

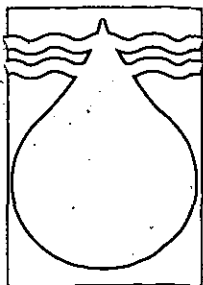


# **FLOOD DAMAGE FUNCTIONS, MODELS AND A COMPUTER PROGRAM FOR IRRIGATION AND URBAN AREAS IN SOUTH AFRICA**

**VOLUME 1**

**LA du Plessis • MF Viljoen • HL Weepener • C Berning**

**WRC Report No 690/1/99**



Water  
Research  
Commission



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**VOLUME 1**

**IRRIGATION AREAS**

by

**LA du Plessis**

**MF Viljoen**

**HL Weepener**

**C Berning**

Report to the Water Research Commission

by the

Department of Agricultural Economics

University of the Orange Free State

Project Leader: Prof M F Viljoen

**WRC Report No: 690/1/99**

**ISBN No: 1 86845 575 0**

**ISBN Set No: 1 86845 577 7**

## ACKNOWLEDGEMENT

The research, on which this report is based, was financed by the Water Research Commission and done by the Department of Agricultural Economics of the University of the Orange Free State.

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A word of thanks to the Water Research Commission for financing the project and members of the Steering Committee for their help and assistance. The following institutions and persons deserve a special word of thanks for substantial inputs to the project.

- ☛ The Department of Water Affairs and Forestry for providing infrastructure, personnel to assist with the irrigation part of the research. Personnel who made substantial contributions are Mr. Chris Swiegers for advice and the provision of the Sun work station; Messrs. Nic Myburg, Gerrit Stemmet and Ms Rongqui Cai from the sub-directorate Hydraulic Studies; Mr. Chris Schutte, Ms. Jeanne de Klerk and ms. Trix Mocke of the Directorate Geomatics and also Messrs. Ivan Tchoukanski, Johan Duvenhage and Adolph Strydom for programming and/or computer assistance.
- ☛ Bosch and Associates for supplying hydrological and topographical data for the Umfolozi River.
- ☛ Mr. Mark Thomas of Environtek (CSIR) for undertaking the Video Remote Sensing survey at Upington.
- ☛ Messrs. Theuns Nel and Gerrit de Jager of the Umfolozi Sugar Co-operative for assistance with questionnaire surveys and information on the Umfolozi floodplain.
- ☛ Prof. Hans Messerschmidt, Department Computer Information, University of the University of the Orange Free State, for advice during the development process of FLODSIM.
- ☛ The Municipalities of Uitenhage and Despatch for supplying maps, information and rendering assistance with surveys in Uitenhage and Despatch, especially Messrs. Anton Snyders and Anton van Heerden of Uitenhage and Mr. Steenkamp of Despatch.
- ☛ The Mzingisi Development Trust for orientation in the Soweto-on-Sea area and assistance with the questionnaire survey.
- ☛ Matt Braune of Steffen, Robbertson and Kirsten for hydrological and flood line information on the Swartkops and Chatty River areas.
- ☛ All members of the research team and persons who helped with the translation, typing and preparation of this report.

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## LIST OF ABBREVIATIONS

CAP:	COMMON AGRICULTURAL POLICY
CFP:	CHANNEL FLOW PROFILE
CSIR:	SCIENTIFIC AND INDUSTRIAL RESEARCH BOARD
DEM:	DIGITALE ELEVASIE MODEL
DPI:	DOTS PER INCH
DTM:	DIGITAL TERRAIN MODELS
ELDO:	EUROPEAN LAUNCHER DEVELOPMENT ORGANISATION
EMR:	ELECTRO MAGNETIC RADIATION
ESA:	EUROPEAN SPACE AGENCY
ESRO:	EUROPEAN SPACE RESEARCH ORGANISATION
FCC:	FALSE COLOUR COMPOSITES
FF:	FLOOD FORECAST MODULE
FFWRS:	FLOOD FORECAST, WARNING AND RESPONSE SYSTEMS
FLODSIM:	FLOOD DAMAGE SIMULATION MODEL
FMC:	FLOOD MANAGEMENT CONSULTANTS
FPMC:	FLOODPLAIN MANAGEMENT COMMITTEE
FPMP:	FLOODPLAIN MANAGEMENT PLAN
GD:	GEOMETRIC DATA
GIS:	GEOGRAFIC INFORMATION SYSTEM
GPS:	GLOBAL POSITIONING SYSTEM
HA:	HECTARE
HD:	HYDRO DYNAMIC MODULE
HRI:	HYDROLOGICAL RESEARCH INSTITTUTE
HRV:	HIGH RESOLUTION VISIBLE
JPEG:	JOINT PHOTOGRAPHIC EXPERT GROUP
KUMEC:	KUBIC METRE PER SECOND
LOGIC:	LONG TERM GROUP OPERATIONAL INTELLIGENCE CENTRE
MAD:	MEAN ANNUAL DAMAGE
MARS:	MONITORING AGRICULTURE USING REMOTE SENSING
MSS:	MULTI-SPECTORAL SCANNERS
NDMC:	NATIONAL DISASTER MANAGEMENT COMMITTEE
NIR:	NEAR INFRARED
RMF:	REGIONAL MAXIMUM FLOOD
RSS:	REMOTE SENSING SECTION
SAC:	SATELLITE APPLICATION CENTRE
SANDEF:	SOUTH AFRICAN NATIONAL DEFENCE FORCE
SAPS:	SOUTH AFRICAN POLICE SERVICES
SAR:	SYNTHETIC APERTURE RADAR
SPOT:	SYSTEME PROBATOIRE D'OBSERVATION DE LA TERRE
SV:	STAKE VALUE
TB:	TOTAL BENEFIT
TC:	TOTAL COST
TD:	DISPERSIEVERVOERMODULE
TEWA:	COMPUTER MODEL FOR TANGIBLE ECONOMICAL FLOOD WATER DAMAGE ASSESMENT
TIN:	TRIANGULATED IRREGULAR NETWORK
TM:	THEMATIC MAPPER
UK:	UNITED KINGDOM
UOFS:	UNIVERSITY OF THE ORANGE FREE STATE
VRS:	VIDEO REMOTE SENSING
WCED:	WORLD COMMISSION ON ENVIRONMENT AND DEVELOPMENT
WQ:	WATER QUALITY MODULE
WRC:	WATER RESEARCH COMMISSION

## **EXECUTIVE SUMMARY**

# **FLOOD DAMAGE FUNCTIONS, MODELS AND COMPUTER PROGRAMS FOR IRRIGATION AND URBAN AREAS IN SOUTH AFRICA**

### **INTRODUCTION**

A new policy on disaster management is currently being developed for South Africa. The Green Paper was published in the beginning of 1998 and the White Paper is due towards the end of 1998. Management of floods is an integral part of this policy and a revised national flood management policy is currently being devised.

The flood management aids (computer programs and loss functions) that were developed during this project will be of great value for making the flood management policy effective. At this stage of development the flood management aids can generally be applied in different floodplains. These aids are necessary tools for effective flood and floodplain management as prior to floods actually occurring, it is possible to determine the extent of the damage for various sized floods and to evaluate the benefits of different flood damage control measures. Benefiting from the use of these aids will be national, provincial and local authorities and institutions that have an interest or responsibility in effective flood and floodplain management.

It must however be emphasized that the flood management aids that have been developed can only be used optimally and efficiently when applied within a holistic and sustainable integrated catchment management framework. To achieve this, an institutional network is suggested for South Africa.

Institutions that have an interest and which can contribute must be brought together to form a multidisciplinary team to provide the expertise and specialized services needed for national, provincial and local government.

The following summary gives an overview of the research results and application possibilities of the flood management aids that have been developed.

## PROBLEM STATEMENT

The previous research titled "development of flood damage functions and a computer program to determine the benefits of flood control and flood damage control measures" was the first project in South Africa aimed at providing *ex ante* information which would make it possible to determine:

- ☞ flood damage in specific areas for different sized floods, and
- ☞ benefits for different combinations of flood control measures.

This information is needed for optimal floodplain and flood management planning within an integrated catchment management approach, for both irrigation and urban areas. Information was developed for the Vereeniging and Uppington areas that made the determined functional relationships, models and programs site specific. In order to make it more widely applicable, it was necessary to adapt and expand the information. This involved *inter alia*:

- ☞ development of flood damage functions for other land use types, and
- ☞ adaptation of flood damage models and computer programs to make it generally applicable in flood prone areas.

## RESEARCH AIMS

The overall aim stated in the project proposal was the development and adaptation of flood damage functions, models and computer programs for irrigation and urban areas in South Africa.

Specific aims were formulated as follows:

1. Development of flood damage functions for a few alternative land use types in floodplains in irrigation and urban areas of South Africa.
2. Further development of flood damage models and computer programs to be more generally applicable in irrigation and urban areas. Besides the utilization of new technology like remote sensing, the models should also be adapted to be applicable at three levels of decision making namely local, provincial and national and also be in accordance with the revised national flood management policy. Development of guidelines to make the policy executable at three government levels should also receive attention.
3. Verifying and validating the models and computer programs in selected areas.
4. Presentation of workshops and seminars to demonstrate the use of flood damage functions, models and computer programs and to promote technology transfer.
5. Development of a theoretical framework for a sustainable flood management system to evaluate FLODSIM and the revised flood management policy of the RSA.

## **STUDY AREA**

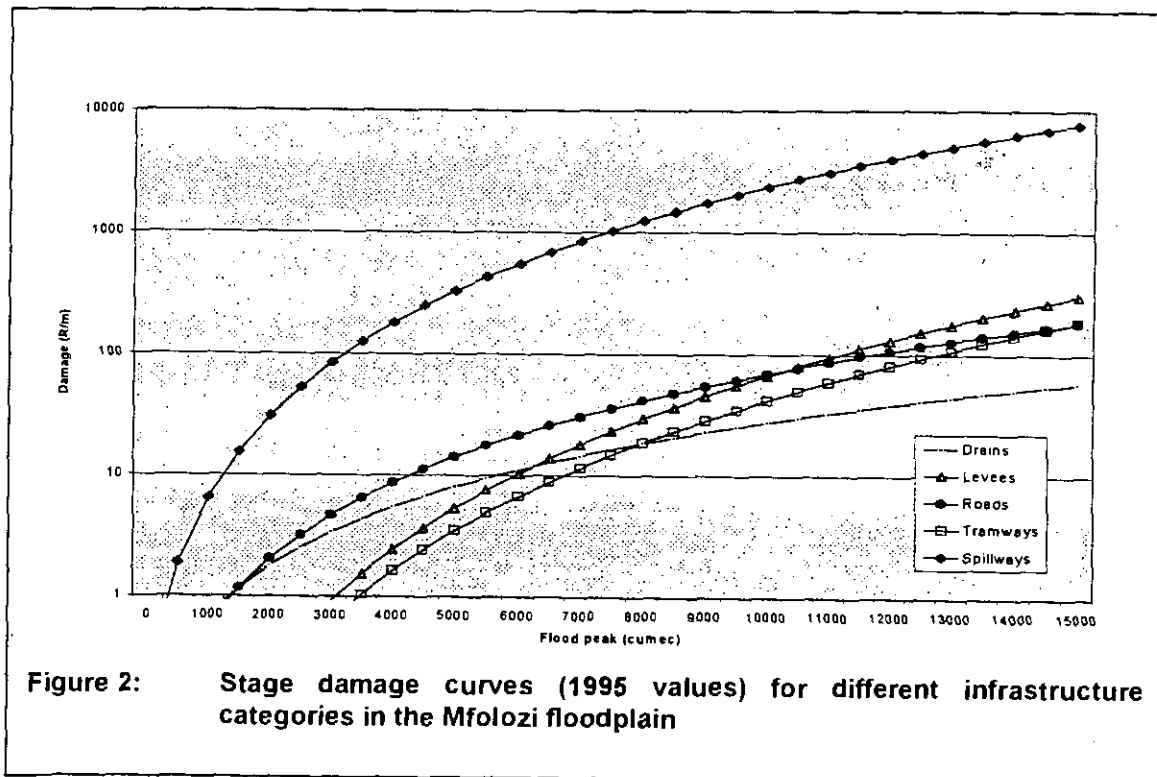
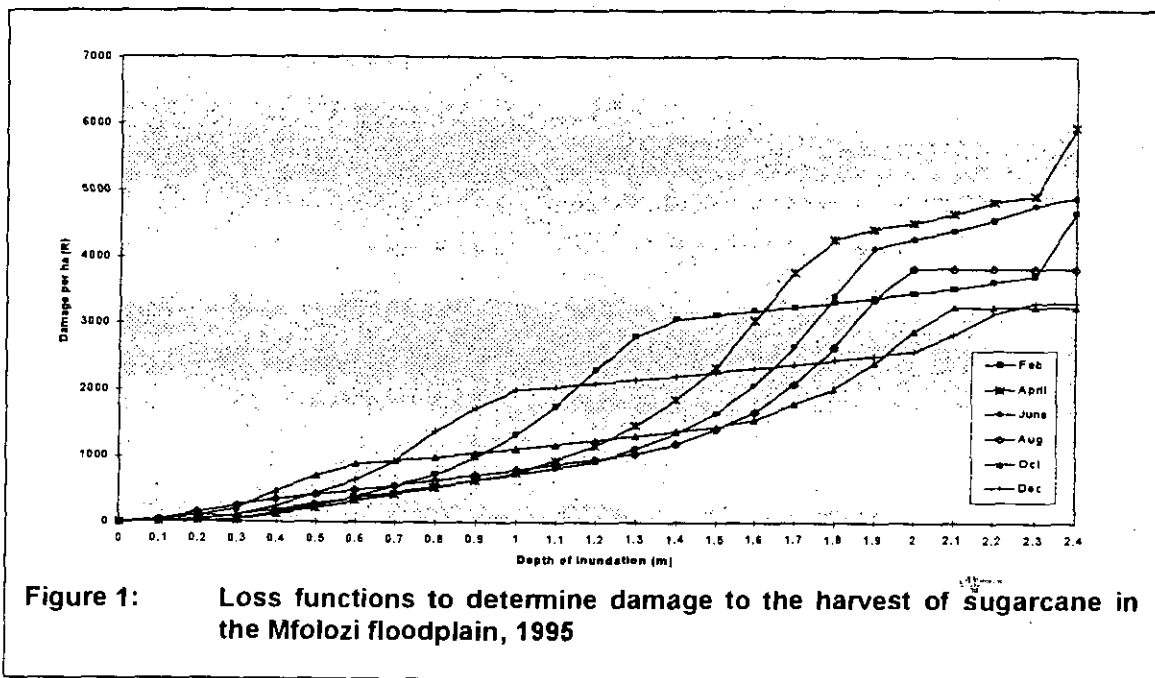
The floodplain between the Mfolozi and Msunduzi Rivers in KwaZulu Natal was selected for development, adaptation and refinement of the irrigation information-base. For the urban research, the floodplains of Uitenhage and Despatch along the Swartkops River were chosen for research on the formal sector and the Soweto-on-Sea area in the floodplain of the Chatty River for the informal sector.

## **RESULTS**

### **RESULTS OF THE IRRIGATION COMPONENT**

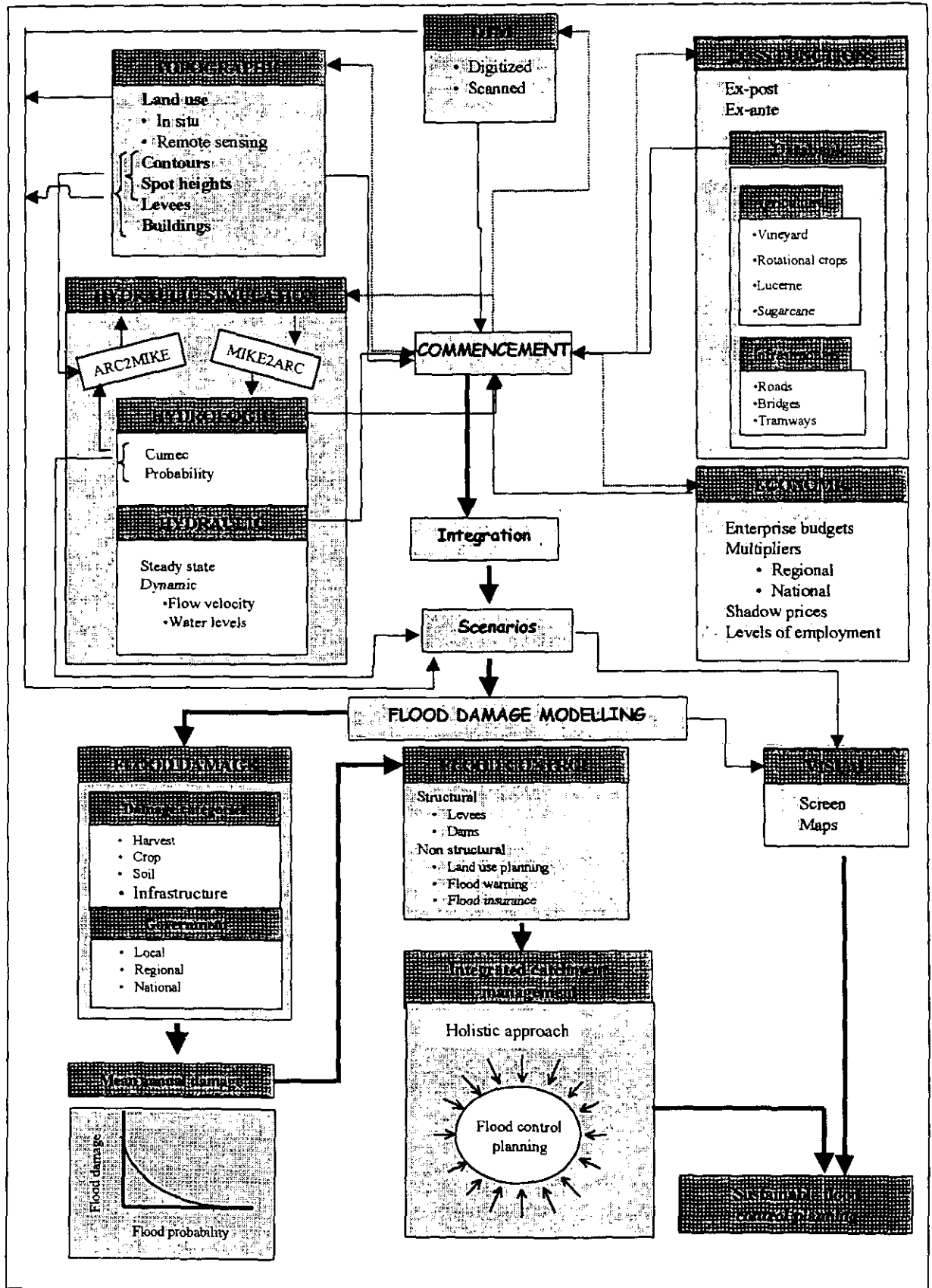
Addressing the first specific aim, it was possible to develop loss functions for two new land use types in the Mfolozi floodplain, namely sugarcane and physical infrastructure, see Figures 1 and 2. In Figure 1 the loss functions (stage damage curves) for sugarcane show that flood damage differs for different depths of inundation and for different months of the year. The stage damage functions for

infrastructure (Figure 2) relate the damage to flood peaks and show that damage to the spillway is by far the largest.



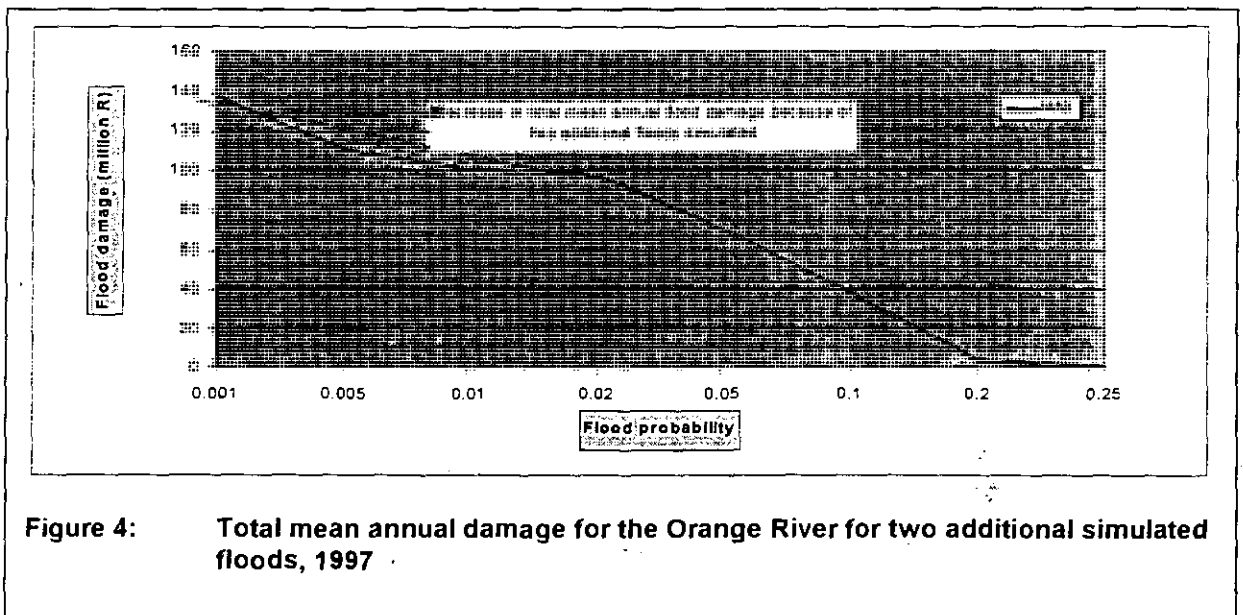
Besides depth of inundation, the duration of flooding plays a very important role in determining damage to sugarcane and was explicitly taken into account.

Regarding the second aim, a lot of effort went into the further development of FLODSIM. See Figure 3 for a diagrammatic outlay.

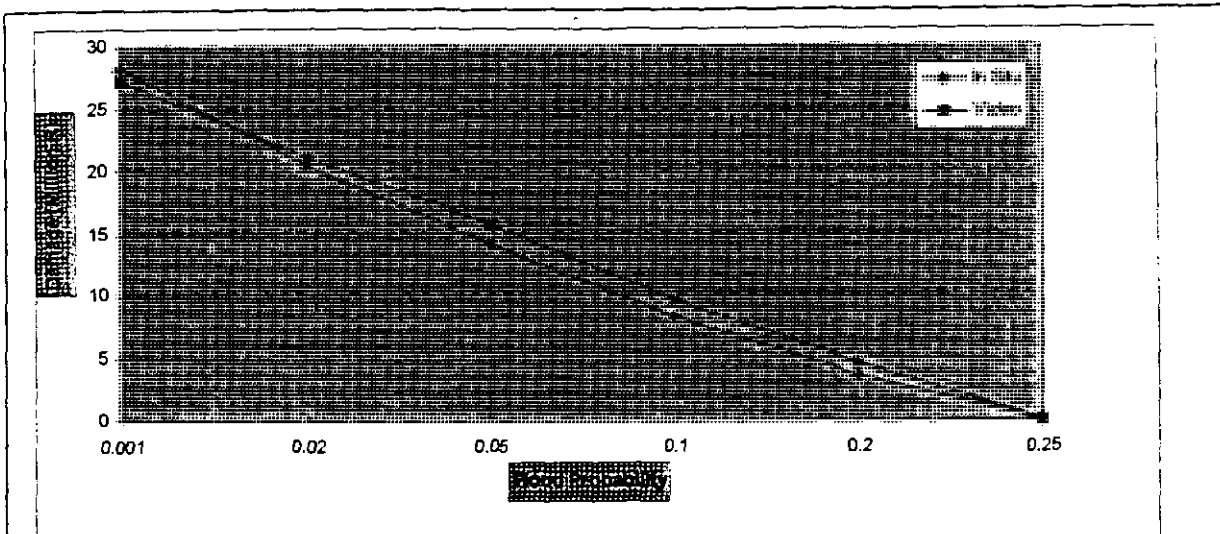


Aspects that received attention, are:

- Dynamic hydraulic simulation can now be handled with the model. This was achieved by establishing interfaces between FLODSIM and MIKE 11 which now makes it possible to handle complicated river morphological and hydraulic characteristics. Figure 4 is a graph of results obtained by applying FLODSIM (incorporating dynamic hydraulic simulation) in a levee manipulation exercise. The impact of the levee is to lower the damage for the less frequent floods as is shown by the shaded area on the curve

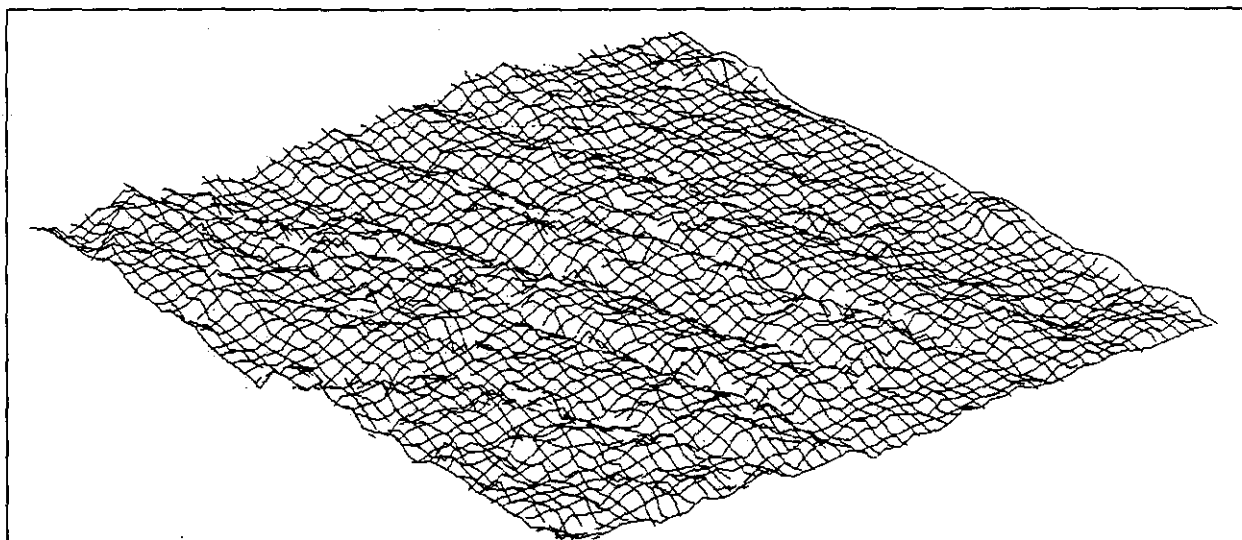


- Identifying land use types *in situ* doing local inspections from a motor vehicle can be very time consuming. Various remote sensing techniques were therefore researched. Video remote sensing (VRS) (using an aircraft) was tested in the Orange River floodplain to evaluate its suitability for identifying land use types. It is concluded from this research that applied under the necessary provisions, VRS can be used (especially on a national level) to determine flood damages for policy recommendations. Figure 5 compares the results of VRS with that obtained by a complete local survey.

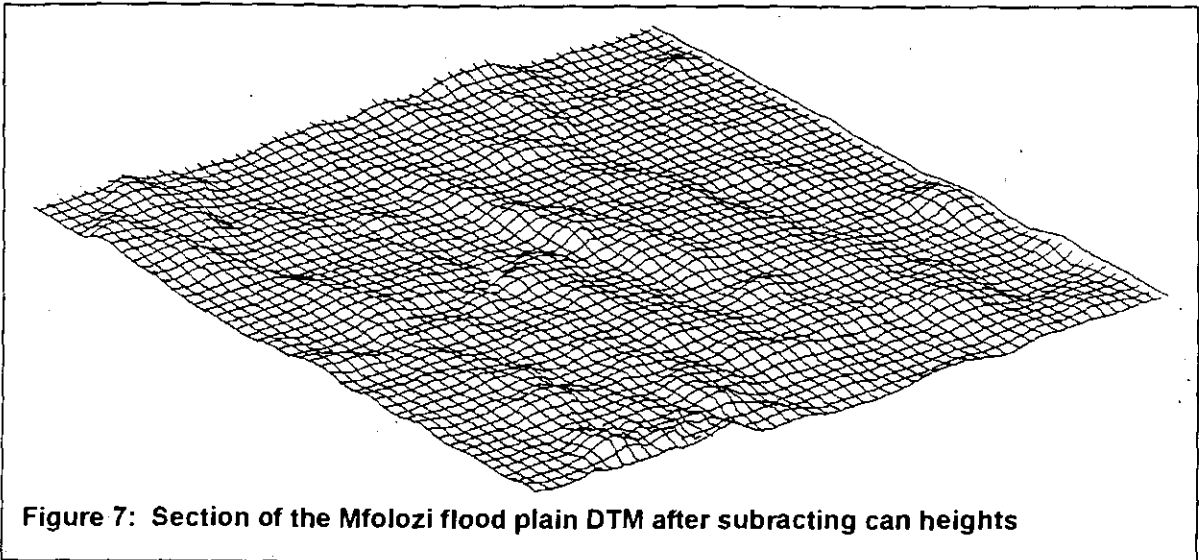


**Figure 5:** Calculation of soil damage based on an *in situ* survey and a video survey for floods with different probabilities of occurrence

☛ Digital terrain models (DTM's) were created by applying different methodologies. Various methodologies were tested in the Upington area and then applied in the Mfolozi floodplain. The height of sugarcane in the Mfolozi necessitates further adaptation in the methodology. Figures 6 and 7 for instance show the differences in DTM's including (Figure 6) and excluding (Figure 7) the heights of sugarcane.



**Figure 6:** Section of the Mfolozi floodplain DTM before subtracting cane heights



- ☛ Where flood control planning previously stopped with the determination of the optimal package of structural and non-structural measures for a floodplain, and therefore led to an escalation of potential flood damage over time, it is now shown how FLODSIM can be used within an integrated sustainable catchment area management system to overcome the above-mentioned problem.

With regards to the third aim, verifying the model received attention throughout the research process by continuously checking for programming and logic errors revealed in the results. Validating the results received attention in an exercise where the predicted flood damage figures from the model were compared with results of ex post flood damage surveys previously done for actual floods in the Mfolozi River. This aspect will *inter alia* be reported on in a master's degree dissertation by Berning of the University of the Free State that is to be completed during by the end of 1998.

The fourth aim received limited attention only during this phase of the project. Researchers exhibited the research project and preliminary results during the 1996 Water Week Exhibition of the Department of Water Affairs and Forestry in Pretoria. They also participated in a workshop on Disaster Management which was organised by the Disaster Management Committee of the Free State in Kroonstad during 1997. Papers on research findings were presented at this

workshop. This aim will however receive due attention during the next phase of the research project, namely.

The more traditional approach to floodplain management is to develop a decision making management model in order to determine the advantages of various structural and non-structural control measures. The main disadvantage of this approach is the escalation of flood damage over time. In order to find permanent solutions for the escalation of flood damages, the flood damage simulation model (FLODSIM) is extended in order to accommodate the formulation of sustainable flood management plans. (See Chapter 7 for a diagrammatic representation of FLODSIM.) In a sense, this gives rise to a new approach to floodplain management which will now be dealt with.

In order to comply with the idea of sustainable, integrated long term planning as well as the compilation of development plans (Adams, 1995; Ghosh, 1991) a holistic approach to integrated catchment management is proposed for South Africa. Various activities are associated with sustainable integrated long-term floodplain planning, as depicted graphically in Figure 8. These activities should be investigated individually by provincial and local authorities, and the results should be integrated in order to attain a sustainable, integrated flood management plan. To put this into effect, a multidisciplinary approach will have to be followed. In terms of this approach it would be unreasonable to expect provincial and local governments to permanently employ expertise and specialist services. Consequently, an institutional network approach is proposed for South Africa whereby specialised services could be provided to provincial and local authorities. This approach will ensure that the desired institutions be implemented for South Africa on the one hand and that hazard losses in the floodplains be reduced on the other.

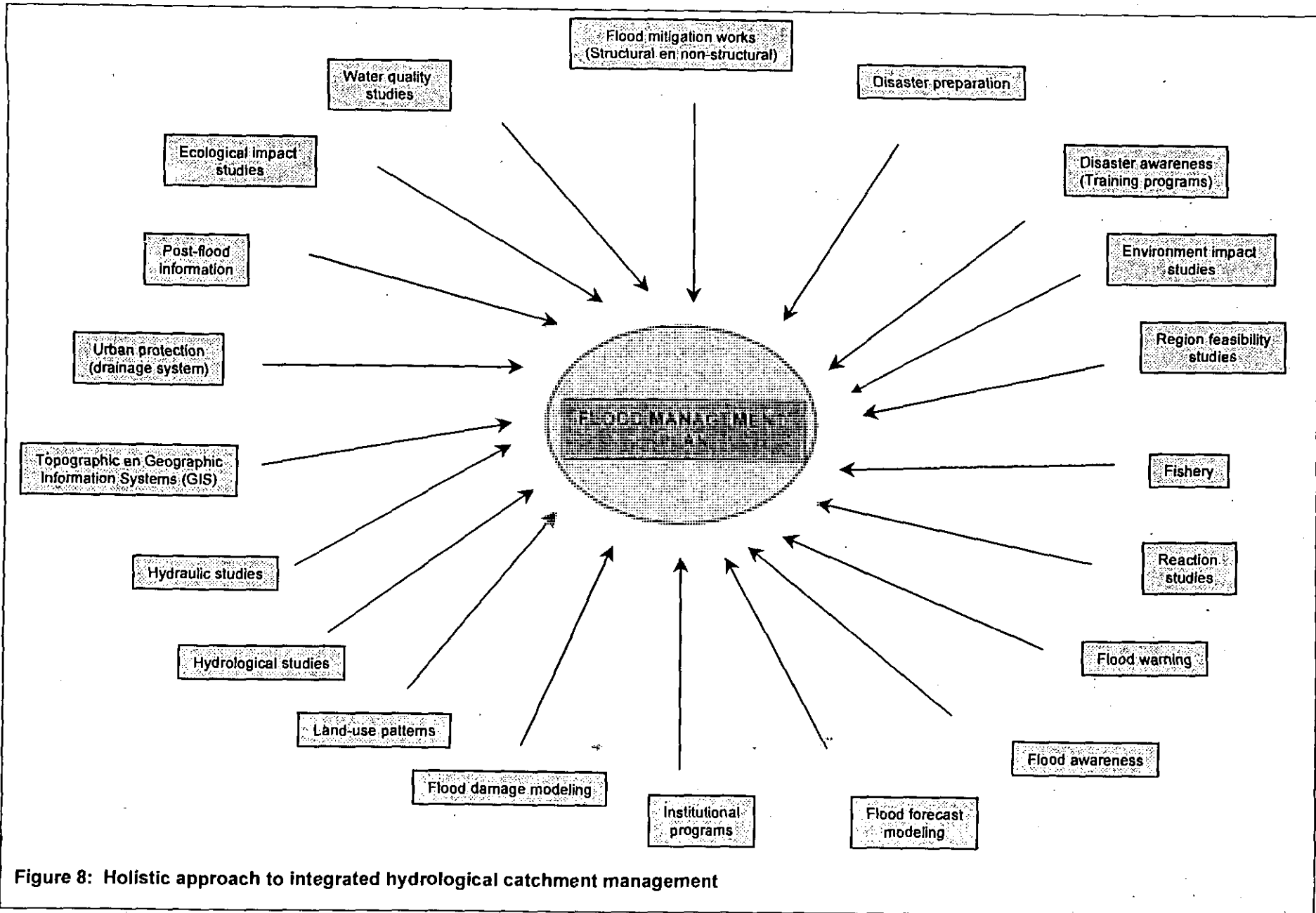


Figure 8: Holistic approach to integrated hydrological catchment management

## RESULTS OF THE URBAN COMPONENT

Concerning the first specific aim, it was possible to determine new loss (flood damage) functions for the residential and commercial sectors of Despatch, the residential and industrial sectors of Uitenhage and the informal residential sector of Soweto-on-Sea in the Chatty River. Besides these site-specific functions standardized loss functions could be developed for the formal residential and commercial sectors. These functions will be generally applicable for floodplains in South Africa. Tables 1 and 2 are examples of loss functions. Where the flood damage function of Table 1 is site specific, the standard function in Table 2 can be generally applied.

**Table 1: Content flood damage functions (1996) as developed for informal housing in the Soweto-on-Sea floodplain**

Category	Depth of inundation (m)											
	0	0.05	0.1	0.2	0.3	0.6	0.9	1.2	1.5	1.8	2.1	2.4
Class 1*	11	65	118	220	316	568	768	915	1009	1051	1051	1051
Class 1**	32	226	414	773	1109	1981	2648	3109	3366	3417	3417	3417
Class 2*	146	323	494	822	1129	1931	2552	2991	3249	3327	3327	3326
Class 2**	72	465	847	1575	2256	4017	5355	6269	6759	6827	6827	6826

\* values as provided by respondents in Rand

\*\* replacement value in Rand.

Class 1 represents houses with one room only and Class 2 represents houses with more than one rooms.

**Table 2: Standard housing content flood damage functions for general application (single-storey)**

	Damage in Rand (1996) for depth of inundation (m)									
	0	0.05	0.1	0.3	0.6	0.9	1.5	1.8	2.1	2.4
<b>Group 1</b>	10 093	13 562	16 939	29 549	45 764	58 739	74 967	78 221	78 234	75 007
<b>Group 2</b>	4 783	8 212	11 554	24 050	40 179	53 169	69 734	73 309	73 746	71 044
<b>Group 3</b>	1 570	3 560	5 498	12 739	22 058	29 526	38 910	40 826	40 892	39 107
<b>Group 4</b>	187	1 775	3 324	9 150	16 768	23 041	31 554	33 793	34 688	34 238
<b>Group 5</b>	281	1 392	2 473	6 503	11 659	15 747	20 721	21 607	21 426	20 178

The different groups in Table 2 are explained in Table 3.

**Table 3: Categories of home units according to which standard flood damage functions are grouped**

Categories	Description
<b>Group 1</b>	Big luxurious houses
<b>Group 2</b>	Big - high economic class - houses
<b>Group 3</b>	Medium - high economic class - houses
<b>Group 4</b>	Medium/Big - medium economic class -houses
<b>Group 5</b>	Small/medium - medium economic class - houses

Regarding the second aim, a flood damage assessment model (TEWA) was developed for South Africa. TEWA utilizes the logic of ANUFLOOD (an Australian based model) and is an interactive GIS PC-model that is able to produce maps on request and which can evaluate the benefits of different flood management options. Besides these characteristics, data can be imported from aerial photos and maps with a scanner. Figure 9 is a flow diagram that shows the input and output of TEWA. To use TEWA, hydrological data, flood damage functions, land use and geographical data are needed. The output of TEWA are the flood damage potential of the study area, maps of the areas under-risk and the benefits of flood damage mitigation options. There are deliverables in each stage; the input data can be used for flood maps, a land use data base and a economical data base, while the output can be used for the development of flood plain management plans and/or emergency plans.

The verification of TEWA (aim 3) took place throughout the project process by comparing the logic with that of ANUFLOOD and testing the results with mathematical calculations. Unfortunately no results of actual flood damage studies are available to compare to the flood damage predictions of TEWA.

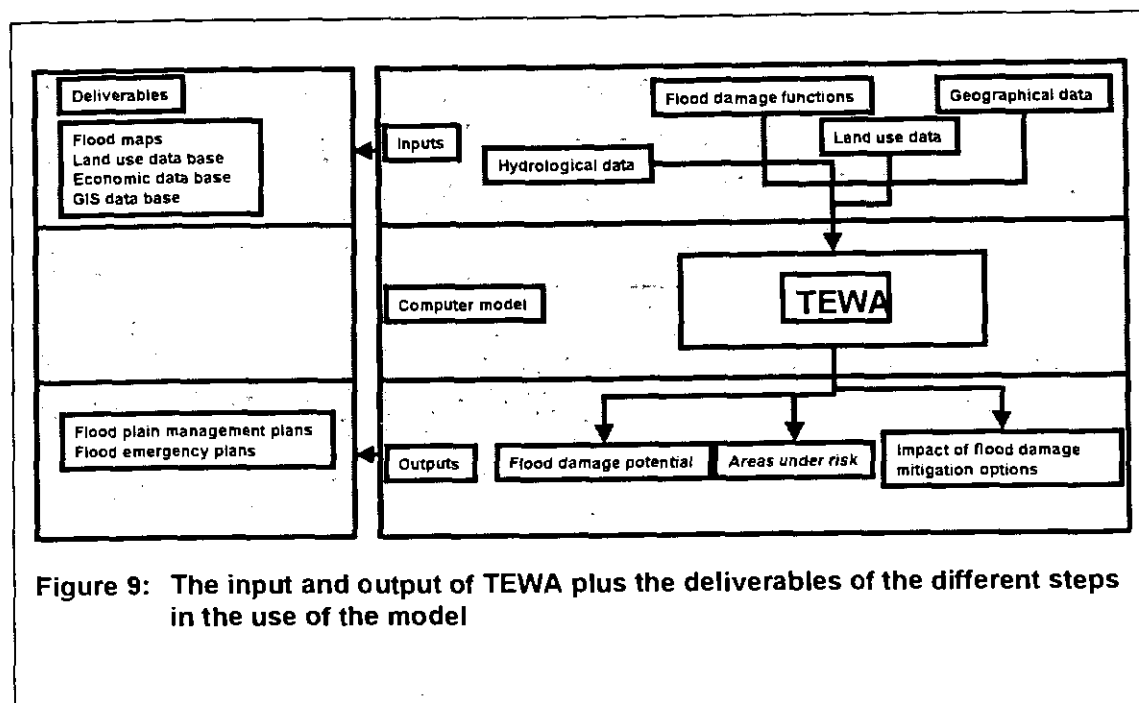


Figure 9: The input and output of TEWA plus the deliverables of the different steps in the use of the model

Concerning the fourth aim, the same can be remarked as for the results of the irrigation research.

## ACHIEVEMENT OF THE RESEARCH AIMS

When the results obtained are compared with the stipulated research aims, it becomes evident that besides the fourth aim all others have been achieved to a satisfactory level. During the course of the research it was mentioned at Steering Committee meetings that the fourth aim will not be achieved during this phase and that a next phase was necessary. It was also pointed out that progress with formulating the revised National Flood Management Policy was slow and that research activities which can only be completed after the policy is formulated and approved, such as providing guidelines for implementation of flood management plans for local authorities, cannot be finalized. With the fourth aim being addressed in a new project, the models (FLODSIM and TEWA) and the loss functions developed during the course of the research have proved potentially very useful but

their true benefits can only be determined once applied within a holistic, integrated and sustainable approach.

## **POTENTIAL USERS OF RESEARCH RESULTS**

Management decision and planning models were created through the research to determine flood damages and the benefits of different flood control and flood damage control measures. The results can be of value to those involved in

- ☞ the planning of land use within floodplains;
- ☞ the development of flood management plans that involve different flood control and flood damage control measures;
- ☞ determining risk and insurance premiums for different land use types, and
- ☞ assessing the nature and extent of the damages caused by different sized floods.

The findings could have value for various institutions and professions i.e. urban and regional planners, architects, engineers, flood management consultants, insurance companies, municipalities, provincial and national government departments and bodies like civil defence, hazard and disaster management committees, the National and Provincial Departments of Agriculture, Department of Water Affairs and Forestry, the Department of Environmental Affairs, the Department of Regional and Land Affairs, the Department of Constitutional Development and the Department of Welfare.

As indicated, many potential users exist therefore necessitating a focussed extension and education effort to transfer the technology (flood management and planning aids) developed during the project. Further development and refinement of the flood management aids (computer models and questionnaires) will be concluded during the subsequent research phase, after which the process of technology transfer will commence.

# CHAPTER 1

## INTRODUCTION

### 1.1 MOTIVATION AND PROBLEM STATEMENT

The Department of Agricultural Economics of the University of the Free State has been busy for a considerable time developing computer models to quantify impact flood damage control measures that can be implemented in floodplains to eliminate or reduce harmful effects of floods. Good progress has been made in South Africa to calculate real (*ex post* - directly after a flood) or to project potential (*ex ante* - before a flood) flood damage. Computer models that have been developed to project potential flood damage in the Orange River irrigation area have till now not been applicable in other flood stricken areas. Besides problems with the application possibilities of the computer models, methods that are being used to gather the needed data are very expensive and comprehensive. An important factor in flood damage simulation models, is the availability of flood damage functions for the different land use found in the flood area. At the moment, flood damage functions for flood sensitive areas are not readily available. This is a consequence of, *inter alia*, limited available data on flood records, as well as problems regarding the determination of damage functions for different crops (Van Zyl and Groenewald, 1984).

Since the beginning of the research in 1992, there were endeavours towards a new national flood management policy for South Africa. Since then, the political scene in the country has changed dramatically. As a result, priorities have changed and the larger part of the national budget is now being allocated to the former disadvantaged communities. Consequently the focus has shifted more toward the establishment of an effective, efficient and affordable disaster management structure, which will eventually enable the formulation of a well-structured national flood management policy for South Africa. For this reason, it is not advisable to draw up policy based guidelines, proposals or recommendations regarding floodplain management for provincial and local authorities at this stage.

In addition to this, due to the establishment and development of regional governments, less allocations from national funds will be available for regional disasters, except if it is classified as a national disaster. This makes it necessary for regions to develop their own funds for disasters, whether for drought-, flood- or fire-disasters. There are considerable shortcomings regarding the determination of real and potential flood damage and floodplain planning. This needs more research.

With such research, management aid will be developed that will help floodplain planners to gain better insight into the river morphology, so that recommendations regarding the economical feasibility of several potential flood control and flood damage control measures could be made. With such a management aid an optimal flood damage reduction package can be developed for flood prone areas, which will assist national, provincial and local authorities to formulate and implement better flood management plans.

## 1.2 OVERALL GOAL

The overall goal of this research is to develop a user-friendly flood damage simulation model (FLODSIM<sup>1</sup>), which can be applied cost-effectively in flood sensitive irrigation-areas in South Africa to determine economic benefits of different combinations of flood and flood damage control measures as part of a sustainable integrated floodplain management system. In this way, more effective flood management plans can be formulated and implemented. Specific objectives and activities will be discussed in Chapter 2.

---

<sup>1</sup> FLODSIM – Flood damage simulation model. The model was developed according to a GIS-approach during the first phase of the research. See Du Plessis (1994) and Du Plessis, Viljoen and Booysen (1995).

### **1.3 RESEARCH AREA**

The floodplain of the Orange River, the Gifkloof weir and to the Manie Conradie Bridge at Kanon Eiland, encompassing between an area of approximately 4 500 ha of irrigation, was chosen to develop the model. Subsequently, this model was refined and during the present phase of the research it was applied in the Mfolozi floodplain (8 000 ha) (Figure 1.1). The Mfolozi floodplain was chosen because there exist well-kept flood records for that area, it is often flooded and because of the river-area's unique morphological characteristics (Chapter 3).

### **1.4 STRUCTURE OF THE REPORT**

The research report consists of eight chapters, besides Chapter 1. The theoretical and methodological framework is discussed in Chapter 2, after which a discussion of the research area is presented in Chapter 3. Remote sensing is discussed in Chapter 4, and hydraulic simulation discussed and illustrated in Chapter 5. Loss functions for both the Orange and the Mfolozi floodplains are reviewed in Chapter 6, while the development and refinement of the flood damage simulation model receives attention in Chapter 7. The total direct flood damage and the secondary effects of the floods for the Mfolozi floodplain are calculated and discussed in Chapter 8. The new flood management policy and several flood management aspects, an approach to integrated floodplain management, flood management systems and sustainable flood management plans, are discussed in Chapter 9.

Important conclusions and recommendations for future research are presented in Chapter 10.

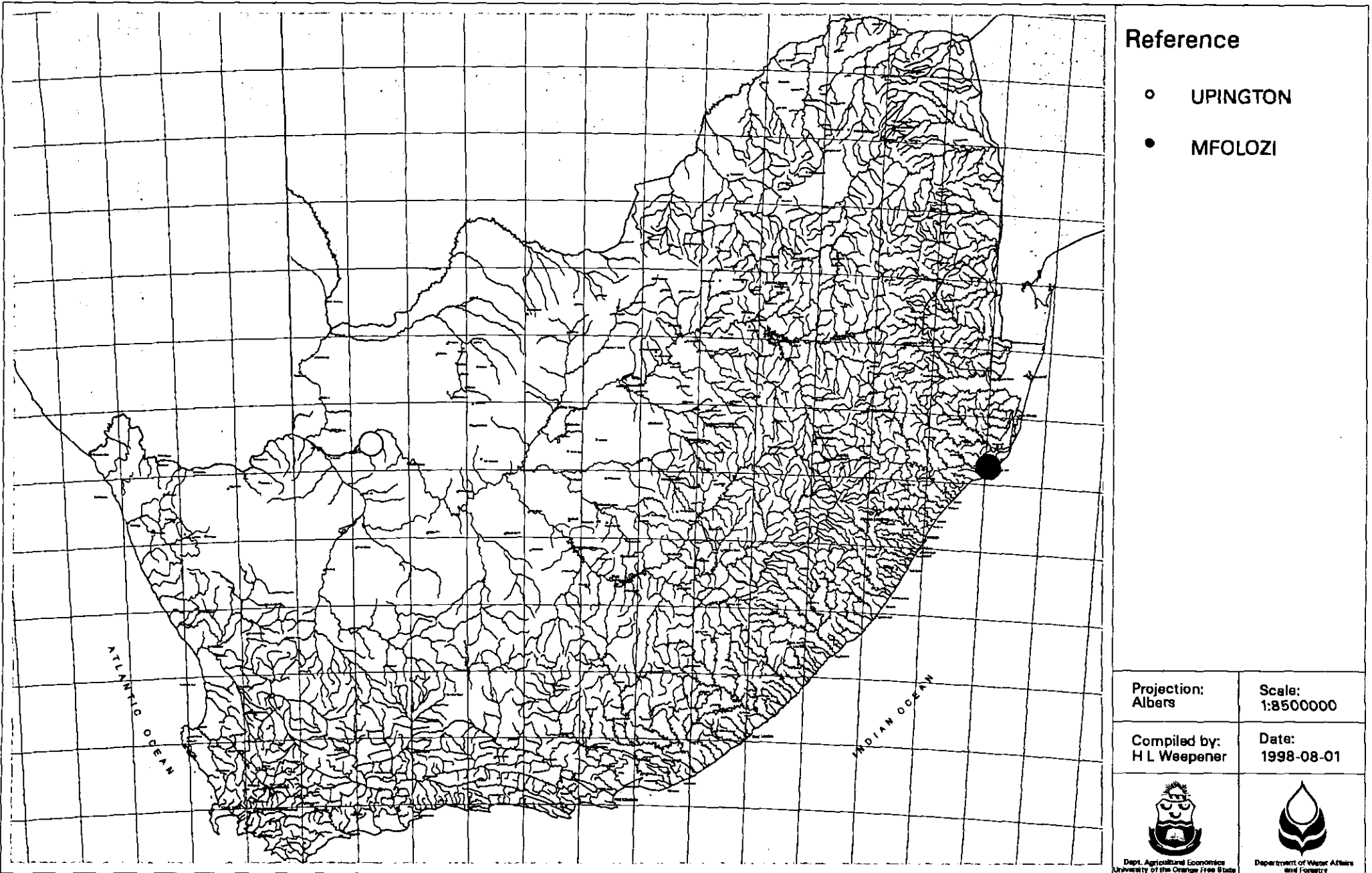


Figure 1.1: Orientation map of the study areas

## CHAPTER 2

### THEORETICAL AND METHODOLOGICAL FRAMEWORK

#### 2.1 CONCEPTS

In the previous phase of this research, concepts such as a flood, floodplain, flood damage, flood damage control measures and flood damage functions were defined (Du Plessis *et al.*, 1995). For purposes of this report it was decided only to define new concepts.

##### 2.1.1 REMOTE SENSING

The collection of primary data can be done *in situ* or with remote sensing (Jensen, 1986). When researchers collect the data personally, whether by the completion of questionnaires or by studying the behaviour of a flood, it is referred to as *in situ*. In contrast to this, sensors, which are used for remote sensing, are not physically in touch with the environment and provide data by means of a high speed communication facility over a remote area.

Short (1982) defines remote sensing as follows: "The acquisition of data and derivative information about objects or materials located at the Earth's surface or in its atmosphere by using sensors mounted on platforms located at a distance from the targets". This definition implies various images, such as photographic radar- and laser-, as well as multi-spectral scanners.

##### 2.1.2 LAND USE

Different disciplines define land use differently. Land use normally refers to land use or land use pattern. A misunderstanding between the concepts land use and land coverage also occurs quite often. Tateishi and Mokouyama (1987), quoted by Lourens (1990), defined the above concepts as follows: "land use is a social

classification indicating man's activity on earth's surface", while land coverage is "a physical classification of the earth's surface". For purposes of this research, the concept land use will be used for both land use and land coverage.

### **2.1.3 FLOOD STUDIES**

A study of floods is a comprehensive technical investigation into flood behaviour. Flood studies present a picture of the character and nature of floods by providing information about flood levels, velocities and proportional flows at specific cross sections in floodplains. There is a distinction between two components of flood studies, namely the determination of flood peak (hydrological data) and the determination of water levels and velocities (hydraulic data).

The term hydrology is used throughout this report to refer to the magnitude of floods in terms of size and corresponding probability to occur in any year. The size of a flood is usually measured in cubic metres per second at a specific point and is presented by a hydrograph. In contrast with hydrological data, the water levels and flow velocities of floods that are measured at specific points in rivers, refer to hydraulic data (New South Wales Government, 1986).

### **2.1.4 FLOODPLAIN MANAGEMENT STUDIES**

Floodplain management studies are usually undertaken after flood studies were completed. During floodplain management studies, several flood management and flood damage management measures are investigated with relevant flood damage simulation models to achieve better floodplain planning (New South Wales Government, 1986).

### **2.1.5 CONSTANT FLOW SIMULATION**

Constant flow simulation is a step-by-step method for the calculation of back water curves, or water surface profiles (Chunnett, Fourie and Partners, 1993). Constant flow simulation is based on one-dimensional analyses to calculate the water surface profile and change in flow depth.

### **2.1.6 DYNAMIC FLOW SIMULATION**

Where more complicated flow in floodplains and the need of more detailed model information (like the indication of dynamic flood zones and even the duration of floods) are needed, dynamic flow simulation data is required. Dynamic hydraulic simulation is still one-dimensional, but it is an excellent technique to simulate flow in more than one channel (e.g. where rivers divide to join again further on). One-dimensional approaches are sometimes not effective to calculate complex topographical conditions and characteristics of a floodplain. As a result of this, two-dimensional flow simulation must be applied (Kawachi *et al.*, 1994; Anderson and Bates, 1994). A one-dimensional simulation was applied.

### **2.1.7 GEOGRAPHICAL INFORMATION SYSTEMS (GIS)**

A geographical information system can be defined as follows: "An organized collection of computer hardware, software, geographic data and personnel designed to efficiently, store, update, manipulate, analyse and display all forms of geographically referenced information" (ESRI, 1994). A geographical information system lends itself to defining a two-dimensional image. With flood research, several aspects need to be defined, like for example the various land use, floodplains, flood lines, water levels, contour lines and levees. With various GIS-techniques, this information can be integrated with each other in order to get quick and accurate answers to specific questions.

### **2.1.8 DIGITAL TERRAIN MODEL (DTM)**

Digital terrain models are usually used with GIS-analyses and play a major role in GIS-processing (Weibel and Heller, 1991). A DTM is a three-dimensional description (x-, y- and z-values occur) of the earth surface that is presented in a specific projection (orientation). DTM's form the base upon which flood damage modelling take place, since the water levels of floods with different probabilities of occurrence are subtracted from the ground surface to determine the average depth of inundation.

Weibel and Heller describe a DTM as follows: "It may be understood as a digital representation of a portion of the earth's surface". Some researchers make a distinction between a DTM and a DEM (digital elevation model). DEM's contain only altitude data that indicate height above sea-level, while DTM's also make provision for other topographical data, like rivers and flood embankments. To calculate flood damage the DTM-definition is used in this report, except where indicated otherwise.

#### **2.1.9 FLOOD STANDARD**

The flood standard, also known as the designated flood, determines the area that should not be made available for development. The determination of a flood standard comprises *inter alia* the balancing of social, economical and ecological aspects without raising the potential damage and risks of property, lives and structures (New South Wales Government, 1986).

#### **2.1.10 FLOOD MANAGEMENT PLAN**

A suitable national flood management policy can be facilitated and co-ordinated best by formulating and implementing flood management plans. Flood studies are also undertaken to determine the extent and intensity of floods for the establishment of several management options. With such information, a catchment-specific management plan can be developed. Flood management plans must make provision for all actions before, during and after floods (New South Wales Government, 1986).

#### **2.1.11 FLOOD DAMAGE SIMULATION MODEL (FLODSIM)**

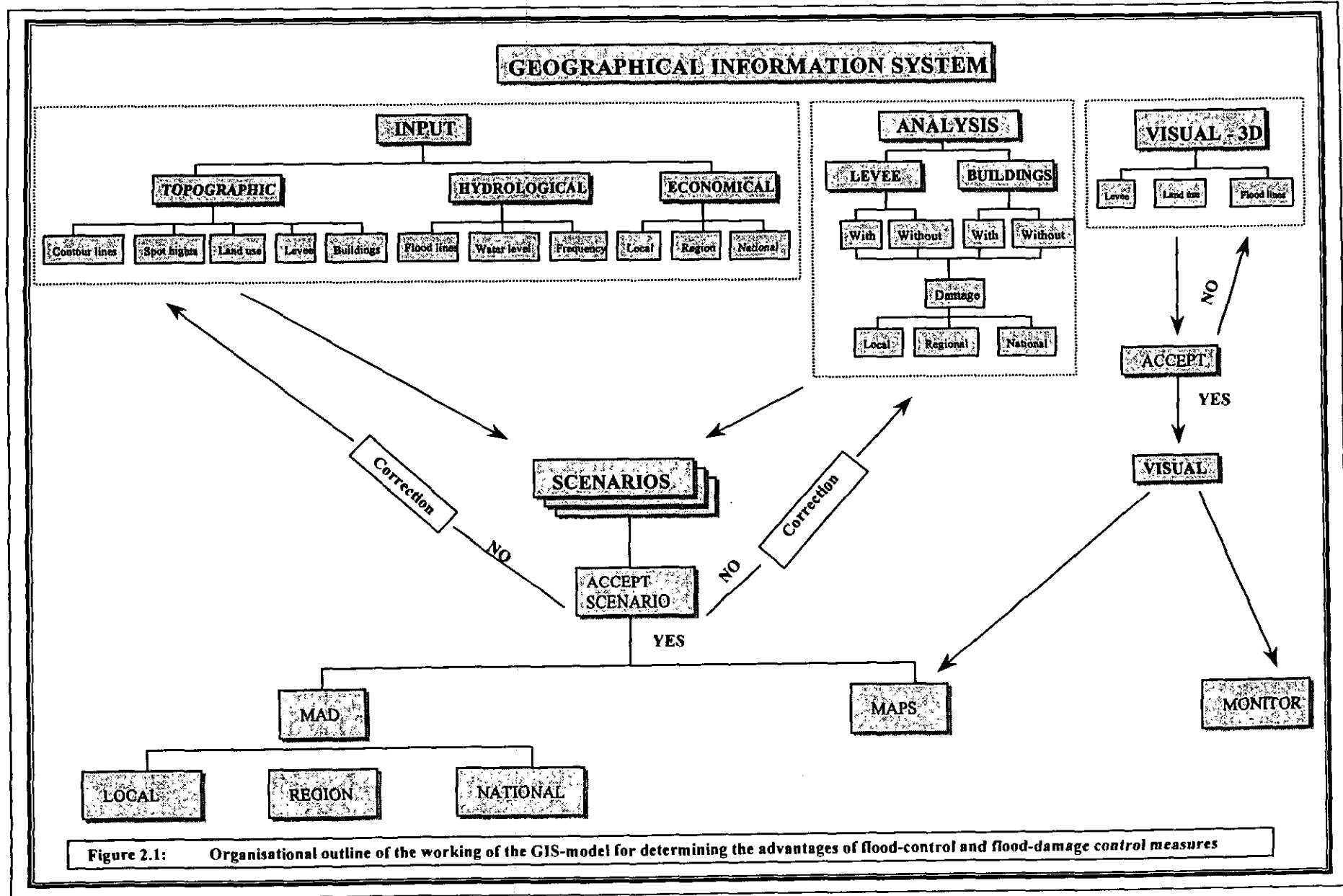
The flood damage simulation model, also known as FLODSIM (flood damage simulation model), was developed as a geographical information system (GIS) because it relies to a large extent on spatial and spatially related data. This renders flexibility, because data can be manipulated in several ways and with the integration of above-mentioned data, alternative floodplain management options can be investigated. This approach is currently generally being used in floodplain management projects.

