direct impact of various floods. TEWA can link with ArcView to visualise results obtained and to execute spatial analysis if required.

2.2 REACTIVE PHASE

Figure 1 represents an adapted approach to improve management of resources during the reactive phase of a flood. Once FLODSIM and/or TEWA are installed for a specific area it becomes possible to simulate the potential damage of the flood that occurred. The magnitude (cumec) of the flood must first be determined. This will give a broad indication of what the potential damage will be and it is therefore not necessary to determine the losses caused by of floods by using questionnaires as a first round of the impact of the real flood. With more data available, predictions will improve. It is therefore recommended that calibration of the simulation model is conducted after the occurrence of floods. This will be discussed in the next section.

2.3 POST DISASTER PHASE

After the disruption of the current flood has passed and all activities have been normalised, it is envisaged that a detail survey must be conducted. Questionnaires developed by the Department of Agricultural Economics have been incorporated into a user-friendly computer model, which can be used primarily to determine the real economic losses of a specific flood. This computer model enables the surveyor to make a recording at flood victims to determine the impact of a specific flood on the irrigation and residential, commercial, industrial and informal communities/sectors. Distinction is made between different damage categories like harvest, crop, soil, infrastructure, household content and building damages. These damages are added to determine the total impact of a flood in a region.

The secondary objective of the above-mentioned computer model is to use the results to calibrate the hydraulic model (Mike II) and flood damage simulation models (FLODSIM and TEWA). If, for instance, the predicted total flood damage is within certain boundaries when compared to the survey results, no calibration of the flood damage simulation models is necessary. If results of predicted flood damage and damage determined by means of a survey differ substantially, it is necessary to execute a calibration process. This may require a specialty service rendered by the Department of Agricultural Economics to make certain adjustments to the different loss functions.

3. **EMPIRICAL RESULTS**

3.1 DEMONSTRATION OF FLOOD DAMAGE SIMULATION MODEL: CASE STUDIES

Different case studies are used to demonstrate FLODSIM and TEWA. For this purpose results of research projects, which were executed in the Mfolozi, Vaal and Orange Rivers regarding the demonstration of FLODSIM and TEWA, will be used.

3.1.1 Pro-active

Floods in the Mfolozi flood plain could occur in any month of the year. Consequently the flood damage (harvest and crop damage without damage to infrastructure) was calculated for twelve months of the year (Figure 5).