## 2.2 METHODOLOGICAL FRAMEWORK

A complete theoretical framework was developed during the previous phase of this research. Du Plessis (1994), Du Plessis *et al.* (1995) and Viljoen (1979) can be consulted in this regard. For the aims of this report, it was decided to present only the methodological framework for this phase of the research. Shortcomings of the already developed framework are subsequently being identified, after which a procedure will be presented to address these shortcomings.

Figure 2.1 shows the methodological framework of the flood damage simulation model (FLODSIM). The framework consists mainly of inputs, analyses and outputs, consisting of a visual and a calculation section. Topographical, hydrological and hydraulic and economic data fall under inputs, while several scenarios can be constructed and analysed under the analysis option. With all the input data, specific scenarios can be developed and analysed. After such scenarios have been developed, several outputs can be obtained in the form of tables and graphs by executing analyses from a local, regional and national viewpoint.

The user can draw up several scenarios by manipulating the databases under inputs. In this way the benefits of several flood control and flood damage control measures that are investigated, can be determined. Besides the mentioned inputs and calculations, visual images can also be developed as part of outputs, which can be presented in maps or on the screen. With these images, the specific region in the research area can be studied three-dimensionally. A better understanding of the flood problem can thus be obtained.



## 2.3 SHORTCOMINGS

A specific methodology was used to gather and store data. Topographical data (1m contour lines, elevations, boundaries of land use, levees and buildings) was digitised from 1:5 000 topographical maps, while the hydrological and hydraulic data were supplied by a consultant (Chunnett, Fourie and Partners, 1993). Besides digitising of boundaries of agricultural fields, a land use pattern survey was done by the Department of Water Affairs for the Uppington research area to determine the land use pattern. This lasted approximately six months. Data on levees were supplied by the regional engineer of the Department of Agriculture. All the economic data were gathered by the research team themselves. This procedure had some shortcomings:

- ☞ A multi-disciplinary approach was applied with the development of FLODSIM and several fields of expertise, eg. economic, GIS, hydrological and hydraulic, were required. This resulted in a non-user friendly product.
- ☞ Methods that were used to compile the databases (Figure 2.1) are expensive and time-consuming, although very accurate. There is a need for a more cost-effective methodology. The accuracy of the method is explained in terms of deviation in the total average annual flood damage.
- ☞ FLODSIM is area specific and can not be implemented in other flood risk areas. One of the largest shortcomings is the availability of applicable loss functions. A complete set of loss functions should be developed for the floodplains of South Africa.
- ☞ Available and applicable support and decision-making aids for the implementation of effective floodplain planning on several governmental levels, does not exist at present in South Africa. To fill this need, a suitable decision making aid (FLODSIM) was developed. Application possibilities should also be pointed out.

## 2.4 RESEARCH PROCEDURE

It was decided to make FLODSIM user-friendlier. Then the flood damage simulation model could be applied in other flood prone areas in South Africa. To do this, the following goals, objectives and activities were identified:

### 2.4.1 GOAL NO 1: TO DEVELOP AN APPLICABLE, USER-FRIENDLY FLOOD DAMAGE SIMULATION MODEL

To ensure that the correct decisions are made during floodplain management, a certain level of expertise should be involved at the implementation of flood damage simulations. It is therefore not deemed necessary to develop flood damage simulation models so user friendly that the average lay person will be able to apply them. User-friendliness also implies that FLODSIM should be cost-effectively applicable in flood prone areas. The following two objectives were identified:

#### ***Objective 1: To develop an applicable methodology to draw up databases in a cost-effective way***

During the first phase of the research land use was determined by means of a local survey (Du Plessis *et al.*, 1995). Local surveys, although very accurate, is time consuming and expensive. Consequently, alternative methods were investigated. More specifically, the following activity was investigated:

#### **Activity 1: Identification of land use in irrigation areas with the aid of remote sensing**

With the development of more advanced computer technology, remote sensing, geographical information systems (GIS) and global positioning systems (GPS) have become the ways to gather and compile data and also the management and decision-making mechanisms for many disciplines. Projects undertaken by several disciplines, make use of traditional local surveys to gather data or to verify and to update existing databases. In most of the cases, the gathering and management of data in this way is a lengthy

process, prone to human error and could be expensive. A system that gathers information from remote sensing sensors and GIS output files, is an essential mechanism to bridge some of these gaps (Chen *et al.*, 1994). During the local surveys man is usually in physical contact with the environment. This is not the case with remote sensing.

Remote sensing is irrigated for analysing and gathering of data; to be more specific satellite, radar and video-remote sensing. The theoretical framework, application of the video remote sensing technique in the Upington irrigation area and the empirical results are discussed in detail in Chapter 4.

***Objective 2: Development of applicable interface between the FLODSIM-model and a dynamic hydraulic simulation model***

As a starting-point, constant flow-simulation was used to provide hydraulic data. The adjustment of the model parameters to reflect any changes in the physical environment flowing from proposed structural control measures, is cumbersome, making this hydraulic model inflexible. Constant flow simulation thus is a major shortcoming with regard to flood damage modelling.

Consequently a need arose for additional and more detailed information, like the inclusion of duration of floods (which is important for the calculation of flood damage to certain crops e.g. sugarcane). To address the hydraulic complexity and the variety of geomorphological characteristics of rivers, the accent was shifted from constant flow simulation to dynamic flow simulation. Subsequently it was decided to combine a dynamic hydraulic simulation model with FLODSIM. By doing this it will be possible to use dynamic hydraulic data, especially during the manipulation of structural control measures, to calculate the total average annual flood damage more accurately. For example, the advantage of this is that water levels and velocity will change dynamically when levees are manipulated in an area.

To achieve the above-mentioned objective, the following activities were carried out:

**Activity 1: Identification and development of a suitable dynamic hydraulic simulation model**

A dynamic hydraulic simulation model was used to simulate the water surface profile of the Orange River between the Gifkloof Weir and the Manie Conradie Bridge at Kanon Eiland. The Department of Water Affairs and Forestry was approached to utilise expertise that already existed with regard to flood hydraulics. The MIKE 11 model was chosen, on the one hand because this hydraulic simulation model is being used generally (also in overseas countries) (Nielsen *et al.*, 1991; Woltemade and Potter, 1994; Havno *et al.*, 1995; Singh, 1995; Muller and Rungoe, 1996), and on the other hand because the Department of Water Affairs and Forestry had already procured the MIKE 11 simulation model that is used by the Section for Hydraulic Studies. MIKE 11 also has ideal application possibilities in the research area where different flood ways, especially with regard to low flows, are applicable.

The above-mentioned aspects, together with the most important conclusions, are discussed in Chapter 5.

**Activity 2: Development of applicable interfaces between FLODSIM and MIKE 11**

To use FLODSIM for effective flood control planning in flood prone areas in South Africa, it is necessary that both flood damage simulation models and GIS-techniques should be used (Muller and Rungoe, 1996). Firstly, it is important to define the river morphology by means of cross sections before a flow simulation model, like MIKE 11 can be set up. In the past, cross sections were taken with great pains from maps, and several visits had to be made to research areas. A method was subsequently developed to determine cross sections quickly, cost-effectively and sufficiently accurate, using ARC/INFO. A procedure was developed to take cross sections from ARC/INFO that can be used as input by MIKE 11.

To integrate data, that was gathered with the MIKE 11 flow simulation model, in a meaningful way with FLODSIM, applicable linkages between MIKE 11 and FLODSIM had to be developed. Special adaptations and linkage programs were thus developed and are discussed in Chapter 7.

### **Activity 3: Calibration of MIKE 11**

For the calibration of hydraulic simulation models, the complexity of the river morphology and the uncertainty of the roughness coefficient of Manning are the two primary variables that should receive attention. Different combinations of these two aspects can cause great variation in calculated water levels (Stemmet, 1997). Woltemade and Potter (1994) showed in an investigation that water levels could differ as much as 49 per cent. As a result, the calibration of models, preferably with perceived flood levels, is of the utmost importance. After the mentioned linkages were developed and the model was verified, MIKE 11 was calibrated for the research area by using historic flood events, perceived flood marks and existing constant flow simulation data. This activity was mainly executed in co-operation with the Department of Water Affairs and Forestry in Pretoria (Hydraulic Studies).

#### **2.4.2 GOAL NO 2: DEVELOPMENT OF LOSS FUNCTIONS FOR THE DIFFERENT LAND USE THAT OCCUR IN IRRIGATION AREAS**

Due to a lack of adequate research funds, it was not possible to compile a complete loss function databank for South Africa. Existing loss functions were refined and additional loss functions were developed for sugarcane.

#### ***Objective 1: Refinement of existing loss functions for the Upington irrigation area***

Existing loss functions for the Upington irrigation area were refined and adapted by means of sensitivity analyses, to determine the extent of the total average annual flood damage.

**Objective 2: Development of loss functions for the Mfolozi floodplain**

Methodology that was developed for the Uppington irrigation area was, where possible, applied in the Mfolozi floodplain. The approach that was used by Weiss (1976) to develop loss functions for sugarcane, was adapted and used. The following two activities were executed here.

**Activity 1: Development of a questionnaire to develop loss functions according to the ex ante approach**

Questionnaires were drawn up and were tested during a pilot visit. Subsequently, the questionnaires were completed during a second visit to 30 farmers in the Mfolozi floodplain.

**Activity 2: Development of sugarcane loss functions**

Information gathered from the questionnaires was used to develop sugarcane loss functions. A distinction was made between harvest, crops and infrastructure damage (Chapter 6).

**2.4.3 GOAL NO 3: ADAPTATION OF FLODSIM TO BE APPLICABLE IN OTHER FLOOD PRONE IRRIGATION AREAS OF SOUTH AFRICA**

Before FLODSIM could be applied in another flood prone irrigation areas, it was - besides the fact that applicable databases had to be developed - necessary to adapt the model. An attempt was made to meet the shortcomings of the model, as discussed in Chapter 7.

**2.4.4 GOAL NO 4: TO APPLY FLODSIM IN A FLOOD PRONE AREA OF SOUTH AFRICA TO DETERMINE THE TOTAL AVERAGE ANNUAL FLOOD DAMAGE.**

After goals numbers 1 to 3 were accomplished, it was possible to demonstrate FLODSIM by applying the model in the Mfolozi floodplain. With the application of FLODSIM, the following activities were carried out.

### **Activity 1: The creation of suitable databases**

Databases for land use, infrastructure, levees, hydrological and hydraulic data and a DTM for the Mfolozi floodplain, were created by using GIS techniques. Information was gained from Bosch and Associates, the Department of Water Affairs and Forestry, the Mfolozi Sugar Mill and Co-operative. Other topographical data that were not available, was digitised from suitable maps.

### **Activity 2: Adaptation of FLODSIM for a dynamic approach to flood damage determination**

Where the depth of inundation is the most important parameter in the Lower Orange River to determine the total average annual flood damage, the duration of the flood is the most important flood parameter in the case of the Mfolozi floodplain. Consequently, an adapted approach was necessary to take the duration aspect of floodwaters into account. To compensate for duration of a flood, the MIKE 11 hydraulic simulation model, that supplies dynamic water levels and velocities, was used. A time dimension is also present, and velocity and water level heights are given in specific time intervals.

### **Activity 3: The determination of the benefits of different flood control and flood damage control measurements**

After FLODSIM was calibrated, benefits of different combinations of flood control and flood damage control measures were determined. Several scenarios were developed for the Mfolozi floodplain, namely:

- ☞ calculation of flood damage for the *status quo*;
- ☞ risk assessment of floods;
- ☞ possible development of land that was bought out by the Government for agricultural purposes after the Domoina flood (controlled vegetation);
- ☞ deforestation of the area from where cane production ends up to where the Mfolozi River flows into the sea;

- ☞ a combination of deforestation and development of land that was bought out by the Government after the Domoina flood, and
- ☞ calculation of the insurance premium for the Mfolozi floodplain.

After the necessary adaptation of FLODSIM was made and the appropriate databases developed, the flood damage simulation model was applied in the Mfolozi floodplain. The scenarios and conclusions regarding the above-mentioned aspects are discussed in Chapter 8.

#### **2.4.5 GOAL NO 5: DEVELOPMENT OF A THEORETICAL FRAMEWORK FOR SUSTAINABLE FLOOD MANAGEMENT SYSTEM TO EVALUATE FLODSIM AND THE REVISED FLOOD MANAGEMENT POLICY OF RSA**

A comprehensive literature study was done for this purpose. Approaches being used overseas were studied and adapted for South African circumstances. The integrated management of a total catchment area is a complex process and the development of flood management plans demands a multi-disciplinary approach. Galloway (1995) shows the necessity that suitable support and decision making aids should be supplied to authorities at all levels, in order that effective floodplain management can be conducted. Several countries that experience problems with regard to floods, decentralise flood responsibilities to local authorities. In New South Wales (Australia) specialised technical knowledge are supplied by federal and government bodies to local authorities (New South Wales Government, 1986). From the mentioned literature study, a suitable flood management system was formulated for South Africa and will be discussed in Chapter 9.

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## CHAPTER 3

### DESCRIPTION OF THE MFOLOZI FLOODPLAIN

#### 3.1 INTRODUCTION

The Mfolozi floodplain served as study area to determine whether the computer program developed by Du Plessis *et al.* (1995) for ex ante flood damage determination in irrigation areas of the Lower Orange River could readily be adjusted for application in other areas. The choice of the Mfolozi floodplain as study area posed challenges, since the area differs significantly from the Lower Orange River in several ways.

One of the main adjustments required to the existing program, was the result of different land use patterns in the two areas. Vineyard, rotation crops and lucerne are cultivated on large scale in the Lower Orange River, while the Mfolozi floodplain is a sugarcane production region. Du Plessis *et al.* (1995) identified depth of inundation as the most important determinant of the extent of flood damage to vineyard, rotation crops and lucerne. With regard to sugarcane not only the time of flooding and the depth of inundation is an important factor, but also the duration of inundation. In order to determine the damage to sugarcane the computer program was adjusted to take duration of inundation into account in addition to depth of inundation and the time of flooding.

A second aspect of importance during the determination of flood damage in the Mfolozi floodplain, is the emphasis placed on the development, maintenance and reparation of infrastructure. The frequent occurrence of floods in the Mfolozi floodplain, often because of excess rain in the Mfolozi catchment area, necessitates expensive structural flood control measures, which are not economically justifiable in an area such as the Lower Orange River, where floods occur less frequently. Since all sugarcane farmers in the Mfolozi floodplain are subjected to floods they

are prepared to pay levies for effective flood control measures. The collection of levies is facilitated because all the sugarcane is delivered to the local sugar mill and all the farmers pay levies according to the tons of sugarcane delivered. It is noteworthy that not all farmers who contribute to flood damage mitigation measures benefit by it. Farmers to the north of the Mfolozi River benefit more than farmers to the south of the river, since the spillway directs the flow of the water to the south.

Thirdly problems were experienced with regard to sand deposits and erosion during floods in the Lower Orange River, while in the Mfolozi floodplain significant amounts of silt were deposited as well. The effect of the latter on production and soil fertility should ideally be taken into account as well. Due to lack of data, the effect of silt deposits has not been taken into account in this study.

The choice of the Mfolozi floodplain as study area was supported by two other considerations. Firstly information on the effect of floods of different size was readily available because of the frequent occurrence of floods in the Mfolozi floodplain. Secondly several researchers have already studied the economic impact of floods on the Mfolozi floodplain and their results were useful for the evaluation of the computer program that emanated from this research.

The Mfolozi floodplain will be discussed with regard to: location and topography, soil, climate, history of previous floods, infrastructure and its protection, non-structural flood control measures, as well as the co-operative and sugar mill.

### **3.2 LOCATION AND TOPOGRAPHY**

The Mfolozi floodplain on the northern coast of Natal originated as a result of the silting up of an old lake between the current course of the Mfolozi and Msunduzi Rivers. The floodplain lies between 28 and 29 degrees latitude and 32 and 33 degrees longitude, to the east of the Lower Mfolozi and Hlabisa districts. It also forms the most eastern part of the Mfolozi catchment area.

The Mfolozi floodplain refers to a terrain less than twenty metres above sea level, which covers a surface of approximately 10 500 hectares, of which 8 500 hectares are under sugarcane. The height above sea level decreases gradually from the west, where the river enters the floodplain, to the coast. The height above sea level at specific places in the floodplain is influenced by silt and sand deposition during floods. During the Domoina flood in 1984, some lands were covered by sand up to one metre deep (Department of Environmental Affairs, 1986). Several measures (Paragraph 3.7) serve to attempt the prevention of movement of sand to lower lying farms in the floodplain during future floods.

In Figure 3.1 the 1:20 year flood line of the Mfolozi floodplain is indicated. The area from the national Road Bridge east of Riverview up to the river mouth in the Indian Ocean, just south of the St. Lucia Lake, is regarded as the floodplain and it includes amongst other the whole area between the Mfolozi and Msunduzi Rivers.

Msunduzi, a small river that can carry up to 200 cumecs water without overtopping its banks, is situated to the lower lying south of the Mfolozi floodplain. It serves as drain for most of the farms on the Mfolozi floodplain and all the water that flows over the spillway during a flood, is carried towards the sea by it (Paragraph 3.6). Possible silting and movement of sand pose a threat to the Msunduzi River and the river mouth (Department of Environmental Affairs, 1986).

Since the possibility of flooding is always present in the low-lying areas, no houses are found in the floodplain and machinery are usually moved to higher areas when flood warnings are given. Most farmers live outside the floodplain in three small villages; Monzi, Riverview and Mtubatuba. The latter is also the trade centre. Flood damage in the Mfolozi floodplain thus entails mainly damage to sugarcane and infrastructure.

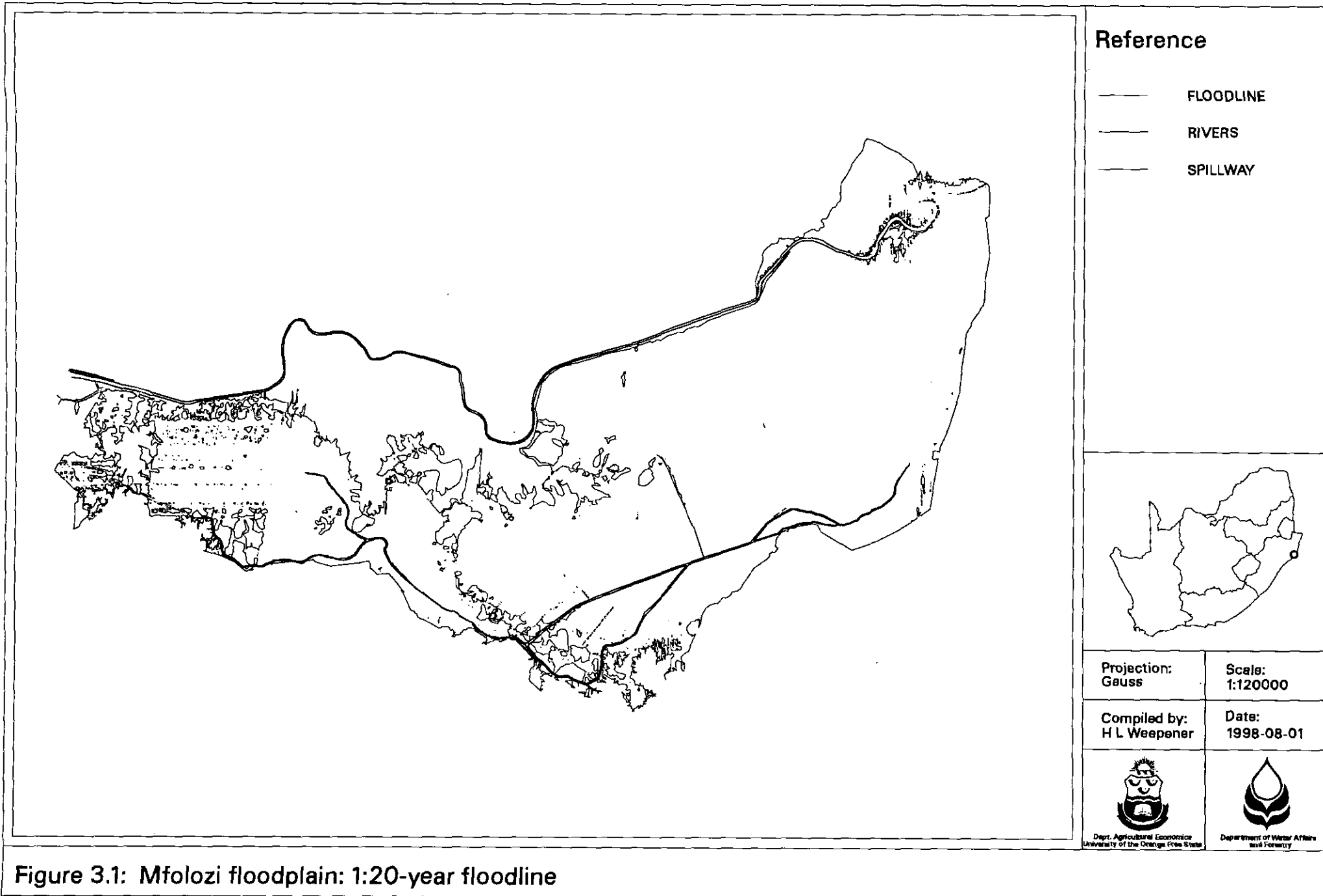


Figure 3.1: Mfolozi floodplain: 1:20-year floodline

### 3.3 SOIL

Stratified alluviums are found in the floodplain, while sandy soil occurs along the coast. The dominant soil types are Dundee, Rensburg and Bonheim. Namib, Oak Leaf, Vals River and Katspruit were identified on some farms. Although a fairly uniform soil profile exists over the Mfolozi floodplain, the clay-content of the soil is influenced by silt and sand deposition during floods over the long run. Since sugarcane performs better on clay soil, a moderate silt deposits is advantageous, while sand deposits is undesirable.

### 3.4 CLIMATE

The average yearly rainfall at Riverview for the thirty year period 1966 to 1995, is 916mm, with most rain occurring during January and February (South African Sugar Association [SASA], 1997). The rainfall decreases gradually when moving from the coast to the interior. In the summer thunderstorms accompany rainfall, but hailstorms are rarely experienced. Summers are warm and winters are moderate and without frost (Van Zyl, 1983). The average temperature is fairly constant and varies between 12° and 23.6°C in July, the coldest month, and between 21° and 30°C in February, the warmest month (SASA, 1997). In the past floods have occurred in winter although the Mfolozi floodplain is a summer rainfall region. Refer to Table 3.1 for the average meteorological data for the Mfolozi floodplain for the period 1966 to 1995.

Table 3.1: Average meteorological data for the Mfolozi floodplain for 1966 to 1995

	Averages					Total rainfall (mm)	Evaporation Class "A"-pan (mm/day)	Average soil temperature °C			
	Temperature (°C)		Relative Humidity		Sun (hours/day)			8:00		14:00	
	Max	Min	8:00	14:00				10cm	20cm	10cm	20cm
January	30.3	20.8	78	63	6.9	117.5	6.7	26.5	26.7	33.8	30.6
February	30.0	21.1	81	64	7.3	137.4	6.3	26.1	26.6	33.4	30.4
March	29.2	20.1	83	62	7.2	98.5	5.7	24.8	25.5	31.8	29.1
April	27.4	17.9	83	61	7.1	61.4	4.5	22.4	23.3	28.7	26.7
May	25.6	15.2	83	57	7.3	54.2	3.5	19.3	20.3	25.0	23.2
June	23.6	12.2	80	54	7.3	42.6	3.1	15.9	17.1	21.9	20.0
July	23.6	12.1	80	53	7.4	32.4	3.3	15.8	16.9	21.8	19.7
August	24.7	13.9	80	54	7.1	37.1	4.1	17.4	18.3	23.7	21.2
September	25.6	16.0	79	60	6.3	73.1	4.7	19.8	20.3	26.1	23.6
October	26.3	17.1	77	63	6.0	94.7	5.4	21.6	21.8	28.1	25.3
November	27.5	18.6	77	64	6.1	85.6	5.8	23.7	23.6	30.4	27.5
December	29.4	20.1	76	63	6.7	81.6	6.6	25.8	25.7	33.0	29.7
Average/Total	26.9	17.1	80	60	6.9	916.1	5.0	21.6	22.2	28.1	25.6

Source: SASA (1997)

### 3.5 PREVIOUS FLOODS

Table 3.2 shows the year and month during which the main floods occurred since 1950, as well as the maximum quantity of water that flowed past a certain point. Until 1963 the flood peak was measured at the Railway Bridge and from 1964 to 1986 at the National Road (N2) Bridge. Since 1986 the flood peak has been measured at the Domoina Bridge near the spillway.

**Table 3.2: Date and flood peak of the main floods in the Mfolozi floodplain since 1950**

Year	Month	Flood peak (cumecs)	Recurrence period (year)
1957	October	5491	14
1963	July	7836	28
1974	February	1918	3
1976	March	1345	2
1977	February	1995	3
1984	January (Domoina)	15445	100
1987	September	6200	17
1989	November	5147	13
1993	October	2600	4
1996	12 February	4320	9
1996	14 February	3640	6
1996	24 February	1925	3

Source: Bosch and Associates (1995) and De Jager (1997)

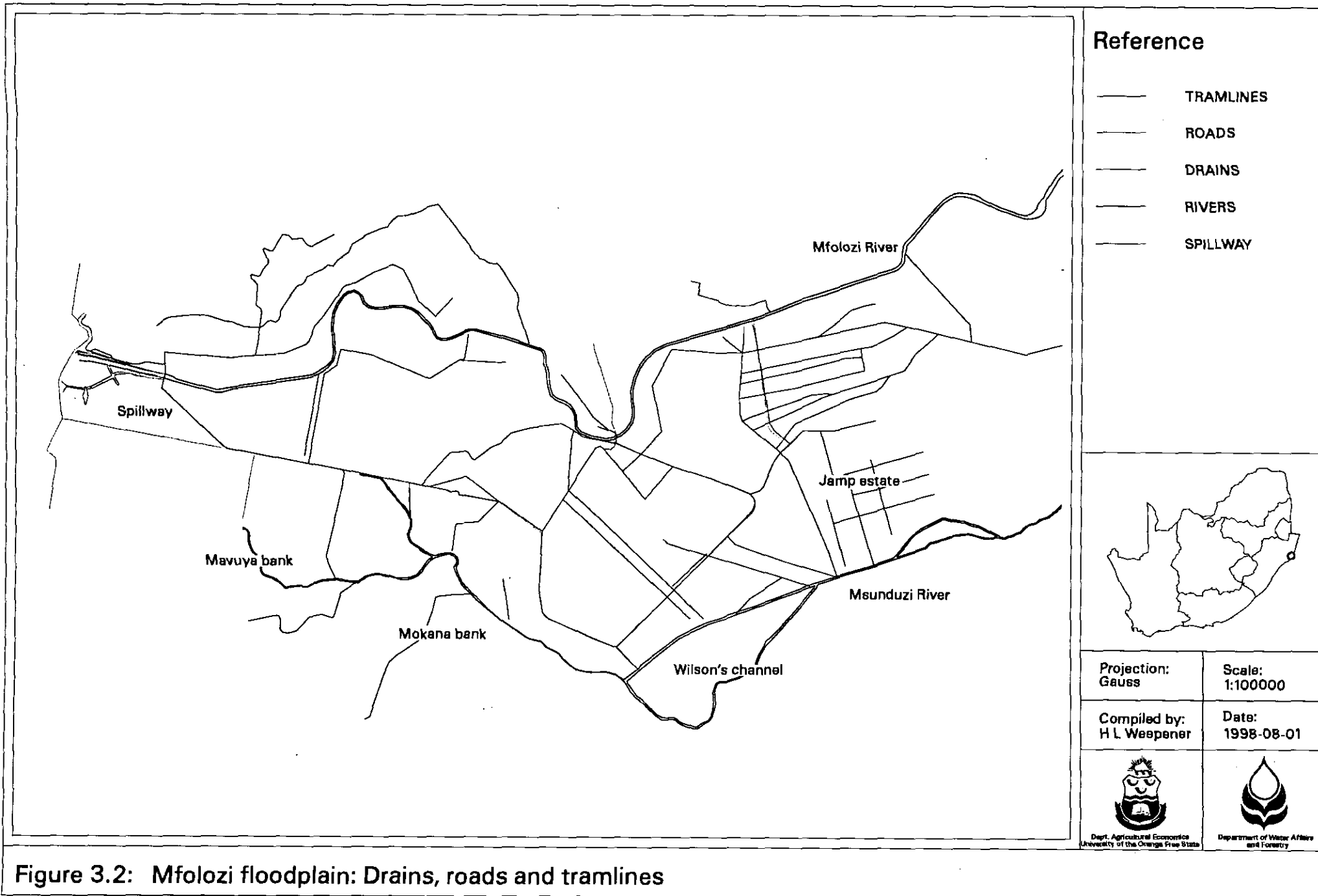


Figure 3.2: Mfolozi floodplain: Drains, roads and tramlines

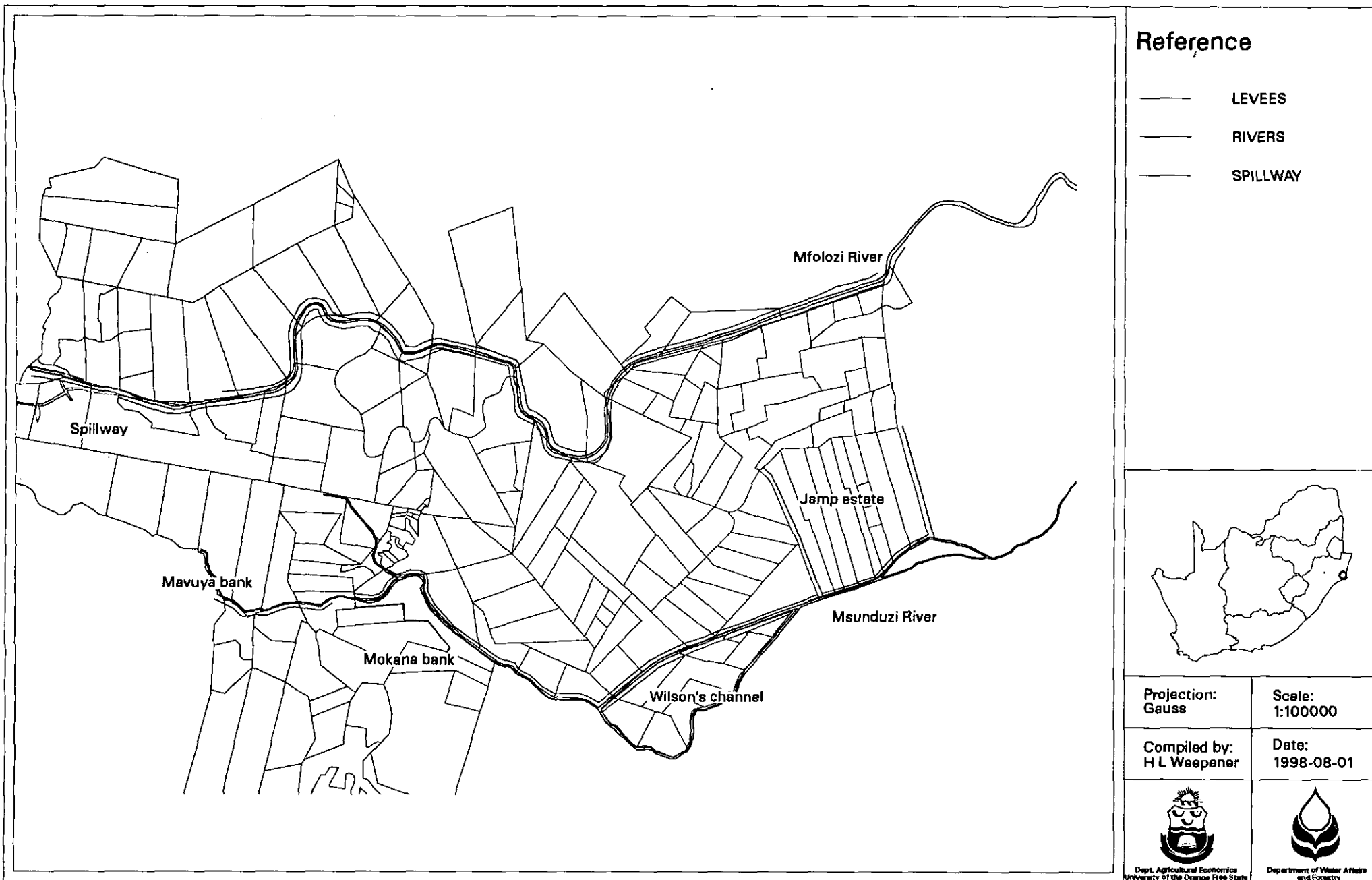


Figure 3.3: Mfolozi floodplain: Levees

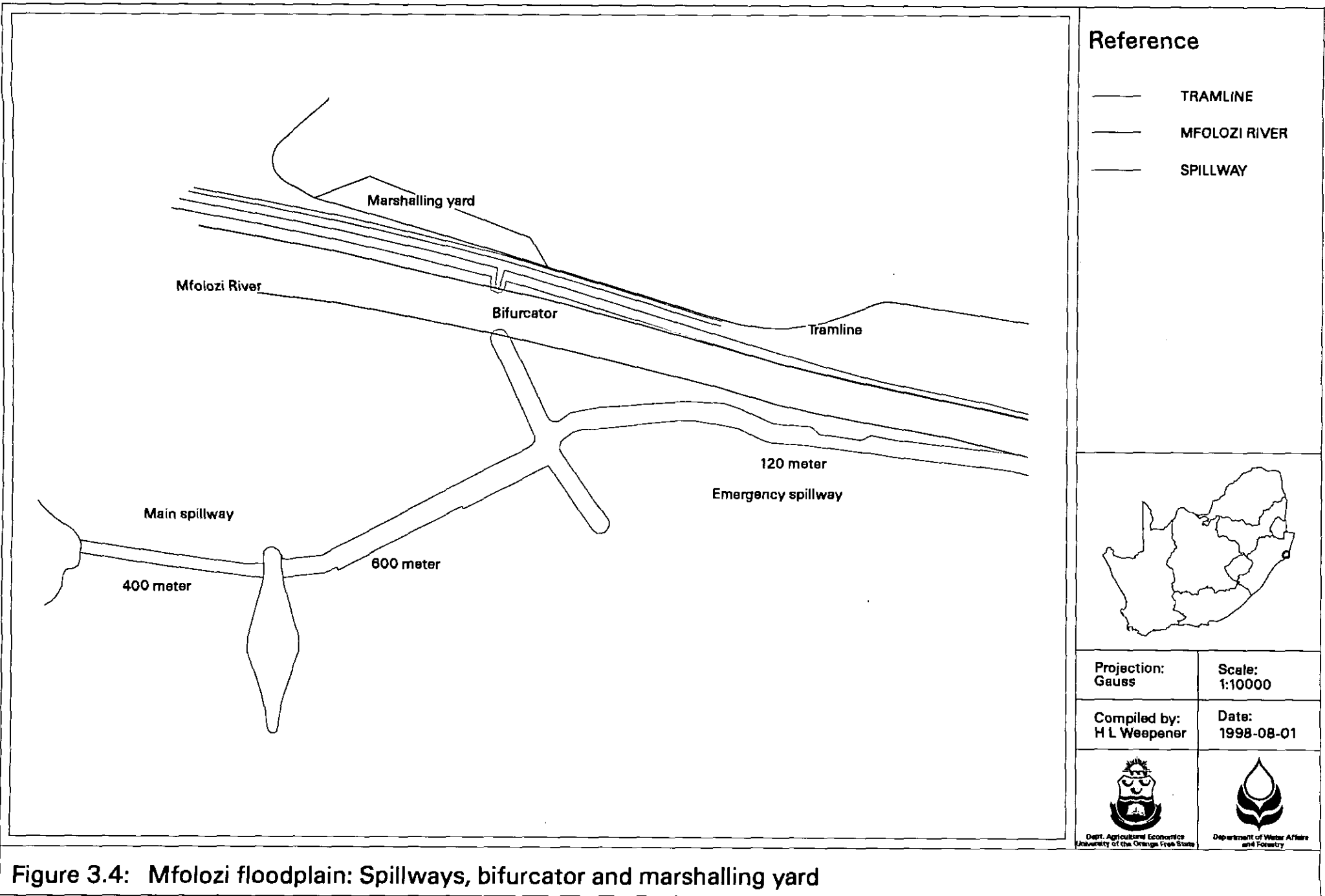


Figure 3.4: Mfolozi floodplain: Spillways, bifurcator and marshalling yard

### 3.6 INFRASTRUCTURE

Refer to Figure 3.2 to Figure 3.4 for the location of infrastructure in the Mfolozi floodplain. Infrastructure includes the following:

A tramline network of 92 kilometre is used for transporting sugarcane to the mill (Figure 3.2). Annually the network transports more than 650 000 tons of sugarcane to the mill over an average distance of 16 kilometre (Department of Environmental Affairs, 1986). The marshalling yard lies to north of the Mfolozi River and it is expected that there will be limited damage only in the case of large floods. The damage as a result of trucks that are washed away will however be greater than the damage to the terrain itself (Bosch and Associates, 1995).

Farmers' houses in higher areas are linked to farms in the floodplain by approximately seventy kilometres of gravel roads (Figure 3.2). Excluding private roads and tramlines, the co-operative is responsible for maintenance and repairing of the above-mentioned. Only limited financial aid is received from the Provincial Administration of Natal (Department of Environmental Affairs, 1986).

Several bridges such as the Domoina-, Wilson's Canal-, 31/2-, Low Level- and Monzi Bridge, must be maintained by the co-operative. After floods farmers are responsible for the reparation of bridges over private drains.

A drainage network of approximately 115 kilometres provides essential drainage of storm water to the Mfolozi and Msunduzi Rivers for farms in the floodplain (Figure 3.2) (Department of Environmental Affairs, 1986). Farmers are responsible for private drains of approximately 32 kilometres, while the remaining 83 kilometres are maintained by the co-operative (De Jager, 1997).

Some farmers in higher areas apply centre pivot irrigation, but usually dragline irrigation is used. Pipes are often placed under the soil, linking the river to adjacent farms to pump water out of the river. Most pumps along the river can be removed relatively easily if farmers are warned in advance if danger of flooding exists.

Levees, with an average height of three metres, are maintained to prevent inundation caused by the overflow of the banks of the Mfolozi River and resulting damage to farms. Refer to Figure 3.3 for the location of levees. For the area where farms border the river, the whole South Bank and the largest part of the North Bank of the Mfolozi River, have levees. Besides the levees on a large part of the northern bank of the Msunduzi River there are also the Mavuya and Mokana Banks and the levees on both sides of the Jamp Estate and Wilson's Channel. Richards Bay Minerals normally contributes 20 per cent of the cost incurred by the co-operative during the reparation of levees (De Jager, 1997).

There are two spillways carrying surplus floodwater of the Mfolozi River to the Msunduzi River to prevent overflowing of the main bank of the Mfolozi River. The emergency spillway, down stream of the bifurcator, is 120 metres long. The bifurcator is a structure that controls the amount of water that is carried by the Mfolozi River. The longest spillway, which was completed after the Domoina flood of 1984, is 1 000 metres long. It starts functioning when discharge reaches approximately 900 cumecs and can handle a 1:7 to a 1:10 year flood. In the case of such a flood (approximately 3 200 cumecs), 1 200 cumecs will flow down the Mfolozi and 2 000 cumecs along the spillway (Department of Environmental Affairs, 1986). The purpose of the spillway is to channel the floodwater evenly over sugarcane lands in the direction of the Msunduzi River. Furthermore the spillway also decreases the speed whereby floodwaters move across the floodplain and less sand is carried by the water and deposited on low-lying farms. After the flood, the drainage network facilitates the removal of water from the farms. Refer to Figure 3.4 for a representation of the location of the marshalling yard, spillways and bifurcator relative to the Mfolozi River.

### **3.7 PROTECTION OF INFRASTRUCTURE**

The following measures were suggested for the protection of infrastructure against flood damage (Department of Environmental Affairs, 1986):

- ☞ Exposed areas, for example the sand area formed by the Domoina-flood, must be covered by vegetation to prevent further movement of the sand.
- ☞ Production methods in the whole Mfolozi catchment area must be aimed at decreasing discharge and sediment deposition in the floodplain.
- ☞ Construction of dams in the Mfolozi catchment area must be analysed since it will decrease the danger of floods in the floodplain.

### **3.8 NON-STRUCTURAL FLOOD DAMAGE CONTROL MEASURES**

Flood damage control measures can be divided into structural and non-structural measures. The aim of structural measures is to influence the size of floods with engineering works as described in Paragraph 3.6. With non-structural measures it is firstly attempted to decrease the impact of flood damage on individuals and the society through the manipulation of human action by using government instruments and secondly to reduce the possibility of flood damage in floodplains by improved organisation and planning (Spies, Viljoen and Smith, 1977).

Non-structural measures in the Mfolozi floodplain include amongst other a flood warning system and regulations with regard to suitable areas for the building of houses and sugarcane establishment, respectively.

### **3.9 THE CO-OPERATIVE AND SUGAR MILL**

Since 1910 sugarcane has been cultivated on the high-lying parts of the Mfolozi floodplain. The "St. Lucia Company" started to function as sugar mill in 1916, but was taken over by the co-operative, the "Mfolozi Co-operative Sugar Planters Limited (UCOSP)" after a flood in 1918. The sugar mill was modernised by the co-operative and after another serious flood in 1925, it was moved to its current site at Riverview. Only after the Second World War did the cultivation of the western half of the marsh soil commence (Van Zyl, 1983).

Until 1992 the sugar mill belonged to the co-operative. In 1992 the sugar mill was sold to CG Smith (Illovo) and the miller and growers became separate economic units (Conningrath Consultants, 1994). The contract of the latter to manage the interests of the co-operative was terminated on 1 April 1997. Since then the co-operative and the sugar mill functioned independently (De Jager, 1997).

The profitability of the sugar mill is directly influenced by the occurrence of floods in the Mfolozi floodplain. Floods cause a decrease in the amount of sugarcane throughput, as well as a decrease in the recoverable sucrose as result of a smaller harvest and a lower sucrose content of sugarcane. Although farmers are penalised for lower sucrose content, the sugar mill suffers damage in terms of lost weight because sugarcane are cleaned at the mill (Bosch and Associates and Conningrath Consultants, 1991). At full capacity the sugar mill can handle 265 ton sugarcane per hour and the refinery 27 tons per hour (Smits, 1997).

### **3.10 CONCLUSION**

The Mfolozi floodplain served as study area for this study. It is the most northern sugarcane production coastal area in South Africa. The fertile alluvial soil and favourable climate makes the Mfolozi floodplain highly suitable for cultivation of sugarcane. Production is however negatively influenced by the frequent occurrence of floods. Several structural and non-structural flood control regulations were established to mitigate flood damage in the area. Damage is caused mainly to soil, sugarcane and infrastructure during floods. The maintenance and reparation of infrastructure is the joint responsibility of the farmers and the co-operative.

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## CHAPTER 4

### ALTERNATIVE METHODS FOR IDENTIFYING AND DETERMINING LAND USE PATTERNS

#### 4.1 INTRODUCTION

After the completion of the first phase of the flood project, it was decided to develop and refine the flood simulation model and to apply it in other flood-prone areas. Alternative cost-effective methods of compiling databases for the flood simulation model were investigated. An important database for the flood damage simulation model is the land use database of a floodplain. During the first phase of the study, land use patterns were determined by means of an *in situ* survey (Du Plessis *et al.*, 1995). This study took six months to complete, and personnel of the Department of Agricultural Economics at the University of the Orange Free State and of the Department of Water Affairs in Upington and Pretoria were involved.

Next, alternative methods of identifying land use patterns and making them available in a GIS format were investigated. Because of limited funds, it was initially decided that only a desk study would be undertaken. After additional funds for the research project had been appropriated, it was possible to apply and evaluate video remote sensing.

A review of alternative methods which could be used to identify the various land use types on a floodplain is presented. Video remote sensing applied in the research area will be discussed. The total mean annual flood damage for the research area is calculated by means of this method and an evaluation of the method will be described.

## 4.2 APPROACHES TO DETERMINE LAND USE PATTERNS

The development and introduction of more advanced computer technology resulted in remote sensing, geographic information systems (GIS) and global positioning systems (GPS). These became the data collection and management and decision-making mechanisms of many disciplines. Projects undertaken by these disciplines traditionally used *in situ* surveys to collect data or to verify and update existing databases. In most cases collecting and managing data in this way is a tedious process subject to human error and is also relatively expensive. A system for collecting data using remote sensing and GIS output files is an essential mechanism for neutralising the above-mentioned shortcomings (Chen *et al.*, 1994). During *in situ* surveys a person is usually directly in contact with the environment, while the same does not apply in the case of remote sensing.

Remote sensing was used as a starting point and investigated as a possible method of collecting data. More specifically, three methods were investigated:

- ☞ satellite remote sensing;
- ☞ radar remote sensing, and
- ☞ video remote sensing.

### 4.2.1 REMOTE SENSING

The aim of the desk study was to use the literature as a basis for finding a method that could be used to identify land use cost-effectively and make it available in a GIS format. Over the past decade the use of multi-spectral remote sensed imagery transmitted from aircraft and satellite platforms has increased dramatically (Goodman, 1984). Satellite remote sensing has especially been developed and used in agriculture to monitor agricultural activities and for agricultural production forecasts (European Space Agency, 1995). A considerable amount of literature on remote sensing is available. It is not the intention to review all the technical aspects involved in remote sensing in this section. Remote sensing has a wide

range of application possibilities, but here we shall focus mainly on the identification of land use.

Short (1982) defines remote sensing as follows: "The acquisition of data and derivative information about objects or material located at the Earth's surface or in its atmosphere by using sensors mounted on platforms located at a distance from the targets." This definition applies to various images such as photographic, radar and laser images, as well as multi-spectral scanners. Following Tateishi and Mukouyama (1987, as quoted by Lourens, 1990) land use and land cover are defined as follows for the purposes of this discussion: "Land use is a social classification indicating man's activity on earth's surface." Land cover, on the other hand, is "... a physical classification of the earth's surface".

Data are *inter alia* collected by researchers to test hypotheses and to simulate the environment with the aid of simulation models. Data can be collected either *in situ* or by means of remote sensing methods (Jensen, 1986). When researchers collect data themselves, whether through the completion of questionnaires or by observing, for example, the behaviour of a flood, it is called *in situ* observation. Sensors, on the other hand, are not in physical contact with the environment. Sensors typically record electro-magnetic radiation (EMR) moving at  $3 \times 10^8$  m/s and thus provide high-speed communication links between the sensor and the distant environment. In certain circumstances *in situ* data capturing is more feasible in practice than remote sensing, while in other cases remote sensing works better than *in situ* data capturing. Ram and Kolarkar (1993) and Ramamoorthi and Rao (1985) state that studies that are largely based on remote sensing hold the potential danger of inaccurate classification of land use, with the result that all such studies should be supported by field control. Everett and Simonett (1976, as quoted by Jensen, 1986) point out that the above-mentioned data capturing processes must be used to calibrate each other. Both remote sensing and *in situ* surveys are therefore used to help planners and engineers solve problems (Ramamoorthi and Rao, 1985).

Aerial photography was the first method used for remote sensing. As far back as the nineteenth century cameras were attached to pigeons in order to photograph Paris (Curran, 1985). The first platform for real remote sensing was an air balloon and a hand-held camera was used as a sensor. In 1858 Gaspard Tournachon took the first aerial photograph of Bievre at a height of 80 m (Lillesand and Kiefer, 1979, as quoted by Lourens, 1990). It was only in 1913 that aircraft were used for the first time to take photographs for the purpose of mapping (Wolf, 1983, as quoted by Lourens, 1990). The value of aerial photography was underlined as far back as the First World War when it was used to identify enemy positions and military bases, and it was especially encouraged strongly during the Second World War. Technological improvements and the development of photographic interpretation techniques proceeded at a rapid rate (Harris, 1987). After the Second World War a start was made with the development of multi-spectral scanners which received reflected energy from the surface of the earth in the form of spectral bands (Lillesand and Kiefer, 1979, as quoted by Lourens, 1990). Scanners were mounted on both aircraft and spacecraft.

The South African Department of Water Affairs and Forestry has already invested in a sophisticated image processing system which is managed by the Remote Sensing Section (RSS) of the Catchment Studies Sub-directorate at the Hydrological Research Institute (HRI, now the Institute for Water Quality Management) (Lourens, 1990). The LANDSAT Multi-spectral Scanner (MSS, now TM, SPOT MS and PAN) provides satellite data which are used by the HRI for the mapping of land cover. The Satellite Application Centre (SAC) of the CSIR upgraded the data capturing capacity so that it became possible to store LANDSAT Thematic Mapper (TM) and SPOT (Système Probatoire d'Observation de la Terre) High-resolution Visible (HRV, now MS and Pan) images. The Institute for Soil, Climate and Water, Environmentek at CSIR and Universities also invest in image processing systems and are able to provide various satellite images.

#### 4.2.1.1 *Satellite remote sensing*

The idea of creating an independent space power in Europe dates as far back as 1960. In 1962 six European countries Belgium, France, Germany, Italy, the Netherlands and the United Kingdom, in co-operation with Australia, founded the European Launcher Development Organisation (ELDO) in order to develop and build a launcher. Also in 1962 the above-mentioned countries plus Denmark, Spain, Sweden and Switzerland established the European Space Research Organisation (ESRO) in order to implement so-called satellite programmes. Ten years later the two organisations met in Brussels and amalgamated to form the European Space Agency (ESA). Ireland also participated and officially became a member of ESA on 30 October 1975, and on 30 October 1980 legal right of existence was granted to ESA at a convention (Radar Brief Conference, 1996).

Jensen (1986) discusses the technical aspects of satellite remote sensing in detail and devotes more specific attention to LANDSAT sensors such as TM and SPOT MS PAN. Lourens (1990) also sums up the technical aspects. The above-mentioned sensors differ with regard to spectral colour and radiometric resolution and consequently also with regard to the data that can be obtained from the sensors (Lourens, 1990). Jensen (1986) adds a fourth distinguishing characteristic, namely temporal resolution.

The dimension or the number of specific wavelength intervals in the electromagnetic spectrum which are sensor sensitive is called spectral resolution. Intervals can be large (0,4  $\mu\text{m}$  to 0,7  $\mu\text{m}$ ) or small (0,63  $\mu\text{m}$  to 0,69  $\mu\text{m}$ ). Spatial resolution measures the smallest angle or linear distance between two objects. In the case of the LANDSAT TM the ground (base) resolution is 79 \* 79 m. The better the spatial resolution, the more powerful the resolution of the sensors. The spatial resolution of TM and SPOT images are 30 \* 30 m and 10 \* 10 m respectively (Jensen, 1986). According to Eloff (1998) SPOT images are also now available at ground resolution of 20 \* 20 m. Temporal resolution refers to how often images can be provided. In some instances the moment at which images must be available is crucial to, for example, the ability to observe change over time. The

availability of a wide range of satellite data with regular intervals according to the latest image interpretation and digital mapping techniques render land use surveys very quickly, more cost-effectively and up to date (Ram and Kolorkar, 1993). The sensitivity of the signal strength detectors in terms of the emissive power of the earth's surface is referred to as radiometric resolution. An improvement of the resolution increases the probability of measuring data more accurately (Everett and Simonett, 1976, as quoted by Jensen, 1986). An improvement in radiometric resolution will lead to additional data processing, be it manually or by means of the computer. Thomas (1996) agrees with this, and confirmed it during a study aimed at the classification of land use conducted in the Lower Orange River Area.

Satellite images for the purpose of analyses are available in both digital and photographic format. Photographic products include prints and transparencies in various sizes, while digital images are made available as computer compatible tapes. Remote sensing images can be analysed in two ways, namely manually (visually) and by means of digital image processing. Thomas (1996) refers to uncontrolled (unchecked) and controlled (checked) classifications, also known as supervised classification. Uncontrolled (unchecked) classifications indicate an absence of any supervisory classification, in other words, the computer automatically classifies image elements under one of the specified groups. Controlled (checked) classification refers to the type of classification where the operator first evaluates and classifies the colour, after which the computer proceeds to classify every pixel according to the pre-specified colour. Computer processing is the most important processing mechanism (Lourens, 1990). Jensen formulates the reasons for this as follows: It is generally accepted that it is impossible for human beings to distinguish between more than 16 different shades of a colour, for example between shades of grey when analysing black and white aerial photographs. If data are recorded in 256 shades of grey, the images will contain more information. This does not only make visual interpretation impossible, but also has considerable implications for the consistence with which it can be done. Consequently computers are used to process, manipulate and store the large amount of information. Consistent repetitions are also executed by means of the computer.

Photographic satellite images are interpreted manually and are therefore based on visual interpretation. Photographic formats of LANDSAT TM images which are interpreted visually include single-band images and a combination of infrared bands (TM-4) and visual bands (TM-1 and TM-2). In the photographic format the infrared bands are red. These products are usually referred to as false colour composites (FCC).

Various studies have already been conducted abroad to monitor the extent of land under irrigation. In South Africa a study aimed at mapping land under irrigation in the Mogol River Catchment Area was also undertaken by Lourens (1990). Lourens (1990) compared the results of various satellite images and used topographic maps to determine farm boundaries and the boundaries of the catchment area. During a study undertaken to determine changes in land use, Ram and Kolarkar (1993), in addition to using LANDSAT TM images and topographic maps, also conducted a field control covering between 25 and 40 per cent of the surface area concerned, in order to support their interpretation of changes in the land use pattern. Results were compared with existing maps, aerial photographs, and secondary and published data. Ram and Kolarkar (1993) mention the fact that detailed land use studies are usually based on cadastral maps.

In the course of a study Van den Brink *et al.* (1986, as quoted by Lourens, 1990) used LANDSAT TM images to distinguish easily between grasslands, forests, agricultural lands, orchards, cities, rural towns and water surfaces. SPOT images provide a 20 m x 20 m pixel size and make detailed analysis possible. According to Wheeler *et al.* (1988, as quoted by Lourens, 1990) LANDSAT TM images work better if one wishes to study large areas, while SPOT images provide more reliable information on individual settlements. In Europe, satellite remote sensing is especially used to control arable and grazing land which benefit from subsidies on a hectare basis. Crop statistics are also collected by means of satellite remote sensing. At a regional and local level satellite remote sensing is increasingly used to collect information on changes in land use and to serve as a basis for production forecasts. The accurate identification of crop types depends on the timely

availability of images during the period of crop growth. Images obtained at specific times of the year can be used to determine the yield of different crops (European Space Agency, 1995). Mauser (1984) also used satellite images to compile flood hydrographs, while Kar (1994) used images obtained before and after a flood to determine the behaviour of floodwater in channels.

Nguyen Thi Phuong Thao (1990) identified the following benefits of satellite images during a flood study conducted in Vietnam on an area of 4 million ha of which 1,4 million ha is flooded annually:

- ☞ Floods can be monitored in swiftly over an extensive area.
- ☞ The images make accurate interpretation of contour lines possible.
- ☞ The direction of flow of the water can be determined by obtaining images during the rising and subsiding phases of a flood.

According to Blasco *et al.* (1992) and Nguyen Thi Phuong Thao (1990) it is not possible to determine the depth of the water.

Lourens (1990) experienced the following problems with regard to the use of satellite images for mapping land under irrigation:

- ☞ Overcast conditions at the time when images must be obtained present the greatest problem as no information on overcast areas can be obtained. Blasco *et al.* (1992) experienced the same problem during a flood study in Bangladesh.
- ☞ Physical land cover, not land use, is determined by the satellite images. In the case of the Mogol River the problem was that it proved impossible to distinguish between tobacco in its early growth stage and uncultivated soil as tobacco in the early growth stage provides very little vegetative cover.

The time of year at which images are obtained is therefore important. Images obtained during summer in the arid Rajasthan in India proved to be of no value due to high reflection, dusty images and the absence of water and vegetative growth (Ram and Kolarkar, 1993). In addition to these problems, problems are also experienced with regard to the mapping of boundaries between the different land use. Mohle and Deen (1991) and Nguyen Thi Phuong Thao (1990) ran field checks, but it still proved problematic to pinpoint the transitional zones between land boundaries, and this resulted in generalisation.

#### **4.2.1.2 Radar remote sensing**

During the Radar Brief Conference held by the Satellite Applications Centre (SAC) on 15 February 1996, various speakers from overseas introduced radar remote sensing. Experience revealed that high-resolution visual and infrared satellite sensors are not always suitable for the collection of data during overcast conditions (European Space Agency, 1995). The recent advent of earth observation (EO) satellites with imaging radar systems, such as the Canadian RADARSAT, the European and Japanese ERS series of satellites and the Russian Almaz, has significantly advanced the production of timely RS data. This new generation of EO satellites is using a synthetic aperture radar (SAR) for recording image data of the earth's surface and its features (Kalensky, 1996). Radar satellites such as ERS-1 and ERS-2 were launched in July 1991, while RADARSAT 1 was launched on 4 November 1995 and served to obviate the problem which was also experienced by Lourens (1990) in the course of his research, namely, that of poor images during overcast conditions. RADARSAT 1 is the first EO satellite with a the SAR payload designed for global, operational applications (Kalensky, 1996). Synthetic Aperture Radar (SAR) transmits microwave energy to the earth surface and records the variation in the strength of the reflected signal. Images are obtained irrespective of overcast and even daylight conditions and collect data on the roughness and dielectric characteristics of the earth surface. Radar is sensitive to the structure and humidity conditions of vegetation as well as to the roughness of the soil surface and the moisture it contains (European Space Agency, 1995). Microwave rays penetrate the canopy to a significant depth and react strongly,

especially with the structure of the vegetation. Below the vegetation the soil does not necessarily react like a mirror. Reflection from the soil is influenced by the roughness characteristics of the soil and the length of the radar waves. The longer the wave length and the drier the soil surface, the deeper do the waves penetrate. Radar waves are reflected by the plant material, for example by tree-stumps in plantations, and are then reflected back towards the canopy and again to the radar sensor. This interaction was modelled mathematically by Enghata and Elachi (1994), Richards *et al.* (1986) and Ulaby *et al.* (1986, as quoted by Imhoff and Gesch, 1990). The canopy-to-surface or the surface-to-canopy reflection is called the phenomenon of interaction or the two-bounce return. In the case of low-density vegetative cover, the soil surface is usually dominant, especially in the case of longer wave lengths. The opposite is also true and canopy reflection will be dominant in the case of especially shorter wave lengths (Imhoff and Gesch, 1990). SAR images also offer the advantage of being able to cover any part of the earth every seventeenth day and due to the properties of microwave radiation, the SAR systems produce clear images of ground surface under most weather conditions, even through heavy clouds, rain, falling snow and fog. As an example the first RADARSAT image, recorded over Cape Breton Island, Canada, on 28 November 1995, was acquired under conditions of darkness, rain and strong, winds. Despite the bad weather conditions, the image was clear without any deterioration of its quality (Kalensky, 1996).