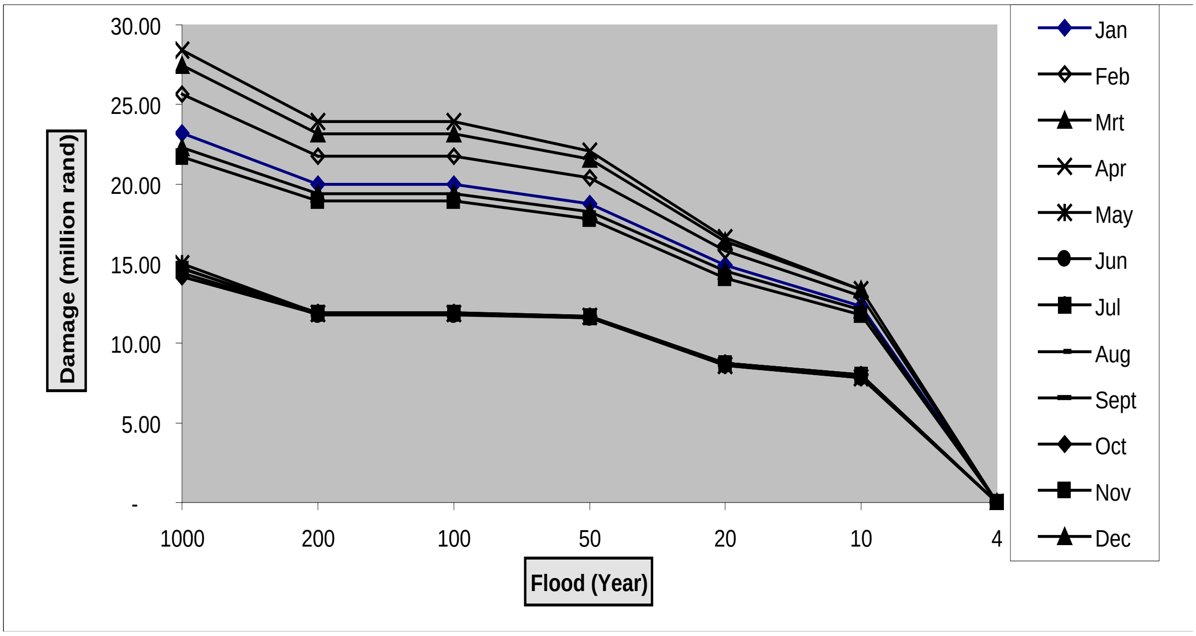


Figure 5: **Total flood damage for the Mfolozi flood plain for twelve months of the year, 1995**
Source: *Du Plessis, Viljoen, Weepener and Berning, 1998*

A clear difference is visible between summer and winter damage. From November to April damage above the average occurs and it increases from month to month. The mean annual damage for the summer months varies from R2,39 million (November) to R2,8 million (April). Flood damage from May to October differs little and the total mean annual flood damage for these months ranges only from R1,56 to R1,58 million.

With the above-mentioned damage figures known, it is possible to determine the total mean annual flood damage for the Mfolozi flood plain. Total mean annual flood damage for an April flood (this is the flood with the highest risk for the Mfolozi flood plain) amounts to R3,27 million. This is a 14 per cent increase in damage for the same flood without the damage to infrastructure. Flood damage decreases to R2 million when floods occur during the winter months. An average flood damage of R2,54 million is obtained in the Mfolozi flood plain (1995) and is R45 000 higher when damage to infrastructure is also calculated. The variation between the total mean annual flood damage, when damage to infrastructure is included, and the mean annual flood damage, when damage to infrastructure is not included, is shown graphically in Figure 6.

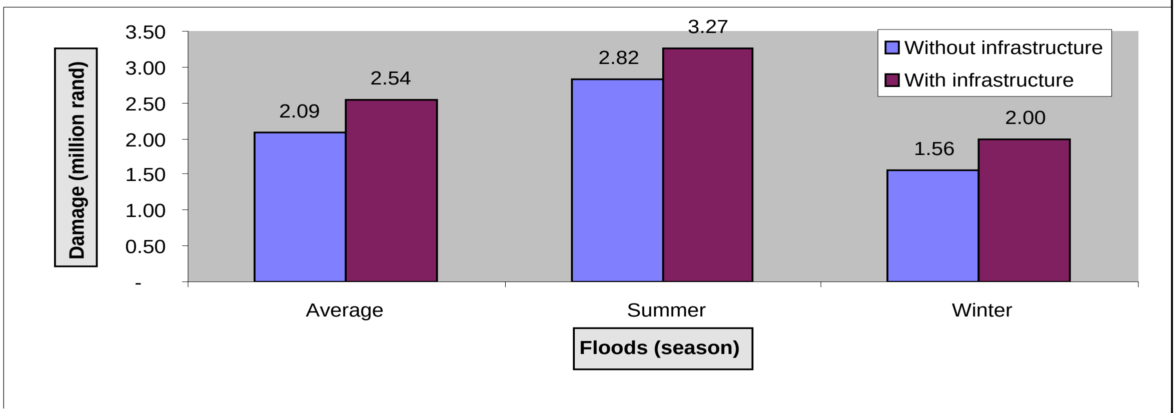
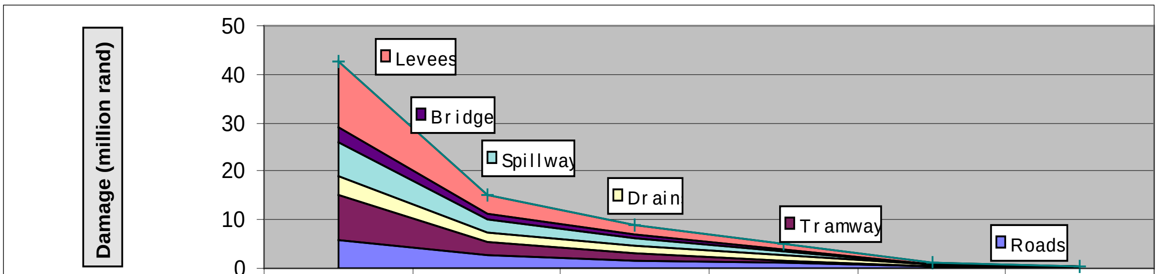


Figure 6: **Total mean annual damage for floods in various seasons, with and without including damage to infrastructure, 1995**

Source: *Du Plessis, Viljoen, Weepener & Berning, 1998*

The composition of damage to infrastructure is shown graphically in Figure 7.



	1000	200	100	50	20	10
Levees	13.76	4.04	2.13	104	0.14	0.03
Bridges	2.90	105	0.62	0.34	0.06	0.02
Spillways	7.07	2.73	166	0.95	0.19	0.06
Drains	3.82	2.07	151	106	0.39	0.18
Tramways	9.25	2.64	134	0.61	0.06	0.01
Roads	5.97	2.68	172	0.99	0.23	0.07
Totaal	42.78	15.21	8.98	5.01	107	0.36

Floods (Year)

Figure 7: **Composition of infrastructure damage**

Source: *Du Plessis, Viljoen, Weepener & Berning, 1998*

The largest mean annual damage, namely 29 per cent, is caused to levees, followed by damage to tramways (19%). Damage to the spillway comprises 17,25 per cent of the total damage to infrastructure, while 16 per cent of the total damage is caused to roads. Bridges comprise the smallest component (6,8%) of damage to infrastructure.

The application of TEWA is demonstrated by the development of flood lines for the Parys flood plain and by discussing its usefulness in risk reduction.

For the Parys flood plain the inundation from different discharges from the Vaal Dam was simulated. Figure 8 shows the position of these inundations near the town of Parys. This information can now be used for disaster management. For example, if the disaster manager receives news that 2 000 cumec of water will be released from the Vaal Dam, he will know where evacuation must take place.