Besides the above-mentioned SAR images the NOAA/TIROS series of polar orbiting meteorological satellites operated by the U.S. National Oceanic and Atmospheric Administration (NOAA) is of particular interest to global environmental monitoring programs, because of its Advanced Very High Resolution Radiometer (AVHRR). Actually, the ground resolution of AVHRR data is only 1.1 km at best, which is rather coarse for land applications, but these are very high resolution data for meteorological applications.

Initially SAR images were merely used as an experiment. Gradually, however, the value of SAR images was realised. However, SAR is not a replacement for LANDSAT TM and SPOT images. Each of the aforementioned types of images

has its advantages and disadvantages, and they should therefore not be used separately, but rather in a mutually supplementary manner.

Crops can be identified and classified by means of SAR images, especially in cases where LANDSAT and SPOT images fail to distinguish clearly between certain crops. During a study rape-oil seed was identified up to 100 per cent correctly by means of SAR images, while grass, linseed, potatoes, oats and barley were classified with 90 per cent accuracy. In contrast to this, fallow lands, barley (summer and winter), wheat, sugarcane and rape-oil seed were only classified with 57 per cent accuracy during another study. The latter classification could have been improved by choosing better imaging dates and by making use of segmentation techniques (European Space Agency, 1995). Schotten *et al.* (1995) studied the value of different images for use in crop classification. In general the accuracy of the classification improved consistently as the number of images increased. If only one image was recorded, land use could be classified with reasonable accuracy, but excellent results were obtained if eight images were recorded. Various crops were classified with 90 per cent accuracy (European Space Agency, 1995). Kohl *et al.* (1993, as quoted by the European Space Agency, 1995) obtained the same results when combining ERS-1 images with SPOT images in order to identify winter wheat, winter barley, summer barley, oats, turnips and maize. The accuracy of the classification improved by eight per cent. James *et al.* (1993) used radar remote sensing to identify storms which cause floods, after which flood hydrographs were compiled successfully on the basis of the data.

In South Africa attempts were already made in 1989 to promote SAR, but initially these attempts were unsuccessful. It was only in 1992 that the first SAR research was started in South Africa and in 1993 SAR images obtained overseas were used (Inggs, 1996). The University of Cape Town demonstrated a prototype SAR survey system in the laboratory in 1994. In addition to the ability of SAR images to penetrate overcast conditions, it is possible to create digital terrain models (DTMs) with the aid of SAR images (Inggs, 1996). Mauser (1984) also created a DTM in the course of a study by reading the heights from orthographic maps. Imhoff and

Gesh (1990) created a DTM for the Ganges River in Southern Bangladesh by making use of an interpolation technique. Shortcomings such as insufficient data and inaccuracy due to interpolation and resolution were experienced by Imhoff and Gesh (1990). The increase in accuracy resulting from the collection of additional data must be weighed against the increased cost (Imhoff and Gesh, 1990). A refined procedure for using SAR images to create DTMs was developed by Ingg (1996). In this case an aircraft was used as the platform instead of a satellite. Although the cost of using this technique as an operational decision-making mechanism is still high, its use for the identification of land use and the creation of DTMs should definitely be considered.

#### **4.2.1.3 Airborne remote sensing**

It is possible to scan images by means of video cameras (Jensen, 1986). Aerial videography as a remote sensing mechanism has developed especially rapidly over the past five years, although video cameras have already been used for remote sensing for the past decade (Mausel *et al.*, 1992). Video remote sensing systems (VRS) have already proved to be an effective research mechanism under various environmental conditions (Vleck, 1983; Nixon *et al.*, 1985; Everitt *et al.*, 1986 and 1989, as quoted by Marsh *et al.*, 1990).

Images can be scanned by means of a video camera by using an analogue-to-digital conversion process. Video scanning comprises the freezing and subsequent scanning of a frame obtained from an analogue video camera. A high-speed analogue-to-digital converter, also called a frame grabber, scans data and stores the information in the temporary memory of the computer. Software is used to store the data on the hard disk. Video images can be created very rapidly, but the results are not always suitable for digital image processing purposes (Jensen, 1986).

Medium-sized or colour infrared aerial photography usually serves as an intermediate step between satellite images and *in situ* surveys (Clerke, 1994). Aerial photography has considerable advantages compared to satellite images. A change in land use can, for example, be observed immediately. It is now possible to record very detailed and multi-spectral images of the surface, process them

according to requirements of the user and make these images available to farm managers within hours of acquisition. Over and above cultural applications, this technology can be usefully applied, for example, to forestry, infrastructure mapping, pollution monitoring, environmental impact assessment and geology as well (Eloff *et al.*, 1998). In addition to the above-mentioned advantage, aerial photography is affordable, it provides a higher resolution than satellite images and can therefore capture more detail on the photographs. Photographs can be mapped easily on a scale of 1:15 000 (Lourens, 1990). Although the information is therefore more accurate, extensive areas cannot be covered in one go (Ramamoorthi and Rao, 1985). Mausel *et al.* (1992) agrees with this and add the following advantages of video remote sensing:

- ☞ The ability to observe live images during data capturing.
- ☞ The fact that analogue images can be interpreted manually from the screen, after which values can be converted to digital values by making use of image processing.
- ☞ The ability to collect spectral data in the very narrow bands (5 to 12  $\mu\text{m}$ ) in the visual to infrared band (near infrared - NIR).
- ☞ The ability to record spectral data in the mid infrared (1,35 to 2,50  $\mu\text{m}$ ) in the water-absorbing regions.
- ☞ The abundance of data obtained as a result of the fact that images are recorded every 1/30 th of a second.

The greatest disadvantage of VRS is the relatively low image resolution when compared to a photograph (Mausel *et al.*, 1992). Besides the disadvantage of low image resolution, airborne remote sensing imagery cannot provide all the necessary information for farm and soil management as well as meteorological data, which are fundamental ancillary variables for the correct interpretation of crop conditions (Eloff *et al.*, 1998). A standard video camera has an image resolution of 240 (colour) and 300 (black and white) lines across the formatted field, compared to the more than 1 500 lines resolution of a 35 mm transparency film. According to Eloff (1998) an image resolution of 2 000\*2 000 m is now possible. Thomas (1996) explains the above-mentioned resolution by referring to the number of pixels in an

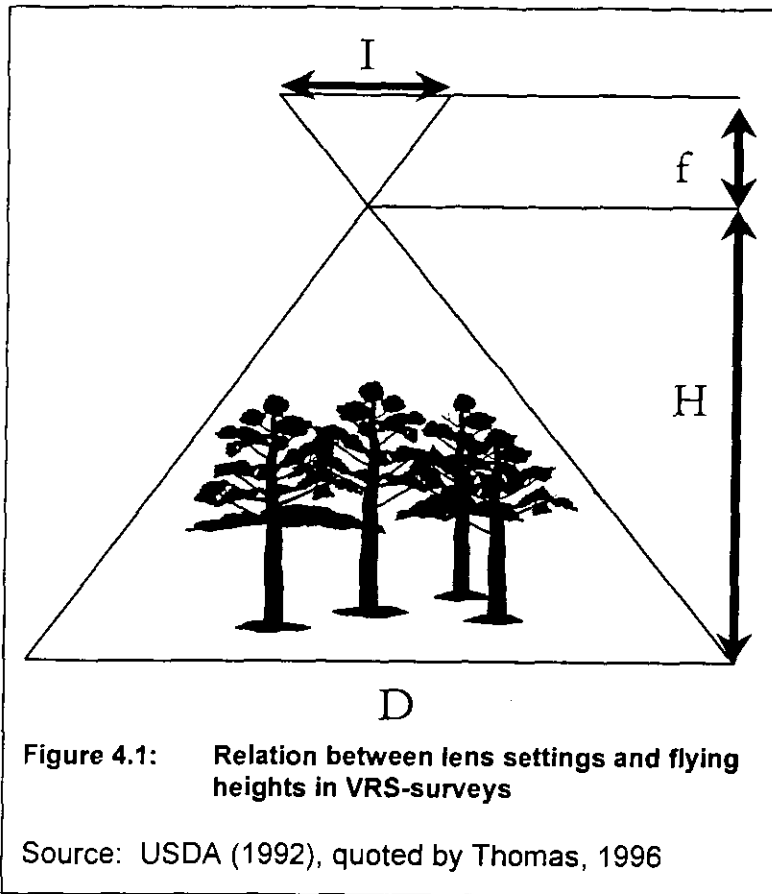


Figure 4.1: Relation between lens settings and flying heights in VRS-surveys

Source: USDA (1992), quoted by Thomas, 1996

image. Each pixel represents a small component of the total image. Consequently the quality of the image is determined by the number of pixels in an image. Hi 8 cameras provide a very high image quality (440 000 pixels per frame), while regular cameras provide 53 000 pixels per frame. A very high resolution is therefore obtained by means of Hi 8 cameras. The above-mentioned implies that,

given a certain height and lens width, operational use of the Hi 8 camera will cover the same ground surface as an ordinary VHS camera, but at a much higher resolution. Put differently, the Hi 8 camera will, at the same resolution, cover a larger area than a VHS camera. Consequently fewer flying hours will be required to cover an area. With an ordinary VHS camera higher image quality can be obtained by flying at a lower height in order to record data at a higher resolution. This requires more flying hours, and results in more data which must be processed, and therefore in higher operational costs. The best middle course between image quality and operational cost can be obtained by setting image quality as a function of camera resolution, lens viewing angle and the height above ground level. Mathematically the relation among the above-mentioned components can be expressed as follows:

$$H = (D * f) \div l$$

where:

H = height above ground level

D = distance on ground (swath)

f = focal length (lens viewing angle)

l = image area (CCD physical dimensions) - and is remains fixed for any camera.

The resolution of the image is calculated by dividing D by the number of pixels:

$$R = D \div A$$

where:

R = pixel resolution

A = the pixels along the axis.

A disadvantage of aerial photography experienced by Lourens (1990) is geometric rectification; this refers to farm units which are usually subdivided by more than one photograph, a fact which makes the scanning of farms difficult. Mausel *et al.* (1992) provide detailed information on the whole range of cameras, from the oldest to the newest, which can be used for VRS.

Studies undertaken with the aid of VRS techniques vary from the determination of cut-down plantation areas, determination of the size, density and spatial distribution of the leaves, branches and trunks of different trees (Wu, 1988), determination of soil salinisation in agricultural areas (Everitt *et al.*, 1988), differentiation between weeds and selected grain and vegetable crops (Richardson *et al.*, 1985), diagnosis of root rot in cotton, determination of an excess of soil moisture (Nixon *et al.*, 1987), evaluation of the influence of wind erosion on cotton, identification of root fungus on citrus trees (Mausel *et al.*, 1992) to the classification of arable soil on riverbanks and stream morphological changes in channels (Hardy and Neale, 1991, as quoted by Mausel *et al.*, 1992). In addition Marsh *et al.* (1990) mapped land use in the agricultural sector by making use of VRS. Supplementary to VRS Marsh *et al.* (1990) also used MSS satellite images and verified data in the field. During the field verification it was found that land use had been classified successfully. The greatest problem was one of distinguishing between cultivated and uncultivated

walo. Cultivated walo was mistakenly classified as uncultivated walo, especially in cases where the walo was in an early growth stage. As a result of the limited spatial resolution (80 m) of MSS images, different land use types were combined and classified as one type of land use. In the case of MSS images the surface area of the walo amounted to 31 per cent, compared to 40 per cent in the case of video images. The controlled classification technique and the GIS mapping process required much less time and manpower than the visual interpretation of the aerial data.

Fouché and Booyen (1994) distinguished avocado, soybeans and maize at a relatively low flying height (100 to 200 m). In addition to the above-mentioned distinction, root rot in the avocado orchards was identified successfully, and moisture stress in the case of soybeans and maize was classified as high, medium and low moisture stress. The results of the study show that a low flying height is a relatively inexpensive technique which can be used to determine moisture stress in crops.

The newest development in airborne remote sensing is precision farming. A semi-operational service of "Precision Farming" is currently being tested providing a number of selected farmers with aerial imagery for yield and soil mapping. This research programme will be addressed principally at establishing a real time processing chain and in performing a thorough analysis of the cost/benefit ratio of these technologies while providing qualitative image information to the user (Narciso and Newby, 1998).

According to Narciso and Newby (1998) the following topics can be addressed:

- ☛ The development of procedures for monitoring the effectiveness of distributing water soluble fertilisers through irrigation systems on short term crops (maize, cotton, tomatoes, potatoes, wheat, etc.).
- ☛ Development of procedures for assessment of crop stress development on irrigation systems for timely irrigation scheduling or testing existing irrigation scheduling models.

- ☞ Development of procedures for checking tree crops (vineyards, citrus, tropical fruit, apples, etc.) for root related diseases resulting from over irrigation and poor soil drainage.
- ☞ Soil mapping for farm investment planning.
- ☞ Development of procedures for monitoring soil salination, especially on irrigated crops.
- ☞ Development of procedures for monitoring sucrose contents over sugar cane ratoons.
- ☞ Identification of the most suitable spectral band combination for the identification of crop macro and micro nutrients stresses.

The fact that video images do not have as high a resolution as the images provided by other sensors results from economic rather than technical factors. Video users usually buy a commercially available high-resolution video camera off the shelf and then use it for scientific research. This type of hardware is, however, intended for commercial, non-scientific users. Consequently the standards applied to this type of hardware focus on the large group of commercial users, and little attention is devoted to the video camera requirements of scientists due to the fact that there is very little profit to be made from catering for the needs of such a small group (Mausel *et al.*, 1992).

Mausel *et al.* (1992) also calls attention to a calibration problem that is encountered when using VRS. There is an increase in literature on the subject and more information on calibration techniques is already available. Geometric calibration or registration *inter alia* can be a problem when using VRS. According to Jensen (1986) one of the more serious problems is "vignetting away from the centre of the image being digitized". Any distortion of the sensors will be carried over to the digital remote sensing data and will make it difficult to compile the frame-by-frame mosaic. Consequently it is important that the video-based data should be combined with data obtained from other data sources, especially in a geographic information system context (Mausel *et al.*, 1992). Alban *et al.* (1992) point out that a global positioning system (GPS) can be used to capture geographic coordinate data directly on video images. Thus the accurate geographic position of the flying

strips or individual image frames of the video images can be determined quickly and easily. Clerke (1994) used the above-mentioned system successfully in a study in East Africa. This study showed that the co-ordinates and time (obtained by means of a GPS) can be entered into a personal computer to provide location data within 10 m accuracy.

Vibration of the aircraft is another factor which can influence image quality significantly, especially if the lens is focused on a larger focal area. Suitable shock-absorbing material should be used in mounting the camera (Clerke, 1994).

### 4.3 DETERMINING THE LAND USE PATTERN

The type of land use information which must be collected, will differ depending on whether one proceeds from a local, regional or national perspective. At the national level the basic land use information required is data on changes regarding crop types and crop yield. For example, the Common Agricultural Policy (CAP) has a complex subsidy and tariff system which is used to control agricultural production in Europe. Monitoring Agriculture using Remote Sensing (MARS) is, *inter alia*, an activity used to forecast production within the European Union. In addition to the MARS program, visual photo interpretation and automatic classification techniques are used to check the subsidy applications of producers. At a local level, on the other hand, decisions are made regarding, crop types, varieties, planting dates, irrigation procedures and the application of artificial fertiliser, and a benefit can be obtained by collecting accurate information concerning production on a land by land basis.

In conducting the research pertaining to this study the possibility of a decision-making mechanism which can be used to identify land use quickly, accurately and cost-effectively and convert them to a GIS format had to be investigated. For this purpose it was decided to investigate the possibility of using colour video remote sensing as an operational aid in the Lower Orange River Area between the Gifkloof Weir and the Manie Conradie Bridge at Kanon Eiland.

The study proceeded from the hypothesis that video remote sensing can be used as an operational management aid to determine flood damage in order to implement sensible floodplain management. The survey was not conducted with a view to updating the existing land use pattern determined by means of an *in situ* survey (1992). Studies on VRS is clear to what degree of accuracy land use can be identified on floodplains. Consequently it was not the primary intention to attempt to classify land use 100 per cent accurately, but rather to use the results obtained by means of VRS to calculate the mean annual flood damage, and to compare these results with those obtained by means of the *in situ* survey. Thus it was possible to determine the value of VRS as an operational decision-making mechanism by weighing the cost involved against the benefits obtained.

#### 4.3.1 PROCEDURE AND METHODOLOGY

Negotiations with a view to obtaining permission and funds to test VRS as an operational decision-making mechanism took a considerable amount of time. Once the additional permission and funds had been approved, VRS was applied in the research area in co-operation with the CSIR. Target dates were set, but problems regarding the availability of a suitable aircraft, global positioning system (GPS) and a pilot resulted in the survey being conducted later than was initially planned.

In order to make progress with regard to VRS, it was decided to conduct the survey during the first week of October (1996). Alternative methods of determining land use patterns on floodplains have to be sufficiently accurate, affordable and time-saving. An optimal middle course between operational affordability and image quality must therefore be taken. The ideal is to obtain the highest possible image quality at the lowest possible operational cost. In order to meet these demands, the survey was conducted from a height of 1 500 m above ground level and with a focal point of 5,4 mm. According to the above-mentioned formula (Figure 4.1), this represents a swath of 2 353 m and an image resolution of 3 m at ground level (Thomas, 1996).

A colour video camera, a monochrome screen, camera mountings and a Cessna 172 aircraft were used. A high image quality camera (Canon UC-40 Hi 8) was used for the study. The camera was mounted in such a way that aircraft vibration would be restricted to a minimum and the best image quality therefore be ensured.

A down-stream route along the centre line of the river was followed during the survey. The flight path followed the meandering of the river and did not consist of a straight line as is usually the case. This was done in order to keep the cost as low as possible. At Kanon Eiland three flight paths were followed in order to cover the northern, middle and southern parts of the island. A second flight was also planned in order to conduct a more comprehensive survey at a 2 m resolution. Due to weather conditions (strong wind etc.) the survey was cancelled.

After the aerial survey an *in situ* survey was undertaken to verify land use identified during the aerial survey. Various places on the floodplain were visited by road and information was recorded on 1:50 000 maps.

#### **4.3.1.1 Processing of the data**

A personal computer was used for frame grabbing which consisted of the capturing of one video frame per 30 seconds. Graphic Workshop 95 was used to convert the images to JPEG (joint photographic experts group) format files. The total research area comprises 14,3 MB digital data.

After the data had been entered into the computer, two classification techniques, namely computer-based digital classification and aerial photograph interpretation (API), were used. Computer-based analysis comprises the use of computerised techniques to classify land use and trace the boundaries of lands by means of an automatic edge-finding technique. API is a statistical approach to the classification of land use which consists of grouping pixels according to reflected light or colour. It is performed by making use of uncontrolled and controlled classification. It was decided not to use the computer-based classification technique, for the following reasons:

- ☞ Overlap with regard to inter-classification colours as a result of poor flying conditions and overcast weather.
- ☞ Intra-frame variable lighting caused by lens effects (Thomas, 1996).
- ☞ The very large set of digital data that was collected.

Next API was used to determine land cover. API is an established technique which is commonly used in conjunction with remote sensing (Thomas, 1996). Marsh *et al.* (1990) used the same technique to identify land use in the agricultural sector. The success of the technique largely depends on a trained eye for distinguishing between different contrasting colours, shades and textures. API was performed by printing each image on a colour printer (HP Deskjet 1200) at a resolution of 300 dpi (dots per inch). After this the prints were mosaicked by overlapping and gluing together successive printouts. By using transparencies as an overlay, land cover was classified by means of API.

An automatic edge-finding technique was used to identify the boundaries between lands. Where there were high boundary contrasts, the technique worked well, but where there were light, vague boundary contrasts, it functioned poorly. In addition to the above-mentioned, the following GIS-based tasks were also performed:

- ☞ Scanning of annotated data in order to create a digital vector data set.
- ☞ Georeferencing of the data set by making use of ground control points.
- ☞ Projection with a view to orientating the data set in such a manner that it would correspond to the existing mapped surface area.

#### **4.3.1.2 Results of video remote sensing**

The colour of each pixel is a function of light condition, land cover and ground resolution. During the survey light conditions were variable and a 3 m resolution was used throughout. The above-mentioned factors made interpretation of the land cover, namely vineyard, rotational cropping and lucerne, with the aid of API quite a challenge, especially where overcast conditions prevailed (Thomas, 1996).

It proved difficult to distinguish between vineyards and rotational cropping in the early growth stage, because both types of vegetation exhibited more or less the same vegetative bare to covered ground relation per pixel<sup>2</sup>. Consequently the colour composition of the pixels were such that it proved very difficult and even impossible to distinguish between vineyards and rotational cropping. During the study it was found that a 3 m ground resolution provided insufficient textural information to enable one to distinguish between crop types (Thomas, 1996). If a suitable resolution is used, it will, however, in fact be possible to distinguish between the pattern of the trellis system of vineyard crops and the more even pattern of rotational cropping, and thus between vineyards and rotational cropping. A suitable resolution can be obtained by making use of a monochrome camera (B&W VIDEK MEGAPLUS 1280 \* 1024 digital frame camera). This type of camera was tested by King *et al.* (1992, as quoted by Mausel *et al.*, 1992)<sup>2</sup> and one meter elevation height was obtained by flying at a height of 1 525 m and using a 60 per cent frame overlapping and 2,6 km<sup>2</sup> coverage. In addition to the above-mentioned problems, printouts with insufficient resolution aggravated the problem. A higher printout resolution (600 dpi) was suggested, but because of problems related to insufficient funds and the fact that the time for completing the task had run out, it was decided to not to act on the suggestion.

In general the boundaries between lands are reasonably straight and where they were curved, they proved easy to distinguish and could be determined with a reasonable amount of certainty. As a result of poor light conditions, it proved especially difficult to distinguish the boundaries between lands planted with the same crops or crops which appeared to be the same.

A considerable amount of time was taken up by the process of ensuring that the registration of ground control points would be executed as accurately as possible. In spite of this a root mean square (RMS) error<sup>3</sup> of 0,408 occurred (recommended RMS error = 0,001). A smaller RMS error (0,193) was effected later by making use

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<sup>2</sup> Lourens (1990) in detail the same problem when using LANDSAT and SPOT. Marsh (1990) also had difficulty distinguishing between cultivated and uncultivated walo when using VRS, especially where the walo was in an early growth stage.

of projected transformation, but it was a time-consuming process<sup>4</sup>. Once the projected transformation was performed, the deviation from the original reference was approximately 38 m. The following factors also had an influence on the large RMS error:

- ☞ Distortion of images as a result of the use of a wide-angle camera. (Wide-angle lenses increase the geometric distortion and result in a shift away from the centre of the image.)
- ☞ A mosaic frame-by-frame set-up error caused by the fact that the flying path was not a straight line, but followed the meandering of the river.

In many cases a global positioning system (GPS) is used to facilitate the georeferencing process and determine it accurately. According to Thomas (1997) the research area had to be covered exhaustively, linearly (from top to bottom) and laterally (from one side to the other) with the aid of a GPS before aerial GPS could be used.

#### 4.4 EMPIRICAL RESULTS

After the completion of the above-mentioned study by the CSIR (Division of Water, Environment and Forestry Technology), the results were converted to a GIS format so that the flood damage simulation model could be used as the land use map. During the 1992 *in situ* survey 4 753 ha were mapped, while only 81 per cent (3 861 ha) of the area was mapped during the video survey (1996). For the purpose of comparison the 1992 land use map was adjusted to correspond more or less to the video survey (1996). Problems such as difficulty in distinguishing the boundaries of lands planted with different types of crops and even the boundaries of lands planted with the same type of crop, distortion of the sensors and problems related to geometric registration resulted in the surface areas identified by the

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<sup>3</sup> Is discussed in detail in Du Plessis *et al.* (1995:57).

<sup>4</sup> Marsh experienced the same problem and states that to devote additional time to re-registration of the video picture frames is impractical. According to Clarke (1994) the USA has already developed software which automatically transforms video images to obtain the best possible orientation of frames.

video-based survey not corresponding with those identified during the *in situ* survey.

According to Du Plessis *et al.* (1995) there is not a significant difference in flood damage between the different vine cultivars. Consequently it was decided to group together sultana, wine-grapes and hanepoot. Table 4.1 shows the total surface area covered by the different crops as identified during the above-mentioned two surveys.

**Table 4.1: Total surface area of land use between the Gifkloof Weir and the Marie Conradie Bridge at Kanon Eiland**

IN SITU SURVEY		VIDEO SURVEY	
Crop	Surface area (ha)	Crop	Surface area (ha)
Vineyards	1 687	Vineyards	971
Rotational cropping	1 038	Rotational cropping	1 766
Lucerne	711	Lucerne	1 009
Fallow lands	44	Fallow lands	115
<b>TOTAL (ha)</b>	<b>3 480</b>	<b>TOTAL (ha)</b>	<b>3 861</b>

Forms of land use that could not be classified, were indicated as unknown. For the purpose of calculation such lands were classified as fallow lands in the flood damage simulation model. Vineyard surface areas differ considerably and indicate the problem experienced by Thomas (1996), namely that it proved difficult to distinguish between vineyards and rotational cropping. If the additional 728 ha rotational cropping identified during the video survey is added to the vineyard surface area (971 ha) identified during this survey, it adds up to more or less the same vineyard surface as that identified during the *in situ* survey. Surface areas of other crops also differ, although only 18 fewer lucerne lands were classified during the VRS survey than during the *in situ* survey. More rotational cropping (152 rotational cropping lands) and fewer vineyards (391 vineyards) were identified during the VRS survey than during the *in situ* survey. Although the total surface area according to the video survey is larger than that of the *in situ* survey, a total of 232 fewer lands (19 %) were mapped during the video survey. This illustrates the difficulty of distinguishing the boundaries of lands. In total 1 224 lands were

mapped during the *in situ* survey, compared to the 992 lands mapped during the VRS survey.

In many cases lands were identified in the flow area of the river, which illustrates the inaccurate georeferencing of VRS (Figure 4.2). It confirms that "vignetting away from the centre of the image being digitized" occurs (Jensen, 1986). Mausel *et al.* (1992) recommends that video-based data should be combined with other data sources, especially in a geographic information system context, and it was therefore also decided to combine the results of the *in situ* survey with those of the video survey. For this purpose the existing land use map (*in situ* survey) was used as georeference and land use identified by means of the video survey were used as a database. In most cases surface areas of different crops were decreased, for example:

☞ Vineyards	841 ha
☞ Rotational cropping	1 565 ha
☞ Lucerne	1 031 ha
☞ Fallow lands	43 ha.

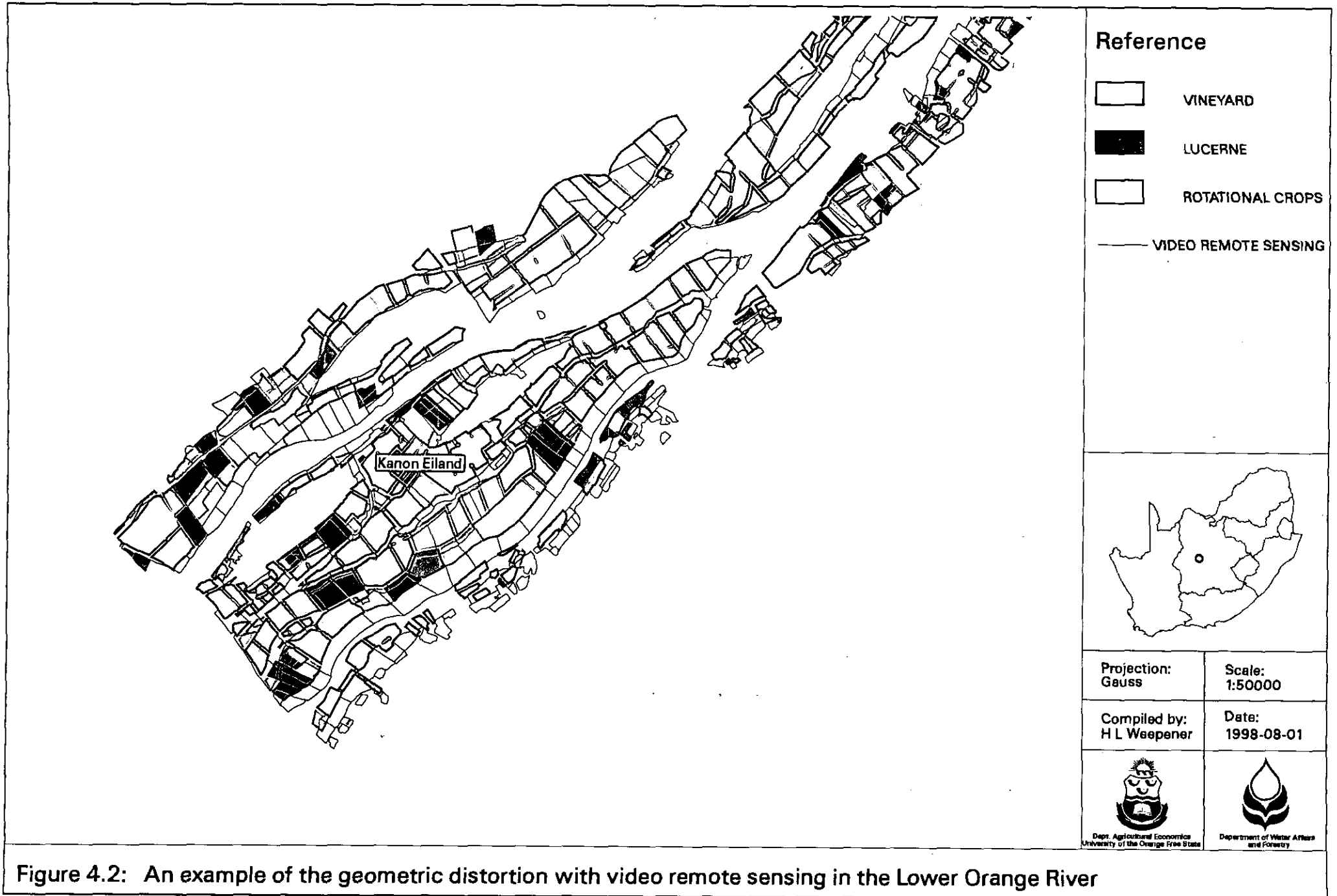


Figure 4.2: An example of the geometric distortion with video remote sensing in the Lower Orange River

After the above-mentioned adjustment had been effected, the total surface area corresponded to the total surface area of the *in situ* survey (Table 4.1), namely 3 480 ha. This indicates an improvement in the geometric registration.

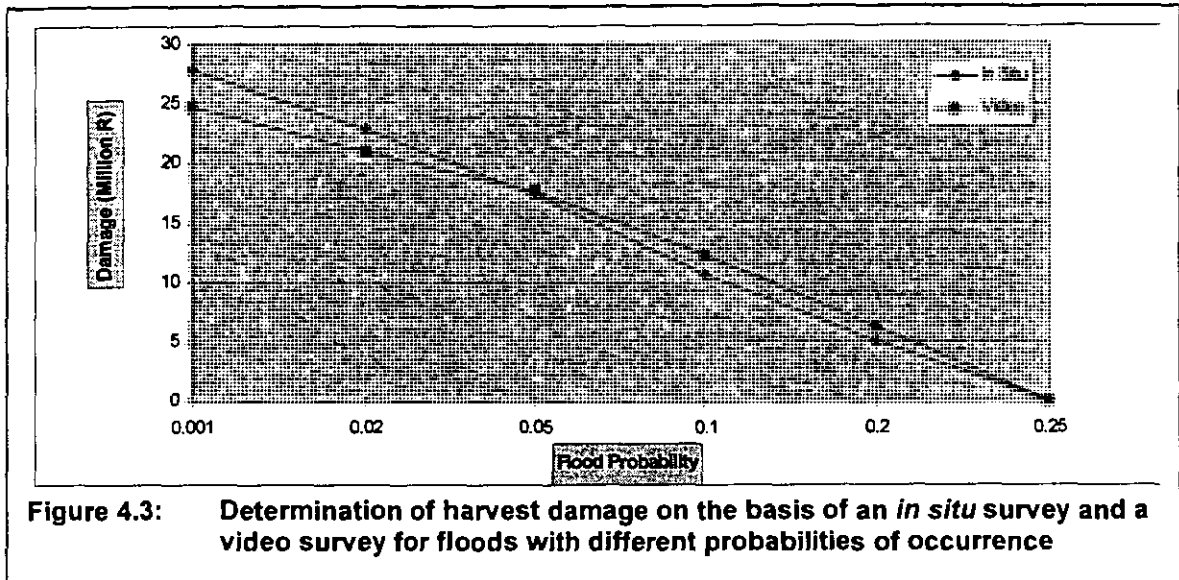
Vineyard crops are long-term crops and if it is accepted that a vineyard has a life-span of 25 years, the land use pattern should not have changed significantly since 1992. The ground control during the video survey nevertheless appeared to indicate that land use has changed to a certain extent. Conversations with Kotze (1997) indicated that fewer vineyards than expected were planted during the past five years. In order to really do a comparative study, the 1992 *in situ* survey should also be upgraded to 1996. As a result of problems related to funding and time, it proved impossible to meet this demand.

Next the above-mentioned land use maps (video and *in situ* surveys) were used as a land use database for the purpose of determining the total mean annual flood damage for the research area. Loss functions were adjusted to provide for the new land use classification. No distinction was made between the different vineyard age groups (new, young, old), and a weighted mean value, according to surface planted, was used to determine the mean annual flood damage (MAD). Crop budgets were adjusted to 1996 as base year.

#### 4.4.1 TOTAL MEAN ANNUAL FLOOD DAMAGE

First the difference between the *in situ* and video surveys with regard to the different damage categories, namely harvest, crop and soil damage, was investigated. Figure 4.3 represents the total mean annual harvest damage according to the *in situ* and video surveys. In general the video survey indicated more damage, especially in the case of lower flow than the *in situ* survey. The opposite is true in the case of higher flows where the *in situ* survey indicated more damage than the video survey. The reason for this lies in the fact that the video survey mapped more rotational cropping than vineyards. Consequently this survey indicated a higher initial impact of flood damage, because damage already occurs at an earlier stage. In spite of these differences, the harvest damage calculated on

the basis of the VRS survey and that calculated on the basis of the *in situ* survey correspond very well. Harvest damage calculated on the basis of the VRS survey exhibits a mere three per cent deviation when compared to harvest damage calculated on the basis of the *in situ* survey, although individual differences between individual floods vary from 1 to 11 per cent.



The opposite is true in the case of crop damage (Figure 4.4). According to Table 4.1 the *in situ* survey mapped 716 ha more vineyards than the video survey, resulting in the calculation on the basis of the *in situ* survey showing considerably more flood damage to the crops, especially in the case of higher flow, than the calculation based on the video survey. There was a deviation of up to 30 per cent with regard to the crop damage resulting from individual floods, although as a whole crop damage as calculated on the basis of VRS corresponds 87 per cent with the results of the *in situ* survey.

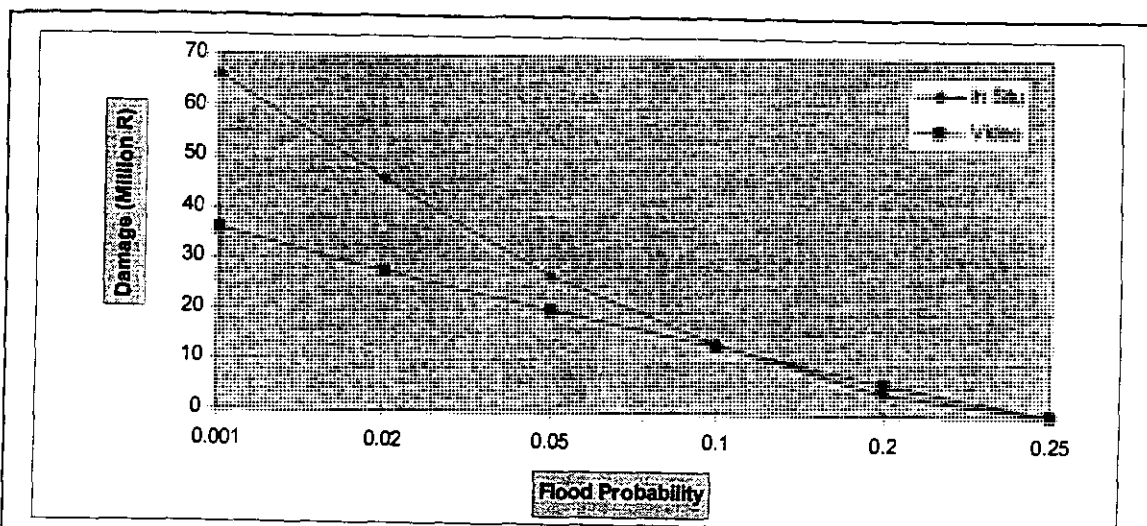


Figure 4.4: Determination of crop damage on the basis of an *in situ* survey and a video survey for floods with different probabilities of occurrence

Figure 4.5 portrays the soil damage as calculated on the basis of the *in situ* and video surveys graphically. Due to lens distortion resulting in geometric distortion and problems with regard to georeferencing, a total of 381 ha more lands were mapped during the video survey than during the *in situ* survey (Table 4.1).

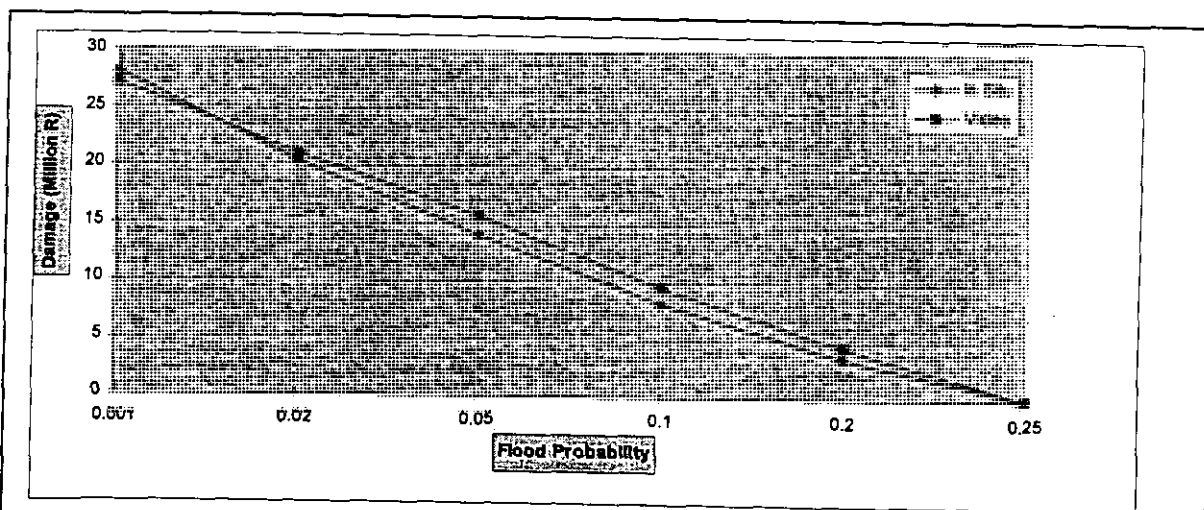


Figure 4.5: Calculation of soil damage based on an *in situ* survey and a video survey for floods with different probabilities of occurrence

The last-mentioned, together with the form of the soil loss function, explains the difference in soil damage as calculated on the basis of the video and *in situ* surveys. The differences are, however, not extensive.

Next harvest, crop and soil damage were grouped together in order to calculate the MAD. Table 4.2 indicates the MAD as calculated on the basis of the *in situ* and video surveys.

**Table 4.2: Total mean annual flood damage (MAD) between the Gifkloof Weir and the Manie Conradie Bridge at Kanon Eiland, 1997**

	<i>In situ</i> survey Damage (R)	Video survey Damage (R)
5 years	12 718 516	16 371 974
10 years	36 064 562	34 776 455
20 years	57 937 529	53 030 358
50 years	88 656 434	69 348 301
1000 years (RMF*)	121 807 123	87 563 658
<b>MAD</b>	<b>9 127 289</b>	<b>8 575 798</b>

\* Abbreviation: RMF = regional maximum flood

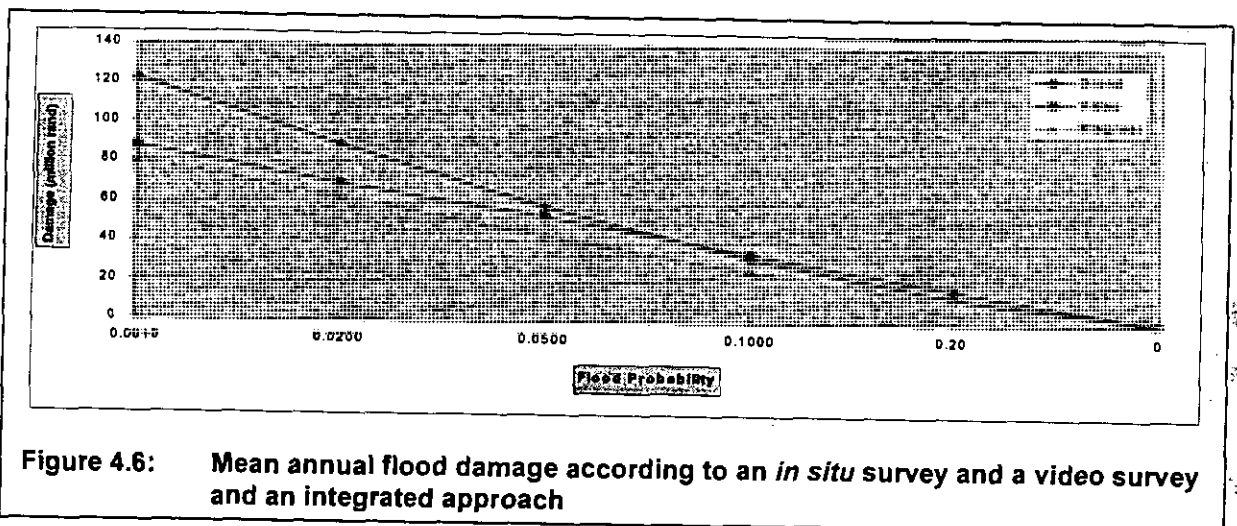
Although the video survey indicates more flood damage in the case of lower flows, the *in situ* survey indicates so much more damage in the case of higher flows that the total mean annual damage as calculated on the basis of the *in situ* survey is six per cent more than that calculated on the basis of the video survey. There is a deviation of up to 30 per cent in the MAD for individual floods as calculated on the basis of the two above-mentioned approaches. In spite of this the MAD, as calculated on the basis of the VRS, agrees 94 per cent with the results of the *in situ* survey.

#### 4.4.2 INTEGRATION OF OPERATIONAL DECISION-MAKING TECHNIQUES

An alternative way in which VRS can possibly be applied, is as a timely and cost-effective method of updating existing land use surveys. This might be chosen in preference to making use of VRS as an independent isolated survey. Surveys can then be made at a lower flying level in order to facilitate API. In the case of most of the remote sensing studies undertaken, operational techniques and visual images, whether obtained from satellite or aircraft platforms, are used in conjunction and not separately. This makes calibration between the techniques possible and better and more accurate results are obtained. Consequently it was decided to integrate

the results of the *in situ* survey (1992) and those of the video survey (1996) and use them together to serve as a land use database. Boundaries of lands and georeferencing of the *in situ* survey were used and the land use classification obtained by means of the VRS was accepted as the land use pattern.

Figure 4.6 portrays the results obtained by integrating the *in situ* and video surveys in order to use them as an operational decision-making technique.



According to Figure 4.6 the results obtained by means of the video survey and those obtained by means of the integrated approach are closer to each other than the results obtained by means of the *in situ* survey. After the geometric distortion was corrected, the flood damage differed 24 per cent from the flood damage as calculated on the basis of the *in situ* approach. The latter phenomenon can be explained by the smaller surface areas after correction of the geometric distortion. Although the VRS technique has certain limitations, it would appear as if the above-mentioned disadvantages cancel out and that this technique therefore provides a more correct mean annual damage than the integrated approach.

Consequently one may conclude that the incorrect interpretation of crops has a greater influence on the determination of the MAD than geometric distortion. In studying the level of accuracy with which video remote sensing can be used to distinguish between crop types, it was found that, compared to the *in situ* survey (1992), at least 24 per cent of vineyards were mapped incorrectly as rotational cropping.

#### 4.5 CONCLUSION AND RECOMMENDATIONS

A logical expectation was that the results obtained by means of VRS would differ from those of the *in situ* survey. The question is therefore not whether the results of the above-mentioned surveys differ, but rather whether the difference is such that it will have a significant influence on flood control and flood damage control measures as well as on flood management plans. The increased costs incurred in order to collect more accurate and refined data, must therefore be weighed against the benefits obtained.

In evaluating the above-mentioned aspects it is important to determine for which purpose analyses will be used and the organisation or level of government involved. Analyses will differ from a national and local point of view. Information which may be considered accurate enough for the purposes of the national government, will not necessarily be sufficiently accurate when viewed from a regional or local government perspective. At the national level the basic information required for the implementation of agricultural policy is data concerning changes in crop types and crop yield. Photograph interpretation and automatic classification techniques can even be used to check producers' subsidy applications. However, at the local level more detailed decisions regarding crop types, varieties, planting dates, irrigation procedures and application of artificial fertiliser have to be made, and therefore production data must be collected on a land-by-land basis.

National authorities can use video remote sensing as a starting point for estimating the MAD with a view to drawing up guidelines for flood-prone areas. Integration of the different techniques and aids such as satellite images, cartographic maps, aerial photography, existing land use data, etc., helps to increase the accuracy with which flood damage can be calculated even further - something which can be of great value to regional and local authorities. However, the fact that it proved difficult to distinguish between vineyards and rotational cropping does not render video remote sensing invalid as an operational decision-making technique. The time of the year at which a survey is conducted is of crucial importance. Various problems such as the lack of availability of an aircraft or pilot, the lack of availability of knowledgeable personnel and target dates for the completion of the research contributed to the fact that it was impossible to conduct the survey at a different time of the year. If the same type of survey could be repeated, for example during the winter season, it would solve many classification problems. Surveys should be undertaken before the growing season of winter wheat.

Although an *in situ* survey of limited extent was undertaken after the aerial survey, spot-checks aimed at verifying land use identified during the aerial survey should be made on a much more extensive basis. In this regard Ram and Kolarkar (1993) recommend field surveys covering between 25 and 40 per cent of the surface area concerned. Where results of *in situ* surveys and cartographic maps and aerial photographs are already available, the above-mentioned aids must be integrated in order to be able to apply VRS successfully as an operational classification technique. Where no data are available, VRS can serve as a starting point, especially in the case of regional and national authorities, for determining the total mean annual flood damage in flood-prone areas with a view to compiling guidelines for local authorities.

The *in situ* survey undertaken during the 1992 basis year took approximately six months to complete, and various personnel of the Department of Water Affairs and Forestry in Pretoria and Upington and of the Department of Agricultural Economics at the UOFS were involved. In spite of several problems encountered with regard to video remote sensing, data were collected within 30 days and were made

available in GIS format. The cost involved amounted to approximately R19 000 (1996) and it proved possible to determine the MAD with 94 per cent accuracy. If the salaries of the above-mentioned personnel and indirect costs incurred as a result of the drawn-out process of an *in situ* survey are weighed against the costs of a VRS survey, the initial hypothesis can be accepted. Consequently VRS can be recommended as an operational decision-making technique for the determination of mean annual flood damage.

Video remote sensing is a relatively new technique and Mausel *et al.* (1992) are quite justified in remarking that there is an increase in literature on the subject. Consequently, and also as a result of the rapid development of computer technology, the problems experienced with regard to video remote sensing may possibly be solved in the near future.

#### 4.6 SUMMARY

Alternative methods of determining the land use pattern on floodplains were investigated during this study. Remote sensing was used as a starting point. More specifically satellite, radar and video remote sensing (VRS) were investigated.

In Europe satellite remote sensing is regularly used to determine arable and grazing land on which a subsidy benefit is payable on a per hectare basis. Crop statistics are also collected by means of satellite remote sensing. At a regional and local level there is an increase in the use of satellite remote sensing for the purpose of collecting information concerning the changes in land use and with a view to making production forecasts. The accurate identification of crop types depends on the timely availability of images during the crop growth period. Images obtained at a specific time of the year can also be used to determine the yield of different crops (European Space Agency, 1995). A too low image resolution (30 m) and poor images, especially due to overcast conditions result in satellite remote sensing not always being a suitable operational decision-making mechanism. Radar satellites such as ERS-1 and ERS-2 were launched in July 1991 and help to surmount the problem of poor images during overcast conditions. Synthetic

Aperture Radar (SAR) transmits microwave energy to the surface of the earth and records the variation in the strength of the reflected signal. Images are obtained irrespective of overcast and even daylight conditions. Radar is sensitive to the structure and humidity conditions of vegetation and also to the roughness and moisture levels of the soil surface (European Space Agency, 1995). However, SAR cannot serve as a replacement for LANDSAT TM and SPOT images. Each of the aforementioned images has its advantages and disadvantages and they should therefore not be used separately and in isolation, but should rather supplement one another. Inggs (1996) developed a refined procedure for using SAR images to create DTMs. Instead of a satellite, an aircraft is used as the platform. Although the cost involved in using this technique as an operational decision-making mechanism is still high, the possibility of using this technique for the identification of land use and the creation of DTMs should definitely be researched.

Besides the SAR images the NOAA/TIROS series of polar orbiting meteorological satellites are of particular interest to global environmental monitoring programs, because of its Advanced Very High Resolution Radiometer (AVHRR).

It is indeed possible to scan images by means of video cameras (Jensen 1986). Aerial video photography as a remote sensing mechanism developed extremely rapidly especially over the past five years, although video cameras have been used for remote sensing for the past decade (Mausel *et al.*, 1992). The ability to observe live images cost-effectively during data capturing, the fact that analogue images can be interpreted manually from the screen, after which images can be converted to digital values by means of image processing, are certainly a few of the most important benefits which can be obtained by using video remote sensing. The greatest disadvantage of VRS is the relatively low image resolution when compared to a photograph (Mausel *et al.*, 1992). Consequently it would prove difficult to distinguish between certain crop types during land use surveys. Problems pertaining to lens distortion and georeferencing are encountered when using VRS and are carried over to the data, resulting in geometric distortion. In spite of these disadvantages, video remote sensing systems have already proved

to be an effective research mechanism in various fields of application (Vleck, 1983; Nixon *et al.*, 1985; Everitt *et al.*, 1986 and 1989, as quoted by Marsh *et al.*, 1990).

After various remote sensing techniques had been investigated, VRS was used to map land use in the Lower Orange River Area between the Gifkloof Weir and the Manie Conradie Bridge at Kanon Eiland. VRS was used five years after the *in situ* survey (1992). Consequently it must be accepted that land use in the research area may have changed. The primary purpose of the study was not to determine the level of accuracy with which VRS classifies land use, but rather to determine the difference between the total mean annual damage as calculated on the basis of the VRS and that calculated on the basis of the *in situ* survey. The reason for this was to determine the value of VRS as an operational management tool which can be used for the purpose of sensible floodplain management.

A distinction was made between vineyards, rotational cropping and lucerne. Flood damage was subdivided into harvest, crop and soil damage. It was found that the video survey indicated more extensive damage in the case of lower flows. In contrast the video survey indicated less extensive damage in the case of higher flow. The reason for this is that certain vineyards were inaccurately classified as rotational cropping. Consequently the survey indicated more extensive flood damage at a lower inundation depth. With regard to harvest and soil damage, VRS and the *in situ* survey indicated a difference of 11 and 12 per cent respectively in the case of individual floods. In the case of damage to harvests, the MAD as indicated by the two above-mentioned methods corresponds 97 per cent, while the MAD with regard to soil damage corresponds 94 per cent. More significant differences are, however, encountered in the case of crop damage, in which case VRS and the *in situ* surveys indicate a difference of up to 30 per cent in the case of individual floods, although there is an 87 per cent agreement between the MAD as calculated on the basis of VRS and that calculated on the basis of the *in situ* survey. If the aforementioned damage categories are combined, there is a difference of only four per cent in the MAD.

The hypothesis formulated initially, namely that video remote sensing can be used as an operational management aid for the purpose of determining flood damage for floodplain management planning, cannot be rejected. The best results can be obtained by integrating available data, such as the results of *in situ* surveys, cartographic maps, aerial photography and satellite images. Great care should be taken in planning VRS in order to ensure that surveys are conducted at the right time of the year. In the case of the present research area surveys should be conducted before the growth season of winter wheat. Surveys can also be conducted at lower heights, especially in cases where digital land use information is already available. A middle course between the highest possible image quality and the lowest possible operational cost should be followed in determining flying heights.

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## CHAPTER 5

### DYNAMIC HYDRAULIC SIMULATION

#### 5.1 INTRODUCTION

During the first phase of the research a firm of consultants, Chunnett, Fourie and Partners, was employed to provide hydraulic data, namely water heights and velocity for floods with different probabilities of occurrence. A steady flow simulation program was used for this purpose. The inflexibility of the model, resulting in shortcomings such as constant flow as one moves downstream, no time dimension (duration), simulation of only primarily open channel conditions and constant water flow during the manipulation of levees resulted in a shift of emphasis from steady flow simulation to dynamic flow simulation. A decision was then made to link a dynamic hydraulic simulation model with FLODSIM. This would enable easier assessment of optimal flood management options, because the impact of typical flow hydrographs on the riverine environment could now be modelled.

There are several approaches which can be used to simulate the hydraulics in channels and rivers and these are discussed first, after which separate scenarios are developed for the research area. Lastly results obtained by means of FLODSIM are discussed.

#### 5.2 APPROACHES TO HYDRAULIC SIMULATION

At present a variety of floodplain flow modelling techniques are used, varying from simple qualitative calculations based on historical flood events after calculation of backwater curves, to sophisticated one- and two-dimensional modelling techniques (Anderson and Bates, 1994).

Although flood data usually meet the requirements with regard to levels of quality and accuracy, there is a possibility that all variables cannot always be taken into

account. The conflict between flow complexity and the availability of sufficient and accurate data leads to various problems in simulating the water flow in rivers. The above-mentioned problems can be obviated by means of data collection activities such as detailed topographic surveys, flow and site inspections. The latter will definitely yield more accurate data, but will need considerable more time and resources for the completion of any such modelling study. Consequently the amount of research which can be conducted will be limited and mistakes in specific areas will constantly occur (Anderson and Bates, 1994).

Next the following three approaches to the simulation of flow in rivers and channels are investigated and discussed briefly:

- ☛ Steady flow hydraulic models.
- ☛ One-dimensional hydraulic models.
- ☛ Two-dimensional hydraulic models.

### 5.2.1 STEADY FLOW HYDRAULIC MODELS

Hydraulic information regarding steady flow in open channels formed a small but important part of the rapidly developing hydraulic science (Woodward and Posey, 1949). The Channel Flow Profile (CFP) Program is a fully interactive simulation program for the analysis of steady flow profiles in open channels, rivers, spillways and water courses. This approach is a well-known step-by-step method for the calculation of backwater curves, i.e. water level profiles (Chunnett, Fourie en Partners, 1993). The minimum hardware requirements for the use of the CFP program is a 286 PC, mathematical co-processor, 640 KB RAM and a Hercules CGA or EGA screen (Jorgensen, 1994). The CFP program can perform the following main functions:

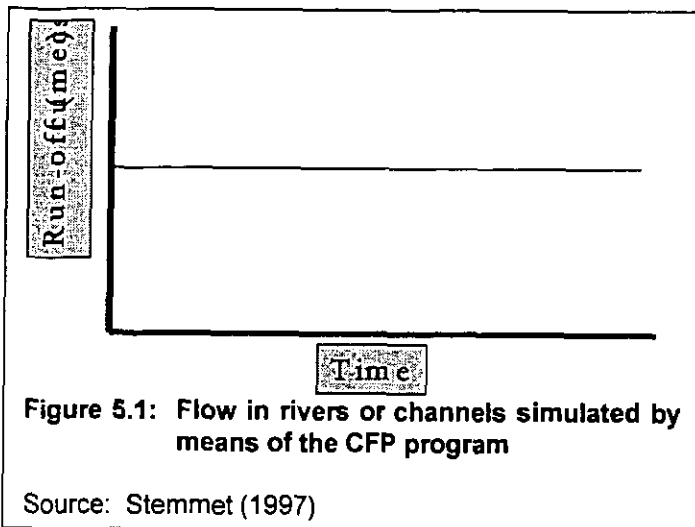
- ☛ One-dimensional analyses with a view to estimating the water surface profile and the incidence of change in flow type (hydraulic jump). The cross section geometry is taken into account.
- ☛ Flow along channels.

- Calculations regarding hydraulic jumps can be specified to be based on momentum equations for a unit width channel or momentum equations for the actual cross section areas.
- Transition losses in the case of channels which divide or merge can be specified.
- Special functions enable the user to copy data easily and cross sections can readily be adjusted.

Information such as prescribed flood peaks, regular cross sections along the particular part of the river, with intermediate distances measured along the main stream, assumptions regarding roughness values, initial value(s) for water level(s) and observed flood marks (Chunnett, Fourie and Partners, 1993) are required for the calculation of floodwater levels.

Before water flow in channels and rivers can be simulated, the form of the channel must first be determined or estimated. The form of the channel is estimated by taking a series of cross sections and assuming that changes in channel characteristics between cross sections occur linearly. Distances along the channel (stake value - SV) indicate the location of cross sections and will increase downstream in the river (Woodward and Posey, 1949). Chunnett, Fourie and Partners (1993) state that cross sections of the river or stream must preferably be obtained from appropriate maps at a scale of no less than 1:5 000. Contour intervals must not exceed one metre and enough spot heights for the definition of the flow channel itself must be available. The distances between successive sections of the expected flow path of the main stream during the flood must be determined. After this the geometry of each cross section can be calculated by defining a series of points. Successive points are connected by means of straight lines. Points are defined by providing a chain distance and a corresponding height. If one faces downstream, chain distances will increase from left to right as far as points in each cross section are concerned. The above-mentioned straight lines between defined points are called the base layer segment. The roughness of the bottom of the channel is defined by means of Manning's coefficients of friction ( $n$ ) (Woodward and Posey, 1949). The use of Chezy's formula is preferred to that of Manning's formula in many instances. Years of experience have shown that water

level profiles for rivers and streams would not necessarily be calculated with a greater degree of accuracy if Chezy's formula was substituted for Manning's formula (Chunnett, Fourie and Partners, 1993). The gradient of the bottom between any two cross sections is defined as the change in elevation between the lowest points in two cross sections (Jorgensen, 1994). Run-off indicates the



volume of water per time unit that passes a specific point or section. If the flow is steady, the run-off will be the same and remain constant over time at all the sections along the channel. Figure 5.1 portrays the above-mentioned aspect graphically. The average speed at a specific section can be calculated by

dividing the run-off by the cross sectional area of the flow at the specific section (Woodward and Posey, 1949). Manning and Cutter's formulas are friction formulas and are frequently used in the USA in cases of steady homogeneous flow conditions. The channel must therefore be homogeneous, the gradient of the water surface must be constant and must correspond to the bottom of the channel (Woodward and Posey, 1949).