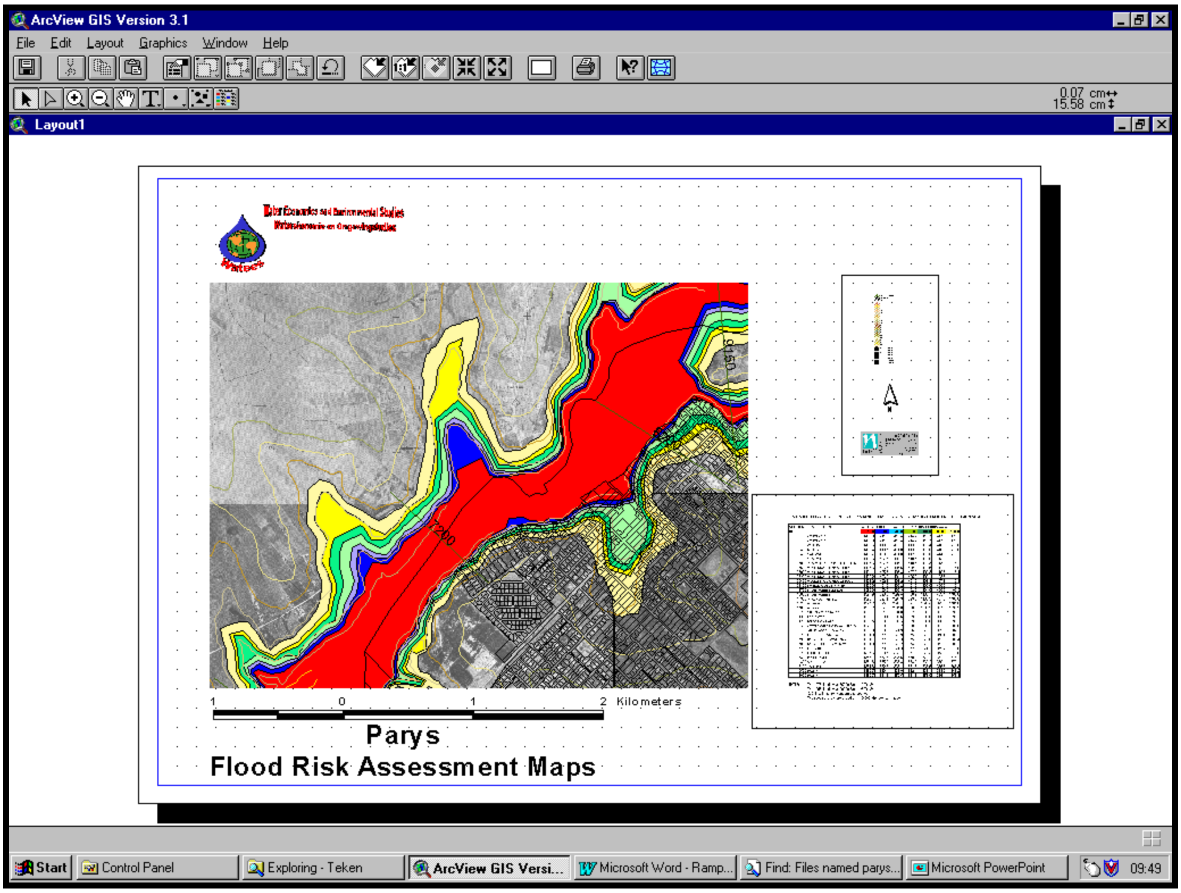


Figure 8Presentation of flood lines that was developed for Parys
Source: Du Plessis, Booysen & Van Bladeren, 1999

For sustainable flood plain management, planning for reducing the risk is also very important and is discussed in the next paragraph.

The information for flood hazard mapping is initially constructed as in Figure 9.

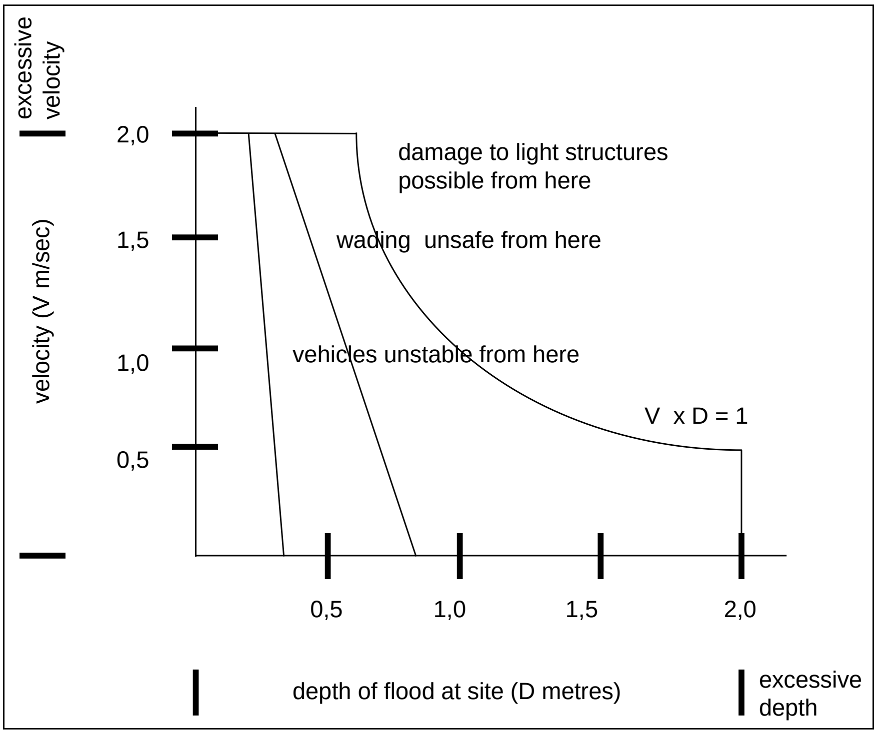


Figure 9: The relationship between velocity and depth of flooding with a certain level of hazard as a result
Source: Flood plain Development Manual, New South Wales Government (1986)

According to Figure 9, if the velocity of the water is 1,5 m/s and the depth of inundation is 1 m, damage to lighter type structures can occur. In Figure 10 these relations are linked to hazard categories. When the velocity is 1,4 m/s and the depth of inundation 1,2 m, this area is classified as high hazard.