Manning's formula can be expressed mathematically as follows:

$$V = \frac{1}{n} R^{2/3} S^{1/2}$$

where:

V = average flow speed (m/s)

R = hydraulic radius (m)

S = bottom gradient

$\eta$  = roughness coefficient (friction factor).

Cutter's formula differs from the preceding and is expressed mathematically as follows (Woodward and Posey, 1949):

$$V = C\sqrt{RS} \text{ and}$$

$$C = \frac{41,65 + \frac{0,00281}{S} + \frac{1,813}{n}}{1 + \frac{n}{\sqrt{R}} \left(41,65 + \frac{0,00281}{S}\right)}$$

where:  $C$  = roughness coefficient

Both formulas reflect the average speed in terms of the hydraulic radius, the gradient and the coefficient of roughness. In the case of homogeneous flow in open channels the following variables are usually estimated:

- ☞ Speed of run-off.
- ☞ Roughness coefficient.
- ☞ Gradient.
- ☞ Depth of flow.

Woodward and Posey (1949) provide Manning's roughness coefficient which can serve as a guideline and which vary from 0,009 to 0,150. In choosing roughness coefficient the possible state of the river and its banks during the flood must be taken into account (Chunnett, Fourie and Partners, 1993). Woltemade and Potter (1994) calculated roughness coefficient in the field on the basis of the size of bottom particles and vegetation on the floodplain. Anderson and Bates (1994) determine roughness coefficient by means of standard photographic interpretation methods developed by Chow (1959). The choice of roughness coefficient plays an important role in flood studies. In a study Woltemade and Potter (1994) show that peak run-off decreases by 27 per cent if the roughness coefficient is increased from 0,053 to 0,100.

Once the run-off, roughness and gradient have been determined, it is possible to estimate the depth of the flow. If the run-off at a specific point in a trapezoidal channel with 8 ft bottom width, side gradient 1:1, a homogeneous bottom gradient of 2 ft per 1 000 ft and a roughness coefficient of 0,017 is 160 ft<sup>3</sup>/sec (cubic feet per

second - c.f.s.), the depth of flow can be calculated as follows according to Woodward and Posey (1949): ( $Q=160$ ;  $b=8$ ;  $S=0,002$ ;  $n=0,017$ ).

$$\frac{Q n}{b^{8/3} S^{1/2}} = \frac{160 * 0,017}{256 * 0,0447} = 0,238$$

The value is looked up in Table 102A in Woodward and Posey, (1949) and a flow depth of 0,783 m (2,61 ft) is obtained. Proceeding from this it is possible to construct backwater curves, (Woodward and Posey, 1949). The height of the water surface is plotted against the friction gradient and curves are estimated for different Q values. By increasing or decreasing these values in relation to the square root of the run-off, other Q values can be determined and plotted.

At a sub-section the geometric data (GD) corresponding to the specific flow depth is calculated proceeding from the GD of the adjacent upstream and downstream cross sections. Calculations involve the linear interpolation of the GD by proceeding from the specific flow depth of the sub-section at each adjacent cross section. It is important to note that the GD is influenced considerably by the angle of the bottom gradient in relation to the form and surface of the adjacent cross section and the desired flow depth at a subsection (Woodward and Posey, 1949).

Sometimes one is expected to calculate backwater curves, for example in the case of a stream flowing around an island. Backwater curves are calculated for each channel up to the point where the two channels merge. After this the height of the water surface levels is plotted against the run-off to determine the total run-off of both channels, provided that the water level is the same in both channels at the upstream point where the channel divides.

## 5.2.2 DYNAMIC HYDRAULIC MODELS

The realisation of the complexity of flow on floodplains and the need for more detailed model information, such as an indication of dynamic flood zones, resulted in the emphasis being shifted from steady flow simulation to more sophisticated flow modelling techniques for a variety of geomorphologic problems (Anderson and Bates, 1994). Numerous dynamic hydraulic simulation models exist, of which the

MIKE 11 Program is frequently used. Broadly stated MIKE 11 is a numeric flow model providing information on flood levels, flow speeds and even the impact of proposed flood control and flood damage control measures on flood levels and flow speeds in floodplains (Muller and Rungoe, 1996). More specifically MIKE 11 is a software package for the simulation of run-off, water quality and sediment transportation in rivers and irrigation system channels. According to (Nielsen *et al.*, 1991) the following basic modules can be handled with the aid of MIKE 11:

- Hydrodynamic module (HD) which calculates run-off and variation in water level in rivers and on floodplains.
- Sediment transportation module (DT).
- Water quality module (WQ).
- Dispersion transportation module (TD).

It is not only possible to handle the above-mentioned modules separately, but data transfer between modules and linkage to physical processes such as river morphology are also possible. A typical MIKE 11 simulation is portrayed by the diagram in Figure 5.2.

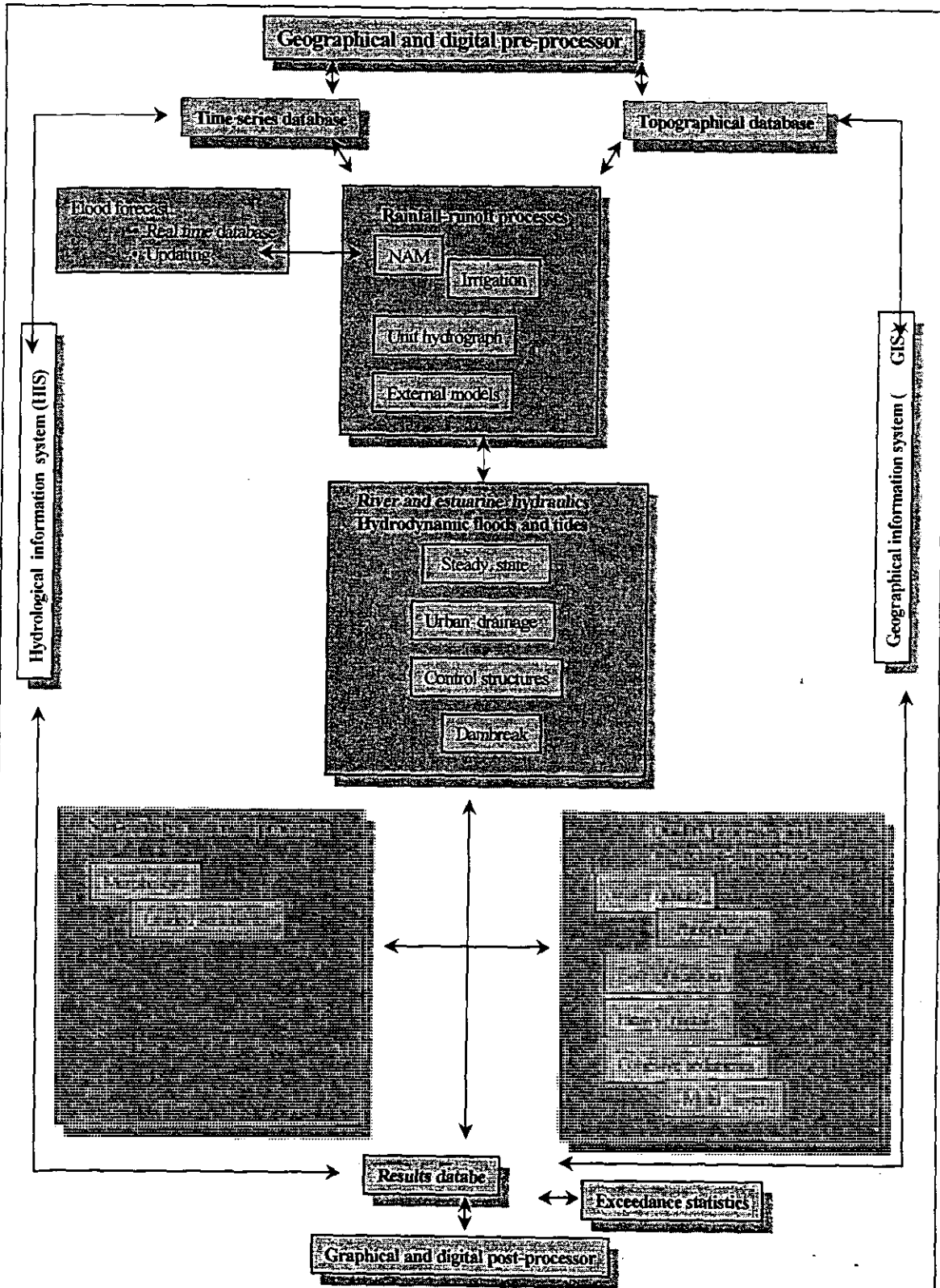


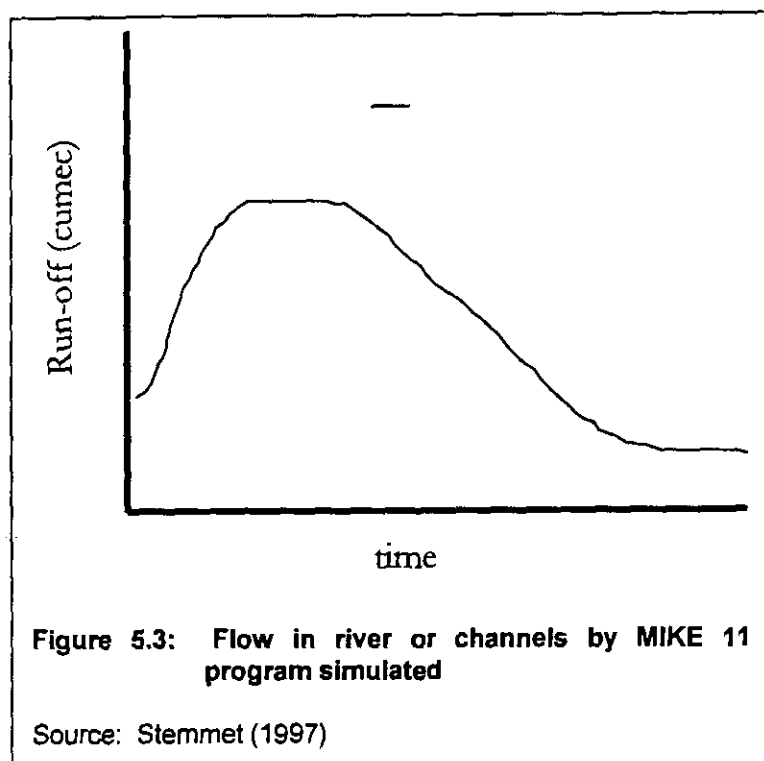
Figure 5.2: A typical MIKE 11 simulation

Source: MIKE 11 General Reference Manual

Activities of the hydrodynamic module include:

- flood forecasting module (FF) which forecasts run-off and water levels on a near real time basis;
- dam break module;
- urban drainage;
- control structures such as simulation of control gates of irrigation channels and reservoirs;
- quasi steady flow, and
- automatic calibration of resistance of soil layer.

The greatest difference between CFP and MIKE 11 lies in the time aspect involved



in MIKE 11. Flow is no longer steady but is simulated in a dynamic manner. Consequently the run-off at all the sections along the channel will change over time. Figure 5.3 is a graphic representation of the above. In addition to the above, MIKE 11 is also quasi two-dimensional. The advantage of this is that more than one flow path

can be modelled simultaneously. A further description of various aspects of MIKE 11 can also be found in MIKE 11 General Reference Manual (1995), Refsgaard *et al.* (1988) and CAI and Myburgh (1988) and it will not receive any further attention here.

In striving to arrive at an effective flood control strategy, Muller and Rungoe (1996) recommend that both flood simulation models and GIS techniques should be used. The successful use of GIS for the management of floodplains depends on the successful interfacing of numerical flood models and GIS models. Muller and Rungoe (1996) succeeded in effecting an interface between MIKE 11 and GIS Arc View. Two- and three-dimensional water level and flood inundation maps can be created by means of the above-mentioned interface. The system uses a three-dimensional soil surface or digital terrain model (DTM) and water levels created by means of MIKE 11 to calculate flow depths. Immersion boundaries for various flood scenarios, such as scenarios with and without flood protection measures, are determined quickly and easily. In addition to the above-mentioned this system is user-friendly (Muller and Rungoe, 1996). Gyasi Agyei *et al.* (1996) also use a DTM in a study aimed at deducing the main channel network.

Woltemade and Potter (1994) calibrated MIKE 11 rainfall run-off and another hydrodynamic model for the Grant River in south-west Wisconsin by making use of 15 years' data on historical flood events. Results reveal that river morphology, valley width, stream gradient and hydraulic roughness influence the flood peak separately and jointly. Flood peaks vary up to 49 per cent from one simulation to the next, depending on the geomorphologic conditions.

As a result of the considerable disruption and loss of life caused by the 1978 floods in India, real-time flood forecasts were made for the Yamuna River in India with the help of MIKE 11. However, the ordinary MIKE 11 Simulation Model was not efficient enough to forecast water level heights for the Yamuna River. Consequently Nielsen *et al.* (1991) developed an additional module providing for water losses in the Yamuna River. The difference between the above-mentioned hydrographs (with and without water losses) represents the effect of the simulated water loss module as a result of retention and infiltration on the vast Yamuna River floodplain stretching from Tajewala to Dehli (Nielsen *et al.*, 1991).

As a result of changes in land use in urban areas as well as in the utilisation of land in the agricultural sector, better drainage management has become essential. Consequently Masumoto and Sato (1993) developed a dynamic program aimed at establishing the optimal location of drainage facilities from an economic investment point of view. Cost functions are an important economic aspect and are used in the dynamic program. The use of the dynamic program for the optimal location of drainage facilities proved successful.

On the other hand Anderson and Bates (1994) point out that one-dimensional approaches are sometimes not able to provide all the information, such as flood zones in areas with complex topographic conditions and the characteristics of the floodplain, required by geomorphologists. According to Anderson and Bates (1994) it would also be of great value if flood level models could reflect accurate hydrographs on floodplain environments, while at the same time also being able

- to identify inundation areas or zones and flood lines in the case of storm events;
- to take topographic complexity and all variables into account in spite of poor and insufficient sets of data, and
- to study the impact of geomorphologic change.

Anderson and Bates (1994) successfully solved two problems, namely that of relatively little available data and the problem of one or more missing data items at measuring stations by means of a two-dimensional flow simulation model.

Kawachi *et al.* (1990) developed an efficient and multi-faceted flow model by making use of a combination of the Standard Galerkin Method and the Newton-Raphson Method which can be used to forecast the water depth and run-off in single and multiple channels. The above-mentioned model functions well in case of complex geometric conditions. Kawachi *et al.* (1990) points out that this model can handle any network complexity without changing the program or formulas. By combining the finite element method with the Newton Raphson Method, Kawachi *et al.* (1990) succeeded in solving problems related to unsteady flow.

The MIKE 21, Version 1.3 has been available since November 1992 and is a typical two-dimensional flood simulation model. Also available is Version 1.4 with its increased number of wave modules, more advanced cohesion sediment transportation and many other characteristics (Department of Water Affairs and Forestry, 1997).

### 5.3 THE INTERFACE BETWEEN FLODSIM AND MIKE 11

The hydraulic complexity of the Orange River, problems regarding variations in geomorphology and a need for more detailed simulation information led to a shift of emphasis from steady flow simulation to more sophisticated flow modelling techniques. Consequently a decision was made to use a dynamic hydraulic simulation model to simulate the water level profile of the Orange River between the Gifkloof Weir and the Manie Conradie Bridge at Kanon Eiland. The Department of Water Affairs and Forestry was approached in order to be able to make use of already developed expertise with regard to flood hydrology. During May 1996 the assistance of the Hydraulics Studies Division of the Department of Water Affairs and Forestry was requested via the Directorate Strategic Planning. The MIKE 11 Model was chosen, on the one hand because this flood simulation model is used regularly (also in overseas countries) (Nielsen *et al.*, 1991; Woltemade and Potter, 1994; Havno *et al.*, 1995; Singh, 1995; Muller and Rungoe, 1996) and, on the other hand, because the Department of Water Affairs and Forestry had already acquired the MIKE 11 Simulation Model and is using it for hydraulics studies at present. In addition MIKE 11 offers ideal application possibilities for the research area where different flow paths are encountered, especially in the case of low flows.

In order to be able 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 should be used (Muller and Rungoe, 1996). To do this, appropriate interfaces between MIKE 11 and FLODSIM had to be developed. Special adaptations and interface programs were developed because the PC version of MIKE 11 had been acquired, whereas FLODSIM requires the UNIX operating system. Chapter 7 contains a comprehensive discussion of the development and refinement of FLODSIM.

Next the interface between MIKE 11 and FLODSIM is reviewed briefly<sup>5</sup>. Two programs, namely Mike2Arc (Mike to Arc) and Arc2Mike (Arc to Mike), were created. Cross section information obtained from ARC/INFO serves as input for MIKE 11 for the purpose of simulating the water level profile. By means of the Arc2Mike Program the above-mentioned data are converted to the correct format to serve as an input in using MIKE 11. Similarly the Mike2Arc Program is used to convert the hydraulic data obtained by means of MIKE 11 to the correct format that can serve as a hydraulic database for FLODSIM.

In addition to the development of the above-mentioned two programs, the channel and cross sections must also be defined. The river channel is defined by accurately indicating the centre line of flow for floods with different probabilities of occurrence. The above-mentioned centre line is a line connecting the points of maximum flow speed of the water in the various cross sections. An engineer in the appropriate field usually determines the latter. The centre line is defined in ARC/INFO and serves as the basis for the chain distances of each cross section. The centre line is defined downstream and consists of just one line. Consequently the chain distance is calculated from the start of the centre line and it is therefore accepted that the centre line has a chain distance of zero. If the water can flow in more than one channel, especially in the case of low flows, such channels must also be defined by means of a centre line. Channels which divide, for instance in order to flow around islands, and which merge again, are also specified. The river morphology can also be defined by means of cross sections obtained from ARC/INFO, something which was not possible before. Cross sections must be straight lines and must be made perpendicular to the centre line. Each cross section must cross the centre line, but they may not cross each other. Care must be taken to ensure that cross sections are not made outside the boundaries of the digital terrain model (DTM) (Tchoukanski, 1996).

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<sup>5</sup> A comprehensive discussion follows when the development and refinement of the FLODSIM are dealt with.

The complexity of the Orange River results in it being possible that more than one flow path can be followed, especially in the case of low flows before levees overflow. When flow in the river has increased to such an extent that the levees start to overflow, there is only one flow path over the full width of the valley. There is also uncertainty regarding Manning's roughness factor that must be used for the purpose of modelling. The same roughness value, namely 0,04, which was also used by Chunnnett, Fourie and Partners (1993), was used throughout this study. A combination of the two above-mentioned aspects can result in great differences between calculated water levels (Stemmet, 1997).

In a study of Woltemade and Potter (1994) it was shown that water levels can differ by as much as 49 per cent. Consequently calibration of models, preferably with observed flood levels, is of the utmost importance. After the above-mentioned interfaces had been developed and the model verification completed, MIKE 11 was calibrated for the research area by making use of historical flood events, observed flood marks and existing steady flow simulation data. Unfortunately only one set of observed flood levels, namely that of the 1988 flood ( $8\,300\text{ m}^3/\text{s}$ ) was available and consequently not all points could be calibrated properly by means of observed flood levels. In spite of a few uncalibrated points, calibration could nevertheless be completed successfully. A few of the points which could not be calibrated can be ascribed to secondary hydraulic effects or wave formation (Stemmet and Myburgh, 1997). MIKE 11 is still a one-dimensional simulation model and it was not possible to take the last-mentioned effects into account as well.

#### 5.4 EMPIRICAL RESULTS

Various scenarios were compiled for MIKE 11. As a starting point the same cross sections that were used by Chunnnett, Fourie and Partners (1993) were used to compare MIKE 11 with the CFP Program. Secondly the river morphology was defined by means of cross sections of the digital terrain model (DTM) created by means of ARC/INFO. Woodward and Posey (1949) remark that the geometric data are influenced considerably by the angle of the bottom gradient in relation to the form and surface of the adjoining cross section, and the desired flow depth at a subsection. In line with this it was decided to take cross sections without the help of

hydraulic experts, in order to determine the impact of these cross sections on the mean annual flood damage. The reason why this was done was to determine the level of hydraulic knowledge required to be able to take cross sections from DTMs successfully. Lastly three emergency levee scenarios were compiled to study the impact of the flood protection measures on the hydraulics of the Orange River and to demonstrate the use of FLODSIM. These scenarios were compiled by means of MIKE 11 and is used repeatedly as an input into FLODSIM for the purpose of calculating the total mean annual damage.

#### 5.4.1 CFP VS MIKE 11

The purpose of the first scenario which was studied was to determine the effect of steady and dynamic flow on the mean annual damage (MAD). As a starting point the same cross sections that were used by Chunnnett, Fourie and Partners (1993) were used for the dynamic simulation. No significant differences in water levels were found between the above-mentioned simulations.

Proceeding from the above-mentioned results the MAD in the case of both steady and dynamic flows was determined by means of FLODSIM. The results of the above-mentioned simulations are summarised in Table 5.1.

**Table 5.1: A comparison of the total mean annual flood damage (MAD) between steady and dynamic flow from the Gifkloof Weir and the Manie Conradie Bridge at Kanon Eiland, taking into account the effect of levees, 1997**

Return period	Steady flow Damage (R)	Dynamic flow - single channel Damage (R)
5 years	22 455 848	18 598 571
10 years	45 591 843	39 733 303
20 years	74 007 485	61 595 975
50 years	104 675 353	97 058 703
1000 years (RMF)*	138 868 041	137 400 423
<b>MAD</b>	<b>12 086 537</b>	<b>10 659 372</b>

\* Abbreviation: RMF = regional maximum flood

In general the calculated flood damage is higher in the case of steady flow than with dynamic flow. A possible explanation for this is the fact that MIKE 11 simulates the flow of water over the full width of the river valley more accurately because the river morphology is defined better. Consequently water will cover more places than would necessarily have been the case with steady flow and MIKE 11 will therefore indicate less damage. Further investigation revealed that Chunnnett, Fourie and Partners (1993) obtained their cross section information from the 1988 aerial photography (May 1988). The aerial photos were taken immediately after the 1988 flood and run-off records show relatively high run-off for the specific date. In contrast the DTM was created on the basis of 1:5 000 contour surveyor maps for 1979 at which date the river flow was relatively low. The result is that lower water levels is obtained with the DTM created from the 1979 aerial photography compared to the 1988 aerial photography and results in less damage being calculated. It is possible to use cross section information obtained from the 1:5 000 contour surveyor maps of 1979 as a basis for steady hydraulic simulation. The latter activity should diminish the magnitude of the flood damage calculated by means of each of the two methods in Table 5.1 and this fact should be investigated further.

For individual floods with different probabilities of occurrence, the flood damage calculated on the basis of steady and dynamic flow varies from as low as R1,467 million to as high as R12,412 million. The smallest difference occurs in the case of the regional maximum flood and the greatest difference in flood damage occurs in the case of the once-in-twenty-years flood. The 1988 flood is classified as a once-in-twenty-years flood (Chunnnett, Fourie and Partners, 1993). During the CFP simulations the flood line of the above-mentioned flood was used, on the one hand, to calibrate the steady flow hydraulic simulation model and, on the other hand, to determine the water levels of floods of different magnitude. This is possibly the reason for the great differences in the flood damage calculated for the once-in-twenty-years flood. No definite pattern could be identified which serves to indicate the complexity of river hydraulics. In the case of steady flow the total mean annual flood damage for the research area is R12,086 million compared to R10,659 million

in the case of dynamic flow. A scenario for conditions without levees was also compiled and more or less the same pattern as in Table 5.1 emerged.

#### 5.4.2 CROSS SECTIONS OBTAINED FROM THE DIGITAL TERRAIN MODEL (DTM)

Muller and Rungoe (1996) and Gyasi-Agyei *et al.* (1996) used DTMs to define the main channel network. Consequently it was decided for this study to develop a procedure to determine the river morphology from a DTM. The advantage this holds for future use is that cross section information can be obtained by means of a computer, thus eliminating the manual method of digitising cross section information from topographic maps. The consequence is that a lot of time is saved and that river morphology can be determined quickly and accurately by means of cross sections, making it possible to carry out hydraulic simulation more rapidly.

In co-operation with the Department of Water Affairs and Forestry a suitable method was developed and applied. Water level heights obtained from the DTM and water level heights obtained from the 1988 aerial photography differ because of the reasons already mentioned. For the purpose of determining hydraulic data, water levels in rivers should be as low as possible and therefore the water level heights obtained from the DTM (which was created on the basis of the 1979 contour surveyor's maps) are more reliable.

As a second scenario a hydraulic engineer (Stemmet, 1997) used cross sections obtained from the DTM created for the research area to define 11 channels along which water would flow in the case of floods of different magnitude for MIKE 11. Figure 5.4 shows the above-mentioned multiple channels for the research area. In this case, where provision is made for more than one flow path (11 flow paths were identified for low flows), large differences were observed at cross sections between steady and dynamic flow simulations. In the case of floods of greater magnitude where there is only one flow path across the whole width of the valley, the calculated water level heights are almost the same in the case of steady and dynamic flow simulation.

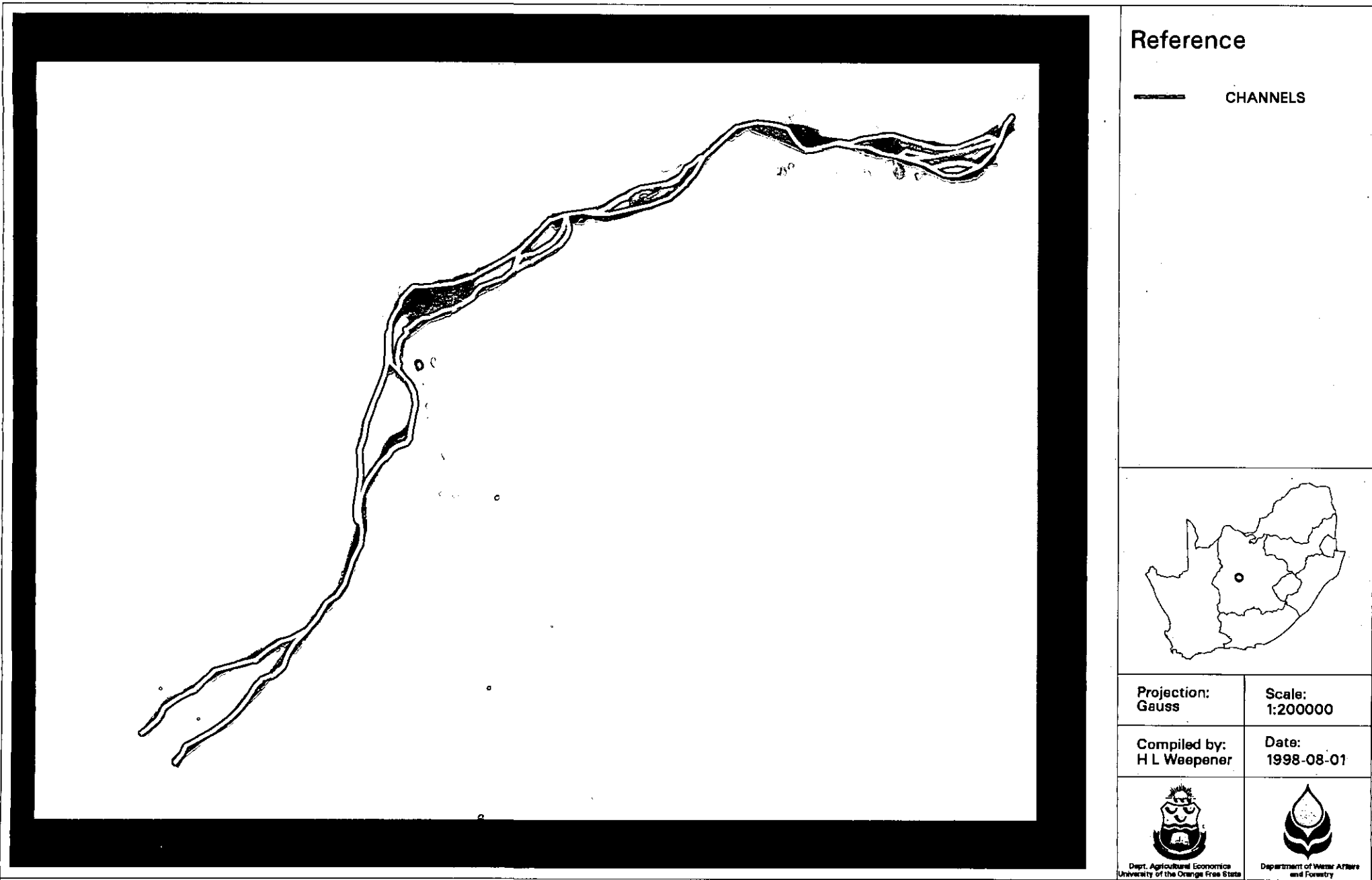


Figure 5.4: Multiple channels for Mike 11 hydraulic dynamic simulation in the Lower Orange River

The above-mentioned aspects can be observed very clearly if Table 5.2 is compared to Table 5.1. The flood damage resulting from the once-in-five-years flood decreases dramatically from R18,6 million to a mere R3 million. The large decrease in damage can be ascribed to the way in which Stemmet (1997) defined the river morphology by means of cross sections. The once-in-five-years flood is forced to stay within the boundaries of the levees, therefore relatively little flooding actually occurs during a once-in-five-years flood. With the exception of the once-in-twenty-years flood there is a reduction in the flood damage resulting from all the remaining floods. No satisfactory explanation could be found for the fact that there was an increase in the flood damage caused by the once-in-twenty-years flood. One possible explanation may be that more levees break during such a flood resulting in a huge escalation in flood damage.

**Table 5.2: Total mean annual flood damage (MAD) between the Gifkloof Weir and the Manie Conradie Bridge at Kanon Eiland when the river morphology is better defined, taking into account the effect of levees, 1997**

Return period	Dynamic flow - multiple channel Damage (R)
5 years	3 033 339
10 years	37 256 153
20 years	69 576 939
50 years	96 963 338
Regional maximum flood (1000 years)	136 363 913
MAD	9 612 212

#### 5.4.3 THE TAKING OF CROSS SECTIONS IN THE ABSENCE OF HYDRAULIC EXPERTISE

It is very important that the river morphology of the research area should be defined as accurately as possible. In order to meet this requirement, MIKE 11 must be provided with accurate and realistic cross section information, chain distances and roughness coefficients. Stemmet and Myburgh (1997) recommended that an engineer in the appropriate field should provide cross section information. Next an effort was made to determine the effect of the chosen locations of cross sections on the MAD.

As a third scenario researchers of the Department of Agricultural Economics, UOFS, took cross sections derived from the DTM to define the river morphology and to provide data for MIKE 11. New water level heights were obtained to serve as a database for FLODSIM. Table 5.3 shows the results of both scenarios, namely those resulting from the researchers cross sections and those resulting from cross sections taken by a hydraulic engineer.

**Table 5.3: A comparison after mean annual flood damage (MAD) with cross sections taken by the research team and a hydraulic engineer, between the Gifkloof Weir and the Manie Conradie Bridge taking into account the effect of levees, 1997**

Return period	Researchers cross sections Damage (R)	Engineer's cross sections Damage (R)
5 years	15 497 210	3 033 339
10 years	35 960 017	37 256 153
20 years	69 580 153	69 576 939
50 years	102 597 711	96 963 338
1000 years (RMF)*	134 193 214	136 363 913
MAD	10 565 171	9 612 212

\* Abbreviation: RMF = regional maximum flood

A very important conclusion which can be arrived at on the basis of Table 5.3 is that if one wishes to determine the effect of individual floods, the river morphology must be defined with great care. The difference in cross sections taken from DTMs especially comes to the fore in the case of the once-in-five-years flood. In the case of the researchers cross sections the damage amounts to R15,497 million compared to R3,033 million in the case of cross sections taken by an engineer with a great amount of hydraulic knowledge. The reason for the large difference is that the cross sections made by members of the Department of Agricultural Economics did not always stop at the appropriate levees, but may have been taken across the levees. This resulted in flood water covering places which would not have been covered in practice.

In contrast with this there is only a five per cent deviation in the MAD calculated on the basis of researchers' cross sections and those taken by an engineer. Consequently it can be concluded that if national or provincial authorities should

require an indication of the total mean average flood damage for a specific area, the river morphology can be determined on the basis of researchers knowledge. Since the research team continuously worked together with experts from the Department of Water Affairs and Forestry and therefore acquired a good background knowledge in terms of flood hydraulics, it can be concluded that, as a first round, the river morphology can indeed be determined on the basis of researchers knowledge. In order to do so, the steps and procedures which must be followed in taking cross sections from DTMs must be performed correctly. Tchoukanski (1996) draws attention to the following aspects that are of importance in defining cross sections:

- ☛ Cross sections must be straight lines.
- ☛ As far as possible cross sections must cross the centre line at right angles.
- ☛ All cross sections must cross the centre line, but they may never cross one another.
- ☛ Cross sections must define the highest possible point which the floodwater may reach.
- ☛ In defining cross sections care should be taken not to exceed the boundaries of the DTM.

In addition to these aspects the cross sections, in facing downstream, must be taken from left to right. Sections must also not be drawn across levees, but must stop on the levees.

This does not imply that cross sections can necessarily be taken with accuracy in the absence of hydraulic engineers. The definition of river morphology is a complex process and wrong information and misinterpretation of answers will have detrimental consequences for the inhabitants of the floodplain as well as for floodplain planners. For optimal floodplain planning in cases where an effort is made to determine the individual effect of floods, it is recommended that a hydraulic engineer specialising in the appropriate field should define the cross sections. However, if a mere indication of the total mean annual flood damage is required, users who have acquired the necessary knowledge and expertise, may define the cross sections themselves.

#### 5.4.4 TOTAL MEAN ANNUAL DAMAGE: MORE FLOOD LINES

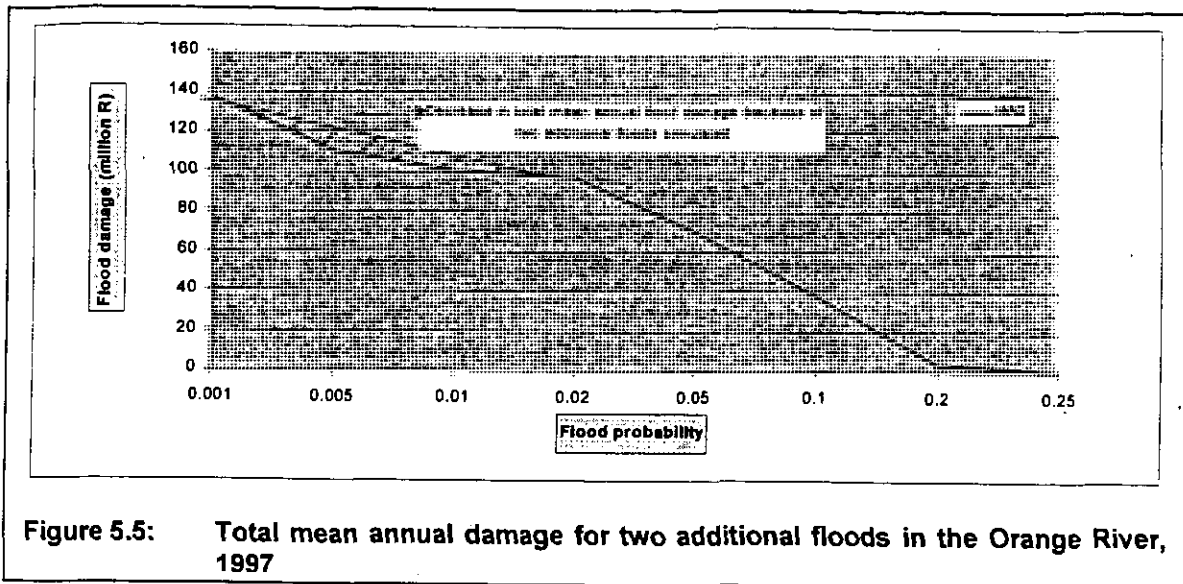
Once a dynamic hydraulic simulation model has been compiled and calibrated for a specific research area, the effect of floods of different magnitude can be simulated relatively easily and quickly, especially if hydrological data on the above-mentioned floods, such as the probability of occurrence and magnitude (cumecs), are available. Smith (1996) points out that although the deviation is relatively small, the effect of exceptionally extensive or rare floods should also be taken into account. Consequently it was decided to also simulate the effect of a 100- and 200-year flood to serve as additional points in the calculation of the MAD. The above-mentioned results are shown in Table 5.4.

**Table 5.4: Total mean annual flood damage (MAD) between the Gifkloof Weir and the Manie Conradie Bridge at Kanon Eiland calculated for additional floods, taking into account the effect of levees, 1997**

Return period	Engineer's cross sections: Flood damage (R)
5 years	3 033 339
10 years	37 256 153
20 years	69 576 939
50 years	96 963 338
100 years	100 044 518
200 years	110 040 052
1000 years (RMF)*	136 363 913
<b>MAD</b>	<b>9 398 662</b>

\* Abbreviations: RMF: regional maximum flood

If Table 5.4 is compared with Table 5.3 there is a deviation of only R200 000 in the MAD. The mean annual damage is therefore not sensitive to a larger number of points, but, according to Smith (1996) these nevertheless provide a better and more accurate answer. Figure 5.5 is a graphic representation of Table 5.4.



According to Figure 5.5 flood damage at the five-year flood line is initially over than in the case of steady flow. Two additional points, namely the 100- and 200-year flood lines result in flattening of the fixed line after which the fixed line once again ascends in the case of the 1000-year flood. The hatched area in Figure 5.5 indicates the decrease of R200 000 in the MAD resulting from the 100- and 200-year flood lines.

#### 5.4.5 MANIPULATION OF LEVEES

During the first phase of the flood damage research it was recommended that levees in the research area should be surveyed fully in order to determine the height of the individual levees in order to be able to do better and more accurate levee analyses. At the time of the completion of Phase 1, the Department of Water Affairs and Forestry in Pretoria offered to survey the levees, but as a result of a shortage of personnel and funds it was decided to do without this aspect. The effect of levees on flood areas were initially calculated manually. During the second phase a program was written to determine the areas that are flooded. The program takes into account the fact that areas that are surrounded by land that lies at a higher elevation than the river water level will not be flooded. The latter is determined automatically by FLODSIM.

In order to be able to compile realistic and viable levee scenarios, discussions were held with Consulting Civil Engineers, the Department of Agriculture and the Department of Water Affairs and Forestry in Upington and Pretoria (Flood hydrologists) leading to the compilation of three scenarios. According to Ekkerd, Nel and Chamberlin, (1997), levees for the research area must be analysed according to four principles, namely

- ☞ The equity principle: All areas in the research area are of equal importance and require the same degree of protection. Levees are of equal importance to every irrigation board and farmer.
- ☞ Economic principle: Levees around islands protect a smaller land surface per levee metre than levees around floodplains. At any rate it seems to be better option in this instance to sacrifice islands as islands hold a higher risk of harvest damage during floods.
- ☞ Urban areas: High priority should be given to levees protecting urban areas. No development should take place below the once-in-fifty-years flood line.
- ☞ The real situation: It is not suitable to increase the height of one levee at the cost of another.

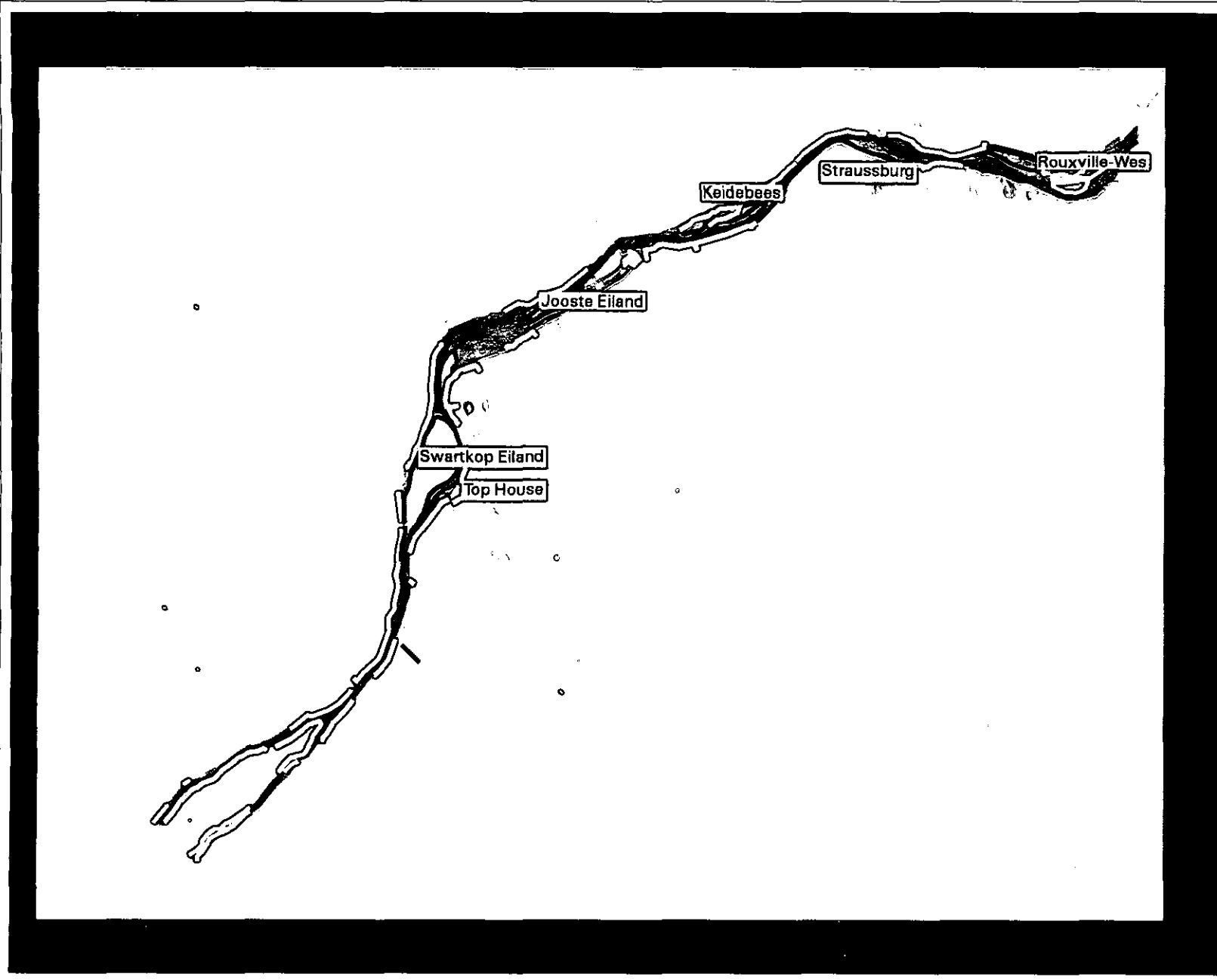
Ekkerd, Nel and Chamberlin (1997) ("experts") recommend that the possibility of controlled inlet of water into floodplains should be investigated, rather than considering the possibility of increasing the height of or reinforcing certain levees to the detriment of others. Threshold values should be studied in order to determine at which levels water should be let in. The essence of this is that flood protection of a particular river reach should be planed holistically, not focussing on only one or the other components thereof.

Subsequently the levees around the island at Keidebees and Jooste Eiland were 'removed', while the rest of the levees were left unchanged, to determine the effect of the change on the hydraulics and in order to be able to use the new hydraulic information to calculate the MAD.

The second levee scenario was compiled in co-operation with the Department of Water Affairs and Forestry in Pretoria, Stemmet and Myburgh (1997). These personnel are not only employed by the Division Hydraulic Studies, but they have acquired considerable experience of flood conditions in the research area. At their suggestion it was decided to increase the height of the levees in certain problem areas. The height of the levees at Straussburg and Swartkop Eiland was therefore increased by one metre, while all the other levees were left unchanged.

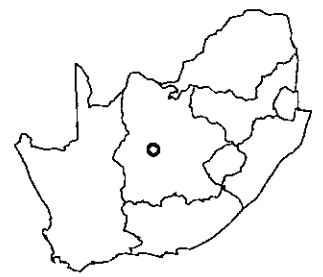
In order to illustrate the use of FLODSIM in a meaningful manner, it was decided to 'erect' new levees at strategic places in the research area. Researchers employed by the Department of Agricultural Economics at the University of the Orange Free State therefore proceeded to compile the third levee scenario, which includes a new levee at Rouxville West and a levee at Top House for the purpose of preventing back up water. The rest of the levees were left unchanged.

The effect of increasing the height of levees, or removing or erecting levees was evaluated by means of FLODSIM in terms of the new hydraulic information. The above-mentioned levee scenarios are portrayed in Figure 5.6.



**Reference**

-  MANIPULATED LEEVES
-  EXISTING LEEVES





Projection: Gauss	Scale: 1:200000
Compiled by: H L Weepener	Date: 1998-08-01
 Dept. Agricultural Economics University of the Orange Free State	 Department of Water Affairs and Forestry

Figure 5.6: Location of hypothetically manipulated levees in the Lower Orange River

#### 5.4.5.1 Removal of levees at Keidebees and Jooste Eiland

Ekkerd *et al.* (1997) recommended that two levees at Keidebees and Jooste Eiland be 'removed'. New cross sections were taken from FLODSIM and used as an input for MIKE 11. New hydraulic information was obtained and the results obtained by means of FLODSIM are indicated in Table 5.5.

Table 5.5: Total mean annual flood damage (MAD) between the Gifkloof weir and the Manie Conradie Bridge at Kanon Eiland with the levees at Keidebees and Jooste Eiland removed and all other levees left unchanged, 1997

Return period	Original damage (R)	Levees removed Damage (R)
5 years	3 033 339	2 395 163
10 years	37 256 153	37 256 153
20 years	69 576 939	69 576 939
50 years	96 963 338	96 963 338
100 years	100 044 518	100 044 518
200 years	110 040 052	110 040 052
1000 years (RMF)*	136 363 913	136 363 913
MAD	9 398 662	9 350 799

\* Abbreviation: RMF = regional maximum flood

If flood protection measures such as levees are removed from floodplains, the flood path is enlarged resulting in a lowering in water levels and less damage. Flood damage caused by floods as specified in Table 5.5 remains unchanged, except in the case of the once-in-five-years flood, where it decreases from R3,003 million to R2,395 million. There is a decrease, although very small, in the MAD from R9,398 million to R9,350 million. This amounts to an average saving of R47 863 per year (1997).

#### 5.4.5.2 Increasing the height of the levees at Straussburg and Swartkop Eiland

At the suggestion of Stemmet and Myburgh (1997) the height of a few levees at Straussburg and Swartkop Eiland were increased by one metre in order to determine the effect of the above-mentioned increase in height on the MAD. Table 5.6 shows the results obtained by means of FLODSIM.

**Table 5.6:** Total mean annual flood damage (MAD) between the Gifkloof Weir and the Manie Conradie Bridge at Kanon Eiland with the height of levees at Straussburg and Swartkop Eiland increased by one metre and all other levees left unchanged, 1997

Return period	Original damage (R)	Height of levees increased Damage (R)
5 years	3 033 339	3 033 339
10 years	37 256 153	37 221 014
20 years	69 576 939	70 676 527
50 years	96 963 338	96 963 338
100 years	100 044 518	100 044 518
200 years	110 040 052	110 040 052
1000 years (RMF)*	136 363 913	136 363 913
MAD	9 398 662	9 440 010

\* Abbreviation: RMF = regional maximum flood

One might expect that increasing the height of the levees in a research area would result in a decrease in flood damage. Contrary to this expectation it was, however, found that the MAD increased from R9,398 million to R9,440 million. During discussions experts (Stemmet, 1997; Myburgh, 1997; Fourie, 1997) pointed out that if the height of levees is increased, flood damage initially decreases until the water level rises above the levees, but that it increases as soon as the flood waters starts to flow over the walls. The reason for the increase in flood damage is that the flood water is channelled into narrower flood paths preventing the water from flowing freely over the whole width of the river valley. The result is rising water levels which results in the breaking of levees with a consequent increase in flood damage. The latter effect can be observed clearly in Table 5.6. Flood damage caused by the once-in-ten-years flood decreases from R37,256 million to R37,221 million if the height of the two levees is increased. In contrast the flood damage caused by the once-in-twenty-years flood increases from R69,577 million to R70,677 million. From an economic point of view, increasing the height of the two above-mentioned levees by one metre cannot be justified, as it results in an increase of R41 348 in the mean annual damage.

During the first phase of the project when only steady flow data were available, it was impossible to point out and address the above-mentioned aspects. At present, however, more accurate and realistic answers are obtained by means of dynamic

hydraulic models, making it possible to manage floodplains in a more sensible manner.

#### 5.4.5.3 Construction of two new levees at Rouxville West and Top House

In order to illustrate FLODSIM further, it was decided to place two additional levees at Rouxville West and Top House. The reason for the placement of a levee at Top House is to prevent flood water damming. New hydraulic information was obtained by means of MIKE 11 and the results obtained by means of FLODSIM are summarised in Table 5.7.

Table 5.7: Total mean annual flood damage (MAD) between the Gifkloof Weir and the Manie Conradie Bridge with two levees erected at Rouxville West and Top House respectively and all other levees left unchanged, 1997

Return period	Original damage Damage (R)	Additional levees Damage (R)
5 years	3 033 339	2 682 361
10 years	37 256 153	37 256 153
20 years	69 576 939	70 305 953
50 years	96 963 338	96 963 338
100 years	100 044 518	100 044 518
200 years	110 040 052	110 040 052
1000 years (RMF)*	136 363 913	136 363 913
<b>MAD</b>	<b>9 398 662</b>	<b>9 401 500</b>

\* Abbreviation: RMF = regional maximum flood

The construction of the two above-mentioned levees results in a decrease of R350 978 in the flood damage caused by the once-in-five-years flood. However, new levees restrict the flood paths and consequently water levels will rise, especially in the case of the once-in-twenty-years flood resulting in an increase in flood damage from R69,577 million to R70,306 million (Table 5.7). The MAD increases by a mere R2 838 and the cost of constructing the levees will definitely exceed the advantages. Other arguments, such as the advisability of reducing the

effect of less extensive floods (once-in-five-years floods) can, however, be advanced in favour of constructing levees<sup>6</sup>.

Further analysis, in the course of which the cost of constructing these two levees is also taken into account, shows that the two levees will only be beneficial in the long term if no repair and maintenance costs are involved. If provision is in fact made for repair costs of 10 and 20 per cent of the building costs following a once-in-ten-years and a once-in-twenty years flood respectively, a net benefit is only achieved at a discount rate of 10 per cent or less. At a discount rate of 12 per cent a negative net advantage of R15 466 is obtained. If an additional 2 per cent maintenance cost is required in respect of the levees, a net advantage of only R16 421 is obtained at a discount rate of 8 per cent. At higher discount rates a negative benefit is obtained. In actual fact relatively little if any maintenance is done on the levees in the research area. With little or no maintenance cost and repair costs of 30 and 50 per cent after a once-in-ten-years and a once-in-twenty-years flood respectively a net benefit of R26 513 is obtained at a discount rate of 8 per cent. At higher discount rates a negative benefit is obtained.

To summarise it appears that the advantages of the above-mentioned levees are marginal. However, whether a net benefit will be obtained from the above-mentioned two emergency levees, will largely depend on the capital and the maintenance costs.

## 5.5 CONCLUSIONS AND RECOMMENDATIONS

In order to be able to conduct meaningful flood damage studies and to develop simulation models, reliable and accurate hydraulic and hydrological data are *inter alia* required. As a first round, steady flow data were obtained from a consultant. During further refinement of FLODSIM and also as a result of the hydraulic complexity of the Orange River, a need for dynamic hydraulic data arose.

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<sup>6</sup> Personal communication by the chairperson of irrigation boards in the Lower Orange River area, 1993.

Consequently it was decided to link FLODSIM and a dynamic hydraulic model in order to get more reliable information.

During initial comparison of the results obtained with steady flow and dynamic flow, it was found that the water level forecasts arrived at by these two approaches did not differ substantially. The hydraulic data received from the consultant proved to be reliable and accurate and that it can be used to calculate the MAD at national and regional level. It is only when a dynamic hydraulic simulation model is compiled in such a way that it makes specific provision for river morphological conditions unique to an area, that steady flow and dynamic flow data differ. More realistic and accurate answers are obtained by means of dynamic hydraulic simulations, making it possible to engage in more reliable planning and management of floodplains and integrated catchment areas.

Where more complex river morphological conditions exist, one could even use two-dimensional hydraulic simulation models such as MIKE 21. The latter has already been used in many studies overseas, but is not yet readily available in South Africa.

## 5.6 SUMMARY

During the first phase of the research a steady flow simulation program was used to obtain hydraulic data. Shortcomings such as constant flow when moving downstream, no time dimension, simulation of primarily single open channel condition and constant water flow during the manipulation of levees resulted in the emphasis being shifted from steady flow simulation to dynamic flow simulation. Thus it was decided to link a dynamic hydraulic simulation model to FLODSIM. In this way it was possible to obtain dynamic hydraulic data for floodplain planning and management.

Flow modelling techniques that are used at present vary from simple qualitative calculations based on historical flood events, to the calculation of backwater curves and to sophisticated one- and two-dimensional modelling techniques (Anderson and Bates, 1994).

Three approaches for the simulation of flow in rivers and channels were investigated, namely steady flow hydraulic simulation, one-dimensional hydraulic simulation and quasi two-dimensional hydraulic simulation. Steady flow programs such as the Channel Flow Profile program (CFP) are fully interactive simulation programs for the analysis of steady flow profiles in open channels, rivers, spillways and watercourses. The CFP approach is a well-known step-by-step method for the calculation of backwater curves, that is to say water level profiles (Chunnett, Fourie and Partners, 1993).

In contrast to this a dynamic hydraulic simulation model such as MIKE 11 is a numeric flow model that reflects information on flood levels, flow speeds and even the impact of proposed floodplain, flood control and flood damage control measures on simulated flood levels and flow speeds (Muller and Rungoe, 1996). In addition to this, simulation of simultaneous run-off in more than one flow path, water quality and sediment transportation in rivers and irrigation channels can also be handled by MIKE 11.

The largest difference between CFP and MIKE 11 lies in the time aspect involved in MIKE 11. Flow is no longer steady, but is simulated dynamically. Consequently the run-off in all the sections along the channel will change over time and the duration of flooding is also taken into account.

Anderson and Bates (1994) points out that one-dimensional approaches are not always able to provide all the information such as flood (inundation) zones in areas with complex topographic conditions and floodplain characteristics. A two-dimensional flow simulation model (such as MIKE 21) was used and applied successfully by the above-mentioned authors. MIKE 21 is a typical two-dimensional flow simulation model and can also handle wave modules and more advanced cohesion sediment transportation (Department of Water Affairs and Forestry, 1997).

As a result of problems such as the hydraulic complexity, the variety of geomorphic conditions in the Orange River and a need for more detailed simulation information, it was decided to use a dynamic hydraulic simulation model to simulate the water level profile of the Orange River between the Gifkloof Weir and the Manie Conradie Bridge at Kanon Eiland. The Department of Water Affairs and Forestry was

approached because this flood simulation model is frequently used (also in overseas countries) (Nielsen *et al.*, 1991; Woltemade and Potter, 1994; Havno *et al.*, 1995; Singh, 1995; Muller and Rungoe, 1996) and because the Department of Water Affairs and Forestry had already acquired the MIKE 11 simulation program and is also using it at present in the Division Hydraulic Studies. Moreover the MIKE 11 has ideal application possibilities with respect to the research area where there are different flow paths, especially in the case of low flows.

In order to be able to use FLODSIM and MIKE 11 meaningfully, the two above-mentioned models had to be linked. Appropriate interfaces between MIKE 11 and FLODSIM were developed.

The river channel is defined by carefully pinpointing the center line of flow for flows with different probabilities of occurrence. The center line is a line connecting points of maximum flow speed of the water between different cross sections. If the water can flow in more than one channel, especially in the case of low flows, such channels must also be defined by means of a center line. In addition to the center line the river morphology was also defined by means of cross sections obtained from ARC/INFO, something which was not possible before. This information has great value and implies a considerable saving of time. Lastly MIKE 11 was calibrated for the research area by making use of historical flood event data, observed flood marks and existing flow simulation data.

Various scenarios were compiled for MIKE 11. As a starting point the same cross sections which the consultant used during steady flow simulation, were also used for MIKE 11. No significant differences in water level heights could be found between the above-mentioned simulations. In general flood damage is calculated more conservatively when using MIKE 11 than when using CFP. The MAD amounts to R12,080 million when CFP is used as opposed to R10,659 million when MIKE 11 is used.

Secondly the river morphology was defined by taking cross sections from the digital terrain model (DTM) created by means of ARC/INFO. In this case flood damage caused by the once-in-five-years flood decreased drastically from R18,6 million to a

mere R3 million. With the exception of the Once-in-twenty-years flood, the flood damage caused by all the remaining floods decreased, and the MAD also decreased further from R10,659 million to R9,612 million.

Lastly three levee scenarios, namely the increasing of the height of specific levees, the removal of two levees and the construction of two new levees at strategic places were compiled. If the height of the levees is increased the flood paths are restricted and water levels rise. The MAD therefore increases from R9,398 million to R9,440 million. The opposite applies when levees are removed. In this case the MAD decreases to R9,351 million. A net benefit is obtained if no maintenance is done on the levees and if the repair cost is lower than 10 per cent of capital cost. The construction of the two above-mentioned new levees causes the MAD to increase to R9,042 million. If maintenance costs, amounting to two per cent and repair costs after a once-in-ten-years and a once-in-twenty-years flood to 10 and 20 per cent of capital cost respectively are taken into account, at a 12 per cent discount rate the cost of erecting the levees exceeds the benefits.

It can be concluded that MIKE 11 has meaningful refinement benefits and the use thereof is consequently recommended. It will be beneficial of benefit to local authorities to be able to determine the effect of individual floods and the benefits attached to various flood protection measures. Steady flow simulation can however still continue to be used by regional and national authorities in order to determine the MAD.

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## CHAPTER 6

### DETERMINATION OF LOSS FUNCTIONS

#### 6.1 INTRODUCTION

The methodology of determining loss functions for sugarcane and infrastructure is discussed in this chapter. In order to estimate flood damage with a simulation model, it is necessary to firstly 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.

The methodology for stage damage curve determination for sugarcane and infrastructure varies greatly and are thus treated in two separate sections in the chapter. The respective sections on sugarcane and infrastructure each start with a discussion on flood damage, with reference to causes and extent of damage. This is followed by an explanation of the methodology for stage damage curve determination where definitions of the different damage categories precede an exposition of the steps followed to determine loss functions for each of these categories. Conclusions are given in the final paragraph of the chapter.

#### 6.2 FLOOD DAMAGE TO SUGARCANE

##### 6.2.1 CAUSES OF DAMAGE TO SUGARCANE

According to Weiss (1976) damage to sugarcane in the Mfolozi floodplain are mainly caused by three factors, i.e.:

- ☞ inundation of sugarcane by flood waters,
- ☞ sediment deposition, and
- ☞ force of flood waters.

The availability of oxygen to sugarcane decreases when the plant is completely or partially inundated by water or sediment. Losses are suffered as a result of inundation either because sugarcane drowns completely (Weiss, 1976), or because of a decrease in sucrose-content (Humbert, 1968). Water moving at high velocity can cause sugarcane to bend, thereby increasing the area of sugarcane inundated as well as the duration of inundation. Even if the bent sugarcane does not drown, growth will be retarded because of an inability of the plant to regain a straight position (Weiss, 1976).