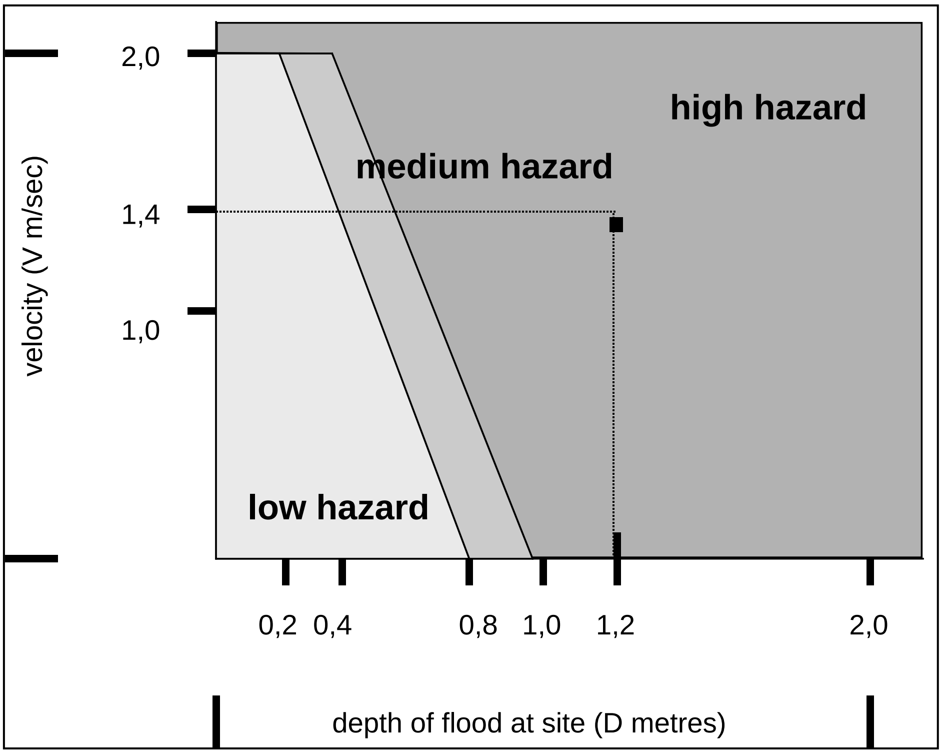


Figure 10: Tentative hazard categories for flood plains
Source: Flood plain Development Manual, New South Wales Government (1986)

An application of this information can be as follows for an area that is located in a danger zone:

- Any portion of a building or structure subject to inundation should be built from flood compatible materials.
- Flood proofing above the standard flood should be required of all new residences, including those associated with commercial, industrial and special use developments. Whilst this condition would generally apply to major developments/extensions, the merits of each case should determine the need.
- Special consideration should be given to caravan parks, as they are difficult to evacuate. Evacuation problems will be compounded by permanent vans and visitors lacking flood awareness.
- The developer or property owner should demonstrate that any building or structure can withstand the force of flowing floodwater, including debris and buoyancy forces as appropriate.
- A detailed report from an appropriate institution may be required in support of a development or building application.

3.1.2 Cost benefit analysis

After the low, medium and high hazard areas have been determined it is possible to assess the benefits of different flood mitigation measures. Although disaster management is not necessarily responsible for the implementation of flood mitigation measures, this is an important part of risk reduction. To illustrate this procedure, research results from Upington was used.

The mean annual flood damage (MAD) was calculated first, after which various flood mitigation measures were investigated. For the purpose of this paper, the optimal levee height will be assessed. Table 1 indicates the financial impact of various flood mitigation options, to prevent especially damage to crops in the flood plain from different sized floods in particular.

Table 1: Net benefit (R million) of various flood mitigation options to determine the optimal levee height for Upington research area, 1999.