Deposition of large quantities of sand on the Mfolozi floodplain during the Domoina floods in January 1984, led to the expropriation of 27 farms in the area (Mfolozi Sand Plain Planning Committee, 1986). In an effort to address the problem of sand deposition, the local co-operative, the Mfolozi Co-operative Sugar Planters limited, constructed a flood control system, which included a bifurcator and spillway. The advantage of the spillway became apparent during the floods of October 1993 when the water carried only silt and no losses due to sand deposition were suffered (Mike Hulett according to editor, 1993). The deposition of silt can even have a positive effect, which is not quantifiable because of a lack of data (Weiss, 1976). In addition the spillway decreases the velocity of water moving over the floodplain, resulting in less damage as the force of water decreases (Mfolozi Sand Plain Planning Committee, 1986). Since damage to sugarcane as a result of sediment deposition and the force of flood waters have diminished significantly during the period following Weiss' research, these two factors have not been taken into account in the construction of loss functions in the present study. In this study only the first factor, namely inundation of sugarcane by flood waters will be taken into account for the estimation of flood damage.

## 6.2.2 EXTENT OF DAMAGE TO SUGARCANE

According to Humbert (1968) the extent of flood damage to sugarcane is determined by variety, temperature, depth of flood waters, duration of flood and whether sugarcane is inundated by moving or stagnant water. These factors will subsequently be discussed with special reference to how each has been treated in the development of loss functions.

### 6.2.2.1 *Cultivar*

Cultivars used in the Mfolozi floodplain include N12, N14, N17, N19, N22, N24, NCo376 and CP66. Most cultivars are fairly resistant to damage when inundated during the dormant or slow growth phases and high producing cultivars are sensitive to wet conditions and requires good drainage (Humbert, 1968). According to farmers in the Mfolozi floodplain floods affect N19 worst, while NCo376 is fairly resistant to floods. Although cultivars react differently to floods, a general stage damage curve was constructed for sugarcane, since differences between cultivars are difficult to quantify. Farmers in the area agreed that the use of a general stage damage curve for sugarcane would be sufficiently accurate to determine flood damage in the Mfolozi floodplain.

### 6.2.2.2 *Temperature*

Damage to sugarcane increases if floods occur during warm conditions as opposed to cold conditions. High temperatures increase plant activity and subsequently plants have greater water and nutrient requirements (Humbert, 1968). The minimum number of days of inundation before sugarcane is completely destroyed, varies between summer and winter months. Based on temperature data for the Mfolozi Floodplain (Table 3.1), May till October is considered cold months while November till April is considered warm. During the survey farmers indicated that completely inundated sugarcane would die after approximately six days if the flood occurred during cold months and after three days during warm months. This agrees with the critical period of three days used

by Weiss (1976) for purposes of modelling on the basis of experience at Mfolozi Sugar Planters Co-operative and Mount Edgecombe Experiment Station. Although Weiss (1976) acknowledged that seasonal variation is to be expected, he assumed the period to be the same for any month of the year. From the questionnaires it became apparent that not only temperature, but also the age of sugarcane influences the critical period. Younger cane appears to be more susceptible to flood damage than mature cane. This factor was however not taken into account in the study.

### **6.2.2.3      *Depth of flood waters, duration of flood and movement of water***

As mentioned in the previous paragraph, sugarcane will be destroyed if the whole plant is inundated for longer than three or six days, depending on the time of year. According to Rege and Mascarenhas (1965), referred to by Humbert (1968), sugarcane will not be irreparably damaged during periods of inundation if the meristem and uppermost leaves of the plant extend above the water level. If sugarcane stands in moving, oxygen rich water, it can survive up to two to three weeks. In stagnant water it takes only several days before suffocation, even if only the roots were covered by water (Weiss, 1976).

Since roots of sugarcane need oxygen for respiration, oxygen shortage in the root zone as a result of floods decreases the rate of photosynthesis and transpiration. The latter has a negative influence on the sucrose content of sugarcane. Under normal circumstances, slightly dry conditions before harvesting result in a desirable increase in the sucrose content of sugarcane (Humbert, 1968). The decrease in sucrose content was determined with data from questionnaires and an average was taken for the whole area. This decrease is directly reflected in lower income for farmers since farmers are paid per ton sucrose delivered and not per ton sugarcane.

## 6.3 LOSS FUNCTIONS FOR SUGARCANE

### 6.3.1 SUGARCANE DAMAGE CATEGORIES

When primary damage or first order effects are considered, damage to sugarcane refers to damage to the harvest (direct damage) and damage to the crop (indirect damage).

Du Plessis *et al.* (1995) determined soil damage (direct damage) besides damage to the harvest and crop for the estimation of flood damage for irrigation areas in the Lower Orange River region. The general absence of fallow land in sugarcane producing areas results in very limited damage to soil during average floods. A stage damage curve for soil was not developed since farmers in the Mfolozi floodplain indicated only minor soil losses during the February 1996 floods.

### 6.3.2 DAMAGE TO HARVESTS

According to Viljoen *et al.* (1981) damage to the harvest is the loss due to a specific flood in the year of investigation. Direct harvest loss occurs when crops are partially or totally damaged. During floods a percentage of sugarcane will be completely damaged, a percentage will be partially damaged and the rest will not be damaged. For purposes of determining loss functions, the relationship between the total area and areas with destroyed, damaged and undamaged sugarcane respectively, 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 = Total area

$A_D$  (%) = Percentage area with destroyed sugarcane

$A_P$  (%) = Percentage area with partially damaged sugarcane

$A_N$  (%) = Percentage area with sugarcane not damaged.

Indirect loss, which may result if the crop could not be harvested due to wet conditions, is not included in the determination of flood damage since sugarcane is less sensitive to delayed harvesting than crops such as vineyard. During the survey farmers confirmed that indirect losses were limited.

In 1976 Weiss developed a mathematical model to predict flood damage in the Mfolozi floodplain. The model included a stage damage curve for sugarcane. In this study the stage damage curve for damage to harvests was based on the stage damage curve developed by Weiss (1976), while the stage damage curve for damage to crops was developed according to the method used by Viljoen and Du Plessis (1996).

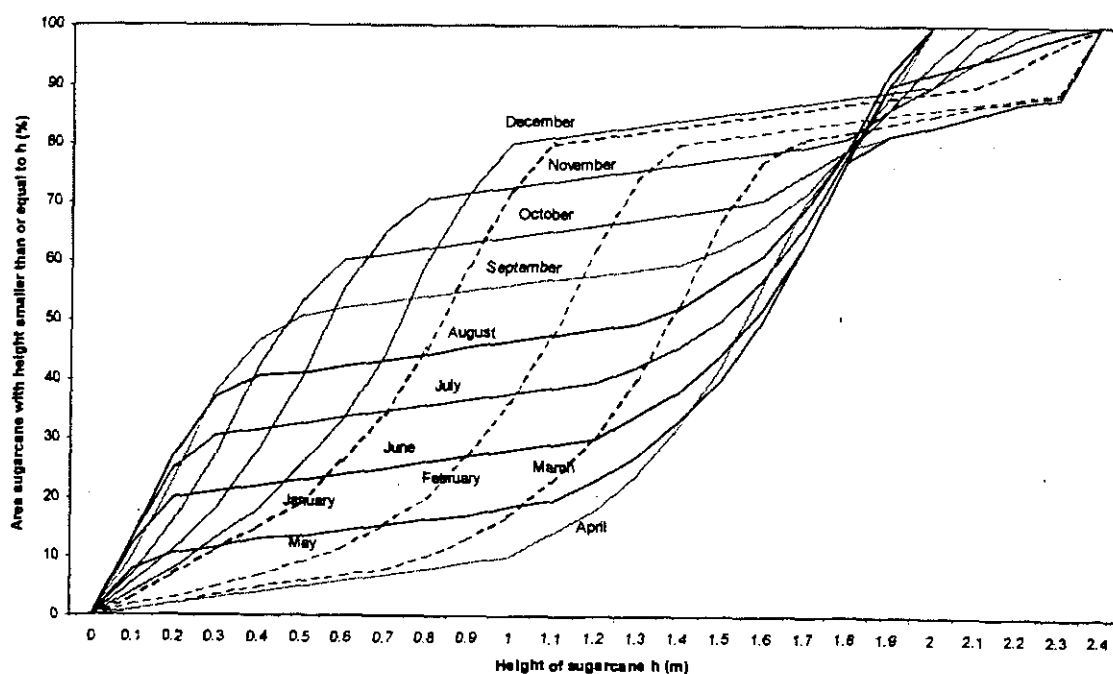
In order to determine the average height distribution of cane for different months, Weiss (1976) combined average monthly growth rates of sugarcane on the Mfolozi floodplain with the time of harvesting. Both the growth rates and period of harvesting used by Weiss (1976) have been updated to prevailing conditions in the Mfolozi Flats. Farmers agreed to the accuracy of average monthly growth rates in Table 6.1. The harvesting season for the Mfolozi Mill generally starts at the beginning of April and continues until the third week in December of each year.

**Table 6.1: Average monthly growth rates of sugarcane in the Mfolozi floodplain**

Month	Jan	Feb	March	April	May	June
Growth (m)	0.28	0.28	0.26	0.18	0.12	0.08
Month	July	Aug	Sep	Oct	Nov	Dec
Growth (m)	0.06	0.08	0.1	0.14	0.18	0.24

Source: SASA Experiment station, 1988

Figure 6.1 indicates an area: cane height: time of year relationship and this can be applied either on an elemental area or whole farm basis. In this study damage is calculated per hectare which is assumed to be representative of the total floodplain. This approach is possible since the aim is to calculate damage for the whole area and not for a specific farm. The dotted lines in Figure 6.1 indicate months falling outside of the harvesting season (January, February and March).

**Figure 6.1: Average height distribution (by months) of cane on the Mfolozi floodplain**

Damage to the harvest (DH) is calculated as the decrease in income due to destroyed sugarcane (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):

$$DH = D - B + P$$

The calculation of the respective components in the above formula is discussed in sections 6.3.2.1 to 6.3.2.3.

### 6.3.2.1 *Decrease in income: destroyed sugarcane (D)*

From the height: area table, the percentage area with sugarcane of a specific height or lower can be determined for every month of the year. Information on the depth and duration of inundation was supplied with the aid of a computer model, Mike 11. Hence the percentage area of sugarcane of different heights which are totally destroyed during the flood, could be determined.

The month during which flooding occurs (Jan to Dec) determines the percentage area with sugarcane of different heights. When immature sugarcane is destroyed, the productive value of the cane is taken as a linear function of that of mature sugarcane, i.e. the ratio of the true height of the damaged sugarcane, to the average height of mature sugarcane.

The decrease in income due to destroyed sugarcane (D) was calculated as follows:

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

$$D_L = A_L * A * \frac{H_L}{H} * C * S_h * GI_s$$

where:

D (R)	=	Decrease in income (destroyed sugarcane)
N (m)	=	Depth of inundation
D <sub>L</sub> (R)	=	Decrease in income for sugarcane with height L
A <sub>L</sub> (%)	=	Percentage area with destroyed sugarcane of height L
A (ha)	=	Total area sugarcane
H <sub>L</sub> (m)	=	Height of destroyed sugarcane (0.1m - 2.4m)
H (m)	=	Average height of mature sugarcane (2.1m)
C (tons/ha)	=	Tons sugarcane per hectare
S <sub>h</sub> (%)	=	Percentage sucrose
GI <sub>S</sub> (R/ton)	=	Gross income per ton sucrose.

With regard to the height of sugarcane (H<sub>L</sub>) and depth of inundation (N), intervals of 10cm (0.1 metres) were used instead of 1cm intervals in order to limit data in the model. The latter can be regarded as a trade-off between accuracy of results and ease of calculation.

### 6.3.2.2 *Decrease in costs: destroyed sugarcane (B)*

The lower yield obtained because of a flood (Paragraph 6.3.2.1) results in lower marketing (harvesting) costs, since destroyed cane need not be harvested nor transported to the mill. The decrease in cost (B) is a direct function of firstly the amount of ton sugarcane destroyed and secondly the marketing cost per ton. The relationship is depicted in the formula below:

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

where:

B (R)	=	Decrease in marketing costs
D (R)	=	Decrease in income (destroyed sugarcane)
GI <sub>C</sub> (R/ton)	=	Gross income per ton sugarcane
M <sub>C</sub> (R/ton)	=	Harvesting cost per ton sugarcane.

### 6.3.2.3 Decrease in income: partially damaged sugarcane ( $P$ )

Partially damaged sugarcane refers to cane that can still be harvested after the flood, but whose quality has deteriorated as a direct result of the flood (Paragraph 6.2.2.3). Sucrose content serves as a measure of the quality of sugarcane. Since farmers are paid per ton sucrose delivered and not per ton of sugarcane, a decrease in sucrose content, adversely affects income. The decrease in income caused by partially damage sugarcane can be calculated as follows:

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

where:

$$A_D = \sum_{L=0.1}^N A_L$$

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

The area with partially damaged sugarcane 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 with sugarcane not damaged, is expected to decrease.

Figure 6.2 shows loss functions for sugarcane in the Mfolozi floodplain based on damage to the harvest that occurs at various depths of inundation. A different curve has been constructed for each month of the year since the area: cane height relationship varies greatly between months, as illustrated in Figure 6.1. In order to keep the graph simple only six months have been represented in the graph.

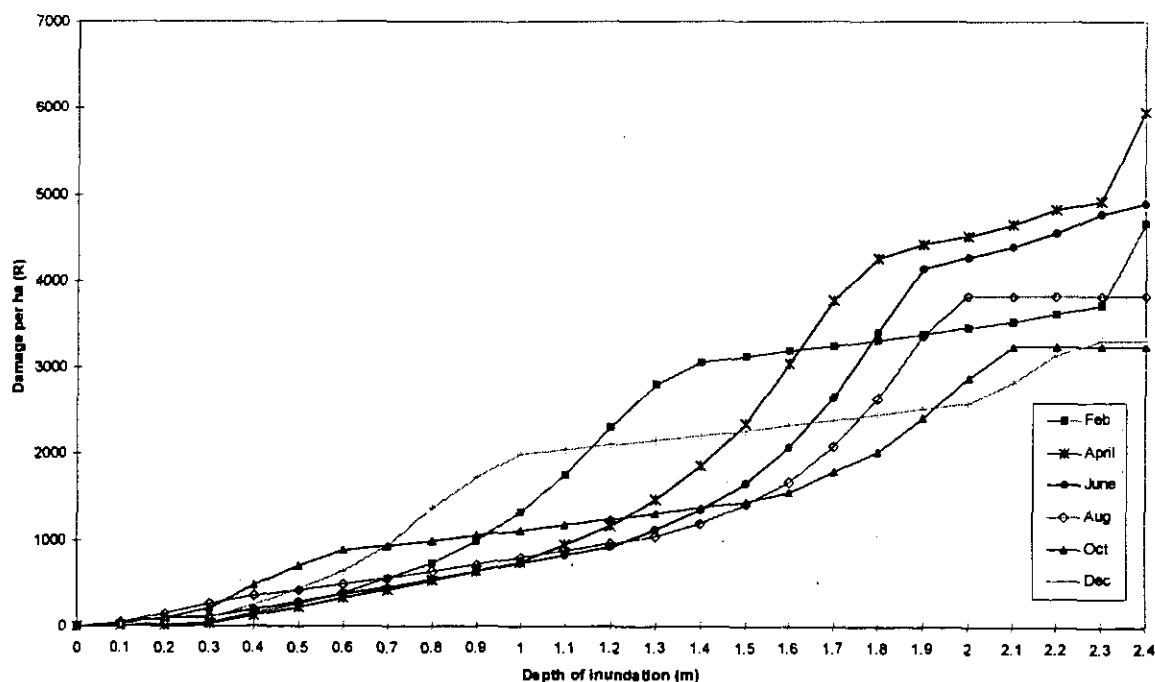


Figure 6.2: Loss functions to determine damage to the harvest of sugarcane in the Mfolozi floodplain, 1995

### 6.3.3 DAMAGE TO CROPS

In the case of perennial crops such as sugarcane, damage to crops can occur besides 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).

After a flood the farmer can decide either to continue production with damaged crops in spite of lower yields in subsequent years, or he can replant sugarcane. In the first case 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 that a lower yield is obtained (Viljoen, 1979). In the second case the damage is the discounted value of additional expenses such as 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 above-mentioned method of determining damage to crops (Viljoen, 1979) was preferred to that followed by Weiss (1976). According to the latter, the extent of damage in the case of replanting sugarcane is determined by a) the cost of establishment, b) loss of growth while planting takes place and c) loss as a result of the lower growth rate of new plantings as compared to ratooning plants.

In order to calculate the value of the loss in income due to damage to the crop, the gross margins of future yields must be discounted to present values (PV) and added together to get the net present value of the gross margin ( $NPV_{GM}$ ). The difference between the  $NPV_{GM}$  without a flood and the  $NPV_{GM}$  with a flood is regarded as the damage to the crop.

The need to discount values where capital investment is involved arises from the time value of money i.e. that money in possession today (presently) is more valuable than the same amount in the future, regardless of the effect of inflation. The time value of money is the result of interest on profit which could have been

earned on the money in the meantime, as well as the risk involved in receiving money in the future subject to many uncertainties (Van Zyl, 1988).

Van Zyl (1988) used short-, medium-, long-term liabilities and own capital of the business to determine the weighted average cost of capital, while Boehlje and Eidman (1987) used only the long-run structure of the farming enterprise. The rationale of the latter is that the cost of capital should be based on the combination of debt and equity capital used to finance the operation in the long run. Hence the weighted average cost of capital ( $d$ ) can be calculated by the following formula (Boehlje and Eidman, 1987):

$$d = k_e W_e + k_d (1 - t) W_d$$

where:

- $k_e$  = after tax rate of return of equity capital
- $W_e$  = long-run portion of equity capital
- $k_d$  = interest rate on debt
- $W_d$  = long-run portion of debt capital
- $t$  = marginal tax rate.

The return on capital consists of a cash return ( $k_{ce}$ ) and an increase in the market value of assets ( $k_{ne}$ ). Given that  $G$  is the proportion of the non-cash return that is subject to tax ( $t$ ), the after-tax cost of equity capital can be calculated with the following formula:

$$k_e = k_{ce} (1 - t) + k_{ne} (1 - tG)$$

Since no questions pertaining to the financial situation of farmers were asked during the survey, several assumptions with regard to the long-run capital structure of the relevant farming enterprises were made in order to illustrate the

calculation of the discount rate. Because of the absence of an accurate discount rate, a sensitivity analysis was carried out with four different discount rates.

With regard to the calculation of a discount rate it was firstly assumed that the average farmer has a capital structure of 60 per cent equity and 40 per cent debt, which would provide reasonable safety against insolvency and opportunity for relatively rapid growth of the business. Secondly the estimate for  $k_{ce}$  was nine per cent, eight per cent for  $k_{ne}$ , 30 per cent for  $G$  and 40 per cent for  $t$ . The resulting after-tax cost of equity capital equalled 13.3 per cent. Lastly  $k_d$  was estimated at 14.5 per cent giving a weighted average cost of capital or discount rate of approximately 12 per cent. The discount rates used in the study were 8, 10, 12, 14 and 16 per cent respectively.

From the questionnaires it appeared that yields are generally lower than normal only during the first two years following the flood. On average yields decreased with twenty and ten per cent 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. Assumptions were made with regard to the option that the farmer will choose:

- ☞ When less than 30 per cent of the sugarcane is destroyed, farmers will not re-establish and production will continue with less than optimal yields in the following two years.
- ☞ When more than 30 per cent of the sugarcane is destroyed, farmers will re-establish sugarcane.

The cost of establishing sugarcane 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. In order to take this into account, it is necessary to have information on the normal pattern of sugarcane establishment. Several farmers indicated that they generally establish ten per cent of the farm annually in the absence of floods and the assumption is made that this applies to all farmers in



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

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

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

Hence damage to the crop if the farmer does not re-establish sugarcane:

$$IC = NPV_1 - NPV_2$$

Damage to the crop if the farmer does re-establish sugarcane:

$$IE = NPV_1 - NPV_3$$

## 6.4 FLOOD DAMAGE TO INFRASTRUCTURE

### 6.4.1 CAUSES OF DAMAGE

Flooding rivers often carry debris, which lead to blockage of narrower parts of rivers and cross sections under bridges. This often causes severe damage to, or total destruction of bridges and can lead to almost immediate overflow of riverbanks. Furthermore, high stream flow velocity gives force to flood waters, potentially causing erosion of riverbanks (Penning-Rowell, 1997). In the Mfolozi floodplain, as in several other flood prone areas, effective structural flood control measures have led to increased activity in the floodplain, with concomitant increased damage during floods. The extensive transportation system and structural flood control measures in the Mfolozi floodplain are frequently damaged by debris deposition and forceful flood waters.

## **6.4.2 EXTENT OF DAMAGE**

The extent of damage to infrastructure depends on the size of a flood, rather than characteristics of a specific flood such as depth and duration of inundation, as in the case of sugarcane. Thus the size of a flood and the distances of roads etc. within the boundaries of each flood, are the most significant determinants of the extent of damage.

## **6.5 LOSS FUNCTIONS FOR INFRASTRUCTURE**

### **6.5.1 INFRASTRUCTURE DAMAGE CATEGORIES**

Infrastructure in the Mfolozi floodplain includes river channels and drains, levees, roads, tramways, spillways and bridges (refer to Paragraph 3.6). Unless otherwise indicated, drains will henceforth refer to river channels and drains collectively. Farmers are responsible for the reparation of private roads, drains and bridges, while the Mfolozi Co-operative carries the cost of repairing spillways, levees and tramways, as well as public roads, drains and bridges.

### **6.5.2 LOSS FUNCTIONS FOR DRAINS, LEVEES, ROADS, TRAMWAYS, SPILLWAYS AND BRIDGES**

Table 6.2 gives flood damage estimates for drains, levees, roads, tramways, spillways and bridges for main floods between 1984 and 1993. Values in Table 6.2 were based on actual flood repair costs for known floods and adapted to present conditions (improved levees and spillway) and escalated to 1995 values (Bosch and Associates, 1995). Flood peak estimates were based on observations and water levels surveyed by Bosch and Associates, as well as data from the Department of Water Affairs and BGA Lund and Partner Consulting Engineers.

**Table 6.2: Flood damage (1995 values) to all infrastructure categories in the Mfolozi floodplain for main floods since 1984**

Flood peak (cumecs)	Date (year)	Flood damage (R'000)						Total
		Drains	Levees	Roads	Tramways	Spillways	Bridges	
800	—	0	0	0	0	0	0	0
2600	1993	141	0	30	80	60	14	325
5148	1989	316	0	240	160	146	47	909
6200	1987	350	932	256	176	160	50	1924
15445	1984	3845	10075	6320	7820	7405	2685	38150

Source: Bosch and Associates (1995)

Damage does not occur until flood peak exceeds 800 cumecs and the spillway only starts operating when flood peak reaches 900 cumecs. The Domoina flood of 1984, which is the largest recorded flood in the floodplain, caused damage to the amount of R38 million of which 26.4 per cent related to damage to levees.

Engineers from the Department of Civil Engineering, University of Pretoria, carried out a regional statistical analysis, using all historical and gauged flood peaks as well as data from four other reliable gauge stations in Northern Zululand. With the General Extreme Value distribution estimated flood peaks for several return periods were obtained. Hence total flood damage to infrastructure for different return periods were estimated (Bosch and Associates, 1995). Table 6.3 gives the respective flood peaks for various return periods as well as the estimated flood damage.

**Table 6.3: Estimated flood peaks and flood damage (1995 values) to infrastructure for various return periods**

Return period (year)	Flood peak (cumecs)	Flood damage (R'000)
2	1302	14
5	2996	395
10	4490	760
15	5700	1100
20	6649	2500
25	7513	3600
50	10750	11000
100	15206	38150

Source: Bosch and Associates (1995)

Flood peaks for different return periods that were calculated for purposes of this study appear in Table 6.4. Engineers from the Department of Water Affairs and Forestry based their calculations on data from Bosch and Associates (1990). The regional maximum flood (RMF) was assumed as a 1:1 000-year flood.

**Table 6.4: Return periods with corresponding flood peak values used in the present study**

Return period (year)	Flood peak (cumecs)
10	3150
20	4720
50	7970
100	9570
200	11280
RMF	15450

Source: Cai and Myburgh (1998)

Determining loss functions for different infrastructure categories for 1:10, 1:20, 1:50, 1:100, 1:200 year and RMF floods, using recorded damage values posed problems for two reasons. Firstly the return periods assigned to different flood peaks by Bosch and Associates (1995) and the Department of Water Affairs and Forestry (1998) respectively, differed to a certain degree and secondly recorded values do not exist for the flood peak values used in the present study (compare Tables 6.2 and 6.4). Hence values for damage to infrastructure for the flood peak values relevant in the present study had to be calculated from the available data in Table 6.2. For each infrastructure category the recorded values in Table 6.2 were plotted and a trend line (binomial function) was fitted through these points. From this trend line the damage for the relevant flood peaks were calculated. The results are presented in Table 6.5.

**Table 6.5: Estimated flood damage (1995 values) for infrastructure categories in the Mfolozi floodplain for relevant return periods**

Flood peak (cumecs)	Return period	Flood damage (R'000)						
		Drains	Levees	Roads	Tramways	Spillways	Bridges	Total
3150	10	182	0	79	0	80	22	364
4720	20	295	0	215	14	136	43	703
7970	50	820	1675	1003	1095	1029	365	5986
9570	100	1289	2928	1791	2071	1954	701	10734
11280	200	1869	4517	2793	3330	3148	1135	16791
15450	RMF	3845	10075	6320	7820	7405	2685	38150

From the estimates in the above table it was possible to calculate the flood damage per metre for all infrastructure categories except bridges. Table 6.6 gives the distances of the infrastructure within the boundaries of the flood lines, which depend on the return period of the flood. It must be noted that the distance of levees and spillways remain constant for all return periods. This is the result of the assumptions that were made in the flood line numerical model (Cai and Myburgh, 1998).

**Table 6.6: Distances of infrastructure within the boundaries of flood lines for relevant return periods**

Flood peak (cumecs)	Return period	Distance (m)				
		Drains	Levees	Roads	Rail	Spillways
3150	10	55540	46010	20000	30870	1120
4720	20	57050	46010	25040	35460	1120
7970	50	57960	46010	29730	46260	1120
9570	100	58090	46010	32050	49760	1120
11280	200	58320	46010	33390	52690	1120
15450	RMF	59660	46010	34260	55000	1120

Table 6.7 shows the calculated damage per metre for the respective infrastructure categories.

**Table 6.7: Estimated flood damage per metre (1995 values) for infrastructure categories in the Mfolozi floodplain for relevant return periods**

Flood peak (cumecs)	Return period	Flood damage (R/m)				
		Drains	Levees	Roads	Tramways	Spillways
3150	10	3.28	0	3.97	0	71.64
4720	20	5.18	0	8.60	0.39	121.32
7970	50	14.15	36.41	33.74	23.67	918.38
9570	100	22.20	63.64	55.88	41.63	1744.82
11280	200	32.04	98.18	83.66	63.20	2810.28
15450	RMF	64.45	218.98	184.48	142.18	6611.61

As mentioned in Paragraph 6.4.2 the main determinants of the extent of flood damage to infrastructure are flood peak and the distance of infrastructure in the floodplain. Furthermore, these relationships can be depicted by loss functions. In regression analysis flood peak (F) was used as independent variable in a Cobb-Douglas function to depict the relationship between damage and flood peak. Since damage to drains, levees, roads, tramways and spillways are influenced by the distance of each within the floodplain, the loss functions of these categories were based on per metre damage values in Table 6.7, while that of bridges and total infrastructure were based on data in Table 6.5. Estimated loss functions are given in Table 6.8.

**Table 6.8: Loss functions (1995 values) for infrastructure categories in the Mfolozi floodplain**

Infrastructure	Stage damage curve*	Adjusted coefficient of determination (R <sup>2</sup> )
Drains	$D_D = (6.12 * 10^{-07}) * F^{1.9020}$	0.983
Levees	$D_L = (1.45 * 10^{-14}) * F^{3.8948}$	0.917
Roads	$D_R = (9.17 * 10^{-09}) * F^{2.4563}$	0.997
Tramlines	$D_T = (1.86 * 10^{-14}) * F^{3.8167}$	0.833
Spillways	$D_S = (1.53 * 10^{-09}) * F^{3.0309}$	0.979
Bridges	$D_B = (9.92 * 10^{-11}) * F^{3.2145}$	0.984
Total	$D_{TOT} = (3.76 * 10^{-09}) * F^{3.1151}$	0.982

\*The F-test statistic and coefficients of all estimated functions are significant at 5% levels  
D: Damage (D<sub>D</sub>, D<sub>L</sub>, D<sub>R</sub>, D<sub>T</sub> and D<sub>S</sub> in (R/m); D<sub>B</sub> and D<sub>TOT</sub> in (R'000))  
F: Flood peak (cumecs)

Figure 6.3 is a graphical representation of the above damage curves for different infrastructure categories that depict flood damage per metre of infrastructure at different flood peaks.

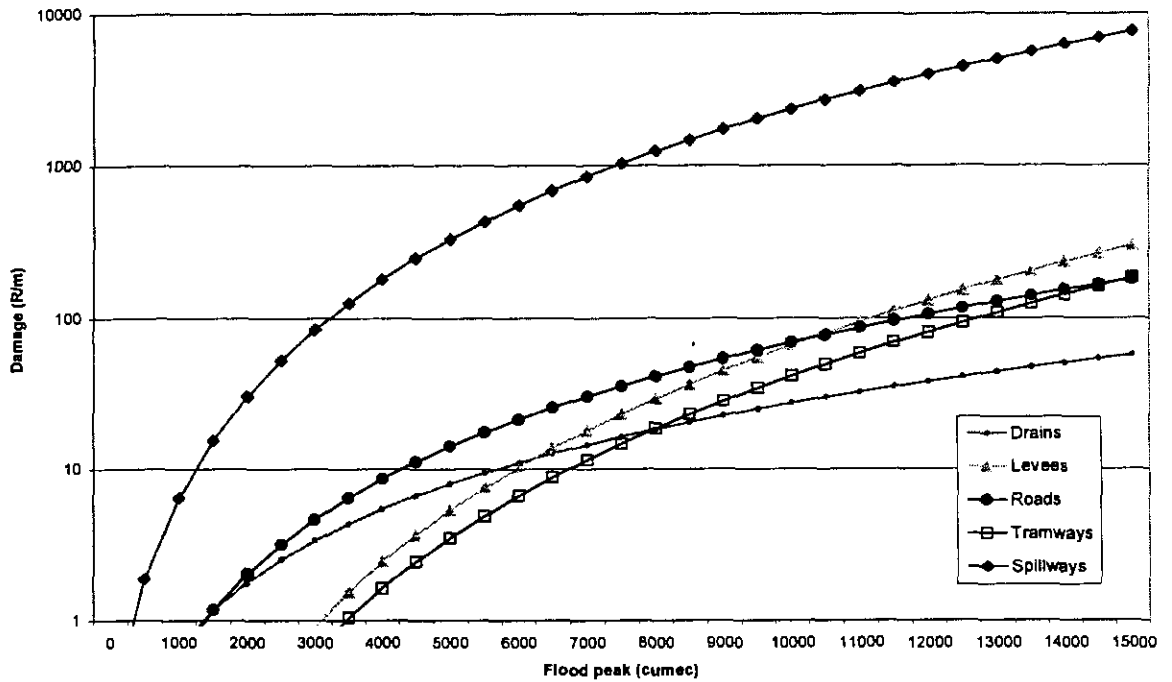


Figure 6.3: Loss functions (1995 values) for different infrastructure categories in the Mfolōzi floodplain

In Figure 6.4 the stage damage curve for bridges is shown together with the recorded flood damage and the calculated flood damage values. Similar graphs exist for all infrastructure categories.

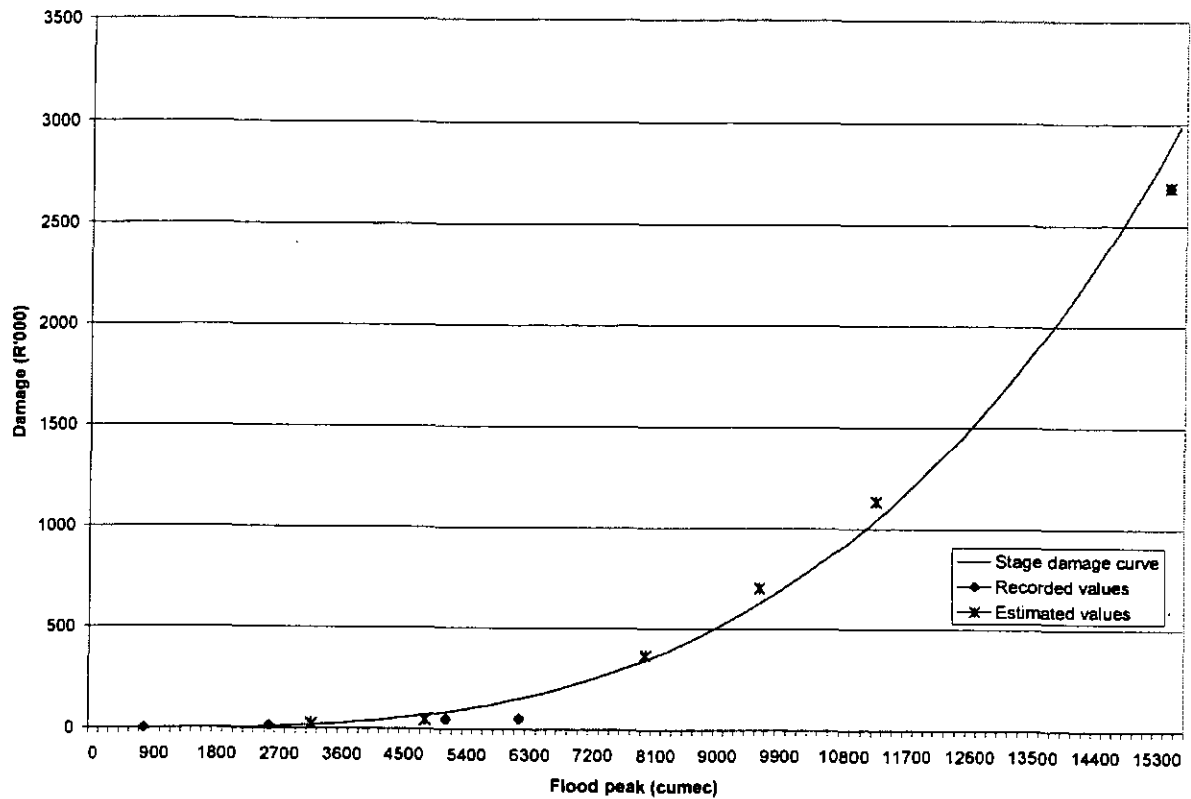


Figure 6.4: Recorded and estimated flood damage values and a loss function (1995 values) for bridges in the Mfolozi floodplain

Figure 6.5 shows the loss function for total damage to infrastructure at different flood peaks.

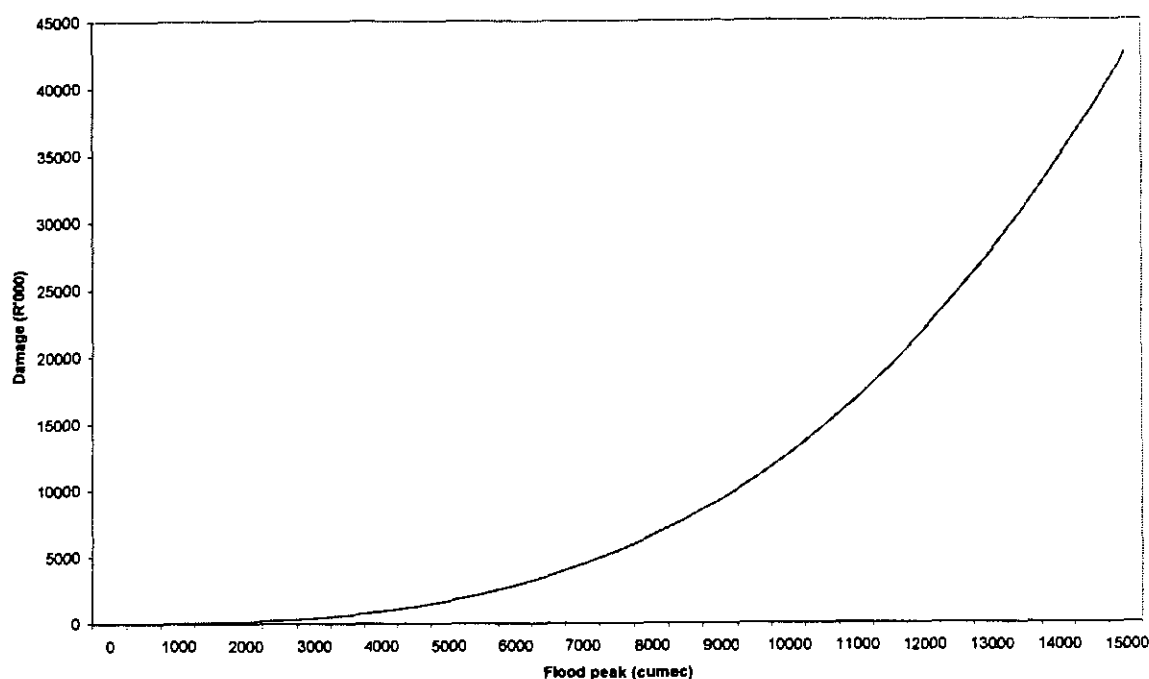


Figure 6.5: Loss functions (1995 values) for total flood damage to infrastructure in the Mfolozi floodplain

## 6.6 LOSS FUNCTIONS FOR TOTAL DIRECT DAMAGE IN THE MFOLOZI FLOODPLAIN

Flood damage to sugarcane and infrastructure were calculated independently of each other. The loss functions for infrastructure was applied to the length of inundated infrastructure for the whole of the Mfolozi floodplain. The loss functions for sugarcane however were applied for each area of land that was exposed to similar conditions of depth and duration of inundation to determine the damage. The different damage values that were derived for various areas of land were subsequently added to get the direct damage for sugarcane for the entire Mfolozi floodplain. This damage value, which is different for floods of different size, were then added to the value of flood damage to infrastructure for the corresponding

flood size in order to reach an estimate of the total direct flood damage to the Mfolozi floodplain.

Several different flood damage simulations were carried out with FLODSIM to determine the total direct flood damage in the Mfolozi floodplain. Results of flood damage simulations for the Mfolozi floodplain are discussed in Chapter 8.

## 6.7 CONCLUSION

Damage to sugarcane and infrastructure in the Mfolozi floodplain constitutes the greatest part of flood damage; thus loss functions were developed for the different damage categories of sugarcane and infrastructure respectively. The loss functions were included in a flood damage simulation model for estimation of ex ante flood damage. Loss functions for sugarcane were developed to estimate damage to harvests and crops. In the case of damage to the harvest, depth and duration of inundation were identified as the main determinants of the percentage of the total area of sugarcane that will be destroyed during a flood. Destroyed sugarcane also represents a saving in terms of a decrease in harvesting and marketing cost. In the case of damage to the crop (vegetative part of the sugarcane plant), potential future yields were 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.

The well-developed infrastructure in the Mfolozi floodplain effectively mitigates flood damage to sugarcane, especially during smaller floods, but annual maintenance and repairs after destructive floods amount to a considerable sum. It was found that there is a higher correlation between the extent of flood damage to infrastructure and the size of a flood than between damage to infrastructure and depth and duration of inundation. With regard to drains, levees, roads, tramways and spillways, the distance of each within the floodplain were determined for different flood peaks, making it possible to calculate damage per metre. The latter was used to determine the loss functions, which took the form

of a Cobb-Douglas function with flood peak as the only independent variable. Since loss functions were calculated per metre, they can be used to determine potential flood damage if additional infrastructure should be constructed in the floodplain.

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# CHAPTER 7

## DEVELOPMENT OF A FLOOD DAMAGE SIMULATION MODEL

### 7.1 INTRODUCTION

In Chapter 2, a methodological framework of the flood damage simulation model (FLODSIM) was discussed. Shortcomings, which were addressed in the previous chapters, were pointed out. After these shortcomings were addressed (which included a literature study of flood damage modelling), it was possible to make the necessary adaptations to FLODSIM.

The aim of this Chapter is to present a synoptic literature study of flood damage modelling, after which the adaptations to FLODSIM will be discussed.

### 7.2 FLOOD DAMAGE MODELLING

#### 7.2.1 FLOOD DAMAGE SIMULATION MODELS

An extensive search for literature regarding flood damage research was done, but little could be found with relation to flood damage modelling. No flood damage simulation model for agricultural irrigation areas could be found. However, flood damage simulation models to calculate flood damage within an urban context do exist.

The loss function concept is fundamental for the determination of flood damage (Smith and Greenaway, 1988) and no alternative approach to determine flood damage could be tracked down. The loss function approach was presented by White and applied by the US Army Corps of Engineers (Flood Damage Analysis Package, User's Manual, 1988), and it forms the basis for the National Flood Insurance Program in urban areas (Smith and Greenaway, 1988). Penning-Rowsell and Chatterton (1977) also executed an extensive loss function study for

the United Kingdom. Stage damage curves (loss functions) that were developed by the US Army Corps of Engineers and Penning-RowSELL and Chatterton, are not directly applicable for Australia (Smith and Greenaway, 1988). As a result, an independent flood damage simulation model, namely ANUFLOOD, was developed for urban areas in Australia. ANUFLOOD is a user friendly computer model for the calculation of potential flood damage, enabling the determination of the benefits of different combinations of flood control and flood damage control measures. An overview of these simulation models was given by Penning-RowSELL *et al.* (1987, as quoted by Smith and Handmer, 1988).

After continuous and extensive flood damage in Bangladesh, the World Bank composed a framework according to which a flood action plan can be drawn up. Several countries, like Japan, the United Kingdom, France, Canada, Denmark and others participated in the undertaking of especially area studies in an attempt to get to a permanent solution for the flood problem in India (Dempster and Brammer, 1995). Denmark got involved in the development of a MIKE 11-GIS model. The MIKE 11-GIS model integrates the dynamic river modelling modules with a geographic information system. The system has the potential to clarify complex floodplain overflow patterns and will aid the distribution of information regarding the impact of floods by means of maps (flood depth, duration of flood and flood phase).

Statutory planning is usually based on spatial information as contained on maps and plans. As a result, spatial information systems are becoming increasingly more essential for the co-ordination of floodplain planning. In this way data on *inter alia* the river geomorphology, which is necessary for the implementation of sustainable local and regional environmental plans, can be stored (Tané and Xingzhao, 1993). MIKE 11-GIS was primarily developed for the creation of two- and three-dimensional water level and overflow maps. A digital terrain model (DTM) and water levels provided by MIKE 11, are used to determine depth of overflow, as well as the extent of the flood. Such flood overflow maps can further on be integrated with other GIS databases, like infrastructure, land use and population density, to provide the basis for impact-of-flood calculations. Overflow maps, that were developed with real-time flood forecasting, form the basis for flood warnings and evacuation plans (Hansen, 1997).

MIKE 11-GIS can supply floodplain topographic data to MIKE 11. Cross sectional profiles and overflow areas versus elevation curves can be obtained from a DTM and exported to MIKE 11. Water level heights and velocities are in turn exported from MIKE 11 to MIKE 11-GIS system. In this way, water levels are being used to draw up flood maps that indicate the depth and duration of overflows (MIKE 11-GIS Reference Manual, 1997).

In the Netherlands, a study was undertaken by Hans Van Duivendijk (hydraulic engineer) to determine flood damage to crops. The primary aim of the study was to set up applicable flood control measures for the area of investigation. The extent of silt deposition, time of the year when the flood occurs in relation to the growth phase of the specific plant, depth and duration of the flood and the velocity of the water were identified as variables that cause flood damage to crops. It was found to be impractical to make provision for all these factors and only duration of the flood was used as a parameter to determine flood damage to crops. In the first place, the relationship between the flood duration and the lowering of production as a percentage of the normal production, was determined. Secondly, the damage per ha and the duration of flood was determined for each crop. The investigation area in the Netherlands was divided into 62 hydraulic units. It is possible, with the computer model, to determine the number of hectares for each hydraulic unit that is flooded for different numbers of days. Consequently, it was possible to determine a relation between damage and duration of floods for each hydraulic unit for a specific year. After this, the total flood damage to annual crops for all 62 hydraulic units, which may occur during a typical flood for a specific year, could be calculated. Land use maps, which indicate the distribution of crops over the 62 hydraulic units, were also printed for the different rotation systems. With this approach, no distinction was made between harvest, crop and flood damage. Little was written on the mathematical model and the main focus was on engineering works. The researcher thus made the deduction that the above mentioned relationships are not necessarily integrated into a simulation model, but that flood damage is rather calculated on an unconnected basis (Van Duivendijk, [s.a.]).

In South Africa a mathematical hydraulic simulation model, that can forecast flood damage to sugarcane crops, was developed by Weiss (1976) for the Mfolozi

floodplain. A sugarcane loss function to determine the damage to a harvest is included in this model. No provision is being made in Weiss's model to calculate damage to crops, soil and infrastructure. The approach that is followed by Weiss's model was discussed more extensively in Chapter 6.

### 7.2.2 GEOGRAPHIC INFORMATION SYSTEMS (GIS)

With the development of advanced computer technology, geographic information systems (GIS), remote sensing and global positioning systems (GPS) became general management and decision-making mechanisms (Chen *et al.*, 1994). Three basic components feature in the GIS-approach, namely technology (hardware and software), data and infrastructure (personnel). It is expensive to develop a GIS and data can form up to 80% of the total costs. Where data are already available in digital format, costs of specific applications can drop (Savitsky *et al.*, [s.a.]). Besides the costs to collect data, much time must be allocated to verifying it. Maps that are available in cartographic format, must be digitised manually or with a scanner.

New information can be obtained by means of a GIS by laying various maps (that are geographically orientated with each other) over each other. This concept is generally used with scientific or policy analysis. (Savitsky *et al.*, [s.a]).

## 7.3 METHODOLOGY

### 7.3.1 THE ACQUISITION OF DATA

The data are usually the most expensive component of a Geographic Information System (GIS) and a large part of development time is spent on the preparation of data. Source data can exist in different formats for example map sheets, ASCII formatted files, remotely sensed data in digital format and files in data exchange formats from other software packages. The source data should be chosen with care. The scale, age, projection and method used to prepare the data should be considered when source data are chosen. When data are obtained from another department or agency, the people who were responsible for the data should be interviewed to make sure that the data are suitable for the envisaged purposes. Aspects essential to your project might not have been important to them.

The scale of a map is the ratio between distances on the map and corresponding distances in real world (Goodchild and Kemp, 1991:2-5). The scale therefore gives an indication of the detail presented on the map. A map with a scale of 1:100 000 will cover a larger area than a map with a scale of 1:2 500 but only the latter will for example show individual houses and lamp posts.

The contents of a spatial database reflects a specific part of the world in a specific way. The world should be represented as close to reality as possible. Shape, area, distance and direction are some of the spatial properties that can be distorted when the curved surface of the earth is projected to a flat plain. Different map projections will minimise distortion of certain properties. It is however possible to convert data from one projection to another.

### 7.3.2 INPUT OF DATA

Spatial data are usually represented in digital form by vector- or raster data. Figure 7.1 gives an example of vector data and Figure 7.2 gives an example of raster data. In ARC/INFO vector data are saved as coverages and raster data as grids. The input of vector data will be described in this paragraph and the information can for example be applied to acquire land use, infrastructure, buildings etc. The only input for FLODSIM in the form of a grid is the digital elevation model (DEM) of the floodplain. The generation of DEMs will be discussed in Paragraph 7.3.3.

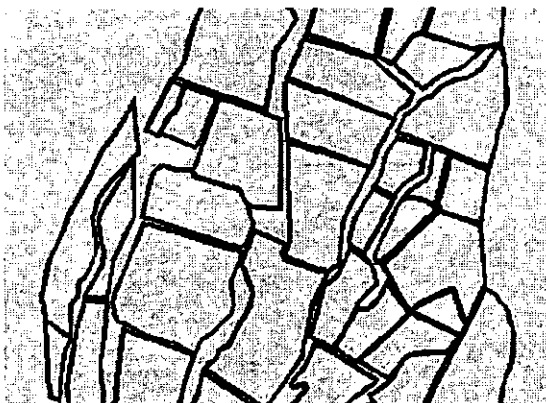


Figure 7.1: Vector data

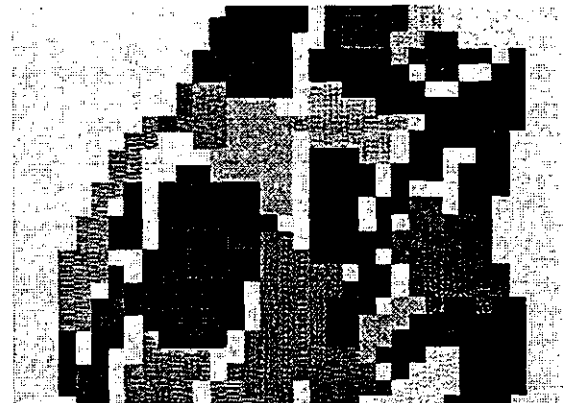


Figure 7.2: Raster data

Depending on the form of the source data, different methods will be used to enter the data (ESRI, 1996). Map sheets are digitised manually on a digitising board or it could be scanned automatically. Scanned data might require considerable processing and editing afterwards. ARC/INFO supports several image formats. The scanned data can be converted to a grid or coverage and then it can be edited using GRID or ArcScan software. ASCII formatted files and files from other systems should be converted into an acceptable format. Survey data can be entered from the keyboard or read from a file.

The devices used for digitising are a digitising board or a tablet and a cursor. The digitising board contains a grid of tiny current-carrying wires that run horizontally and vertically. The digitising cursor has an optical viewer with a target (usually crosshairs) that allows the user to visually locate a point on the map. The most common cursor has at least 16 buttons. The operator mounts a map on the digitising table and then uses the cursor to capture the co-ordinates of features on the map by pressing a button on the cursor after a point is identified. The button that was pressed will define the action to be taken in ARC/INFO. By using the recorded x,y co-ordinate location of the point, features in the coverage can be added, selected, deleted or edited.

Each theme is digitised into a separate coverage. Roads, land use and levees for example would each be saved in different coverages. Themes can be saved as points, arcs or polygons. Points are the most basic features and each point consists of a single x,y location and its attributes. Examples of point features are wells and houses. Arcs represent linear features like roads or streams and each arc consists of a string of points. The beginning and ending points are referred to as nodes. Aerial themes are homogeneous areas enclosed by boundaries and are represented with closed polygons. Each polygon consists of one or more lines with a label point on the inside.

Topology defines the spatial relationships between points, lines and polygons. The direction of an arc for example is determined by the direction from the first node to the last node. When the direction of an arc is known, the polygons on the left and right sides can be identified. Adjacency of polygons can thus be found. Other spatial properties that are defined through topology are the length of arcs, area and perimeter of polygons, connectivity of arcs, etc. There are two commands in ARC/INFO with which topology of coverages can be created namely 'build' and 'clean'.

### **7.3.3 GENERATION OF DIGITAL ELEVATION MODELS (DEM)**

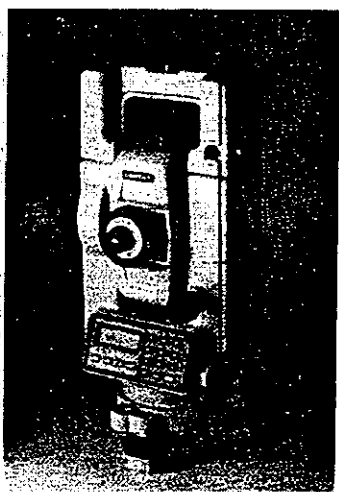
A digital elevation model (DEM) is an ordered array of numbers that represents the spatial distribution of elevations above some arbitrary datum in a landscape (Moore *et al.*, 1991). DEMs are subsets of Digital Terrain Models (DTMs) which can be defined as ordered arrays of numbers that represent the spatial distribution of terrain attributes, such as gradient, aspect, catchment areas, etc.

The sources used to derive DEM data vary from ground surveys, photogrammetry and existing contour maps to radar or laser altimetry. The source used will determine the quality and cost of the DEM. According to Weibel and Heller (1991:271) a DEM constructed from ground surveys is very accurate seeing that surveyors usually adapt the survey to the character of the terrain in measuring significant terrain points. Unfortunately ground surveys are time consuming and are usually only applied to small areas. Laser technology is relatively new, but according to Schutte (1997) the accuracy is quite impressive and current users achieve 15 centimeter elevation accuracy. According to ESCOM's estimate the cost of acquiring DEM data using an airborne laser system is in the order of 25 to 40 per cent of that of acquiring the same amount of DEM data by aerial survey methods (Schutte, 1997). If contour maps of the area exist it is perhaps the cheapest way to acquire a DEM, but with a loss of accuracy. The main disadvantage of contour maps is that an excessive number of points are sampled along contours and no data are sampled across contours (Weibel and Heller, 1991).

### 7.3.3.1 Ground surveys

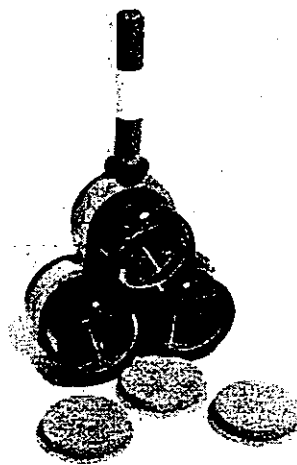
Elfick *et al.* (1995:1) defines surveying as the science and art of determining relative positions of points above, on, or beneath the surface of the earth. It is the researchers' experience that photogrammetry has replaced ground surveys in many kinds of projects, except for small areas. Conventional ground methods are still used to acquire horizontal and vertical control points when photogrammetry is used (Elfick *et al.*, 1995:6). Surveying is a specialised field and it should only be done by professional surveyors who are familiar with the different kinds of measurement errors, their sources and expected magnitudes under varying conditions and the manner of propagation (Elfick *et al.*, 1995:13).

Total station instruments (Figure 7.3) (also known as electronic tacheometers) are usually used for ground surveys (Elfick *et al.*, 1995:72-81). A total station instrument consists of an electronic distance measuring instrument (EDM), electronic digital theodolite, and computer-in-one-unit. EDM's determine lengths by measuring the time it takes laser or infrared light to travel from the total station instrument to a retro-reflector and back (Figure 7.4). The travel time multiplied by the velocity yields the distance. The electronic digital theodolite automatically measures and displays horizontal and vertical angles. The horizontal and vertical angles together with the slope distance are automatically transmitted to the built in computer where the horizontal and vertical distances are computed and stored.



**Figure 7.3: The Pentax PTS III-05 total station instrument**

Source: Elfick *et al.* (1995:81)



**Figure 7.4: Triple retro-reflector**

Source: Elfick *et al.* (1995:77)

A grid method or an irregular method can be used in the field for collecting DEM data (Elfick *et al.*, 1995:243). In the grid method elevations are determined on points which conform to a regular square or rectangular grid while elevations of all low and high points as well as points where slopes change are determined with the irregular method.

When a DEM is created with a total station instrument the data should be saved as a DXF file that can easily be converted to an ARC/INFO point coverage with the 'dxfarc' command. If the grid method was used in the field, the point coverage can be converted into a grid with the 'pointgrid' command. With the irregular method the 'topogrid' command should be used to create a grid.

A new approach to surveying is the satellite surveying systems of which the current system is called the Global Positioning System (GPS) (Elfick *et al.*, 1995:321-349). GPS is based upon signals transmitted from satellites whose orbits are precisely known. Accurate distances from the satellites to the receivers are determined from the signal information, enabling receiver positions to be computed. After the field observations are done the data are transferred to a computer to do the final processing.

GPS can also be used for establishing ground control points for photogrammetric mapping (Elfick *et al.*, 1995:464). This is usually done with two receivers where the one receiver is stationed at the ground control point while the other is taken with the camera in the aircraft. The camera's position is therefore precisely measured for each photo that is taken.

According to Elfick *et al.* (1995:344) GPS equipment is cost effective despite the fact that the initial cost is relatively high compared to other traditional surveying equipment. These systems will become smaller, more accurate and less expensive as technology improves.

### 7.3.3.2 Photogrammetry

Analogue stereo-plotting instruments (Figure 7.5) and later analytical stereo-plotters (Figure 7.6) were the principal photogrammetric technologies in recent years, but according to Gordon (1997:18) the Digital Photogrammetric Workstations (DPW) increased in importance since its commercial advent in 1988 to be the analytical plotter's major competitor today. Gordon (1997), Wong (1997) and Schutte (1997) agree that the DPW will become the dominant photogrammetric technology in future.



**Figure 7.5: Kern PG-2 mechanical projection stereoplotter**

Source: Elfick *et al.* (1995:459)



**Figure 7.6: Kern DSR11 Analytical Plotter**

Source: Elfick *et al.* (1995:460)

Observing DEMs on an analytical stereoplotter is a semi-automatic procedure and although it is time consuming, the operator has the ability to differentiate between objects observed in the stereoscopic model (Schutte, 1997). A reliable and accurate DEM is therefore provided. A digital data file is created with the stereoplotter and it can be exported to a DXF- or text file.

Madani (1996:1) defines an integrated digital photogrammetry system as hardware and software configurations that produce photogrammetric products from digital imagery using manual and automatic techniques. The two major differences between analytical stereoplotters and DPW's lie in the input data and the level of automation. Analogue diapositives are used with stereoplotters while digital images are used as input for DPW's. The digital image files are extremely large. Image tiling-, image pyramid- and image compression techniques are used to handle these large files. Image pyramids are used to display imagery at all

zoom levels very quickly. Automatic measurement and image matching techniques are provided by the new digital technologies and Madani (1996:2) considers this to be of great value to photogrammetry.

According to Mayr (1997) digital photogrammetry is now available for all basic photogrammetric tasks. Digital Photogrammetric Software is used to set up stereoscopic models, to import necessary project data, for the preparation of imagery for extraction, to display images, to perform various image enhancement operations, to extract terrain and feature data from imagery, to create products such as orthophoto's, perspective scenes, etc. and to export softcopy databases and hardcopy products (Schutte, 1997).

As opposed to the method using analytical stereoplotters, the DEM is automatically extracted with digital photogrammetry after the initialising photogrammetric procedures are completed (Schutte, 1997). This process is significantly faster. The main drawback however is that it fails completely in extreme vegetation and water areas, where direct operator observations are needed to compensate for the error in the measurements of elevation.

According to Schutte (1997) the height accuracy obtained from aerial photography is directly proportional to the scale of the photography. A rule of thumb is that planimetric (xy) accuracy is 10  $\mu\text{m}$  at the photo (image) scale, while the height (z) accuracy is 0.01 per cent of the flying height of the aerial photography. It is thus estimated that an accuracy of approximately 0.455 m in height can be expected for 1/30 000 aerial photography (with a flying height of  $\pm$  4550 m), but for extensive vegetation coverage the accuracy can be reduced up to two to four times.

### **7.3.3.3      *Creating a DEM from contour maps***

Generally raw elevation data in the form of stereo photographs or field surveys, and the equipment to process these data, are not readily available to potential end users of a DEM (Moore *et al.*, 1991:4). An alternative is to use public topographic maps. The contour lines can be digitised manually on a digitising

board or it can be scanned automatically on a scanner. Interpolation is used to derive a DEM from contour lines. Oliver and Webster (1990) provide the rationale for interpolation when they describe the nature of natural properties of the earth. The values of properties at sites that are close together in space are more likely to be similar than those further from one another because of the fact that the properties are continuous. The properties are therefore depending on one another in a statistical sense. The authors mention that the variation from place to place of most properties is usually so erratic that no simple mathematical expression can describe it and they are of the opinion that the properties behave as essentially random variables rather than as mathematical ones.

Interpolation methods can be divided into two main groups namely global and local (Oliver and Webster, 1990:314). Global methods take all the elevation data into account when the elevation at a new point is determined while the fitted surface at a point depends only on nearby data when a local method is used. The main advantage of global methods is the reasonable continuity that is derived (Hutchinson, 1989:214). A disadvantage however is the high computational cost of  $O(n^3)$ . Local interpolation methods are not as computationally intensive as global methods but have the disadvantage that spurious edge effects can be generated.

Local interpolation methods incorporated into ARC/INFO include inverse distance weighted interpolation (IDW), kriging and splines (ESRI, 1997). ARC/INFO provides one global method namely the trend surface interpolation; IDW interpolation can however be shifted from local to global by changing the 'power' option. These four methods are general-purpose interpolation methods and take point coverages as input. The vertices in the arcs should therefore be converted to points if one of these methods is used. A fifth interpolator 'topogrid' is optimised to create hydrological correct DEMs and is based on an interpolation method that was developed by Hutchinson (1989). Additional local interpolation methods can be acquired by first applying Delauney triangulation with the 'createtin' command. The triangulated irregular network (TIN) can then be converted into a grid using linear- or bivariate quintic interpolation by using the

'tinlattice' command. The 'topogrid' and 'createtin' commands accept both contour lines and spot heights as input.

A linearly weighted combination of a set of sample points is used with IDW interpolation to determine the cell values of a grid. The weight is a function of inverse distance. A major disadvantage of IDW observations is that the range of interpolated values is limited to the range of measured elevations (Watson and Philip, 1985:320). IDW will therefore not be able to interpret local trends for example hill tops and valley bottoms correctly.

Kriging is based on the regionalised variable theory that assumes a constant local mean and a stationary variance of the differences between places separated by a given distance and direction (Oliver and Webster, 1990:314). A plus point of kriging is the fact that the estimation variances can be determined and mapped and the reliability of the estimates can therefore be calculated by assuming a particular distribution. The term kriging embraces a set of methods including ordinary kriging, co-kriging, universal kriging and disjunctive kriging. Ordinary kriging and universal kriging are implemented into Arc/Info (ESRI, 1997). Ordinary kriging assumes that the variation in cell values is free of any structural component. Universal kriging should be used when the spatial variation in cell values in the data is suspected to contain local trends.

A spline is a two-dimensional minimum curvature interpolation resulting in a smooth surface that passes exactly through the input points (ESRI, 1997). The method ensures a smooth (continuous and differentiable) surface together with continuous first-derivative surfaces. The algorithm was first developed as the solution to the problem of a thin plate which is forced to pass through certain points (Franke, 1981)

The trend surface interpolator uses a polynomial regression to fit a least-squares surface to the input points (ESRI 1997). According to Oliver and Webster (1990:314) this approach has several shortcomings:

- It loses detail because of powerful smoothing.

- Outliers or observational errors can cause instability.
- Variation in one part of the region affects the fit of the surface everywhere.

A procedure developed by Hutchinson (1989) is incorporated into the 'topogrid' command in ARC/INFO. 'Topogrid' uses coverages of contour lines, streamlines, sample points, and known sinks to create a hydrological correct DEM. The advantages of both local and global interpolation methods are implemented in the procedure in the sense that it has the efficiency of local methods without sacrificing the continuity and rotation invariance of global methods. The approach couples a drainage enforcement algorithm with an iterative finite difference interpolation technique that is based on minimising a terrain specific, rotation invariant roughness penalty. The drainage enforcement algorithm automatically eliminates spurious sinks.

A depression is an area surrounded by higher elevation values (Jenson and Domingue, 1988:1593). Depressions are sometimes referred to as sinks or pits in the literature (Weibel and Heller, 1991:278; Hutchinson, 1989:213; Nelson and Jones, 1995:38; Petras *et al.*, 1997; ESRI, 1997). The term used in ARC/INFO namely, sinks, will be used for the purposes of this report. The presence of spurious sinks in a DEM makes it inappropriate for the calculation of certain surface characteristics such as drainage networks and catchment areas. Sinks are rare in nature (Hutchinson, 1989:212) and are therefore usually referred to as spurious. There are however places such as the prairie pothole region in the upper Midwest of the United States, where sinks dominate the hydraulic response of the landscape (Moore *et al.*, 1991). Spurious sinks can usually be attributed to mistakes in the input data, unsuitable interpolation routines or the interaction of grid spacing with contour spacing and valley orientation. The process of removing spurious sinks manually is time consuming and subject to errors from the operator (Hutchinson, 1989:213). Mainly two approaches are followed to eliminate spurious sinks with automatic methods, namely the smoothing of the DEM data or the filling of depressions (Jenson and Domingue, 1988:1593). Deeper sinks will remain when the smoothing process is used and another disadvantage is that all the elevations are affected. With the second approach the elevation of cells within the depression are raised to the lowest value on the

boundary of the depression. The 'Fill' command in Arc info uses this approach. Well-defined surface features are often over smoothed with these methods and it is therefore better to eliminate the spurious sinks during the interpolation process from the original points. The drainage enforcement algorithm implemented into the 'topogrid' command automatically eliminates spurious sinks. Natural sinks represented with a point coverage can be given as input to this procedure to ensure that these sinks are not removed. Depending on the tolerances used, 'topogrid' may or may not remove all spurious sinks.

Building triangulated irregular networks (TINs) from contour maps is one of the most common methods of building surface models for regions where elevation data are not available in digital form (ESRI, 1997). Unfortunately contour lines is also one of the most difficult data sources from which to build a good TIN. Mirante and Weingarten (1982) defines a TIN as a mesh where the three dimensional co-ordinates are linked into non-overlapping triangles of irregular size (Buys, 1991:9). Delauney triangulation (Delauney, 1934) is usually used to allocate a unique set of triangles to describe the terrain and ensure bounded errors on the interpolation of bi-variate data at randomly sampled points (Tsai, 1993). Delauney triangulation selects triangles on the criteria that no data point lies inside the circumcircle of any other triangle. The 'createtin' command implements Delauney triangulation. Caution must be taken that the density of the vertices representing the contour lines is less than the distance between contour lines (ESRI, 1997). If the vertices are too dense, triangles will be formed along the same contour, resulting in flat triangles. The 'weed-tolerance' option in the 'createtin' command can be used to reduce the number of vertices that will be used in the triangulation process. This process is automatic and important vertices might be ignored. Extra points may be included into a point coverage to ensure that the surface is represented correctly at these places. The TIN can be converted into a grid using linear- or bivariate quintic interpolation with the 'tinlattice' command.

In linear interpolation only the nodes of the triangle, within which the surface value to be interpolated lies, are used (ESRI, 1997). The surface value is obtained by the intersection of a vertical line, at the position of the required value, with the

plane defined by the three nodes. With quintic interpolation a smooth surface will be derived. This is accomplished by considering the geometry of the neighbouring triangles. The 'tinlattice' command employs a breakline bivariate quintic interpolation using a fifth-degree polynomial in  $x$  and  $y$ . Both these methods honour the  $z$  values at the triangle nodes. The linear interpolation method is quicker and the results are more predictable, but abrupt changes in slope might occur at triangle edges. The breakline bivariate quintic interpolation method produces more realistic results, but is computationally more intensive than linear interpolation. The linear facet is planar (Figure 7.7), while the quintic facet is curved (Figure 7.8) and can be concave or convex depending on the behaviour of its adjacent triangles.

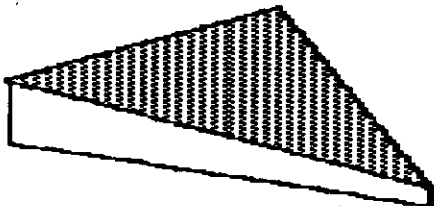


Figure 7.7: The planar facet of the linear interpolation method

Source: ESRI, 1997

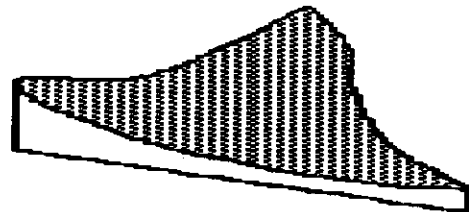


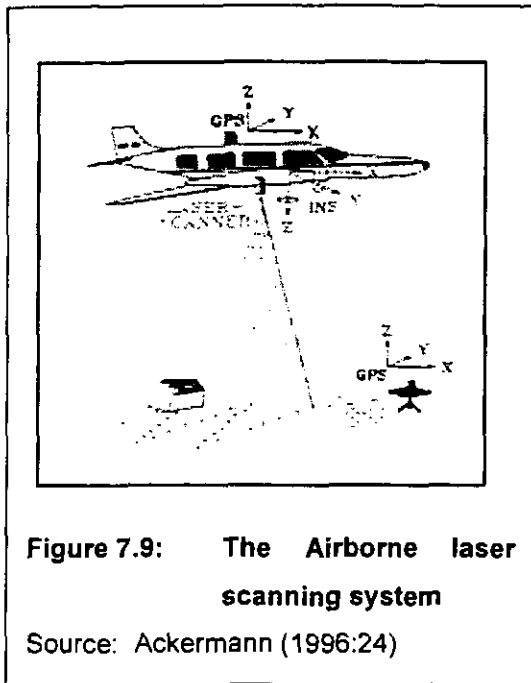
Figure 7.8: The curved facet of the quintic interpolation method

Source: ESRI, 1997

#### 7.3.3.4 Radar or laser altimetry

Airborne laser scanning is a relatively new method to create DEMs. The development of airborne laser systems started in the 1980's in the USA without reaching a breakthrough until 1987 (Ackermann, 1996:24). These systems are efficient in difficult cases such as forest areas (Hoss, 1996:28), coastal geology where it is necessary to differentiate between beaches and dunes (McCaskill, 1997), mountain glaciers (Echelmeyer *et al.*, 1995) and shallow coastal water surveys (LADS Corporation, 1997). The laser pulses are capable of at least partly penetrating through vegetation to reach the ground.

Three different sensors are used in airborne laser systems (Figure 7.9). Differential GPS provides the co-ordinate reference, inertial navigation system (INS) the spatial direction of the aeroplane and the laser the length of the vector



**Figure 7.9: The Airborne laser scanning system**

Source: Ackermann (1996:24)

from the pulse emitter to the ground. A ground reference station that is also recording GPS data determines the position of the differential GPS. Precise time tags are supplied by the differential GPS. The INS measures various attitudes of the aeroplane for example roll, pitch and heading information. The laser records the time difference between the emission of the beam and the reception of the reflected laser signal in order to measure the length to the ground. In cases of dense vegetation the laser beam is often divided

into several distinguishable return signals as it penetrates the vegetation. The last return signal is usually recorded because it refers in many cases to the terrain surface. The main improvement on laser scanners is the considerably higher measuring rate. The Spectra Physics TFR laser of the airborne topographic mapper used by NASA is for example operated at 2000 to 5000 pulses per second (Krabill, 1995; McCaskill, 1997). The laser beam is oscillated perpendicular to the flight direction and a swath width of 540m is reached from 1000m flying height above the ground (Ackermann, 1996:25). The TopScan / Optech system gives a swath every 3 meters when the scan rate is set to 10Hz, at a flying velocity of 215km/h and a flying height of 1000m above the ground. With a set scan angle of  $2 \times 15 \text{deg}$  and a measuring rate of 2kHz there is 100 points within each swath, at an average distance of 5m. The vertical accuracy of a laser point is in the order of 10-20cm, but results better than 10cm were obtained in ideal laser reflection on smooth surfaces.

The data from the different sensors data calibrated, synchronized and integrated with a post processing system to provide a precise horizontal and height location for each laser pulse. Processing rates of 2-5km<sup>2</sup>/h have been quoted for topographic DEMs.

#### 7.3.4 ATTAINMENT OF LAND USE

After a suitable DTM was created and developed for the area, the land use database is chosen. An *in situ* and a remote sensing survey were compared with one another and the results are discussed in Chapter 5.

#### 7.3.5 LOSS FUNCTIONS

Once the land use pattern is known, it is possible to draw up suitable loss functions for the investigation area. As loss functions for different flood afflicted areas in South Africa become available, it becomes possible to choose from a databank of loss functions to determine the results of floods. A complete discussion of loss functions was done in Chapter 6. Modules were extended to accommodate additional loss functions; also to make provision for a more dynamic loss function approach, like taking the duration of overflows into account.

#### 7.3.6 INTERFACES BETWEEN FLODSIM AND NUMERICAL FLOOD MODELS

Numerical flood models should be used by engineers or hydrologists to provide the hydraulic data required by FLODSIM. Topographic data for numerical flood models usually consist of a river network and cross sectional profiles of the floodplain which can be exported from FLODSIM.

Examples of numerical flood models<sup>7</sup> which use cross-sections to describe the topography are HEC-RAS, XP-SWMM, MIKE 11 and WSPRO (Van Bladeren, 1998). Mike 11 and XP-SWMM are dynamic models while HEC-RAS and WSPRO are steady state models. The difference between dynamic models and steady state models lies in the absence of the time dimension in steady state

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<sup>7</sup> Also known as backwater packages

models. A dynamic model enables a hydrographs as input while a steady state model allows only a specific discharge as input. Dynamic models should be used when duration of inundation is required by the loss functions in FLODSIM.

The topographic data that are exported from FLODSIM should be converted into a format supported by the numerical flood model with which the simulation is to be done. FLODSIM then integrates the hydraulic data from the numerical flood model with the original topographic data. Finally hydraulic data, for example the average depth of inundation, are calculated for each cultivated field and these results are then used to determine flood damage.

Coupling environments can be categorised in isolated-, loose-, tight-, and integrated environments (Wolff-Piggott, 1994). Isolated and loosely coupled systems are based on a file transfer method where the user is expected to exchange the files from the one system to the other. With tight coupling the file transfer is performed automatically by the software and in an integrated system the GIS and hydrological model have been developed as a single software system.

According to De Vantier and Veldman (1993) connections with GIS can be expected in the hydrologic engineering field since large parts of hydrological analyses are linked to processes on the surface of the earth. Spence *et al.* (1995) supports this statement and adds that GIS can bring a spatial context to hydrological models that lacked in the past. The authors are of the opinion that the input data to hydrological models should also be enhanced, seeing that the models become more complex and describe more physical processes. The output data from hydrological models are complex and the large volume of data makes it difficult to relate the results directly to locations (Muller and Rungoe, 1995). GIS can therefore provide the input data for hydrological models and it can make the process of analysing the output data more efficient.

An interface with Mike 11 was developed as an example system to demonstrate the coupling between FLODSIM and a numerical flood model. The interface entails two processes. The output file from FLODSIM must first be converted into

an acceptable format for Mike 11 and then the output file of Mike 11 must be converted into the format required by FLODSIM. This interface can be categorised as an isolated system. The software that converts the input- and output data are independent of both models. It is therefore possible to create interfaces between FLODSIM and other numerical flood models as well.

Software which was developed by the Department of Water Affairs and Forestry in a study on digital terrain models of dam catchments and reservoirs (Tchoukanski, 1995) was used as basis for the interface. The software first had to be adapted in order to apply it to FLODSIM and then it was developed further to handle the different channels of the Lower Orange River and to determine the duration of inundation for sugarcane in the Mfolozi floodplain.

#### **7.3.6.1 *Defining the river network and cross sections in FLODSIM***

A module was developed with which topographic data can be extracted from the DTM to be used with numerical flood models. With this module the river network and cross sections can be digitised on the screen. The module provides functions to add, select or delete cross sections and a profile of a selected cross section can also be displayed. The user may choose any of the themes from the model to be displayed in the background while he is digitising. The module also enables the user to define the different channels of the river network. The exporting process is fully automatic and is activated by the click of a button.

The river is represented by a network configuration as a system of inter connected branches. The network consists of centre lines representing the different channels. A centre line can be defined as a line connecting the points with maximum water speed in the cross sections (Tchoukanski, 1996). Chainages are calculated for the connections of centre lines and for the intersections between cross sections and centre lines. Chainages are calculated from the beginning of each line and starts at zero for all channels.

The following rules must be taken into consideration during the digitising process:

- ☞ Centre lines must be directed downstream.
- ☞ Cross sections must be taken from left to right over a centre line when looking downstream.
- ☞ Cross sections are not allowed to cross each other.
- ☞ Cross sections must cross a centre line, but are not allowed to cross more than one centre line.
- ☞ Cross sections should be approximately perpendicular to the centre line.
- ☞ Cross sections should extend far enough to cover the highest elevation expected to be reached by the flood.
- ☞ Cross sections should not extend beyond the boundary of the DTM.

The output data are saved into two files. The first file describes the river network and gives the chainages where the different channels connect. The second file describes the cross sections and consists of three parts (Figure 7.10). The different parts are delimited with a line that contains only a '0'. The first part gives the section id, chainage of the section on the centre line of a channel in meters, and the channel name of each cross section. The second part gives the section id, surface id, the distance in meters from the starting point of the section and the x-, y-, and z- co-ordinates of three points for each cross section. These three points include the starting point and ending point of the cross section as well as the point on which the section crosses the centre line of a channel. The last part of the file describes the profile of each cross section. The x-, y-, and z- co-ordinates are given for regular points along the line. The user determines the intervals between the points, and for this example a distance of 33m was taken. The cross sections in the output file will be in the same order in which they were digitised.

Mfolozi						
1,	26452.950,	MAIN				
2,	25678.560,	MAIN				
3,	25051.370,	MAIN				
0						
1,	1,	0.000,	-60480.41009,	-42760.42602,		10.194
1,	1,	3334.375,	-57359.47412,	-43934.22909,		3.629
1,	1,	3922.329,	-56809.15573,	-44141.20719,		24.641
2,	1,	0.000,	-60537.26579,	-42914.74836,		15.304
2,	1,	3352.527,	-57665.97439,	-44645.38992,		4.278
2,	1,	3461.496,	-57572.64692,	-44701.64210,		12.054
3,	1,	0.000,	-60585.99918,	-43085.31545,		15.613
3,	1,	3420.693,	-57914.20798,	-45221.35680,		3.742
3,	1,	3993.179,	-57467.05759,	-45578.84421,		9.549
0						
1,	1,	0.000,	-60480.41009,	-42760.42602,		10.194
1,	1,	33.000,	-60449.52247,	-42772.04304,		9.873
1,	1,	66.000,	-60418.63486,	-42783.66006,		7.591
1,	1,	99.000,	-60387.74724,	-42795.27708,		7.218
1,	1,	132.000,	-60356.85962,	-42806.89410,		7.530
...						
1,	1,	3922.329,	-56809.15573,	-44141.20719,		24.641
2,	1,	0.000,	-60537.26579,	-42914.74836,		15.304
2,	1,	33.000,	-60509.00274,	-42931.78362,		10.215
2,	1,	66.000,	-60480.73969,	-42948.81888,		8.746
2,	1,	99.000,	-60452.47664,	-42965.85414,		8.312
2,	1,	132.000,	-60424.21360,	-42982.88941,		9.605
...						
2,	1,	3461.496,	-57572.64692,	-44701.64210,		12.054
3,	1,	0.000,	-60585.99918,	-43085.31545,		15.613
3,	1,	33.000,	-60560.22397,	-43105.92220,		13.051
3,	1,	66.000,	-60534.44875,	-43126.52895,		13.059
3,	1,	99.000,	-60508.67353,	-43147.13570,		11.517
3,	1,	132.000,	-60482.89831,	-43167.74245,		8.988
...						
3,	1,	3993.179,	-57467.05759,	-45578.84421,		9.549

Figure 7.10: The output file of FLODSIM

### 7.3.6.2 The interface between FLODSIM and Mike 11

Mike 11 is a professional engineering software package, developed at the Danish Hydraulic Institute (DHI). Mike 11 consists of several modules and can be used for the simulation of flows, sediment transport and water quality in estuaries, rivers, irrigation systems and similar water bodies (DHI, 1992). The hydrodynamic module of Mike 11 is an implicit, finite difference model for the computation of

unsteady flows and are often applied as a flood management tool to simulate flooding behaviour of rivers and floodplains.

A stream network together with profiles of cross sections is represented in the output file of FLODSIM and it is then expected of the numerical flood model to provide the hydraulic information for each cross section in return. Two programs were written for the interface between FLODSIM and Mike 11. The first program, Arc2Mike, does the conversion from the output file of FLODSIM (Figure 7.10) into a format supported by Mike 11 (Figure 7.11). The second program, Mike2Arc, converts the Mike 11 output file (Figure 7.12) into the format of FLODSIM's input file (Figure 7.14). The input and output files of Mike 11 will be described in the remainder of this paragraph.

Cross-sectional data can be read from a text file into the database of Mike 11 (DHI, 1995:2-14). The text files may exist in several formats. The format used for the interface is described in Figure 7.11. The cross sections are specified by a number of x-z co-ordinates where x is the distance from the beginning of the section and z is the corresponding bed elevation. A maximum number of 300 points are allowed for each cross section (DHI, 1995:2-9). The cross sections of the input file may be in any order and will be sorted in Mike 11 by channel name and chainage.

Mfolozi			<i>Topographical identification</i>
MAIN			<i>River or channel name</i>
26.453			<i>Chainage in kilometers</i>
Co-ordinates			<i>Explanatory text</i>
1	-57359.47	-43934.23	<i>Horizontal co-ordinates</i>
Profile	121		<i>Number of x-z co-ordinates</i>
0.00	10.19		<i>x1 z1</i>
33.00	9.87		<i>x2 z2</i>
66.00	7.59		<i>x3 z3</i>
99.00	7.21		<i>x4 z4</i>
132.00	7.53		<i>x5 z5</i>
...			
3922.00	24.64		<i>x121 z121</i>
*****			<i>End of the first cross-section</i>
Mfolozi			<i>Topographical identification</i>
MAIN			<i>River or channel name</i>
25.679			<i>Chainage in kilometers</i>
Co-ordinates			<i>Explanatory text</i>
1	-57665.97	-44645.39	<i>Horizontal co-ordinates</i>
Profile	107		<i>Number of x-z co-ordinates</i>
0.00	15.30		<i>x1 z1</i>
33.00	10.22		<i>x2 z2</i>
66.00	8.75		<i>x3 z3</i>
99.00	8.31		<i>x4 z4</i>
132.00	9.61		<i>x5 z5</i>
165.00	8.76		<i>x6 z6</i>

Figure 7.11: The input file of Mike 11

The results of the simulation can be written to a text file (DHI, 1995:2-14). A summary or time series can be given for each cross section. The summary file only gives the minimum and maximum water level of the flood for each cross-section. This file can be used when durations are not needed as is the case with the Orange River. A file containing a time series is illustrated by Figure 7.12 and Mike2Arc can convert these files into the format-used by FLODSIM. With this file water levels are given over time-intervals, for example every hour during the total duration of the simulation. The interval can be defined in Mike 11. The channel name and chainage (in kilometres) identify the cross sections. The first cross-section in Figure 7.12 is for example 51 metres from the beginning of the main channel. The minimum distance allowed between two cross sections can be defined in Mike 11 (DHI, 1995:2-22). If the distance between two cross sections is longer than the defined distance Mike 11 will generate a cross section at the

required position. Hydraulic parameters at these additional cross sections will be calculated by interpolating between the specified cross sections. The results of the cross sections that were generated by Mike 11 will also be shown in the output file.

+-----+-----+						
! DATA FILE: MFOLOZI.RDF		BOUNDARY FILE: 10.BSF				!
! PARAMETER: 10-1.RRF		CALCULATED : 12-JAN-1998, 16:10				!
+-----+-----+						
! HOURS:MIN		MAIN	MAIN	MAIN	MAIN	MAIN
!		0.051	0.231	0.411	0.566	0.721
+-----+-----+						
1998	1 1 0 0	12.83	12.67	12.46	12.16	11.77
1998	1 1 1 0	13.05	12.88	12.63	12.28	11.84
1998	1 1 2 0	13.21	13.04	12.79	12.40	11.91
1998	1 1 3 0	13.35	13.18	12.89	12.47	11.97
1998	1 1 4 0	13.47	13.29	12.98	12.53	12.02
1998	1 1 5 0	13.58	13.39	13.06	12.58	12.07

**Figure 7.12: The output file of Mike 11**

The two elevations at which the water will be for longer than two critical periods can be determined with Mike2Arc (Figure 7.13). This is done by determining the duration of the water at levels from the flood peak downward with an interval declared by the user. The required elevation will then be the first elevation at which the duration is longer than the critical period. In the case of sugarcane the critical periods would be the periods (for winter and summer) that the plant could be inundated before it is destroyed.

Two input files are required by Mike2Arc namely the output file from FLODSIM and the output file from Mike 11. The output file from FLODSIM is necessary to identify the original cross sections. Only the original cross sections will be included in the input file of FLODSIM.

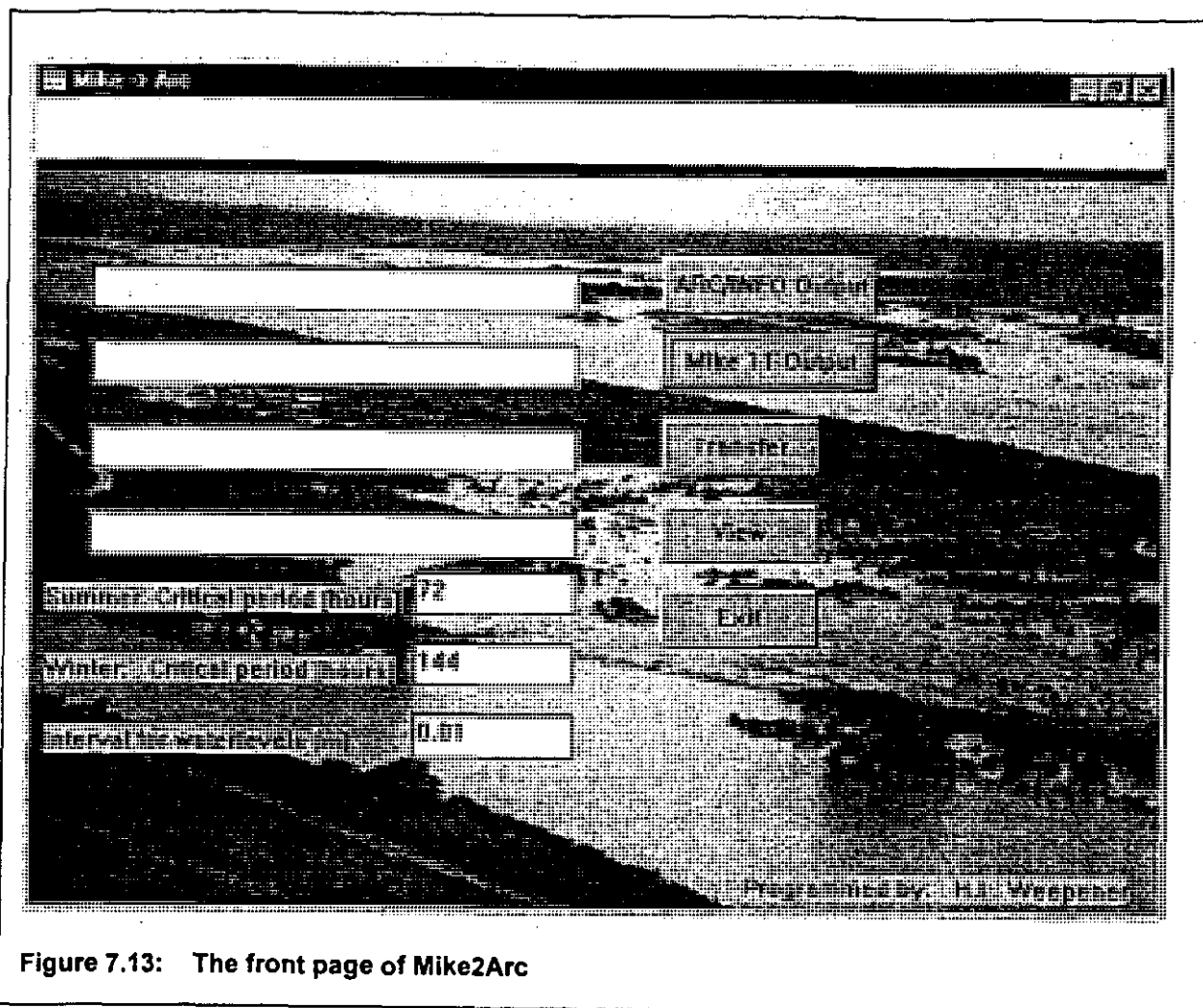


Figure 7.13: The front page of Mike2Arc

### 7.3.6.3 Importing hydraulic data into FLODSIM

An engineer or hydrologist should process hydraulic data for FLODSIM with a numerical flood model. Topographic data for numerical flood models usually consist of a river network and cross sectional profiles of the floodplain which can be exported from FLODSIM.

FLODSIM contains a module with which a water grid can be created from the hydraulic data and cross sections. For the purposes of this document a water grid will be defined as a grid representing the elevation of water for specific floods over the floodplain. The values in the cells of the water grid are acquired by interpolating between the water levels at adjacent cross sections.

The input file required by FLODSIM must consist of at least three columns namely the channel name, chainage and flood peak of each cross section. Any number of additional fields may be added after the flood peak when additional data are required by the loss functions. The same calculations, which are done on the flood peak, will also be done on the additional fields. Sugarcane may for example only be inundated for a certain period before it would be damaged. This period will differ between winter and summer. Two additional fields were therefore added to the input file for the Mfolozi river. These two fields represent respectively the elevation at which the water would stay for the critical periods of the winter and summer.

<i>Channel name</i>	<i>Chainage</i>	<i>Flood peak</i>	<i>Summer</i>	<i>Winter</i>
MAIN,	51.00,	15.36,	14.23,	13.22
MAIN,	411.00,	14.56,	13.57,	12.81
MAIN,	721.00,	13.58,	12.50,	11.93
MAIN,	1196.00,	13.02,	11.80,	11.03
MAIN,	1682.00,	12.83,	11.72,	11.01
MAIN,	2196.00,	12.70,	11.68,	10.99
MAIN,	2665.00,	12.55,	11.62,	10.98
MAIN,	3144.00,	12.08,	11.35,	10.86

**Figure 7.14: Input file for FLODSIM**

The values of hydraulic data in the input file will be appended to the attributes of corresponding cross sections. When the hydraulic attributes of the cross sections are known, water grids are created by interpolating between the attributes of adjacent cross sections. The linear interpolation method (Paragraph 2.3.3) of the 'tinlattice' command was used. Extra vertices were inserted into the cross sections in order to optimise the triangulation process of the 'createtin' command. The average distance between cross sections was calculated to determine the distance at which the points should be inserted.

The average depth of inundation for each cultivated field is usually needed in the loss functions for different crops. The depth of inundation of fields are calculated by taking the average of the cells within cultivated fields after the elevation of the water grids have been subtracted from the elevations of the DEM. This will only

be done for flooded areas. There are sometimes areas that are lower than the water level, but cannot be reached by the water. An example would be when a levee lies between the area and the water. A program was written to determine the flooded areas.

#### **7.4 DEVELOPMENT OF A FLOOD DAMAGE SIMULATION MODEL FOR SOUTH AFRICA (FLODSIM)**

A geographic information system has already proved to be a potentially valuable organised concept for spatial data in water resources management (Muzik and Chang, 1993). It was thus decided to continue working on the approach that was used during the previous phase of the research. With the shortcomings of FLODSIM (as discussed in Chapter 2) in mind, several adaptations were made and new modules for this module were developed. A typical flood damage modelling process (FLODSIM), based on a GIS, is portrayed diagrammatically in Figure 7.15 and is subsequently discussed.

##### **7.4.1 FLODSIM**

As a starting point a database has to be developed. Several alternative methods were investigated to create specific databases. After the creation of the databases, the modelling process starts by choosing between the different databases that were developed with several techniques. A DTM is essential for flood damage modelling and can be created in several different ways (as was discussed above).

After a suitable DTM was created, a land use database has to be established. The user can choose between an *in situ*- or a remote sensed database. Loss functions that were developed specifically for the land use in the area of investigation are utilised, and the next step will be to choose loss functions from the databank. With the interface between FLODSIM and MIKE 11 (Arc2Mike and Mike 2 Arc), it is possible to obtain hydraulic data from MIKE 11 with reference to specific scenarios that were drawn up with FLODSIM.

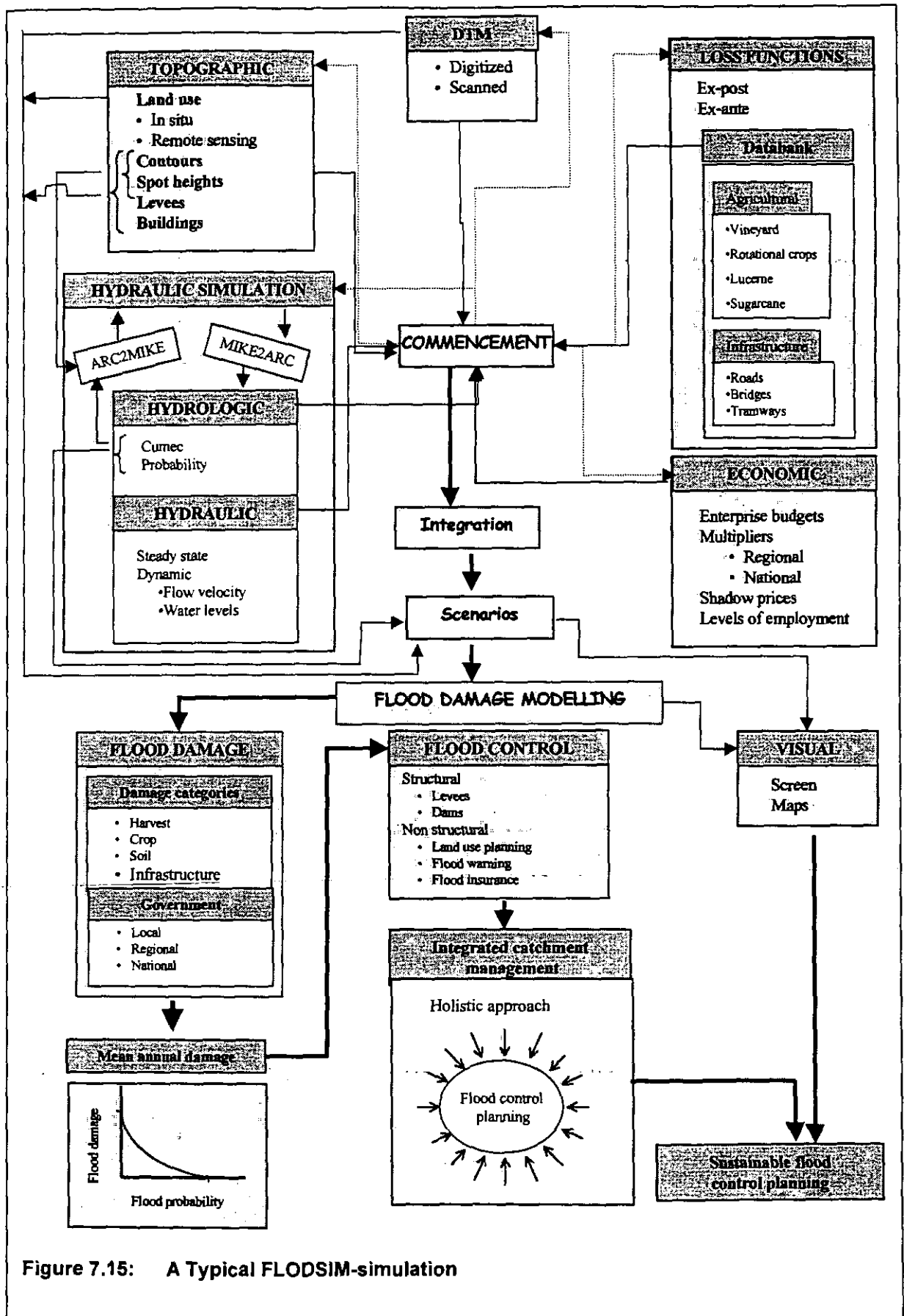


Figure 7.15: A Typical FLODSIM-simulation

After this, the economic database is chosen. The economic database consists of enterprise budgets, multipliers (regional and national), shadow prices and employment rate. Information from enterprise budgets are 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 by using suitable multipliers. When flood damage is calculated from a national viewpoint, the under- and over supply of agricultural commodities are of importance. To make sure that the real economic value of the various agricultural commodities is reflected, it is necessary to make some shadow price adaptations. The employment rate of the South African economy is also of importance, seeing that floods have a stimulating effect on the local economy when it does not function at full employment level (Du Plessis *et al.*, 1995).

After the database has been specified in FLODSIM, it is possible to set up 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 a national point of view. Scenarios can also be shown visually on the screen or on maps. Maps are essential for floodplain planning, and the depth and duration of overflows, as well as flood lines and flood areas can be shown. These are especially essential for flood management plans. A difference is being made between harvest, crop, soil and infrastructure damage. When the flood damage for floods with different probabilities of occurrence is known, it is possible to calculate the mean annual damage (MAD).

Structural and non-structural control measures can only be evaluated adequately if the MAD is known. Traditionally, flood damage modelling calculated only structural and non-structural control measures. This gave rise to the escalation of flood damage and the non-optimal utilisation of floodplains. Additional aspects also have to be considered, so that especially local authorities can be in the position to formulate sustainable long-term flood management plans. For this purpose, a holistic approach to integrated catchment area management is necessary. This will be discussed in Chapter 9.

## 7.5 MODEL VERIFICATION AND VALIDATION

Model verification was executed after each phase of programming to see to it that logical programme faults do not occur. Where faults have occurred, the necessary defaulting procedures were carried out.

Model validation is done after the development of the complete model and incorporates the validation of the simulation model. Seeing that future floods which might occur are imitated, model validation is practically difficult to execute. Flood damage that is calculated, is a forecasted damage figure and is difficult to be compared with damage done by real floods. For this reason, not much attention was paid to model validation during this phase of the research.

## 7.6 SUMMARY

Flood damage modelling was discussed in this chapter. More specifically, a short overview of flood damage simulation models was given. Besides flood damage simulation models for urban areas, limited literature is available for simulation models to calculate flood damage in irrigation areas. A loss function approach to calculate flood damage, was presented by White. Currently, this approach is applied generally to determine the extent of flood damage of floods with different probabilities of occurrences. Penning-Rowse and Chatterton (1977), Smith and Greenaway (1988), Dempster and Brammer (1992), Van Duivendijk [s.a.], Weiss (1976) and the US Army Corps of Engineers (Flood Damage Analysis Package, 1988) developed flood damage simulation models in the United Kingdom, Australia, Bangladesh, the Netherlands, South Africa and the United States. With the exception of the model of Van Duivendijk and Weiss, these models were developed for urban areas.

Geographic information systems (GIS) are becoming popular management and decision-making mechanisms with the advancement of computer technology, remote sensing and global positioning systems (GPS). For the purpose of this research, it was decided to develop a flood damage simulation model (FLODSIM) for irrigation areas in South Africa by means of the GIS-approach. This enabled

the integration of topographical, hydrological, hydraulic and economical data, together with loss functions. Furthermore it is possible, with the integrated data, to compose several scenarios for a floodplain and to calculate the mean annual damage (MAD) from a local, regional and a national viewpoint. With the MAD known, a package of flood control measures for an investigation area can be compiled. After a package of flood control measures has been developed, it is possible to draw up sustainable flood management plans for floodplains. The latter will be discussed in more detail in Chapter 9.

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## CHAPTER 8

### APPLICATION OF THE FLOOD DAMAGE SIMULATION MODEL IN THE MFOLOZI FLOODPLAIN

#### 8.1 INTRODUCTION

During the first phase of the research, several shortcomings of the flood damage simulation model (FLODSIM) were identified. Shortcomings have already been addressed in the previous chapters. One of the shortcomings of FLODSIM was that it was not generally applicable. To develop FLODSIM to be more widely applicable, it was decided to apply the model in another flood afflicted area of South Africa. The Mfolozi floodplain was chosen for this purpose.

In this chapter, the procedure that was followed to apply FLODSIM is discussed, and the extent of the total average annual flood damage for the Mfolozi floodplain is also indicated.

#### 8.2 IMPLEMENTATION OF FLODSIM

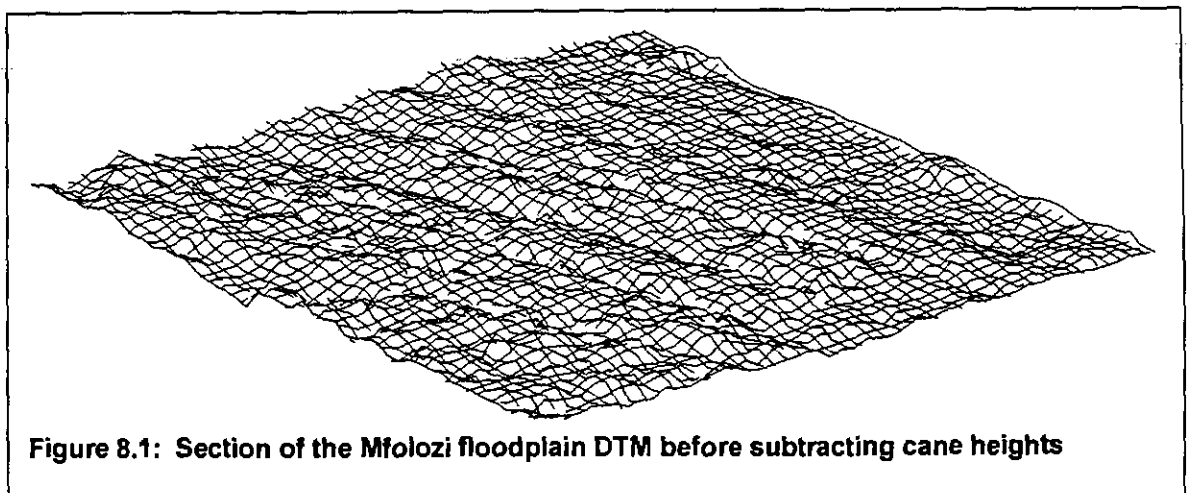
As a starting-point, applicable flood damage functions for the Mfolozi floodplain were developed (Chapter 5). After this, suitable databases had to be developed. The various databases are discussed subsequently:

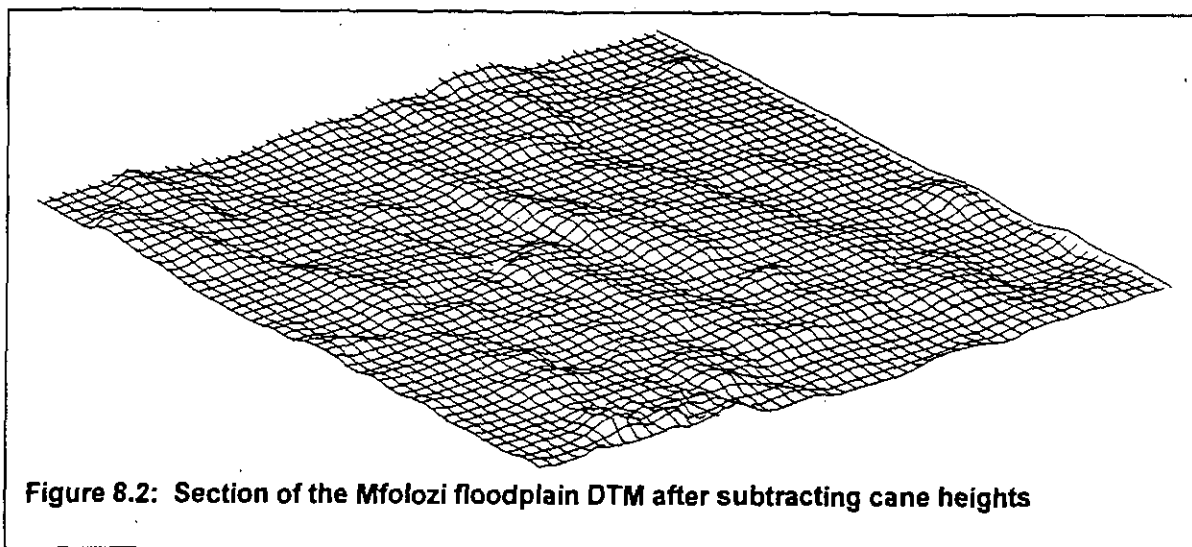
##### 8.2.1 OBTAINING TOPOGRAPHICAL DATA

Land use, roads, tramways, levees, drainage systems and rivers were digitised from 1:10 000 orthophotos. Unfortunately the most recent available orthophotos were created from old (1979) photography. The digitised data were therefore updated with information derived from 1996 air photos and digital data that were kindly made available by Bosch and Associates, Civil Engineers, Durban.

Two methods were applied to obtain a DEM for the Mfolozi floodplain. With the first method digital photogrammetry was used (Paragraph 7.3.3.2). The results from this method were unreliable due to the dense vegetation. A second DEM was created with an analogue stereoplotter. With this method points within cultivated fields could be ignored.

With the first method the Helava Digital Photogrammetric Stereoplotter installed on a Sun Ultra computer was used to obtain a DEM for the Mfolozi floodplain from controlled aerial photography with a scale of 1:30 000 (Schutte, 1997). A photogrammetric scanner was used to convert the analogue diapositives into a digital image format used by the Helava system, namely VITEC. It is worth mentioning that these files are quite large. Each image file is approximately 85 Mbytes when scanned at a 25 micrometer resolution. The 31 images with their pyramid and data files, used 5.6 Gbytes of disk-space. Caution must be taken when ground control points are entered to ensure that the different images will connect at the same level. While sugarcane in the Mfolozi floodplain is cut during different times of the year and is thus not always of the same height, compensations had to be made for the height of sugarcane for each cultivated field. The effect of the height of sugarcane on the DTM is quite extensive and is illustrated in Figure 8.1 and 8.2.





### 8.2.2 PROVISION OF HYDROLOGICAL AND HYDRAULIC DATA

The Hydraulic Studies Sub-directorate from the Department of Water Affairs and Forestry did the floodline calculations (Cai and Myburgh, 1998). Mike 11 was used to develop the dynamic floodline model for the Mfolozi floodplain. The cross sections and river network, required by Mike 11 to describe the floodplain topography, were defined in FLODSIM (Paragraph 7.3.6.1).

Unlike the case of vineyards, the duration of inundation is the most important variable that determines flood damage with regard to sugarcane. Besides the depth of the inundation and the velocity of flood waters, duration of the inundation in the form of flood hydrographs was provided by from MIKE 11. The duration of inundation is explicitly being taken into account in the determination of sugarcane loss functions.

FLODSIM was extended to calculate harvest and crop damage of sugarcane. Damage to the soil, largely as a result of the high coverage by cane in the area, is very low and is not calculated. The total average annual flood damage can be calculated by imitating various floods, namely the five-, ten-, twenty-, fifty- and regional maximum flood (RMF).

### 8.2.3 INFRASTRUCTURE

Besides harvest and crop damage, appropriate loss functions were also constructed for infrastructure like levees, drainage systems, roads, bridges and railways in the Mfolozi floodplain. Depth of inundation for the infrastructure is calculated by using FLODSIM. With the infrastructure inundation known, the total damage to infrastructure is determined by multiplying the Rand damage value per km with the total length of inundated infrastructure.

### 8.2.4 ECONOMIC DATABASE

Only sugarcane is cultivated in the Mfolozi floodplain and a budget was drawn up for that. A complete sugar cane budget is given in Appendix B. Besides this budget, regional and national multipliers were calculated in order to calculate regional secondary effects of the floods. Table 8.1 shows the economic data for the Mfolozi floodplain which were used for the simulation.

Table 8.1: Economic data for the Mfolozi floodplain (1995-values) for the calculation of the total direct and secondary flood damages

DIRECT DAMAGE	
Sugarcane	Amount
Sucrose per ha (ton)	94
Normal sucrose content (%)	12,3%
Lowered sucrose content due to flood (%)	10,3%
Gross Income (R/ton sucrose)	112,55
Gross Income (R/ton cane)	915
Harvest costs (R/ton sucrose)	32,40
Lucerne	Amount
Establishment costs (R/ha)	2 599
Gross Income (R/ha)	3 920
Harvest costs (R/ha)	791
Gross margin (R/ha)	2 264

### 8.3 CALCULATION OF THE TOTAL AVERAGE ANNUAL DIRECT FLOOD DAMAGE

#### 8.3.1 DISCOUNT RATES

After the databases for the Mfolozi floodplain were drawn up and integrated with FLODSIM, flood damage for floods with different probabilities of occurrence could be calculated. A distinction is made between harvest, crop and infrastructure damage. The infrastructure in the floodplain is maintained by the Mfolozi Co-operative, and flood damage to infrastructure is therefore not a direct damage to producers. While damage to infrastructure stays constant during all months of the year and is thus not influencing the course of damage, damage to infrastructure was not taken into account initially. It will be discussed more completely later. The methodology regarding the determination of harvest and crop damage was discussed in Chapter 6. It is only with regard to crop damage that a discount rate is used. To determine the impact of various discount rates on the total average annual flood damage, five discount rates were used, namely 8, 10, 12, 14 and 16 per cent.

Crop damage for individual floods with the mentioned discount rates increases progressively as larger floods occur. Difference of R1 074 million for the 10-year flood and R2 625 million for the regional maximum flood occur between the highest and lowest discount rates respectively. When the total average annual flood damage is calculated with different discount rates, a deviation of R231 609 occurs between the highest and lowest discount rates (Figure 8.3). A smaller deviation occurs in the MAD between 14 and 16 per cent (R40 388) than between 10 and 12 per cent (R76 519).

Due to a relative small deviation in MAD (8%) between the highest and lowest discount rate, flood damage will subsequently only be calculated at a 10 per cent rate.

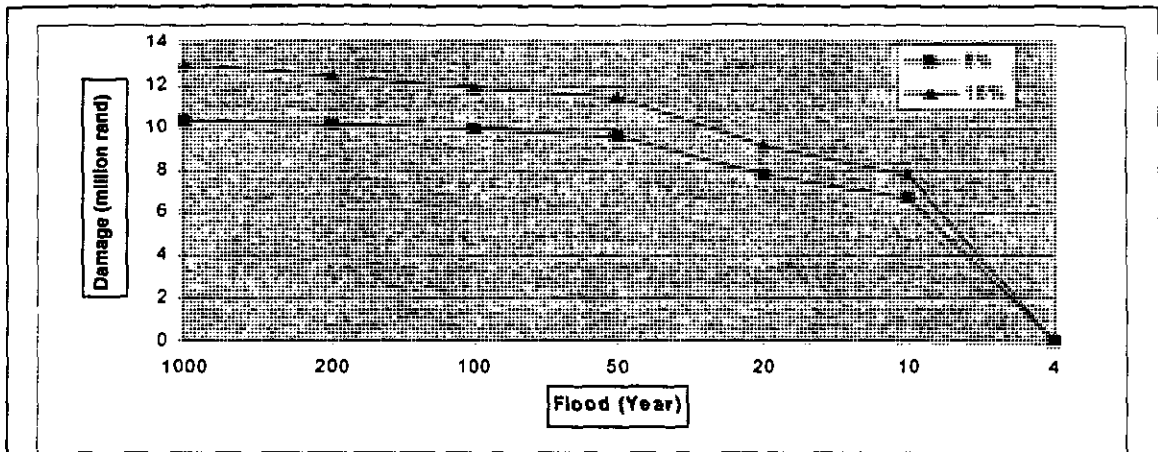


Figure 8.3: Total harvest damage for two discount rates, 1995

### 8.3.2 MONTHLY FLOOD DAMAGE

Floods in the Mfolozi floodplain could occur any month in any year. Consequently the flood damage (harvest and crop damage without damage to infrastructure) was calculated for all twelve months of the year (Figure 8.4).

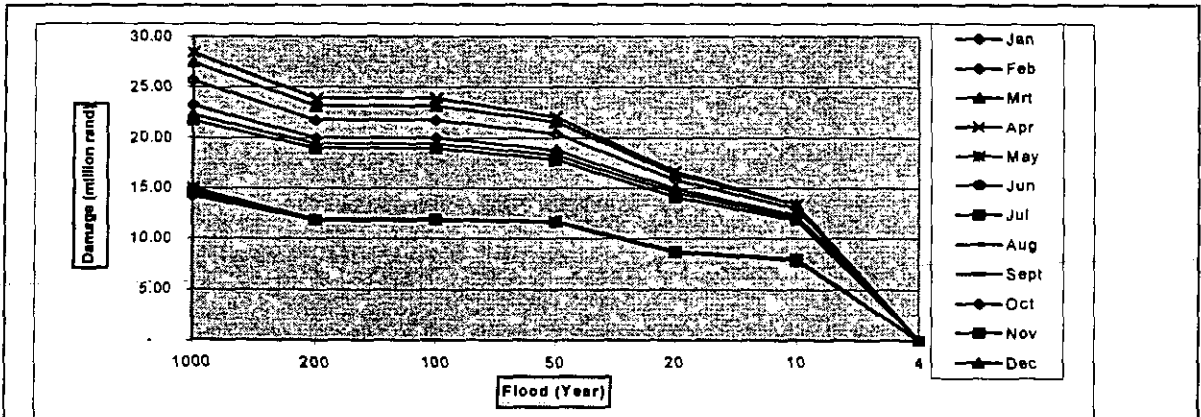


Figure 8.4: Total flood damage for the Mfolozi floodplain for twelve months of the year, 1995

A clear distinction is made between summer and winter damage. From November to April above average damage occurs and it increases from month to month. The average annual damage for the summer months varies from R2,39 million (November) to R2,8 million (April). Flood damage from May to October differs very little, because the total average annual flood damage for these months varies only from R1,56 to R1,58 million. Figure 8.5 shows the average annual flood damage

per month graphically, and aspects that were determined in Figure 8.4 are clearly noticeable.

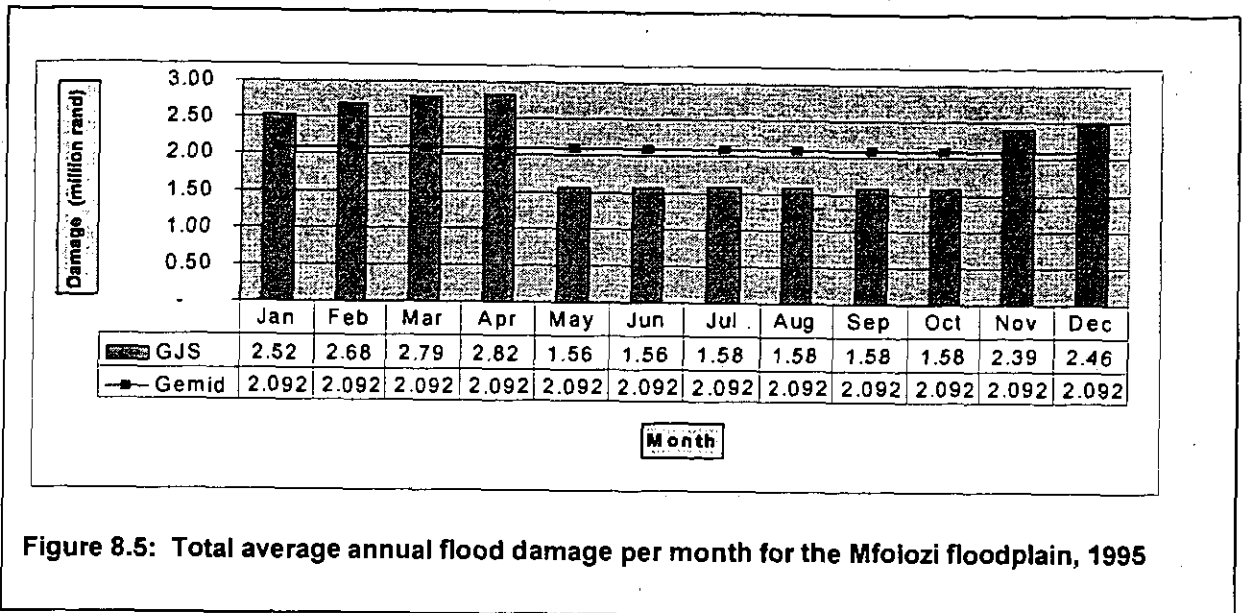
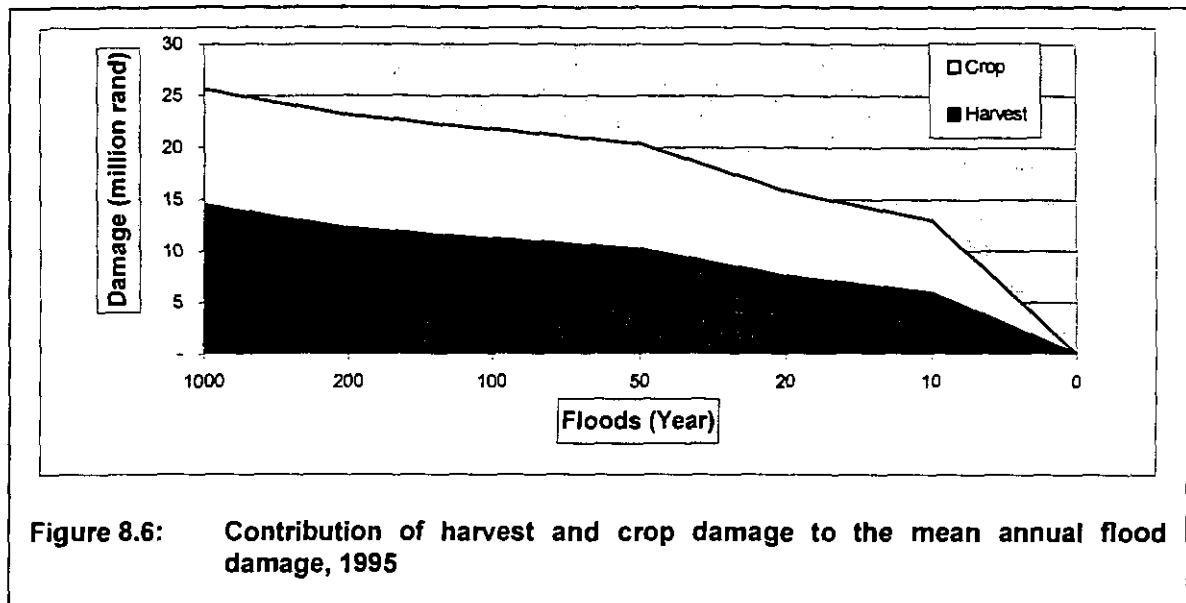


Figure 8.5: Total average annual flood damage per month for the Mfolozi floodplain, 1995

### 8.3.3 HARVEST AND CROP DAMAGE

When historical floods in the Mfolozi floodplain are observed, it becomes clear that a large percentage of floods occur during February. The 1995 flood also occurred during the month of February. An *ex post* survey was executed in this area (findings of this survey fall outside the scope of this research) and it was decided - for comparison between the *ex post* and *ex ante* approaches - to execute simulations only for a February flood. Other than in the case of the Upington irrigation area, where damage to crops exceeds harvest damage, damage to crops in the Mfolozi floodplain is nearly equal to the damage to harvests (Figure 8.6). The contribution of infrastructure damage is discussed later.