Mitigation option	MAD	BENEFIT	COST	TOTAL BENEFIT	TOTAL COST	NET BENEFIT
No levees	16.78	-	-	-	-	-
Prevent 5 year flood	15.38	1.40	72.22	17.08	80.33	-63.25
Prevent 10 year flood	8.98	7.80	89.76	95.31	93.06	2.25
Prevent 20 year flood	5.01	11.77	117.87	143.96	117.28	26.68
Prevent 50 year flood	2.67	14.11	157.89	172.51	151.73	20.77
Prevent 100 year flood	1.71	15.07	192.90	184.33	183.13	-1.20
Prevent 200 year flood	1.18	15.60	230.21	190.77	217.00	-26.23
Prevent 500 year flood	0.89	15.89	286.56	194.28	268.27	-73.99
Prevent 1000 year flood	0.76	16.02	347.36	195.91	324.11	-128.20
Prevent 5000 year flood	0.70	16.08	452.65	196.68	420.93	-224.25
Prevent 10000 year flood	0.68	16.10	573.95	196.96	533.24	-336.29

The MAD is first calculated when no flood mitigation measure is applied. From Table 1 the MAD for this option is R16,78 million. Levees are constructed to prevent agricultural production and residential properties in the flood plain from being flooded by the 5 year flood. The benefit of this is equal to R1,40 million. When comparing this benefit with the cost involved (R72,22) of constructing the levees, it seems that no net benefit occurs. It is

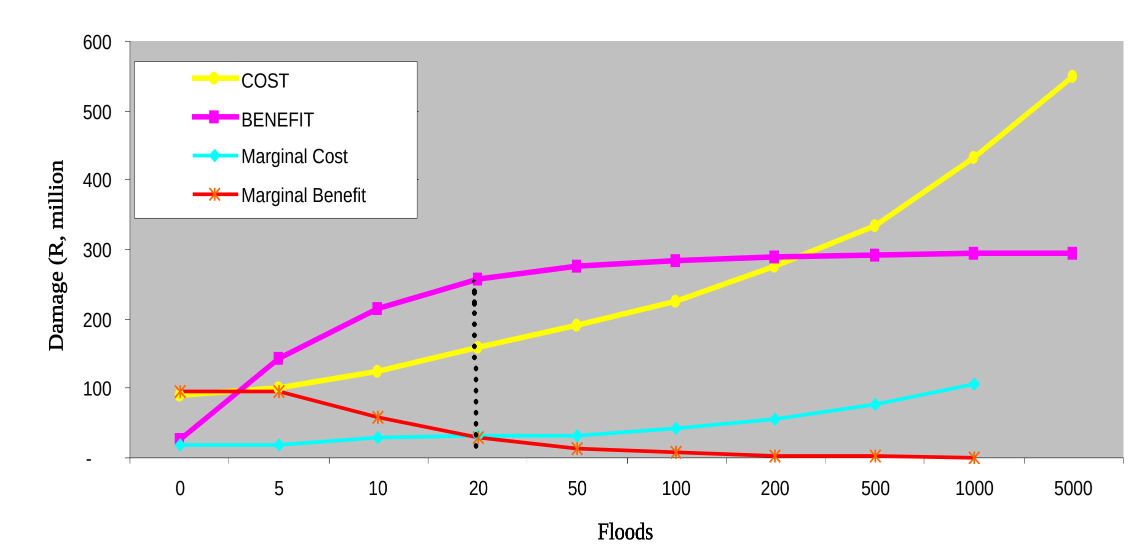


Figure 11: **Cost and benefits of levees in Upington, 1990**

important to note that this benefit is a mean annual benefit and must first be discounted over the life span of the specific mitigation measure. After this has been done, a total benefit of R17,08 million is obtained (an 8% discount rate has been used). Apart from the total direct construction cost, additional costs such as maintenance and repair costs due to floods, must also be taken into account. When such costs are added to the total direct construction cost, the present value of the total cost involved in preventing the 5 year flood, equals R80,33 million. The net benefit can be calculated by subtracting the total cost from the total benefit. In this case a negative net benefit of R63,25 million occurs. From Table 1 it can be observed that the highest net benefit (R26,68) is obtained when the flood plain is protected against the 20 year flood.

These costs and benefits are displayed graphically in Figure 11.

3.1.3 Post disaster phase

To illustrate the applicability of FLODSIM (and TEWA) during the post disaster phase as well as the calibration process, the February 1996 flood in the Mfolozi flood plain and a hypothetical flood occurring in February with a recurrence period of 20 years (probability of five per cent to occur in any year) were used. The damage to the February 1996 flood was determined ex post and that of the hypothetical flood ex ante.