#### 8.3.4 TOTAL AVERAGE ANNUAL FLOOD DAMAGE

With the above mentioned amounts known, it is possible to determine the total average annual flood damage for the Mfolozi floodplain. In the first case it is necessary to calculate damage to infrastructure for the study area. When flood damage for an April flood (this is also the flood with the highest risk for the Mfolozi floodplain) is calculated, the total average annual flood damage amounts to R3,27 million. This is a 14 per cent increase in damage for the same flood without the damage to infrastructure (Figure 8.7). Flood damage decreases to R2 million when floods occur during the winter months. An average flood damage of R2,54 million occurs in the Mfolozi floodplain (1995) and is R450 000 higher when damage to infrastructure is also calculated. The total average annual flood damage for a February flood is estimated as R3,122 million. This is 4,5 per cent lower than the damage caused by an April flood. The variation between the total average annual flood damage, when damage to infrastructure is calculated, and the average annual flood damage, when damage to infrastructure is not calculated, is shown graphically in Figure 8.8.

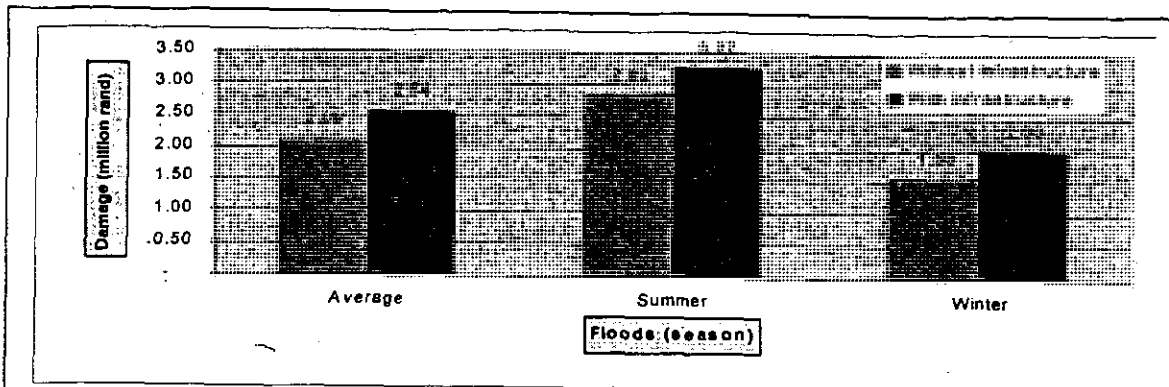


Figure 8.7: Variation in total mean annual damage for floods in various seasons, when excluding and including damage to infrastructure, 1995

The compilation of damage to infrastructure is shown graphically in Figure 8.8.

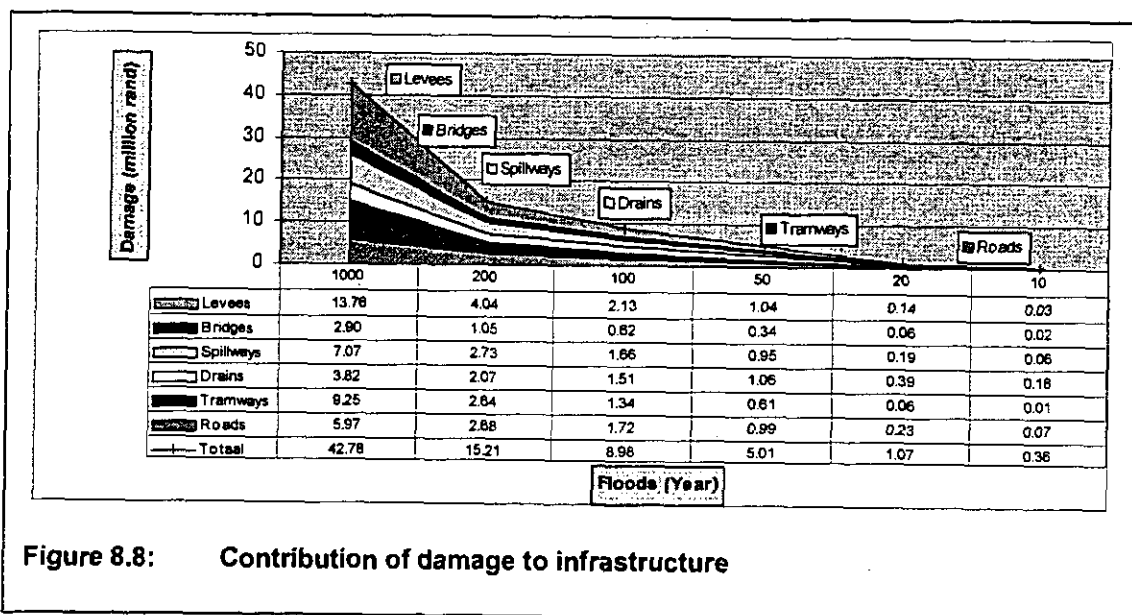


Figure 8.8: Contribution of damage to infrastructure

The largest average annual damage, namely 29 per cent, is caused to levees, followed by damage to railways (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 form the smallest component (6,8%) of damage to infrastructure.

### 8.3.5 RISK OF FLOODS

Flood damage is traditionally expressed in terms of the average annual flood damage, especially when flood control measures are evaluated. When using this approach, the risks of floods are not formulated clearly. Consequently it was decided to use an adapted approach so that the risk of flood damage for communities can be pointed out. With Figure 8.4 as background, the two outer boundaries of flood damage is taken as a starting point. Flood damage is plotted against the cumulative flood probabilities (Figure 8.9). Damage to infrastructure is included here:

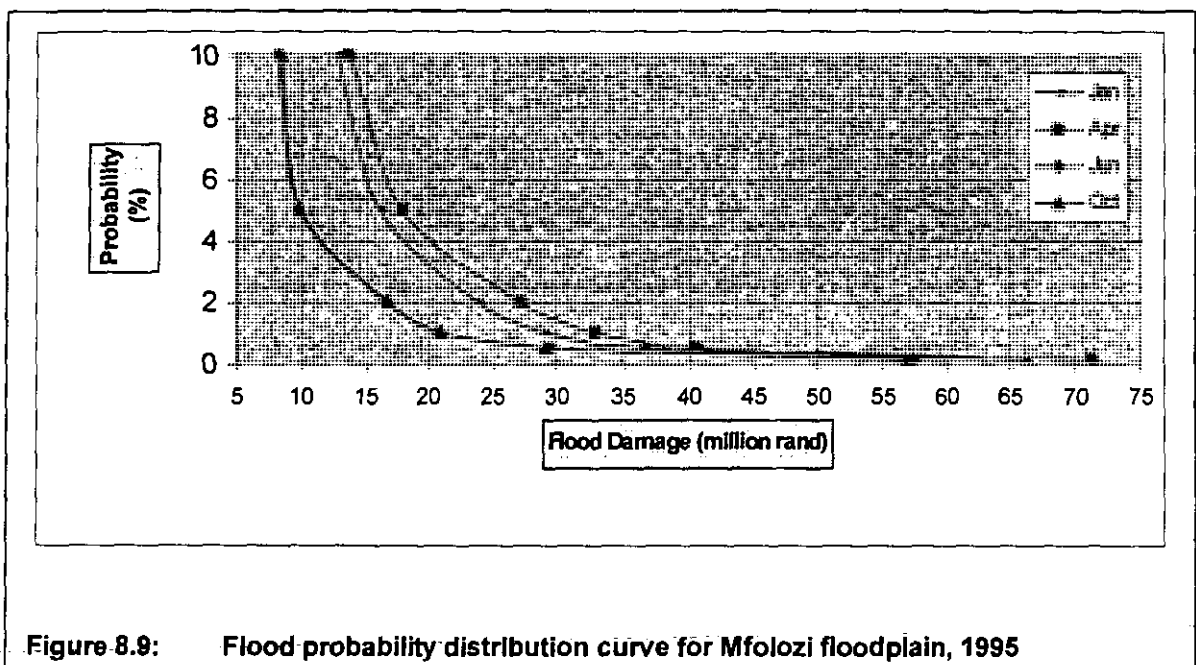


Figure 8.9: Flood probability distribution curve for Mfolozi floodplain, 1995

The April and June flood lines in Figure 8.9 show the outer boundaries of floods in the Mfolozi floodplain, followed by a January and October flood respectively. There is a 10 per cent chance that damage, depending of the time of the year that the flood occurs, can vary between R8,19 and R13,74 million in any year. There exists a five per cent chance that flood damages between R9,69 and R17,71 million can occur in any year. From this it is evident that floods that occur during April have a larger damage risk for the community, while a June flood causes the least damage. While the mentioned curves are initially (with a smaller flood) very high, it can be assumed with reasonable certainty that a specific damage in a specific year is not likely to be exceeded (Van Zyl, 1998). The latter is true, because the largest contribution to the total average annual flood damage can to a large extent be

explained by smaller floods. Damage, due to the RMF, can vary between R57,5 (June) and R71 million (April) in any year, although it has only a chance of 1 per cent to occur.

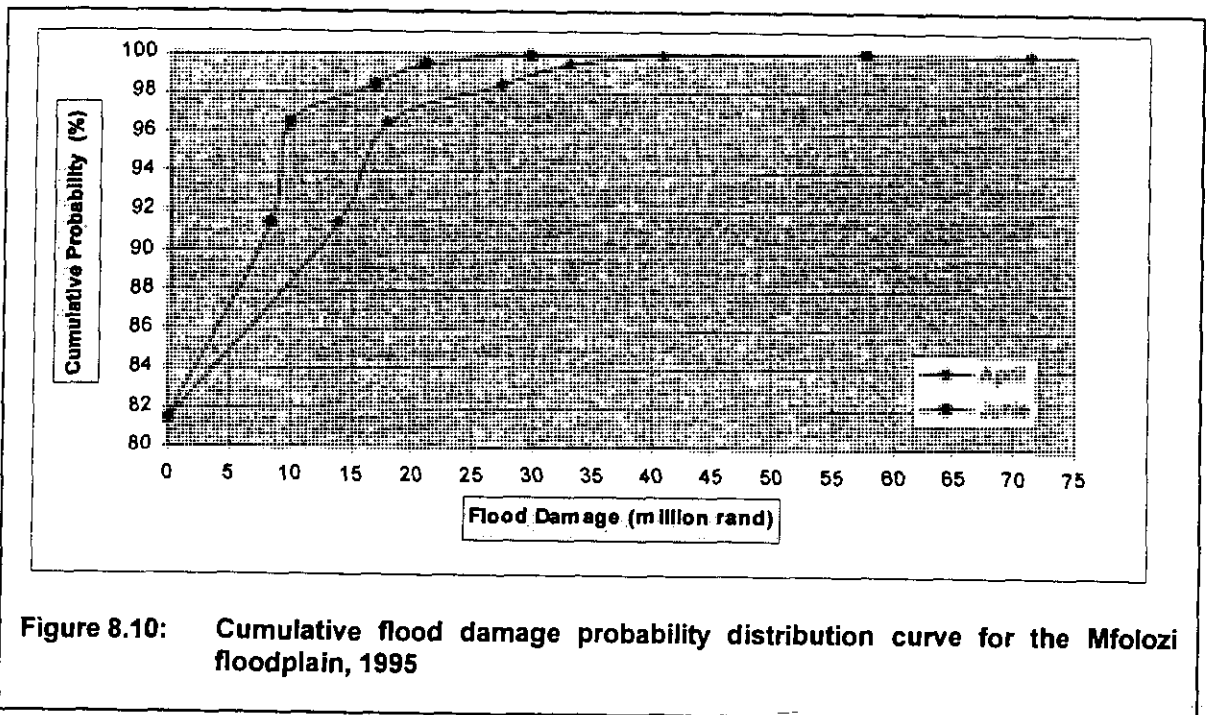
Although it can be assumed with great certainty that damage in Figure 8.9 will not be exceeded, the extent of certainty is not known. Therefore it is necessary to discuss additional information, namely the cumulative probability distribution (Figure 8.10). Before Figure 8.10 can be discussed, it is necessary to make the following assumptions:

- ☞ As a starting point it was decided to follow an approach of damage occurrence (or at least of damage that is known), against no damage occurrence. The assumption is that in the absence of a flood, no damage will occur. Due to a lack of historical flood records, it is not possible to determine exactly the amount of times that a flood of a specific size occurred over a long period of time.
- ☞ In the second place, the assumption is made that floods that have been simulated, namely a 10, 20, 50, 100, 200 and 1 000 year flood, were distributed over 1 000 years, and a one-in-ten-year flood will thus occur 100 times. The same principle applies to the other floods.
- ☞ The assumption is made that during 814 years of the 1 000 years, no floods will occur, when only the mentioned six simulated sizes of floods over the 1 000 year period will occur.
- ☞ Due to existing flood control measures in the Mfolozi floodplain, the smaller floods (smaller than the 10 year flood) cause no damage. The assumption applies that damage will occur after levees have been inundated, and not earlier as a result of erosion or collapse of levees.

According to these assumptions, damage will start setting in for the first time with the 10-year flood. As a result of this, there are indeed years when no damage will occur in the Mfolozi floodplain. On the one hand, this happens because no floods occur during specific years, and on the other hand because of flood control

measures, smaller floods (that occur more periodically and more often), will cause no damage.

It can thus be assumed with an 81 per cent certainty that no damage will occur in the Mfolozi floodplain in a specific year. Stated otherwise: there will be an 81 per cent chance that floods smaller than the 10 year floods will occur, but that - due to flood control measures - these smaller than 10 year floods will cause no damage. It is however important to notice that there is still a chance of 19 per cent that damage may occur in any year.



At the 96 per cent cumulative probability, damages can vary between R9,69 and R17,71 million, depending on the time of the year that floods occur, and it can be assumed with a certainty of 96 per cent that damage will not exceed R17,71 million in any year. With a 98 per cent certainty it can be assumed that flood damage in the Mfolozi floodplain will not exceed R32,89 million in any year. There is still a chance of 1,5 per cent that damage may exceed R32,89 million. This confirms the view that with great certainty it can be stated that flood damage of a certain magnitude will not be exceeded in any year (Van Zyl, 1998).

### 8.3.6 FLOOD SCENARIOS

Subsequently, apart from the *status quo*, four scenarios were investigated as an exercise to demonstrate how FLODSIM can be applied in flood damage control planning. With the analysis of flood damage of all four scenarios, damage to harvest, crop as well as infrastructure were taken into account. Each scenario was compared every time with the current situation (*status quo*) in the Mfolozi floodplain. A new set of hydraulic information was supplied for each scenario by the Division of Hydraulic Studies of the Department of Water Affairs and Forestry (Cai and Myburgh, 1998). Four cross sections were taken in the study area (Figure 8.11) and flood hydrographs were simulated for each flood size at each cross section. Graphic presentations of the hydraulic information (flood hydrographs) of all the scenarios for a 10 year flood (the tendency of the flood hydrographs for all the other floods looks more or less the same) are presented in Appendix A. In order to explain flood damage in the research area, it is necessary to study the hydrographs.

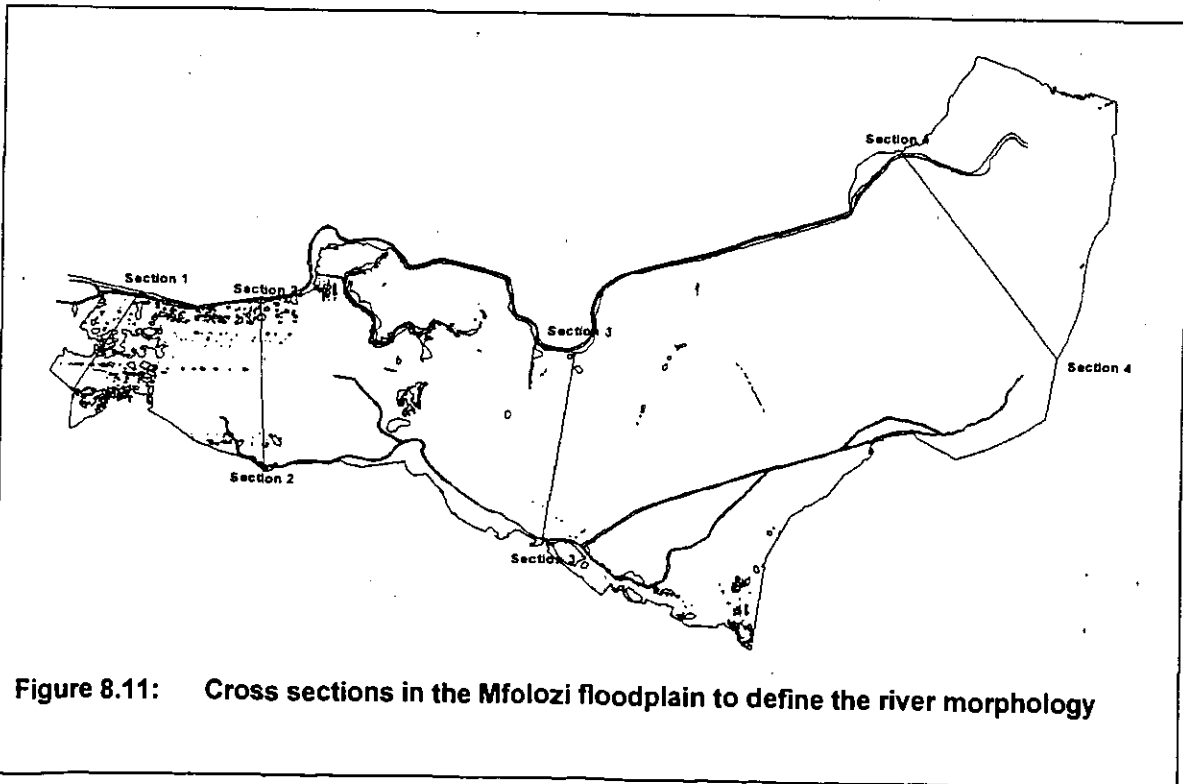
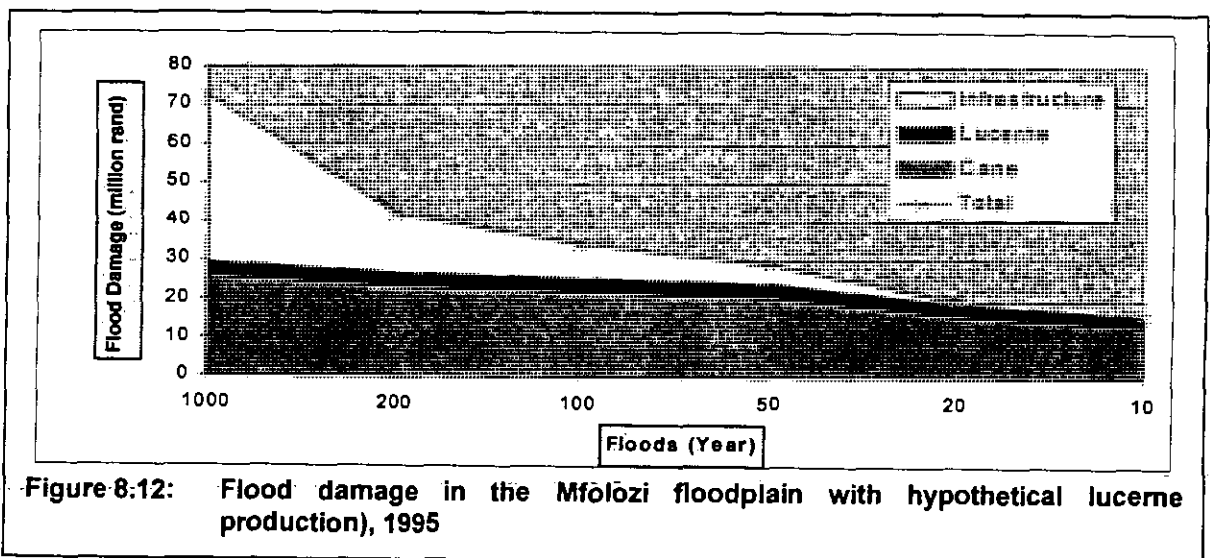


Figure 8.11: Cross sections in the Mfolozi floodplain to define the river morphology

A discussion of all the scenarios that have been investigated, follow.

### 8.3.6.1 Controlled vegetation

As the first simulation, it was decided to hypothetically replace the area that was expropriated after Domoina in 1984, with controlled vegetation. This area is not currently being used productively and by means of simulations it can be determined whether controlled vegetation can lower the negative impact of floods. It was decided to use lucerne, because of the positive effect it had on Manning's roughness coefficient, and also because lucerne loss functions were available (developed by Du Plessis, 1994). Because lucerne is not normally cultivated in the Mfolozi floodplain, there are no verified budgets for lucerne in this area. A budget for lucerne was thus taken from the enterprise budget for Kwazulu-Natal (1995). A gross margin of R2 264 per ha was calculated for lucerne (Appendix B).



In spite of the fact that the flood hydrograph (Appendix A) at cross sections 1 and 2 (Figure 8.11) is lower as a result of the lucerne, lucerne causes an additional damage of approximately R508 000 per annum, which raises the total average annual flood damage from R3,122 to R3,633 million. The economic life expectancy of lucerne is taken as 10 years. An average annual gross margin of R2,914 million can be expected with the additional 1 639 ha, and this is the net benefit that is obtained with the cultivation of lucerne when lucerne is replaced every ten years. When lucerne has to be replaced every seven or three years respectively, due to floods, average annual gross margins of R2,57 and R1,05 million are obtained.

This is still larger than the additional damage that occurs. To put this into practice, other factors such as the utilization and marketing of lucerne in the Mfolozi floodplain should also be investigated. The principle of this scenario is to establish controlled vegetation, other than sugarcane, that can control the flow of the water.

#### **8.3.6.2 Economic benefit of the spillway**

After the Domoina flood in 1984, floodplain inhabitants decided to develop a spillway for the Mfolozi floodplain, with the sole aim of lowering the velocity of the flood waters. A drop in velocity of flood waters prevents sand particles from being carried by the water and silt instead of sand is deposited on cultivated lands. This has a beneficial effect on future harvests in floodplains. This was not taken into account with the loss functions.

The impact of the spillway on the hydraulics in the Mfolozi floodplain was determined with MIKE 11 and the economic benefit of the overflow was calculated with FLODSIM. When it is assumed during simulations that the spillway does not exist, new cross sections had to be taken for MIKE 11, because flood waters will react differently without the spillway. Due to time constraints, new cross sections were not taken. As a result, accurate answers were not attained and it was decided not to draw any conclusions before improved hydrological data become available.

#### **8.3.6.3 Deforestation**

Where the Mfolozi River flows into the sea, flood waters normally rise as a result of dense vegetation. Deforestation of this area will improve the flow capacity of the river consequently leading to lower water levels in the river. Table 8.2 shows flood damage for the Mfolozi floodplain for floods with different probabilities of occurrence. Flood damage is lower for all the floods when it is compared to the *status quo*. The average total annual flood damage is 17 per cent (R529 438) lower. Deforestation can only be of economic benefit if the costs of deforestation do not exceed the average amount of R529 438 per annum (1995).

Although this option may look economically beneficial, ecologically it can be a very sensitive alternative. A comprehensive ecological impact study should be undertaken before any recommendation can be made. Ecological aspects are discussed in Chapter 9.

**Table 8.2: Total average annual flood damage (R) for the Mfolozi floodplain when deforestation hypothetically takes place, 1995**

<b>Flood (year)</b>	<b>Flood damage</b>
10	10 336 538
20	13 769 055
50	22 211 294
100	27 739 631
200	35 586 296
1000	65 525 134
<b>Total average annual flood damage</b>	<b>2 593 403</b>

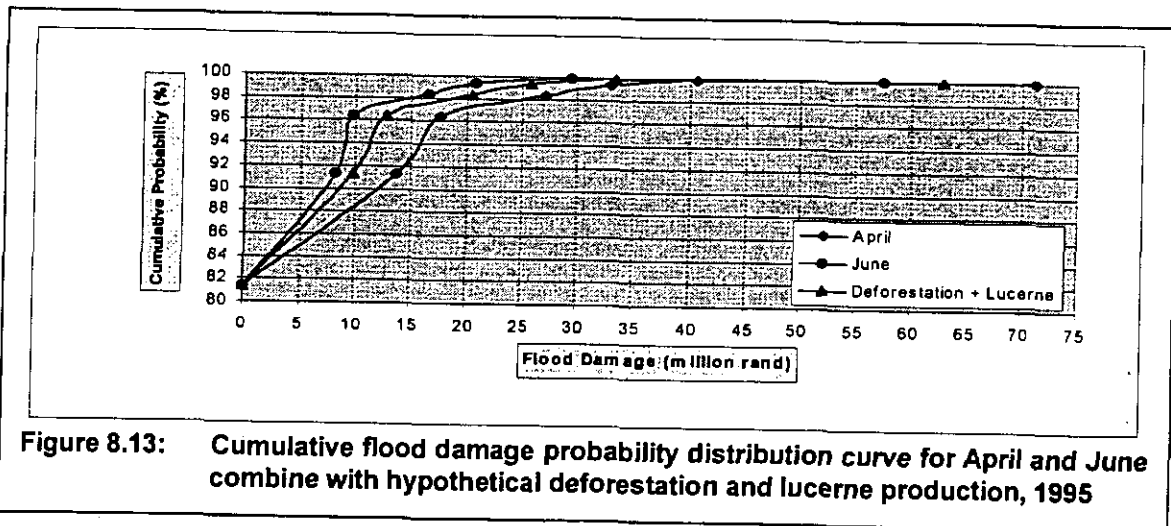
#### **8.3.6.4 A combination between deforestation and controlled vegetation**

Eventually it was decided to combine deforestation and controlled vegetation as an option. To understand the logic of this scenario, the flood hydrographs (Appendix A) should be studied in detail. Lower flood hydrographs are attained at cross sections 1 and 4. This causes lower than normal flood heights and duration of inundation. As a result of this, the total average annual flood damage of R3,122 million is lowered to R2,430 million (Table 8.3). Flood damage is thus lowered with an average annual amount of R692 674. Benefits attained from additional lucerne harvest were not included, because the inclusion of lucerne already has a positive impact on the total average annual flood damage.

**Table 8.3: Total average annual flood damage (R) for the Mfolozi floodplain when hypothetically lucerne is established and deforestation occurs, 1995**

Flood (year)	Flood damage
10	9 776 670
20	12 775 337
50	20 426 635
100	25 861 919
200	33 419 379
1000	62 867 518
<b>Total average annual flood damage</b>	<b>2 430 167</b>

Subsequently, the lowering of flood damage risk by means of the above-mentioned option for the study area, is shown in Figure 8.13.



When the cumulative flood probability distributions of a February and June flood are compared with the distribution of the hypothetical deforestation and cultivation of lucerne option for a February flood, in Figure 8.13, a distinctive lowering in flood damage risk with deforestation and the cultivation of lucerne can be observed. At 91,4 per cent cumulative probability, an average annual flood damage of R13,32 million would have occurred under normal conditions for a February flood. By accepting deforestation and the cultivation of lucerne as a flood control option, the damage is lowered to R9,78 million. In other words, it can be assumed with 91,4 per cent certainty that the damage in any year can be R13,32 million of less. With the same certainty it could be assumed that the damage will be R9,78 million or

less when deforestation takes place and lucerne is hypothetically established in the study area. The flood damage risk of a June flood is however lower.

### 8.3.7 FLOOD INSURANCE

With the previous discussion as background, it is also possible to determine an insurance premium for the Mfolozi floodplain. The annual flood premium should abnormally, at least, equal the expected mean annual flood damage. Although insurance companies are reluctant to offer flood insurance due to problems of distributing risk over time and space, the size of the premium shows the risk to settle in a floodplain. More discussion about a national flood insurance program is presented in Chapter 9. Table 8.4 shows insurance premium for the *status quo* and when hypothetical deforestation takes place in the Mfolozi floodplain. No additional administrative charges are included in the premium.

**Table 8.4: Insurance premiums for the Mfolozi floodplain (infrastructure included), 1995**

Option	Insurance premium (Rand/ha)
Average flood ( <i>status quo</i> )	430
Hypothetical deforestation and lucerne establishment	412

The average insurance premium can be R430 per ha and will drop with R18 after the option lucerne establishment and deforestation is implemented.

For implementing of insurance premiums it may be acceptable if the premiums could differ according to risk zones. Sugarcane lands which are inundated more often and/or deeper and/or for longer periods should have higher premiums than for example lands on higher areas in the floodplains. Because floodplains are normally flat, inundation of most lands happen whenever flooding occurs, making it difficult to apply a differential premium system. The contribution of different floods to the total premium is presented in Figure 8.14 for the Mfolozi floodplain. The largest contribution to the premium (15%) is for floods smaller than 20 year. The approach in Figure 8.14 can be used as a point of departure for calculating differential premiums between different flood zones, if deemed appropriate.

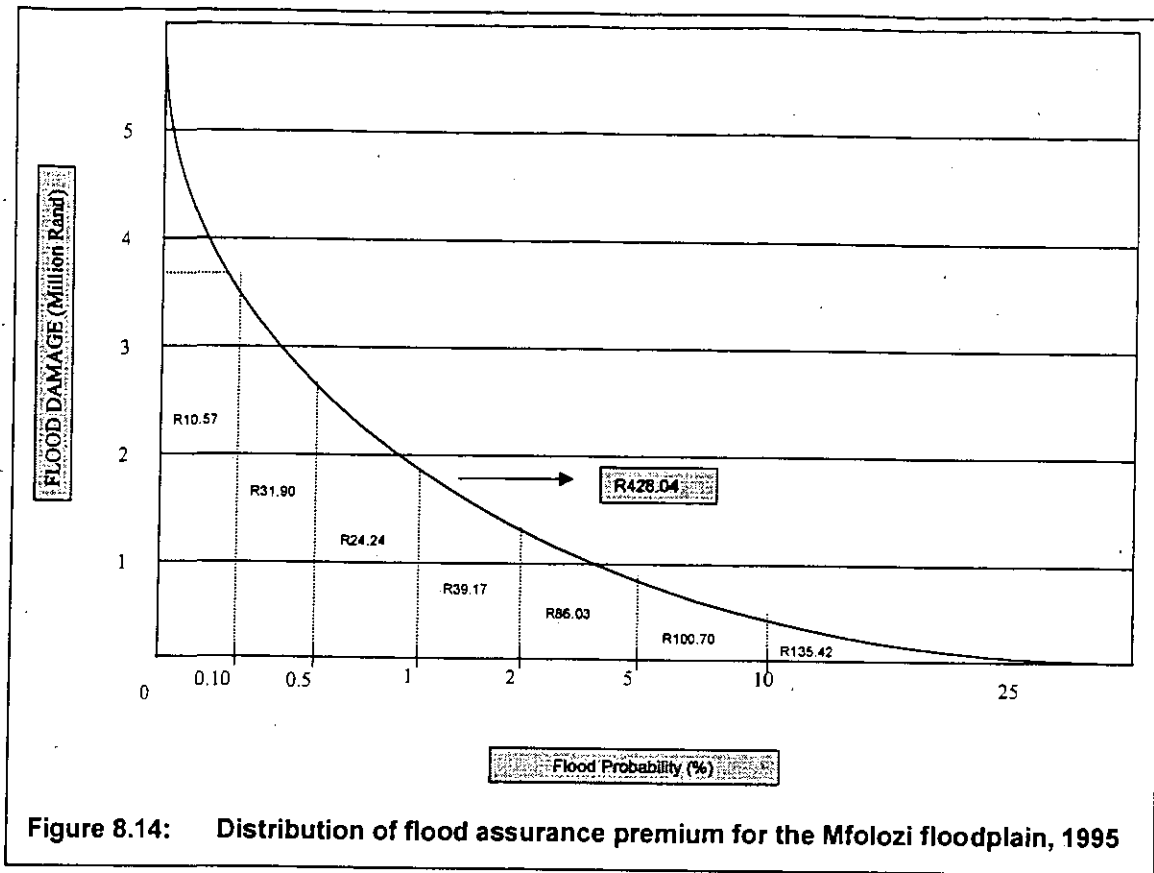


Figure 8.14: Distribution of flood assurance premium for the Mfolozi floodplain, 1995

#### 8.4 CALCULATION OF SECONDARY FLOOD DAMAGE AT REGIONAL LEVEL

Because of the backward and forward linkages of the agricultural sector with other economic sectors, the economic impact of flood damage extends beyond the boundaries of the agricultural sector. These secondary effects can be either positive or negative depending on whether economic activity is stimulated or whether production is decreased as a result of the flood.

In the Mfolozi floodplain the loss of harvest implies a loss of production, which negatively affects the sugar industry. Since sugar refining takes place within the region, the secondary damage has to be added to the direct damage to the harvest when calculating total (direct and secondary) damage to the harvest.

From the input-output table of local production in 1985 (1985 prices) for Region E (National Regional Development Program, 1991), the interdependence coefficients for nine sectors were derived (Table 8.5).

The damage to the harvest for the region was calculated by multiplying the total direct damage to the harvest with the multiplier for agriculture (1.013671). The damage to the harvest represents a drop in agricultural products in the region and thus a loss to the regional economy.

Although damage to crops implies a loss of income to farmers, the fact that sugarcane has to be re-established in certain areas implies stimulation of the regional economy. The stimulation results from an increase in the demand for products within the region as well as products imported from other regions. This positive effect on the economy thus mitigates the negative economic impact of the flood. Hence the damage to the crop for the region is calculated by subtracting the stimulation from the total direct damage to the crop.

**Table 8.5: Interdependence coefficients for Region E**

Sector	Agriculture	Mining	Manufacturing	Electricity	Construction	Trade	Transport	Financial	Services
1 Agriculture	1.000499	0.000434	0.014280	0.000069	0.000640	0.000731	0.000690	0.000107	0.000760
2 Mining	0.000067	1.000305	0.002553	0.005838	0.003051	0.000095	0.000568	0.000169	0.000150
3 Manufacturing	0.010040	0.013214	1.109523	0.003913	0.048553	0.027594	0.032379	0.004787	0.042407
4 Electricity	0.000122	0.001929	0.001909	1.007266	0.000202	0.001152	0.002624	0.000697	0.001164
5 Construction	0.000103	0.000230	0.000046	0.000687	1.028535	0.002286	0.002015	0.001257	0.000401
6 Trade	0.001207	0.002171	0.001924	0.001120	0.003940	1.010237	0.008164	0.001737	0.012172
7 Transport	0.001242	0.002546	0.001038	0.002715	0.006438	0.008381	1.008488	0.002623	0.020130
8 Financial	0.000159	0.000250	0.004380	0.000503	0.003713	0.013421	0.003149	1.010595	0.013109
9 Services	0.000230	0.006316	0.005919	0.002328	0.004458	0.002082	0.002105	0.001783	1.009785
Total	1.013671	1.027394	1.141572	1.024439	1.099530	1.065979	1.060182	1.023756	1.100078

Source: National Regional Development Program (1991)

The method followed to determine the stimulation on the regional economy was to calculate the increase in demand for the products supplied by the nine sectors as a result of one hectare of sugarcane that needs to be re-established. The value calculated for each sector represents the percentage of the cost of establishment per hectare that is paid to that specific sector. When multiplying these percentages with the total direct damage to the crop, the increase in demand for the products supplied by the sectors as a result of the total area of sugarcane that needs to be re-established after a flood, is found. The values so obtained must finally be multiplied by the multipliers of each sector and added in order to reach an estimate of the stimulation of the regional economy.

Because of a lack of detail in available input-output tables for the region, several assumptions had to be made with regard to the percentage of establishment cost which is spent in each of the different sectors. It was assumed that the total amount spent on seed cane (21.7 per cent) goes to the regional agricultural sector. Approximately 44 per cent of the cost of establishment was spent on products of the manufacturing sector. It was furthermore assumed that 20 per cent of this amount goes to the regional manufacturing sector, while the rest leaves the region. According to the National Regional Development Program (1991) there exist a number of well developed advanced technological manufacturing industries in Region E. Manufacturing of chemicals, metal products, machinery, and transporting equipment are examples of industries that make an important contribution to economic activity in the region. The high partial multiplier of the manufacturing sector also reflects the above-mentioned.

Secondly the insurance and interest on working capital was estimated at approximately five per cent of the cost of establishment and the entire amount was allocated to the financial sector. Thirdly the cost of repairs and maintenance of machinery and equipment, approximately six per cent, goes to the service sector.

With regard to the stimulation on the regional economy caused by the damage to infrastructure in the Mfolozi floodplain, it was assumed that 70 per cent of the cost of repairing the infrastructure would go to the regional construction industry.

**Table 8.6: Total direct and direct plus indirect damage for the Mfolozi floodplain, 1995**

Flood frequency (year)	Item	Direct damage (R)	Direct and indirect damage (R)
1:10	Harvest	5 918 567	5 999 480
	Crop	7 045 678	6 885 447
	Infrastructure	357 556	332 645
	Total	13 321 801	13 217 572
1:20	Harvest	7 596 957	7 700 815
	Crop	8 197 481	8 011 056
	Infrastructure	1 072 555	997 829
	Total	16 866 993	16 709 701
1:50	Harvest	10 186 851	10 326 116
	Crop	10 209 017	9 976 846
	Infrastructure	5 006 291	4 657 499
	Total	25 402 159	24 960 461
1:100	Harvest	11 200 258	11 353 377
	Crop	10 531 724	10 292 215
	Infrastructure	8 981 127	8 355 405
	Total	30 713 109	30 000 997
1:200	Harvest	12 213 381	12 380 350
	Crop	10 870 378	10 623 167
	Infrastructure	15 211 695	14 151 885
	Total	38 295 454	37 155 403
RMF	Harvest	14 488 502	14 686 575
	Crop	11 156 299	10 902 586
	Infrastructure	42 775 262	39 795 079
	Total	68 420 063	65 384 239

Particulars of the direct, and the direct plus indirect damage are given in Table 8.6. What is clear from the table, is while the inclusion of indirect damage (for all floods) increases the total harvest damage, it actually decreases the total damage to crops and infrastructure and also the net total damage. The results show that indirect damage has a tendency to cancel out and that the net effect of the indirect impact can be positive on the region. However, these conclusions should be further verified.

## 8.5 SUMMARY

In this chapter, the application of the flood damage simulation model (FLODSIM) in the Mfolozi floodplain was discussed. Topographical data were digitised from 1:10 000 ortho photos (1979) and was updated with 1996-air photography and digital data obtained from Bosch and Associates. A digital terrain model (DTM) was developed by the Division Geomatics of the Department of Water Affairs and Forestry. For each sugarcane field there had to be compensated for heights of sugarcane in order to create a more accurate DTM.

Hydraulic data were supplied by the Division Hydraulic Studies of the Department of Water Affairs and Forestry. The MIKE 11 hydraulic simulation model was used for this. Besides damage to harvest and crops, damage also occurs to infrastructure like the drainage system, roads, bridges, levees, railways and the spillway. Crop budgets for sugarcane and lucerne were drawn up and multipliers for Region E were calculated from Input-Output tables and saved in the economic database.

Flood damage was calculated with different discount rates. Meaningful variation in damages occurred between different floods for the different discount rates, with only small deviations in the total average annual flood damage. A discount rate of ten per cent was subsequently used to calculate damage to crops in the Mfolozi floodplain. Damage for 12 months of the year was calculated and a clear distinction between summer and winter floods was apparent. Damage during April is the highest (R2,824 million), in comparison with damage in June (R1,562 million) with damage to infrastructure not included. Different from the Upington irrigation area, damage to harvests and crops are more or less equal.

The total average annual flood damage for the Mfolozi floodplain, when damage to infrastructure is included, is R3,27 million during the summer months. This exceeds annual damage than when damage to infrastructure is not included with more or less R450 000 more. Damage to various infrastructure categories was also calculated, and the largest damage is damage to levees (an average of R105 000 per annum). This is followed by damage to railways with least damage to bridges.

Traditionally flood damage is presented in terms of the total average annual damage, especially where flood management measures are compared from a benefit-cost point of view. One of the disadvantages of this method is that it does not explicitly point out the risk of floods. Subsequently an adapted method was used to show the risk of flood damage for communities. It was shown that it can be assumed with an 81 per cent certainty that no damage in the Mfolozi floodplain is likely to occur in any year. Although the possibility that smaller floods might occur does exist, no damage will occur as a result of existing flood control measures that control such smaller floods. It can also be assumed with a 98 per cent certainty that flood damage in any year will not exceed the amount of R27 million.

Several scenarios were evaluated as an exercise for the Mfolozi floodplain. Due to incomplete hydraulic data, it was decided not to calculate the economic benefit of the spillway. An option was investigated where the area that was expropriated after Domoina was hypothetically planted with lucerne, and where the area where the Mfolozi River flowing into the sea, was deforested. This option offers the largest benefit for the Mfolozi floodplain and lowers the total average annual flood damage from R3,122 to R2,43 million. Consequently the risk of flood damage could be lowered when these options are applied in this area. Other aspects, e.g. ecological, should however also be taken into account before any practical recommendations can be made.

As far as indirect damages are concerned, it was found that the indirect effect of harvest damage increased the total damage while the indirect effect of damages to crop and infrastructure actually decreased the total damages. These results should however be further verified.

**LIST OF REFERENCES: CHAPTER 8**

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## CHAPTER 9

### SUSTAINABLE INTEGRATED FLOODPLAIN MANAGEMENT

#### 9.1 INTRODUCTION

The question whether the solution to reside in structural or non-structural measures has been debated extensively by academics and politicians over the past number of years. Authorities across the world are reluctant to acknowledge this critical point, namely that non-structural measures are also required (White, 1945). The reason for this is that this territory has been largely dominated by the engineer and to a lesser extent by the economist (Vos, 1982). Several studies have shown that flood risks in floodplains continue to rise despite efforts aimed at reducing flood losses by the introduction of flood attenuation works. This results in an increase in the potential flood damage. Structural programmes in the United States were regarded as extremely important and the main purpose of funding was the introduction of structural control measures in an effort to curb the rising flood losses. It is only in the past few years that the Federal Government in the USA has begun to support non-structural measures (Galloway, 1995).

Generally speaking, structural flood control measures are introduced on the strength of a positive cost benefit ratio. Cognisance is not always taken in the course of cost benefit analyses of additional development resulting from either new structural works or from the upgrading of existing ones (Parker, 1995). Apart from new developments, the detrimental environmental impact of some development projects is likewise underrated or generally omitted during cost benefit computations (Salem-Murdock and Horowitz, 1991). Consequently, the potential flood damage escalates despite the existence of a positive cost benefit ratio (Parker, 1995). The introduction of a sustainable floodplain development policy is advocated here, one which would further the philosophy of learning to live with floods and other natural disasters (Haque and Zaman, 1993).

The more traditional approach to floodplain management is to develop a decision making management model in order to determine the advantages of various structural and non-structural control measures. In order to act on the aforementioned comment by Haque and Zaman, namely the institution of a sustainable floodplain development policy, the flood damage simulation model (FLODSIM) is extended in order to accommodate the formulation of sustainable flood management plans. (See Chapter 7 for a diagrammatic representation of FLODSIM.) In a certain sense it gives rise to a new approach to floodplain management and this aspect will now be dealt with.

The purpose of this chapter is to identify aspects that will have to be addressed in the pursuit of sustainable flood management plans. A new approach to floodplain management will be discussed as a point of departure, whereafter a methodological framework for a flood management system will be proffered. Finally, relevant aspects concerning flood management aspects applicable to South Africa will be discussed.

## **9.2 NEW APPROACH TO FLOODPLAIN MANAGEMENT**

### **9.2.1 TRADITIONAL PROCEDURE AND METHODS**

Although the question whether the solution to floodplain management resides in structural or non-structural measures has been debated intensively in the last decade, both control measures resort under the traditional approach to floodplain management. Traditionally, floodplain simulation models were developed for both urban and irrigation areas, by determining the maximum benefit produced by various combinations of control measures. As far back as 1948 White observed that non-structural elements were also necessary, but authorities across the world were reluctant to pay attention to non-structural aspects as well. Only when countries experience serious loss of life due to floods do national authorities conduct studies to reduce the impact of floods, to find structural and non-structural solutions and to adjust flood management policy (Haque and Zaman, 1993; Dempster and Brammer, 1995).

## 9.2.2 PROBLEMS WITH FLOODPLAIN MANAGEMENT

### 9.2.2.1 *Governmental responsibilities*

The Federal Government in the USA fulfilled a dominant role in the past with regard to floodplain management by financing structural flood control measures and flood damage reinstatement in an effort to reduce flood losses. Witt (Director, Federal Emergency Management Agency) reacted as follows in October 1993, subsequent to the 1993 flood in the Mississippi River (USA): "The time has come to face the fact that this Nation can no longer afford the high costs of natural disasters. We can no longer afford the economic costs to the American taxpayer, nor can we afford the social costs to our communities and individuals". In 1994 President Clinton appointed an Interagency Floodplain Management Review Committee to find permanent solutions for reducing flood risk. Only now are the real benefits of non-structural measures appreciated (Galloway, 1995).

Proof also exists in England and Wales that flood damage increases with time. This increase in flood damage gives rise to policy debates regarding flood control and flood damage control measures, appropriateness of floodplain development control and future utilisation of floodplains in England and Wales (Parker, 1995). Australia, who has experience in centralised decision making, points out that many authorities, businesses and private concerns receive limited incentive to make decisions or voice proposals concerning floodplain management. For this reason the flood management policy of Australia has been adapted repeatedly in order to provide functional and feasible guidelines to regional and local authorities to ensure that meaningful floodplain management can be applied (New South Wales Government, 1986). The same happened in India. National and local plans were not interrelated and as a result of poor communication and centralised authority, information was not exchanged amongst the various tiers of government (Ghosh, 1991). The liaison between the various tiers of government in India was evaluated in order to determine the degree of preparedness of floodplain dwellers (Mukhopadhyay and Das, 1992). Similarly in South Africa flood damage grows with time (Schoeman, 1991) and increasingly improved protection becomes necessary (FMC, 1998).

The following major problems posed in floodplains can be noted (Galloway, 1993):

The risk to persons and property in floodplains is still considerable. Many floodplain dwellers do not fully comprehend the nature, scope and potential effects of such risks. Inhabitants furthermore do not fully share the burden of fiscal implications inferred by those risks.

- ☛ Given the tremendous loss of ecological habitat to plant and animal life over the past two decades, serious ecological consequences are threatening communities.
- ☛ The responsibilities of units dealing with floodplain management at national, provincial and local governmental level are not adequately defined.

#### **9.2.2.2 Community involvement**

In the past communities were not consulted in the process of approval and execution of projects (New South Wales Government, 1986). This led to *inter alia* conflict among producers, fishermen and members residing within and outside of the artificial levees. Public participation in the planning, design and operation of projects is indispensable to floodplain management (Dempster and Brammer, 1995). Plans drawn up must be made public (Ghosh, 1991). Innovative ideas must be proposed by river authorities in order to enhance public participation in especially levee maintenance programs and to attempt to minimise the opposition of persons to certain constructions. In the past in Bangladesh a handful of agents was responsible for the identification, planning, design, construction, operation and maintenance of all major water management projects. Projects were developed exclusively with a view to agricultural advantage while other economic and social interests as well as liaison with other government institutions such as local and public authorities were afforded minimal consideration. BANCID (1995) takes the aforementioned aspects a step further and states the following: "Evaluations of a cross section of such projects completed in the past show that the agricultural and socio-economic benefits resulting from these projects can be greatly enhanced and their sustainability can be assured by integrating local people and their representative in all stages of project activities". It is generally

accepted by institutions tasked with the formulation of policy that community participation is the key to not only flood control measures, flood damage control measures and water management activities, but also to overall economic development and growth. A flexible approach to the integration of local expertise and professional skills and resources is therefore advocated. This will reinforce the decision making process with regard to local needs, project formulation and implementation as well as operation and maintenance. In this way the needs of a totally diversified local group can be satisfied and negative effects due to conflict can be minimised (BANCID, 1995). The foregoing points to the multi-disciplinary approach essential to floodplain management.

### **9.2.2.3      *Institutional problems***

It was established in the course of a comprehensive literature study that a number of countries have experienced serious institutional problems at one time or another. The result of this is that potential flood damage continues to increase as time passes, with accompanying serious consequences in respect of loss of life. Proof exists of institutional network benefits which result in a decrease in hazard losses. In cases where appropriate institutions have been established, floodplain dwellers are considerably more aware of flood hazards and also handle floods more effectively (Haque and Zaman, 1993).

### **9.2.2.4      *Escalation of flood damage***

Projects which are investigated to reduce the effect of floods, are usually implemented on the strength of a positive cost benefit ratio. Various aspects such as additional development in floodplains, upgrading of existing structural works and detrimental environmental impact of some development projects are not always accounted for in cost benefit analyses (Parker, 1995; Salem-Murdock and Horowitz, 1991).

Backed by 20 years' experience, the World Bank comes to the conclusion that many of the projects do not succeed in determining the exact magnitude of the internal rate of return because the aforementioned factors are not taken into consideration (Salem-Murdock and Horowitz, 1991). The net result of this is an increase in the flood risk in floodplains and an escalation of potential flood damage despite the evidence of a positive cost benefit ratio (Parker, 1995).

The escalation effect (Figure 9.1) is illustrated in terms of a hypothetical example.

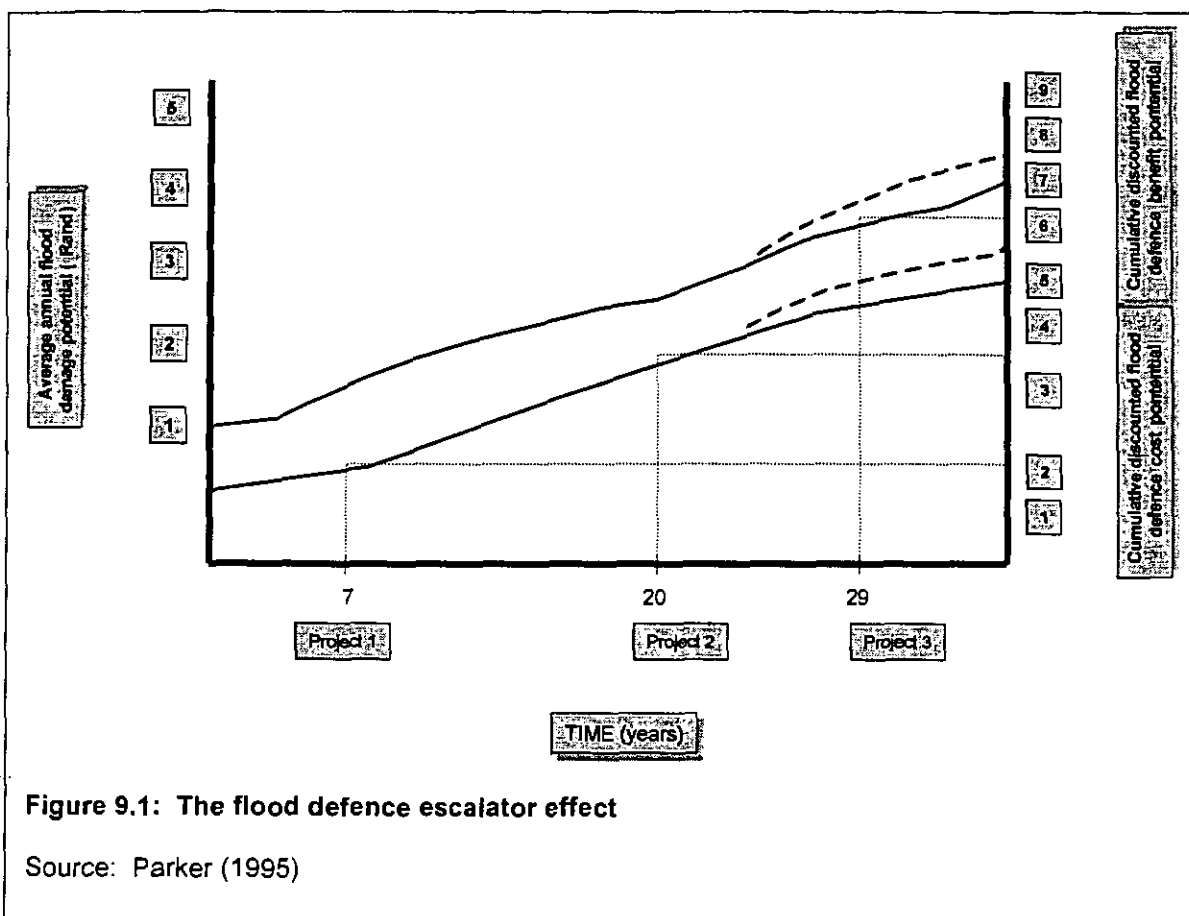


Figure 9.1: The flood defence escalator effect

Source: Parker (1995)

The first project (Project 1) is implemented in a floodplain where the annual potential damage of a 50 year flood is taken as R0,8 million. The potential benefit from this flood control measure exceeds the cost related thereto and results in a positive cost benefit ratio. At the onset of year 19 the mean annual potential flood damage had risen to R1,25 million. This increase in potential flood damage is attributable mainly to further development in floodplains resulting from increased structural flood control measures. Flood control measures and flood damage control measures are thus re-evaluated by taking into account the increased potential flood damage and as a result a further flood control project is developed

on the grounds of the positive cost benefit ratio, namely Project 2. This new project is constructed in accordance with a higher protection standard, that is, to protect the floodplain against the 70 year flood. The project is implemented and gives rise to, say, a raising of the artificial levees. By the year 29 flood damage had risen again in real terms. Consequently Project 2 is again adjudicated and the flood protection standard adjusted to a 100-year flood. Development in floodplains is encouraged by the artificial lowering of the risk due to the new flood control measure. The mean annual potential flood damage continues to rise (due partly to improvement in the living standard of the floodplain inhabitants), but in this case at a decreasing rate since few new entrants can settle in the floodplain.

### 9.3 METHODOLOGICAL FRAMEWORK

#### 9.3.1 SUSTAINABLE MANAGEMENT SYSTEM

Several flood management systems exist in the world, although the accent has been displaced during the past decade to sustainable development of floodplains. The World Commission on Environment and Development (WCED) defines sustainable development as follows: "...development that meets the needs of the present without compromising the ability of future generations to meet their own needs..." (WCED, 1987). Adams (1995) quotes Barbier (1987) in this regard as follows: "There is an emerging consensus that sustainable development should be directly concerned with increasing the living standards of the poor and it must address intergenerational equity and the extent to which costs and benefits of development are unequally borne by different people" (Pearce *et al.*, 1988, quoted by Adams, 1995). According to Haque and Zaman (1993) sustainable development can be viewed as the furtherance and management of all resources in floodplains, in such a way that the economic, social, aesthetic and environmental needs can be actualised while cultural integrity, essential ecological processes and life support systems are maintained. Sustainable development must embrace transparent and effective utilisation of the ecosystem in such a way that the advantages are promoted in the long term.

Many, if not most development projects, have a significant impact on the environment in floodplains (Adams, 1995; Salem-Murdock and Horowitz, 1991). In order that sustainability is ensured, the harmful effects of development must be eliminated as far as possible (Walmsley and Davies, 1991). Jacobs and Iwra (1994) put it as follows: "While everyone agrees that sustainable development is desirable, it has to be admitted on the basis of results so far that the translation of the concept into operation is still a very difficult task. It is clear that development must be environmentally sound so that during the process of development we do not destroy the resource base on which development itself depends".

Technology and practices employed in progressive developed countries will not necessarily be suitable in developing countries. The opposite is also true (Jacobs and Iwra, 1994). Haque and Zaman (1993) point out the essentiality of an holistic approach, as opposed to the structural strategy, whereby human aspects of water resource management and a sustainable floodplain development system is included which will ensure benefits to all participants. Further to the aforementioned 'sustainable' viewpoint Ghosh (1991) points out that flood management schemes should be handled within the framework of integrated long term planning and that this should take place in consideration of plans for other development such as irrigation, electricity and household water provision as well as orderly development of the local economy and urban development.

### **9.3.2 FLOOD ATTENUATION MEASURES**

Where floods are as critical to the economy and the community as in Bangladesh, a policy aimed at the attenuation of floods certainly is not the ideal solution (Haque and Zaman, 1993). Structural solutions will at best provide a limited solution to an intricate and extensive problem and could give rise to disadvantageous consequences for the ecology and the environment. The traditional approach to water management, namely by means of cement and bulldozers has proved to be ineffective (Van Zyl, 1995). Custers (1993) offers criticism on the flood management plan co-ordinated by the World Bank and states that structural measures such as artificial levees do not reduce the flood water but rather displaces it to other areas.

According to Haque and Zaman (1993) the accent of a flood management system should shift from flood prevention to flood adaptation. This approach will still afford limited protection to important areas. Notwithstanding the above, the primary objective of a flood management policy ought to be to encourage and assist floodplain dwellers to find the best possible way of protecting themselves, their crops and livestock by the development of improved flood management measures and flood preparation. The flood problem in Bangladesh is however not purely a case of "hydraulic thrusts", but much rather problems related to delicate consequences of the economy, ecology, community, demography, transport, settlement patterns and even political and cultural problems (Islam, 1990). Consequently flood aspects should be approached from a sustainable and long term developmental viewpoint. A comprehensive strategy is required to deal with the aforementioned aspects.

### **9.3.3 STRATEGY TOWARDS FLOOD PREVENTION**

Preparation is the key strategy to disaster mitigation (Mukhopadhyay and Das, 1992). The accent thus shifts from reactive to pro-active action. In order to be pro-active, flood management plans are required. The latter generally comprise a combination of flood control and flood damage control measures. In India a Disaster Management Centre has been established which undertakes in depth research on floodplains with the following objectives:

- Evaluation of the preparation plan for communities residing in floodplains in terms of pre, during and post phases of disaster management.
- Identification of shortcomings in the plan and the combination of districts according to preparation status making use of preparedness indicators.
- Reinforcement of the plan by proposing measures which will effectively lower the effect of disasters.

In order to put this into practice, it is the general tendency in the world in places experiencing problems with floods to devolve flood responsibilities down to local government level.

A floodplain management system is depicted diagrammatically in Figure 9.2 and will be discussed forthwith.