Table 2: **Comparison of the direct damage to sugar cane in the Mfolozi flood plain for a February flood according to the ex post and ex ante approaches (1996 value)**

Damage category	Damage (R'000)			
	Ex post	Ex ante	Difference	% Difference1[11]
Damage to harvests	R 10 357	R 7 597	R 2 760	27%
Damage to crops	R 5 928	R 4 532	R 1 396	24%
Total damage to sugar cane	R 16 285	R 12 129	R 4 156	26%

1 The percentage difference was calculated by taking the difference as percentage of the ex post values.
Source: *Du Plessis, Viljoen, Weepener & Berning, 1998*

From Table 2 it can be seen that the total direct damage to sugar cane calculated from survey data exceeds the total direct damage calculated by FLODSIM by 26 per cent. The damage to harvests according to the ex ante approach was calculated as the decrease in income due to destroyed sugar cane, minus the decrease in harvesting cost saved as a result of the smaller harvest, plus the decrease in income due to lower sucrose content. Results from the ex post approach (survey) showed that there exists little saving in terms of a decrease in harvesting cost. The cost of labour increases after floods since additional labour is required to clean dirty cane and the harvesting proceeds much slower due to muddy conditions.

Loss functions for infrastructure used in the ex ante approach were based on historic data of direct primary flood damage to infrastructure in the Mfolozi flood plain and do not include the flood damages recorded during the February 1996 floods. Table 3 provides a comparison of the direct flood damage to infrastructure as calculated according to the two approaches.

Table 3: Comparison of adjusted ex post and ex ante direct damage to infrastructure in the Mfolozi flood plain for a 20-year flood (1996 value)

	Direct damage (R'000)			
Damage category	Ex post	Ex ante	Difference	% Difference1
Drainage	R 766	R 611	R 155	20%
Spillway	R 246	R 228	R 18	7%
Tramlines and tramline bridges	R 401	R 73	R 328	82%
Roads	R 45	R 268	(R 223)	83%
Bridges	R 17	R 75	(R 58)	77%
Total	R 1 475	R 1 255	R 220	15%

1 The differences between the ex post and ex ante values were expressed as percentage of the greatest value of either the ex post or ex ante values.

Source: Ex post: *De Jager, 1997*
Ex ante: *Du Plessis, Viljoen, Weepener & Berning, 1998*

The table shows that with regard to the water related works (drainage and spillway), the direct damage was fairly accurately estimated with FLODSIM. In contrast, the ex ante estimates of the transportation network (tramlines, bridges and roads) deviated considerably from the actual cost of repairs during 1996. A probable explanation for this deviation is that the direct damage on which the loss functions were based are not representative of the general pattern of direct damage for different flood peaks. In order to improve the accuracy of loss functions for infrastructure, the direct flood damage of the February 1996 flood in the Mfolozi floodplain should be included in the data set on which the loss functions were based. The loss functions were based on repair costs that were incurred as a result of the flood, i.e. the direct damage, while maintenance cost and the cost of upgrading the infrastructure were excluded from the calculations.

It follows from the foregoing that the integration of the ex post and ex ante approaches to flood damage estimation entailed that flood damage as a result of the February 1996 floods in the Mfolozi floodplain could be used to validate FLODSIM. The integration of the two approaches serves to overcome some of the shortcomings of focusing on either approach separately. When applied simultaneously in flood damage assessment, information and models will be available for forecasting purposes and they can be supplemented by inductive procedures to obtain more accurate estimates of the flood damage.

CONCLUDING REMARKS

Flood damage management aids developed by the Department of Agricultural Economics at the University of the Free State are particularly relevant to increase the practicability of the new policy on disaster management with regard to floods. It was inter alia shown how these decision support tools can be used continuously, thus pro-actively, reactively as well as in the post flood phase. It also follows readily from the presentation that effective cooperation/partnerships between all relevant role players and institutions in the government and private sector are paramount for sustainable and effective flood disaster management. The establishment of a National Disaster Management Centre as is proposed in the White Paper is considered absolutely essential, but for this Centre to fulfill its role and functions properly, specialized information and expertise which can be provided by non-government institutions as is demonstrated by the flood damage research team of the University of the Free State, is very important.

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