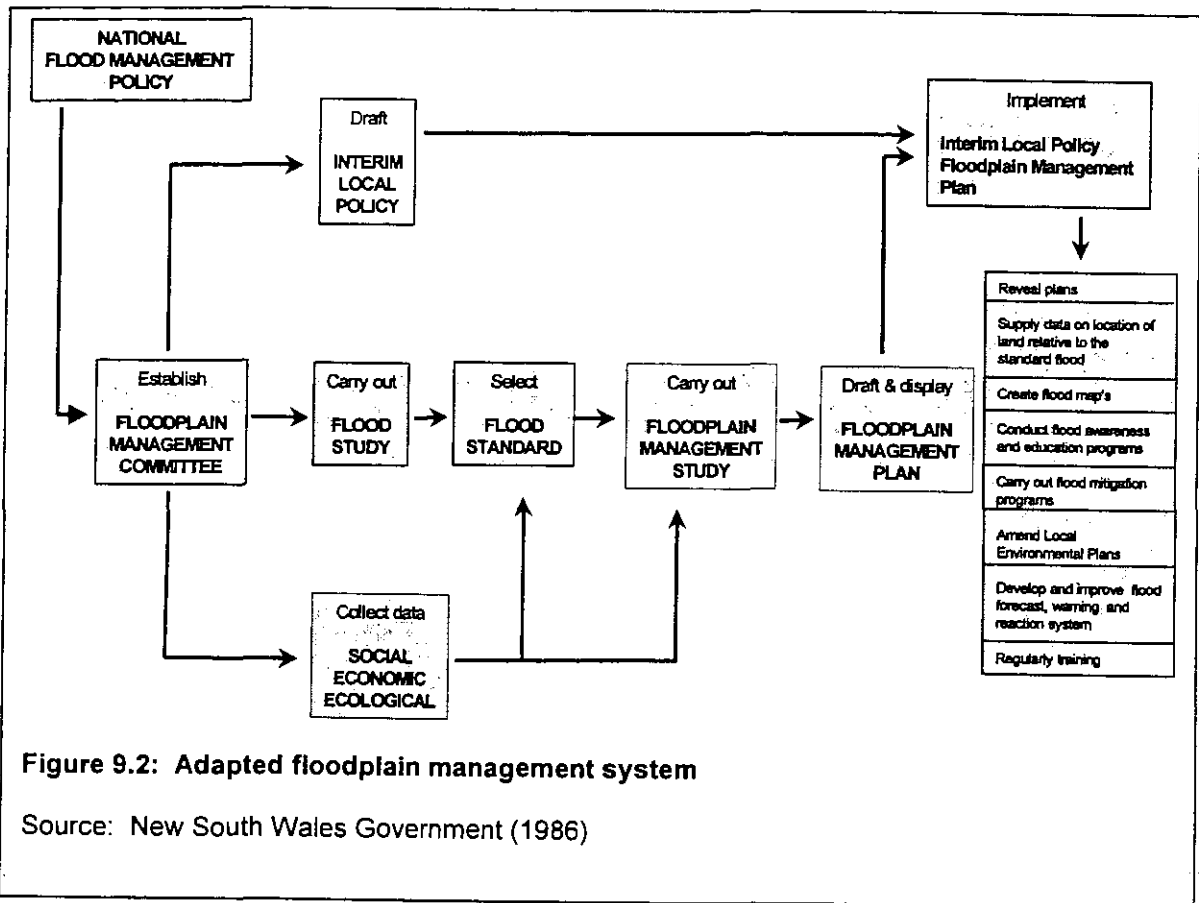


Figure 9.2: Adapted floodplain management system

Source: New South Wales Government (1986)

### 9.3.4 FLOODPLAIN MANAGEMENT SYSTEM

#### 9.3.4.1 Flood management policy

In order for the flood management systems of regional and local authorities to be guided and ordered, it is essential that national government formulates and implements an appropriate flood management policy. The following aspects should be covered during the formulation of such a national flood management policy:

- Land prone to flooding is a valuable asset that should not be allowed to fall into disuse by unnecessary restriction on development.
- Should all development be treated on an equal basis, by for example imposing a single flood line as the flood standard, certain proposals which may otherwise have succeeded could possibly be disapproved or unjustifiably limited (New South Wales Government, 1986). It is therefore a requirement that all development proposals be treated on individual merit.
- National flood management policy has as objective the *minimisation* of flood impact on individuals, inhabitants and private and public institutions.

Following the formulation of an appropriate flood management policy the application of the policy can be facilitated and co-ordinated by the formulation and implementation of the floodplain management plan (FPMP). This objective could best be realised if a local authority appointed a floodplain management committee (FPMC) (New South Wales Government, 1986).

#### **9.3.4.2 Floodplain management committee (FPMC)**

The question is often posed whether expertise should reside in national and provincial authorities. It would be unreasonable to expect of any local council to maintain a high level of expertise in all specialist fields (New South Wales Government, 1986). For this reason it is incumbent on the national government to provide expertise by making available engineers and planning and emergency services. The most obvious method of co-ordinating experts and information, especially in view of the multidisciplinary nature of floodplain management, is by means of a floodplain management committee (New South Wales Government, 1986). The local authority constitutes the FPMC. The primary purpose of the FPMC is to support the authority in the development and implementation of a flood management plan for the areas falling within the authority's jurisdiction. Further to the functions mentioned, the FPMC can also give assistance in respect of the following aspects:

- Formulation of interim development control measures to be used until approval and implementation of the flood management plan have been finalised.
- Establishment of appropriate control over conditional development.
- Development of a strategy for the implementation of the flood management plan.
- Directional guidance and the control of feasibility studies undertaken as well as the co-ordination of plans in various stages of development.

The committee must be representative of a community. In New South Wales the committee consists of elected members of the council, council staff, representatives of local governments, Department of Planning and Environmental Affairs, Public Works, Department of Water Resources Commission and representatives of State Emergency Services. Representatives of other state departments can be co-opted when necessary.

#### **9.3.4.3 Flood studies**

After the institution of a suitable FPMC the committee is responsible for the supervision of the execution of appropriate flood studies in the area. A flood study is a comprehensive technical survey concerning the behaviour of floods. These studies constitute the primary technical foundation for the formulation of an FPMP and provide technical background from which authorities can derive a suitable flood standard. Thereby management measures or precautions in respect of flood prone areas can be defined. The nature and character of flood hazards are provided by flood studies in that hydrological and hydraulic data (flood level, flow velocities and proportional flow at various cross-sections, flood probabilities and the extent of flooding) in floodplains are made available. Existing problems and future development proposals can be taken care of by undertaking more intensive studies in order to obtain detailed and accurate information concerning the flood characteristics.

#### 9.3.4.4 Flood standard

With the abovementioned hydrological and hydraulic data known, the next step is to choose a suitable flood standard. The choice of a flood standard for an area is a fundamental decision which must be taken since the standard is the point of reference for the preparation of the FPMP. The flood standard, also known as the designated flood, determines the area available for development. Consequently the merit approach is indispensable to the choice of a flood standard (New South Wales Government, 1986). The establishment of a flood standard on a merit basis entails the balancing of social, economical and ecological aspects without the raising of potential risk to property, life or structures. For this purpose information concerning the magnitude of a flood, flood behaviour, land uses and the consequences of greater floods, is required. Should the accepted standard be too low, new developments will take place in a sensitive area. The latter is also true in cases where a flood occurs which is greater than the accepted flood standard. In consequence the developments referred to will be flooded regularly and the potential exists that greater loss of life and flood damage to property and crops may occur. If no development took place, the opposite is also true; too high a flood standard will unnecessarily exclude land from development. The level of the flood standard is not necessarily the level to which protective flood attenuation works (mainly artificial levees) should be constructed. The height of artificial levees are usually dictated by the economic situation, physical restrictions on the site and the height relative to the ground that a flood can rise (New South Wales Government, 1986).

The present and proposed land use can also have a specific influence on the choice of a flood standard. In the case where ground is already developed, options for further management of land use are reduced as a result of massive investments from both public and private concerns. Management options and development control in areas not yet developed are considerably more available or possible. This is because the opportunity exists for implementation of appropriate planning measures that can prevent flood damage to vegetation and private and public property. These aspects should also be taken into account during the establishment

of a flood standard, especially in areas which are not developed yet (New South Wales Government, 1986).

Historical floods are usually the only basis on which flood standards can be established. Where only relatively short historical flood records exist, inappropriate decisions may be taken (New South Wales Government, 1986; Myburgh, 1998). With the development of appropriate flood damage simulation models it would be possible to determine a suitable flood standard by means other than through only historical flood records (Du Plessis *et al.*, 1995).

Due to the importance of the choice of a flood standard, the grounds on which this decision is made should be properly conveyed to communities and/or documented.

#### **9.3.4.5 Floodplain management studies**

Having determined the entire social, economical, ecological, hydrological, hydraulic and flood standard data, it is now possible to conduct floodplain management studies. Floodplain management studies are undertaken in order to identify suitable flood control and flood damage control measures. The effectiveness of these control measures towards improved management of floodplains can then be determined in an attempt to reduce the effect of floods on existing and proposed developments. No single floodplain management option will generally be sufficient. Consequently an optimal combination should be investigated, which will require complicated and extensive studies as well as professional services. The aspects mentioned can only be executed meaningfully if appropriate flood damage simulation models are available. (See Du Plessis, 1994 and Du Plessis *et al.*, 1995 for more details of specific flood control measures.) Harmful effects which may possibly be caused by flood control measures upstream or downstream have to be assessed during floodplain management studies. Should detrimental effects indeed be encountered the necessary compensatory adjustments should be made (New South Wales Government, 1986).

The influence of different flood control and flood damage control measures on the characteristics of various flood magnitudes can be taken into account once appropriate interfaces have been created between a hydraulic and a flood damage simulation model (Chapters 5 and 6).

Social disruption caused by flooding is often more meaningful than the directly tangible flood damage. Conventional procedures are commonly used to conduct economic analyses (New South Wales Government, 1986). The economic advantages of various flood control and flood damage control measures are established by estimating the damage which could be prevented in each case as indicated by the flood damage simulation models. Floodplains are preferentially reserved for agriculture, plantations, urban settlements, irrigation and flood attenuation works (New South Wales Government, 1986), of which agriculture is the most important land use in the floodplains in African wetlands (Kimmage and Adams, 1992). In this context Tané and Xingzhao (1993) define sustainable ecological development as follows: "Ecologically sustainable development is about adapting and designing human activities to work with, not against, the normal, dynamic processes of our environment". The method of executing integrated catchment planning is displaced from a deterministic and forecasting approach to a holistic and discovering (heuristic) approach (Tané and Xingzhao, 1993). In order to ensure that no further degradation of floodplains occurs, floodplain management plans should contain all relevant ecological aspects for further development. To this end knowledgeable analyses concerning the environment of the river system and catchment areas are required (New South Wales Government, 1986).

In addition to ecological sustainability, environmental development also has to be carried out in order to protect the main elements contributing to the integrity of the river and floodplain such as land uses, hydrology, plants, animals, humans, water courses, water quality and aesthetic attractiveness and to identify the main threats to the aspects mentioned. Consequently the implications of alternatives must be developed and flood attenuation proposals be estimated for the environment (New South Wales Government, 1986). According to Adams (1995) development projects have a significant impact on the environment in floodplains. Measures such as dams and artificial levees will influence the extent and duration of a flood. The life

cycles of indigenous plants, fisheries and water bird species are dependent on floods and can be affected by the measures mentioned. Particularly in river courses, structural measures have a very significant environmental impact and have to be handled with great circumspection to ensure that the flow in river courses is assured even in the off season. Negative impacts are found in Africa because the engineer, economist and other developers possess limited knowledge about the preferable ecological and human usage of wetlands in Africa (Adams, 1995).

The admissibility of development of any area is usually specified in a local environmental plan (New South Wales Government, 1986). The preparation of an FPMP for a specific area should not be done in isolation but should be viewed as a component of a river system in a totally integrated catchment area.

#### **9.3.4.6 Floodplain management plan (FPMP)**

Once the aforementioned steps have been concluded it will be possible to develop an appropriate policy and a floodplain management plan. The primary objective of a FPMP is to lower the negative impact of floods and to spell out the flood-related responsibilities of individuals, owners, floodplain inhabitants and private and public concerns. Aspects such as hydraulic categorisation, hazard categories, development type, land uses, ecological and social description and analyses, flood control and flood damage control measures, local flood management policy and requirements of environmental legislation must be afforded attention during the preparation of an FPMP (New South Wales Government, 1986). Guidance with respect to development decisions can be provided by means of an interim local flood policy until such time as the FPMP is prepared and ready to be implemented. The FPMP should also embody the National Governmental Policy as its point of departure.

The formulation and implementation of an FPMP should *inter alia* take cognisance of the following aspects:

- The nature, duration, extent and behaviour of floods as well as the risk of floods, prevailing flood hazards and the potential effect of current developments.

- Economic benefits of potential flood control measures and flood losses, as they relate to both the private and the public sector.
- The environment in which floods occur, including the social, economic and ecological factors.
- Local planning requirements, limitations and opportunities.
- The impact floods have on development and the impact development in floodplains may have on floods.

In this manner assurance can be given that community safety, health, prosperity and welfare needs are taken care of, that all information concerning the nature and character of possible future floods have been imparted to the public, that an appropriate and effective flood warning system is in place and that emergency services have been instituted for future flooding.

With the drafting and implementation of an FPMP all actions to be taken before, during and after a flood have to be investigated. For this purpose data can be collected at various tiers of government. Detail aspects of action plans implemented to date and also reasons for not implementing certain actions must be highlighted (Mukhopadhyay and Das, 1992). Communication between various tiers of government is essential for optimal application of floodplain management.

Tiers of government, flood prone areas, flood hazards, development categories and plans and levels must be clearly defined and incorporated in the FPMP. After finalisation of the local flood management policy the FPMP can be accepted and implemented. Some aspects can be implemented swiftly and with ease while others may take longer. A local environmental plan is one of the most effective methods of restricting development in flood sensitive areas and is compiled subsequent to the FPMP (New South Wales Government, 1986).

The expertise and support of the entire community must be acquired during the preparation of an FPMP. Members serving on the council as well as members of the floodplain management committee must represent the community and the FPMP must be made available for comment. Commentary, criticism and proposals received must be duly considered at the finalisation and acceptance of the FPMP (New South Wales Government, 1986).

No plan can be implemented at once. Availability of funds will play a decisive role in determining the timing of certain actions. A strategy is therefore required for implementing the FPMP over time. Procedures should also be introduced for the appropriation of financial aid from national government by local authorities when they need funds for implementing the FPMP.

## **9.4 NATIONAL FLOOD MANAGEMENT POLICY OF SOUTH AFRICA**

### **9.4.1 FLOOD MANAGEMENT CONSULTANTS (FMC)**

Since the start of research into the ex ante approach in 1992 it has been envisaged by the Department of Water Affairs and Forestry (DWAF), that a new national flood management policy should be formulated for South Africa. The Department appointed a consortium of consultants, called Flood Management Consultants (FMC), to assist it with investigations aimed at the formulation of a flood management policy for South Africa. Those investigations culminated in a number of reports on various flood management issues, e.g. the impact of floods in South Africa, flood warnings, the value of flood control, and various others.

### **9.4.2 TOWARDS A NATIONAL FLOOD MANAGEMENT POLICY**

The way forward in terms of flood management now has to be outlined by means of a summary report, *inter alia* building on FMS's reports, but also incorporating recent developments and policies. In this regard the playing field has changed substantially since 1993.

Whereas a line-function department (DWAF) had to take the initiative during the early nineties to move toward a better structured national flood management policy, the broader issue of disaster management is now receiving attention in South Africa and indeed on an interdepartmental basis. This movement will greatly enhance the formulation of a national flood management policy, because a balanced flood management approach is interdisciplinary, multi-sectoral and involves all tiers of government, specifically focussing on local government. While

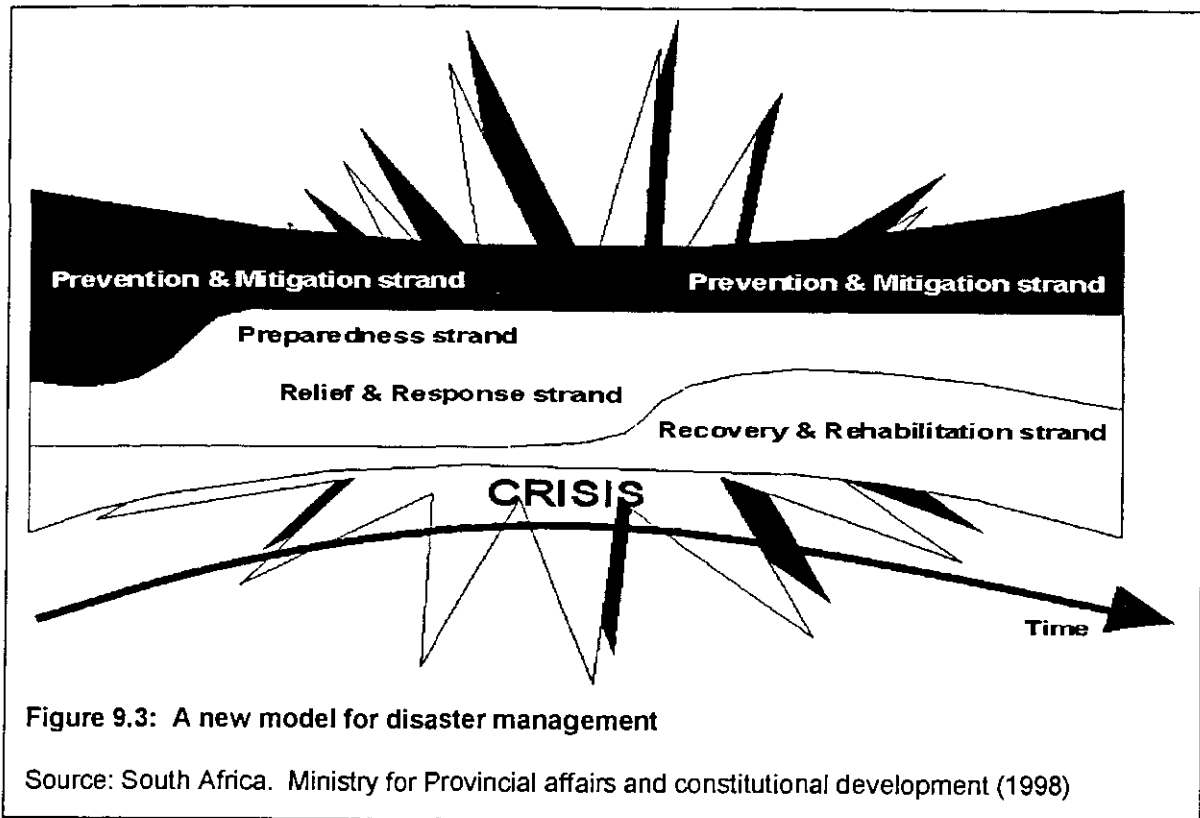
flood management constitutes but one aspect of disaster management, a national disaster management structure, with ownership amongst all government departments on all tiers, will obviously be in a better position than a single, national line-function department to formulate and, more importantly, to further and implement a balanced national flood management policy.

### **9.4.3 DISASTER MANAGEMENT**

Good progress has been made with respect to disaster management in a broader context in South Africa. In this regard a Green Paper which embodies a draft framework for disaster management has been passed to provinces and the public for comment (1998). The Green Paper highlights possible management strategies for improved management of different types of calamities. Therefore the objective of the Green Paper on Disaster Management is to develop an effective disaster management system and to implement it by means of an appropriate policy, which will be embodied in legislation. Aspects which have a bearing on flood management will be discussed later as required.

The process started during 1995 when Cabinet approved that a formal structure for disaster management be created. A National Disaster Management Committee (NDMC) was founded at the national level. During 1997 Cabinet also established an Inter-Ministerial Committee on Disaster Management to serve as the apex for disaster management. While awaiting the formalisation of the envisaged national disaster management structure, an Interim Disaster Management Centre was created, consisting of ten national government departments, to be able to manage currently urgent disasters over the short term (Green Paper on Disaster Management, 1998).

Traditionally a disaster management system was subdivided into different phases, namely the pre-disaster risk reduction phase and the post-disaster recovery phase. A new disaster management approach (Figure 9.3) depicts a continuous process whereby progress from the one phase to the next is achieved in orderly fashion. Disasters are thus managed as parallel activities rather than activities in series.



## 9.5 FLOOD MANAGEMENT STRATEGY FOR SOUTH AFRICA

The methodological framework concerning flood management systems which has been discussed previously in this chapter will serve as framework on which to base comments concerning the proposed flood management policy for South Africa.

With the flood damage simulation model discussed in Chapter 6 as background, this section is aimed at discussing aspects associated with sustainable flood management plans. The methodological framework related to flood management systems which has already been covered in this chapter, will serve as framework to make inputs towards the proposed flood management policy for South Africa. The aspects referred to will be integrated in order to identify and discuss activities

of concern to a flood management strategy for South Africa. When these aspects are integrated, the escalation of flood damage in floodplains can be prevented or at least retarded.

### 9.5.1 FLOOD MANAGEMENT PLANS

The primary objective of a flood management plan is to attempt to find permanent solutions to flood problems in floodplains. In order to be able to sensibly coordinate the activities in a flood management plan, it is imperative that river management be applied correctly. More specifically, it is the primary goal of a flood management plan to create a safer environment for inhabitants, infrastructure and economic activities (New South Wales Government, 1986). Consequently, the dynamic character of a floodplain eco-system must be carefully mapped, monitored and modelled in order to properly comprehend its functioning and maintenance roles (Tané and Xingzhao, 1993).

Subsequent to the recent floods (of the past 10 years) which manifested in various places in the world, several studies have shown that the flood management policies of specific countries have influenced the course of development in floodplains without, however, managing to halt it (Dempster and Brammer, 1992; Parker, 1995; Galloway, 1995; New South Wales Government, 1986). As a result of extreme pressure on communities within floodplains and unsystematic development, the flood situation deteriorates daily, notably in India (Ghosh, 1991). Development in floodplains is still the order of the day and hence the potential for flood damage in floodplains escalates. To enable authorities to manage floodplains effectively and to ensure that sustainable development takes place inside of it, authorities are compelled to compile a floodplain management plan. A floodplain management plan must be comprehensive and must provide an effective framework for the development of ground and water resources in catchment areas (Dempster and Brammer, 1992).

In order to comply with the idea of sustainable, integrated long term planning as well as the compilation of development plans (Adams, 1995; Ghosh, 1991) a holistic approach to integrated catchment management is proposed for South Africa. "A

holistic co-operative approach is necessary which would ensure in achieving a sustained minimal standard human life for the people and protection of the environment. There is no other alternative for the survival and betterment of the people of the region" (Bancid, 1995). The following guidelines and implications of a holistic floodplain development strategy are provided (Haque and Zaman, 1991):

- ☛ The implementation of a sustainable floodplain development policy will shift the focus away from the traditional sectoral planning and towards a total flood prevention approach. The accent must be placed more firmly on the control of a flood, but only when the severity exceeds a certain extent, in order that all development and ecological aspects can be accommodated.
- ☛ Floodplain development plans which may result in cultural or environmental losses, will have to indicate with increasing assurance how future generations could be compensated.
- ☛ Development plans should circumvent all actions which may possibly encourage irreversible natural processes. Some physical and cultural resources may be replaceable but future generations will not be able to enjoy crops, plants, wild life, fish and other species once they have been destroyed.
- ☛ A long term development plan may require inter regional/provincial co-operation and in some cases even co-operation between neighbouring countries. Regional/provincial water resource planning must be integrated into the economic planning and management of the environment.
- ☛ Rehabilitation and flood management measures must be so executed as to reflect the concept of sustainable environmental development.
- ☛ During flood control the movement of social components and minimum physical adjustments should be used to allow normal ecological processes to continue.
- ☛ A sustainable floodplain development policy must stimulate the approach of living with floods and other natural processes.

Various activities are associated with sustainable integrated long-term floodplain planning, as depicted graphically in Figure 9.4.

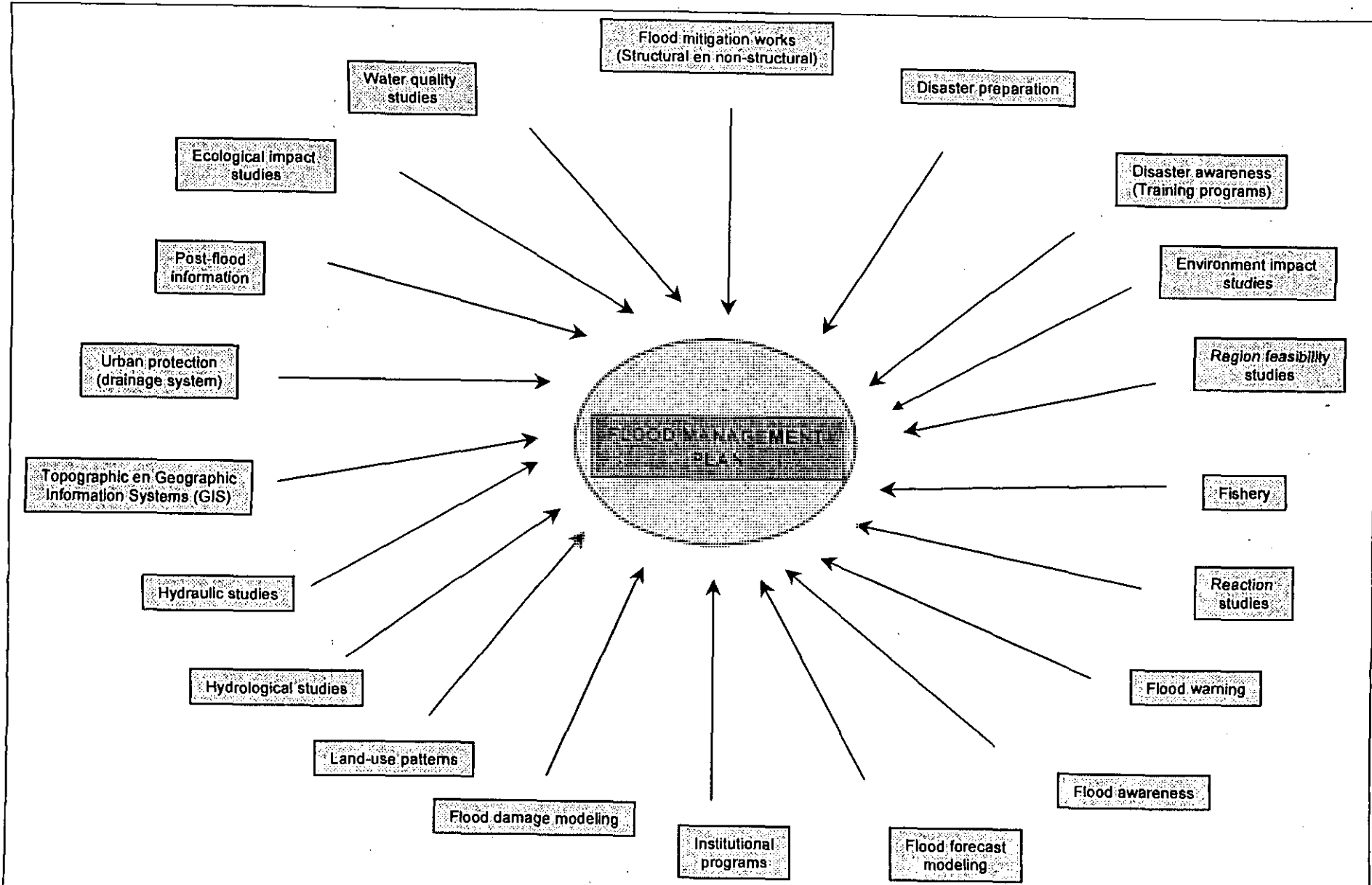


Figure 9.4: Holistic approach to integrated hydrological catchment management

Activities named in Figure 9.4 should be investigated individually by provincial and local authorities, and results should be integrated in order to arrive at a sustainable integrated flood management plan. To put this into effect, a multi-disciplinary approach will have to be followed. In terms of this approach it would be unreasonable to expect from provincial and local governments to house expertise and specialist services on a permanent basis. Consequently, an institutional network approach is proposed for South Africa whereby specialised services could be provided to provincial and local authorities. This approach will ensure that the desired institutions could be installed for South Africa on the one hand and that hazard losses in floodplains be reduced on the other (Haque and Zaman, 1993).

It would not be possible to discuss all activities appearing in Figure 9.4 in depth. To this end a new research project should be undertaken which should be voluminous enough for an independent doctoral study. This section therefore aims purely at introducing the new concept towards floodplain management and to provide commentary on some of the findings of Food Management Consultants with regard to a proposed flood management policy (FMC, 1998).

### **9.5.2 CATCHMENT MANAGEMENT**

The management of water resources is becoming increasingly complex and this is especially true in South Africa which is characterised by conflict from a third world, a first world, developing cultures and varying norms and standard systems. Strong focus is placed on social upliftment and economic growth and development, each of which has to be supported by effective resources management, with water resource management as a primary function (Van Zyl, 1995).

With the management of a total catchment the focus is usually placed on problems such as soil erosion, vegetative cover, slope, river embankment stability and disease control. Despite this, the protection of water resources and water quality, as well as the creation of new livelihoods based on ecologically sustainable development is also important. In order to plan for change in land use and resource development in catchment areas, local authorities will have to be grouped in regional context. In this

way forces towards environmental planning and resource management can be coordinated (Tané and Xingzhoa, 1993).

The concept of integrated catchment management has been accepted by a number of countries such as Canada, England, Wales, New Zealand, Australia and the USA (Johnson *et al.*, 1996), although very little has been written about the application of this concept (Van Zyl, 1995). One of the greatest problems with this concept is the lack of a definition of water management. For most people it means water resource management, which implies the building and control of dams and/or the issuing of quality control permits (Van Zyl, 1995). A bigger problem however arises with the definition of totally integrated catchment management. An integrated approach to flood management necessitates the integration of present approaches as well as approaches used in the past with the consideration of structural as well as non-structural control measures for comprehensive water and flood management strategies (Bancid, 1995). The development of a systems approach, wherein the supply and risk of water management can be evaluated on a regional and stochastic (random) basis, was a great breakthrough for water management in South Africa (Van Zyl, 1995). With this systems approach the attention is not only focused on natural and human systems, but divisions and interrelationships are also addressed (Mitchell and Hollick, 1993).

Over and above management concepts such as planning, organising, control, monitoring, evaluation, implementation, leadership, communication, team work and negotiation (Van Zyl, 1995; Blackmore, 1995), participative decision making, ownership and empowerment (Van Zyl, 1995) of communities should be applied visibly in the water resource management process. Blackmore (1995) puts it as follows: "Community involvement and commitment are the key to successful natural resources management". Integrated management means that different people or sectors with varying personal objectives work towards a common goal.

The concepts mentioned above do not only entail a market orientated approach, in other words to satisfy the needs of people ("to place the focus on the care of human life" - Van Zyl, 1995), but also includes a strategic approach, namely the formulation of a vision, objectives and goals in order to ensure that the correct road is followed

with full knowledge of the destination sought. A total natural resources strategy can then be implemented. A strategy does not however contain a solution to every resource problem, but provides a framework within which the aspects referred to can be dealt with (Blackmore, 1995).

In Australia the "Murray-Darling Basin Commission" is responsible for the co-ordination of all planning, development and management of water resources in the Murray-Darling and also to monitor environmental resources on a catchment basis. Tané and Xingzhoa (1993), distinguish between catchment planning and catchment management. Integrated catchment planning refers to regional environmental planning based on catchment regions, while integrated catchment management refers to natural resources management of water and soil activities which is the responsibility of certain governmental institutions. Integrated catchment planning is necessary for the co-ordination of changes in the land use pattern and to set guidelines and criteria for development which may have a significant influence on flood waters (Tané and Xingzhoa, 1993).

Planning and management strategies for catchments can occur via statutory planning and resources management. Local and regional environmental plans are statutory instruments which empower local authorities to co-ordinate land uses and development strategies at community level. Land care and catchment management plans are guidelines drawn up by resources management agents in order to aid with the co-ordination of resources management programs on a catchment basis (Tané and Xingzhoa, 1993).

As a result of specific characteristics of the water resources of South Africa in terms of physical properties, specific land uses and people involved, it is not possible to manage the water resources on a national basis without basing it on local management units (Van Zyl, 1995). Since it is a natural resource driven by the hydrological cycle, using a river catchment area as a unit makes sense (Van Zyl, 1995). Local governments normally have a problem executing catchment management efficiently by means of statutory planning, especially with limited technical and professional resources. In order to enable local authorities to execute catchment management efficiently, full support must be given to environmental

planning and resource management agents. Agents must compile guidelines and technical data in close co-operation with local governments (Tané and Xingzhoa, 1993).

In South Africa an integrated catchment management approach was adopted in the eighties in order to resolve water problems in various catchments in the then Eastern Transvaal (now Mpumalanga) and Northern Province. Between 1985 and 1989 eight catchment management projects were launched. In conjunction herewith, a new approach to water quality management was also adopted in 1989 to the effect that integrated catchment management plays an integral role. In 1992 more than fourteen catchment management projects were registered. Apart from the projects mentioned, consultants have initiated various other independent catchment studies in the past fifteen years. The projects referred to were not properly rounded off, primarily due to a shortage of funds and to a lesser extent as a result of a lack of a sound grasp of catchment management (Van Zyl, 1995). Besides funding, trained manpower also seemed to be a problem (Walmsley and Davies, 1991).

With an integrated catchment management approach, complex water resource problems are addressed and water resource management can only be applied effectively if all authorities sharing land development control and water management, co-operate. The latter implies sound communication and role definition amongst the various managers and institutions. In order to be able to manage a semi-arid, semi-industrialised and multicultural country with developed and developing communities, such as South Africa, managers must picture a total image, understand the resources and the consumer, know the needs of the consumer and be able to make wise and intelligent decisions. To this end a holistic approach to management is required which would integrate various engineering, economic, political, social and environmental skills (Van Zyl, 1995). With this philosophy as point of departure, various disciplines can be united in order to institute a multidisciplinary team.

All efforts should be made to ensure that a new flood management policy for South Africa is underpinned by integrated catchment concepts. In order to be able to address complex water resource management problems in future, this approach should be assimilated in the new flood management policy of South Africa. It is

therefore necessary that the new flood management policy provides for the establishment of appropriate institutions for this purpose. The FMC report (1998) puts it as follows: "The integrated catchment management approach currently under consideration relies heavily on the existence of a controlling or monitoring body".

### **9.5.2.1 Flood Management as Integral Part of Catchment management**

Flood management in the context of integrated catchment management, highlights several areas of serious conflict.

One problematic area is the fact that structural measures to control floods are very expensive and can seldom be viable on their own. This means that structural flood management measures mostly constitute but one aspect of a number of issues which requires consideration when planning, building and operating water management systems, mostly dams or series of dams. This is especially the case in an arid country such as South Africa with typical carry-over periods of many years, where the value of water in dams, especially towards the end of rainy seasons, is so overshadowing that there is very little leeway for structural flood management. The situation is further complicated by the fact that water from a specific catchment is often of crucial importance to other catchments, while structural flood management benefits in a specific catchment would primarily accrue to that catchment. These aspects not only represent a conflict of interests between user sectors, but also between different catchments.

Further removed from the rivers, but still in a catchment context, the conservation of agricultural resources by means of, for instance, stock reduction schemes, will not only benefit water management in general, but will greatly enhance flood management. Well-preserved catchments tend to hold back runoff, leading to reduced silt loads, increased infiltration, extended base-flows and reduced flood peaks. Although it is obviously beneficial to preserve our land, there are serious problems to introduce, manage and finance the necessary initiatives. In the recent past, an internationally acclaimed stock-reduction scheme was introduced and funded by the agricultural departments. The scheme and its origin in combating the impacts of droughts and the water management fraternity never

participated actively in furthering the scheme, because it was viewed as being completely within the line functions of Agriculture. Of lately, the scheme has fallen into disuse. Most probably the scheme would still have prevailed if a more holistic view as to the benefits thereof also to the water management field existed. From a flood management perspective, the conservation of agricultural resources is very important, because flood peaks are influenced by the way in which these resources are managed during severe droughts. Hopefully the integrated catchment management approach will soon enable these holistic viewpoints, also with regard to flood management.

In this regard the new National Water Act (No 36 of 1998) makes provision for the establishment of Catchment Management Agencies, which will be funded from the catchments which they serve. It is envisaged that these Agencies will fulfil a very important co-ordinating role with regard to holistic and integrated catchment management, encompassing both flood and drought management. In this regard the provisions of Section 145 of this Act are very exciting, viz.:

**“Duty to make information available to public**

145. (1) A water management institution must, at its own expense, make information at its disposal available to the public in an appropriate manner, in respect of -

- (a) a flood which has occurred or which is likely to occur;
- (b) a drought which has occurred or which is likely to occur;
- (c) a waterwork which might fail or has failed, if the failure might endanger life of property;
- (d) any risk posed by any dam;
- (e) levels likely to be reached by floodwaters from time to time;
- (f) any risk posed by the quality of any water to life, health or property, and
- (g) any matter connected with water or water resources, which the public needs to know.

(2) The Minister may, where reasonably practicable, establish an early warning system in relation to the events contemplated in subsection (1).”

### 9.5.3 TOPOGRAPHICAL, HYDROLOGICAL, HYDRAULIC AND GEOGRAPHICAL INFORMATION SYSTEMS (GIS)

Statutory planning is normally based on plans and maps. As a result spatial information systems are essential for the co-ordination of floodplain planning. In this way *inter alia* the extent of flood prone ground and the river geomorphology can be stored on a regional basis. This information is required particularly for the implementation of local and regional environmental plans (Tané and Xingzhao, 1993). With the aid of fast track computer technological development it is possible to simulate various topographical, hydrological, hydraulic and morphological properties by means of GIS techniques. In the course of a rehabilitation project executed by Marchand *et al.* (1994) it was shown that it was possible to unravel complex relationships between the environment and human intervention/interference by employing dynamic and water quality models in tandem with the GIS. A comprehensive discussion regarding the GIS techniques has already been covered in Chapter 6 and can be consulted for more details.

In the course of hydrological analyses runoff hydrographs are compiled. An hydrograph determines the runoff of flood water at a specific point within a river catchment in  $\text{m}^3/\text{s}$ . In addition to the establishment of hydrographs, flood probability studies are also undertaken during hydrological analyses. A frequency distribution is matched with the peak annual flood discharge records. The peak runoff of a flood event of any probability is derived from the aforementioned distribution (New South Wales Government, 1986). A rainfall runoff model is a mathematical representation of various interception processes which convert precipitation to runoff. With these models it is possible to compile runoff hydrographs for areas of investigation and as such they form part of hydrological investigations.

After hydrological studies have been completed the extent of the floods are determined by means of hydraulic investigations. Numeric and physical hydraulic models are available. Numeric models are used to solve equations which represent the flow of water in a river system. In this way water levels and flow velocities are determined. One and two-dimensional numeric simulation models are commonplace. One-dimensional models are utilised where the floodwater runs parallel to the

main stream. Two-dimensional models are employed where the floodwater flows away from the main stream (New South Wales Government, 1986). Physical models on the other hand are scaled down three-dimensional replicas of the river system. The construction of physical models is an extremely time consuming and costly process. Physical models simulate the water movements of complex situations in a river system more accurately than numeric models and are used in particular where flow is uncertain at critical physical aspects. Model calibration is very important and is carried out for both, physical and numeric models. (See Chapter 5 for more details regarding hydraulic modelling.)

Relatively little quantitative information exists for integrated catchments in South Africa (FMC, 1998). Where information does exist, differences in answers between concerns (state and consultants) occur fairly often. Over and above differences between concerns, substantial variance is evident in hydraulic data when purely the roughness coefficient alters (Chapter 5), which may impact negatively on residential development (FMC, 1998). Appropriate applied research projects should be undertaken for this purpose so that a refined methodology can be developed. In addition to the research mentioned above, a greater amount of flood hydraulic research should be undertaken in South Africa in order that quantitative hydraulic information with respect to catchments is available for management decisions (FMC, 1998). Although the current hydraulic simulation models are suitable for the determination of flood lines (FMC, 1998), little topographical data is available in the right format and scale for the execution of flood and flood management studies. In many cases only 1: 50 000 topographical maps are available for flood prone areas in South Africa, which is unsatisfactory for modelling of flood damage.

#### **9.5.4 ECOLOGICAL AND NATURAL ENVIRONMENTAL IMPACT STUDIES**

In the past human interference in the environment has caused the destruction of the habitat of various species. The rehabilitation of the environment is aimed at the improvement of the natural impetus of the water regime and the quality of the water. A successful habitat can only be realised by applying total integrated water resource management. Water quality in rivers and secondary canals and floodplain lakes are becoming increasingly important. Local interference of any sort in water

management usually gives rise to changing water quality processes. A sophisticated water quality model is therefore required. (Marchand *et al.*, 1995).

The Zambesi system for instance has erected dams such as Kafue Gorge, Itezhi-Tezhi, Kariba and Cabora Bassa which are used particularly for exercising river control and transformation of the flood pattern. These dams pose serious detrimental ecological implications for floodplains. Dam construction, specifically the Masinga Dam, caused the order of magnitude of floods to wane, with the result that the survival of forests can be threatened and even terminated in the long run. Likewise in Bangladesh the withdrawal of water upstream had a detrimental effect on forests. Sunderban, one of the largest mangrove forests in the world, experienced detrimental effects due to the salt content in nearby rivers (Bancid, 1995).

In an investigation Salem-Murdock and Horowitz (1991) tested the hypothesis that the net benefit of local, regional and national economies would be greater under an artificial flood than under a water regime which limits floods to that required for maximum hydro-electrical power generation and irrigation. The termination of artificial floods will lead to swift deforestation and consequently to a significant drop in the water table. The Senegal River valley is famous for its remarkable tree coverage which is extremely dependent on the ground moisture for growth and reproduction. A German environmental analyst (Van Lavieren and Van Wetten, 1990, quoted by Grosenick *et al.*, 1990) estimated the annual timber production at approximately 8,2 m<sup>3</sup> per ha and concluded that total flood prevention would pose seriously harmful consequences for timber production. Environmental specialists (Grosenick *et al.*, 1990; Gritzner, 1988) agree that the River Woodlands would not be able to survive a significant reduction in annual flow.

Control measures sometimes also have detrimental effects on the impact of floods, in that some areas become considerably more damp than before, followed by a reduction in the duration of floods with severe fluctuation in water levels during the dry season (Turner, 1984), with detrimental results on the agricultural sector. In the Benue floodplain in Nigeria the construction of the Lagdo dam had a significant impact on flood recession in the production of sorghum. During the mid eighties the

production of crops fell by 50 per cent and large fluctuations in production manifested as a result of the unpredictability and level of a flood. Rice production, for instance, became much more risky during the wet season (Adams, 1995).

In addition to the aforementioned aspects the change in the annual flow regime caused by dams also had a considerable impact on the fish population. The life cycle of many fish species is linked to seasonal flooding (Adams, 1995). The inundated floodplain is very rich in nutrients and causes a swift development of water plants coupled with a bloom in micro-organisms. The latter releases vast quantities of nutrition for fish (Adams, 1995; Salem-Murdock and Horowitz, 1991), which causes fish spawned during floods to grow rapidly. Studies conducted in 1960 on the Niger River, downstream of the Kainji dam have indicated that the size of the fish decreases and that the composition of the fish population changes (Lowe McConnell, 1985). The same phenomena were observed in the Sokoto valley in Nigeria. Fishermen complained about the drop in catch numbers after construction of the Bakolori dam in the late seventies. It is forecast that the Diama Barrage dam, which was built to counteract the increase in salt content during low floods, causes extreme losses of prawns and fish in the Senegal Delta (Adams, 1995; Salem-Murdock and Horowitz, 1991). There is still a lot to be learnt regarding fish biology, ecology and floodplain fisheries (Adams, 1995).

In addition to the aforementioned aspects, total flood reduction also has detrimental effects on the underground water carrying capacity of certain areas in floodplains (Adams, 1995). Hydrological findings show that the underground water is augmented by the infiltration of floodwater. In Senegal the drying up of shallow dugs (from which inhabitants draw water for human and animal consumption) caused inhabitants to have to find water elsewhere from rivers, with the possibility of health and sanitation risks, or alternatively face the drilling of boreholes at the extremely high cost of approximately \$40 million for 85 000 people. Despite the high cost of sinking boreholes it would serve as no solution to the problem since both shallow surface water and deep borehole water are replenished by flood water (Gersar/CACG *et al.*, 1989, quoted by Salem-Murdock and Horowitz, 1991).

Floods per se are not exclusively malign to the environment. In Bangladesh distinction is made between "borsha" and "bonna" floods. Borsha floods refer to normal seasonal floods while bonna floods are abnormal floods which are accompanied by considerable damage and disruption (Haque and Zaman, 1993). Borsha floods have a particularly beneficial effect on the ecology and on floodplain dwellers (Haque and Zaman, 1993). Apart from ecological benefits from floods, alluvial soils and inorganic material are deposited in floodplains which have beneficial effects for farmers (Haque and Zaman, 1993). Brammer (1990) states the foregoing as follows: "flood-related soil fertility is generated from nitrogen-fixing blue-green algae living in the water from decomposing, submerged, plant remains, and from the increased availability of phosphorus and other nutrient elements in the chemically reduced, submerged top-soils". Total flood prevention will prevent the aforementioned natural fertilising benefits from accruing again.

In the past water legislation did not provide for the allocation of water for environmental management purposes. The need to allocate water for environmental purposes was first expressed by Roberts (1981; 1983, quoted by Walmsley and Davies 1991) and it was shown that this allocation would represent approximately 11 per cent of the mean annual runoff of the RSA. To determine the quantity of water which should be allocated for environmental purposes would require a multi-disciplinary team effort so that all political and socio-economic factors could also be considered (Walmsley and Davies, 1991). The latter authors illustrated in three case studies in South Africa that objectives of river management and the minimum flow requirements in rivers were not adequately defined. Human carrying capacity was not considered during planning and development phases in the past and ecological functioning received little or no attention. Therefore the South African community and policy makers ought to revise their ideology concerning environmental aspects to also compensate for other opinions (Walmsley and Davies, 1991). The impact of various projects, as referred to herein, is not always taken into account during cost benefit analyses (Salem-Murdock and Horowitz, 1991).

The options mentioned have proved not to be in disagreement with the aims of the presently envisaged flood management policy of South Africa, but a more forceful philosophy around water quality and ecological sustainability should be entertained

in the bill. The FMC report mentions the fact that the flood management policy of South Africa must be linked to other relevant policies in order that more efficient conservation of South African river systems can be assured (FMC, 1998). Already the water requirements of the natural environment have been forcefully provided for in the new National Water Act (no. 36 of 1998), where it forms part of the so-called Reserve.

#### **9.5.5 POST FLOOD INFORMATION**

Documentation of historic flood records can be of great value for future flood damage determinations, particularly where significant floods had occurred (New South Wales Government, 1986). The willingness of communities to learn from the past and the exhibition of an open attitude towards criticism, are indicative of their commitment to improve future projects (Jacobs and Iwra, 1994). By keeping post flood information updated, changes in return period can be determined. Such changes are used for calibration purposes of simulation models (Dhake, 1995). In addition to the benefits of calibration of post flood information a flood forecasting and warning system can also be improved by proper documentation of appropriate and relevant information after a flood.

Historic floods are poorly documented in South Africa (Report: Task 9, 1994). Actual water levels of historic floods are available as incomplete data. These levels of flood water are of cardinal importance to the calibration of hydraulic simulation models. The problem is aggravated since institutional aspects in South Africa have not been duly addressed. The FMC also refers to this situation, namely that no organisation in South Africa is tasked with the collection and maintenance of scientific flood records (FMC, 1998). Consequently, no institution accepts ownership of and responsibility for the documentation of the information mentioned. The envisaged flood management policy of South Africa ought to make provision for the appointment of appropriate institutions for the systematic documentation of post flood data.

### 9.5.6 FLOOD FORECASTING, WARNING AND RESPONSE SYSTEMS (FFWRS)

The main purpose of an FFWRS in the United Kingdom is to avert or minimise loss of life. France expands this vision and defines the purpose of the FFWRS as a means of establishing public safety, to reduce damage to property and to relieve public anxiety (Parker and Fordham, 1996). A warning and evacuation system should be developed for South Africa in order to lower the risk of human loss of life cost effectively (Alexander, 1993). BANCID (1995) expresses it as follows: "Flood forecasting and warning has been identified as a key component that could exert major benefits on numerous aspects of national life, with considerable potential for improving the national economy. As such it is recognised as a highly cost effective, non-structural measure". In Europe an FFWRS is implemented to reduce material, human and cultural losses (Parker and Fordham, 1996). Put differently, FFWRS is one component of various flood control options that could be installed to reduce tangible flood losses (Smith and Handmer, 1986; Krzysztofowicz and Davis, 1983).

Although flood forecasting, warning and awareness programs are depicted separately in Figure 9.4, they cannot be regarded as such but should rather be treated in harmony with one another. The literature refers to these aspects as being a unit and names them "flood forecasting, warning and response systems" (FFWRS). As soon as one of these components fail, the whole system will be rendered ineffective (Parker and Fordham, 1996). Recent floods in France (1987, 1988 and 1992) claimed 83 lives and led to billions of franc in flood damage because they could not be forecast and since no FFWRS had been available (Parker and Fordham, 1996). Sixty per cent of the Netherlands lies below mean sea level and hence flood protection and FFWRS is strategically very important. Consequently The Netherlands decide in terms of its Water Board Law of 1992 that members of the public may be used to join the "dike army" for service during urgent flood hazard situations. Two infantry companies are placed on early warning during the flood season to augment the dike army. Key elements involved in a flood warning system can be represented diagrammatically (Figure 9.5).

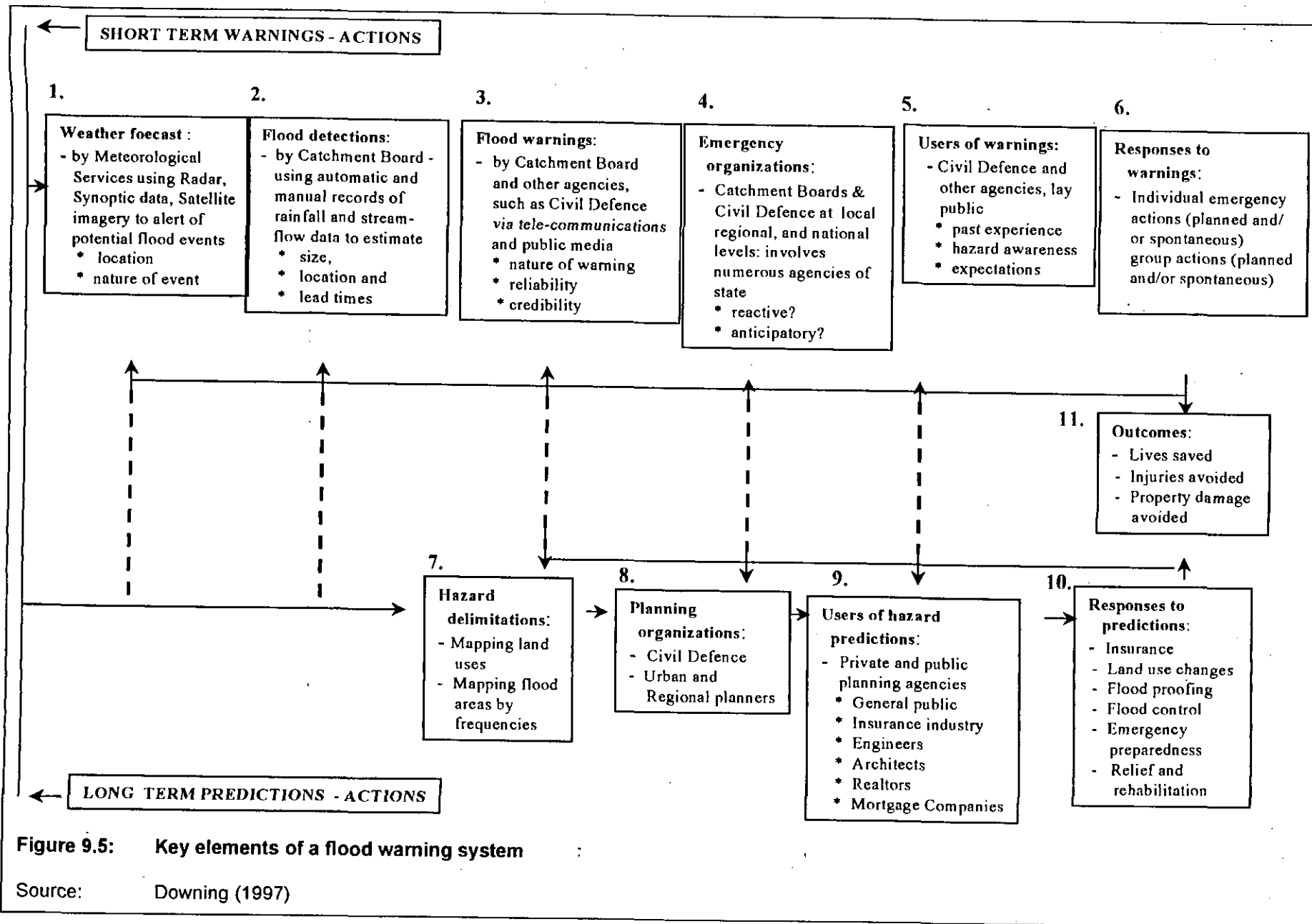


Figure 9.5: Key elements of a flood warning system

Source: Downing (1997)

### 9.5.6.1 Integrated flood warning system

Smith and Handmer (1986) stress four important properties of an FFWRS, namely:

- ☞ An FFWRS is distinguished as a cost-effective option of flood reduction.
- ☞ FFWRS remains applicable to situations where other flood control strategies are no longer relevant or feasible.
- ☞ At the recognition of new risks that have to be reduced, greater accent is placed on FFWRS.
- ☞ With the development of new forecasting techniques greater accent can be placed on FFWRS.

Alexander (1993) distinguishes between a passive and an active flood warning system. Passive warning entails making inhabitants conscious of flood hazards by *inter alia* the marking of flood lines, beacons and telephone standards. In this way responsibility can be transferred to communities for watching floodwaters and taking the necessary actions. The greatest disadvantage of a passive warning system is that inhabitants start to lose interest and the required results are therefore not achieved. Active warning is more formal and should comply with three conditions, namely: immediate action when warning is issued; it must be physically possible to inform all people timely about flood hazards; and an appropriate public control centre so that information can be received, processed and interpreted in order that appropriate action can be taken. Situations do exist inside and outside the jurisdiction of local authorities where active flood warning is unpractical. The only feasible solution, especially for smaller communities, is to provide facilities which enable communities to handle their own river watch system (Alexander, 1993). An integrated flood warning system can be divided into four stadia, namely preparation, warning decisions, warning distribution/broadcasting and the receipt and response stage (Smith and Handmer, 1986). In contrast with Smith and Handmer (1986), Krzysztofowicz and Davis (1983) merely distinguish between forecast and response stages. Rainfall data processing is divided into three separate phases by some authors, namely the registration of field data, data collection and hydraulic processing, while response is again divided into the decision making process, the

decision that is taken and the implementation stage (Krzysztofowicz and Davis, 1983; BANCID, 1995). The decision to warn is critical to a FFWRS. Consequently, a standardised warning system is required within one catchment. A network of data collection should exist which is forwarded to a river forecasting centre, after which it is transformed to an hydraulic forecasting procedure.

Sound communication among weather forecast, flood forecast, flood defence, civil defence and media agents are required for effective FFWRS (Parker and Fordham, 1996). For forecasting purposes data communication and a data distribution system are the most important components in the transformation process of hydraulic data such as water levels, rainfall, flow velocities and runoff. Methods such as real time data distribution by means of wireless stations are commonly used in Bangladesh (BANCID, 1995). The forecasting procedure includes all hydrological and hydraulic models (rainfall-runoff models). The extent of a flood as well as a specific time of occurrence is included in a forecast. A manner of communication must be established (radio, TV and telephone) to identify an appropriate broadcasting/distribution channel. Private and other organisations can then transmit the information in the form of a flood warning to potential endangered inhabitants after having received a flood forecast from the river centre. The decision making actions include all formal decision making such as the degree and extent of response, type of protection and allocation of resources to various protection activities.

Considerably more attention should be given to false warnings, since false warnings can lead to a lowering in response of floodplain dwellers. An integrated flood warning system focuses on three important factors namely relevant institutions, technology used in flood forecasting and issuing and the level of education of inhabitants receiving warning as well as their reaction thereupon (Smith and Handmer, 1986). Smith and Handmer (1986) depicts a conceptual integrated flood warning system diagrammatically and can be consulted for more comprehensive information.

Where a short warning time and inaccurate forecasts are evident, flood warnings are found to be ineffective in practice. Therefore flood warning systems are worthless if the warning does not reach the inhabitants timely and will also be of no value if

inhabitants do not understand the warning in order to be able to respond to it (Krzysztofowicz and Davis, 1983). In this connection Parker and Neal (1990) declare that floodplain dwellers would prefer a warning during daytime as opposed to night time. The handling and evacuation of equipment and livestock are clearly implemented more easily at day time.

The methodology should take into consideration all stages of flow of information, from the establishment of data, preparation of forecasts, issuing of warnings by the media and the decision-making and implementation of various actions by inhabitants. Planning and investment decisions concerning the development or improvement of a specific FFWRS should be based on a systems analysis at local level. Such an approach is indispensable since differences occur between individual systems. Variations occur due to multiplicity and complexity of factors such as hydrology, organisation, behaviour and the economy, all of which affect the FFWRS (Krzysztofowicz and Davis, 1983).

An appropriate FFWRS must be instituted in flood prone areas, irrespective of the type or degree of sophistication thereof. Even the best-designed system can fail in the absence of effective organisation, structure and sound leadership. Leadership is the driving force behind the implementation of a system. It includes co-ordination of tasks and activities and communication at all levels. A poorer system effectively implemented will function better than a better system poorly implemented.

Finally, FFWRS has to be evaluated after the flood incident had passed. If systems are evaluated on a regular basis the necessary adjustments can be made, with resulting improvement of their effectiveness.

#### **9.5.6.2 Cost effectiveness**

The potential damage which can be obviated from a national point of view, by responding to a flood warning, is much greater than the cost of installing an FFWRS (Krzysztofowicz and Davis, 1983). Usually the cost associated with flood warning is lower than other flood control measures, with the result that more communities could benefit therefrom (Smith and Handmer, 1986).

The maintenance of an existing FFWRS and the development of future systems require funding. Expenses such as general overheads associated with the functioning of a flood forecasting and warning centre (buildings, office space, furniture and so forth), remittance to personnel staffing and operating the centres, capital investment on equipment for the measurement of river levels and precipitation, communication systems, hydrological models and expenses on communication reports for the issuing of warnings to the media and public as well as maintenance costs, must be incurred.

The upkeep and operation of FFWRS can be sustained more cost effectively when, for instance, the maintenance and functioning of both river level and rainfall stations are run by one organisation. A flood forecasting and warning centre should provide back-up assistance such as advice, stream flow simulation, software, meteorological and hydrological forecasts, training in equipment and monitoring of floods, to provincial and local authorities. Local authorities on the other hand should purchase equipment for testing stations, install and maintain it and be responsible for development and implementation of a flood response plan.

#### **9.5.6.3      *Evaluation of FFWRS***

A flood forecasting and warning system can be regarded as an information system. The appropriateness of the system can be evaluated by determining the potential and actual quality of the information provided. The response system on the other hand can be regarded as a decision-making system and can be evaluated on the basis of an optimal and actual response strategy (Smith and Handmer, 1998).

Evaluation of warning systems is aimed at bringing about improvement of existing systems. Methodological and conceptual problems, such as for example the definition of warning, warning accuracy and problems of conceptualising of floods as disasters, give rise to the problem that research findings from different researchers cannot be easily compared. Practical and technical problems cause invalid results. Jointly, these problems harm the institution of appropriate policy with-non structural measures. Improvements in a FFWRS can indeed be economically advantageous

but can also lead to negligible additional consumer satisfaction (Smith and Handmer, 1986).

Several steps should be present in the evaluation process. Firstly, appropriate performance standards (quantitative and qualitative) should be established. More specifically, quantitative standards refer to input, output and effectiveness standards. Input standards will typically deal with inputs required for an appropriate FFWRS, while output standards concentrate on forecasting, warning and response.

Efficiency standards can then be formulated by expressing certain inputs and outputs which have a narrow and meaningful relationship, by a ratio. In this, corrective actions must be taken in order that the performance of a warning system can be improved.

Parker and Neal (1990) distinguish between four approaches towards evaluation of an FFWRS. The first approach investigates the size of the area to be served with flood warning (extent of coverage). Although this approach does have strategic planning value in particular, it does not measure the quality of a warning system and thus does not take into account any failures or shortcomings within a warning system. It is therefore indeed possible when employing only the approach mentioned, to have the situation where the quality of the warning system decreases while the area covered is expanded.

A second approach is to determine the losses that can be prevented by a flood warning system. The larger the benefit that can be achieved, the better a flood warning system can function. The greatest problem with this method is that it is necessary not only to determine the tangible direct flood damage, but to also identify the indirect, non-tangible losses. By not quantifying the latter impacts, a distorted picture could be obtained of the behaviour of a flood warning system. The advantages of an improved FFWRS is rather the difference in the impact of floods that occur with a longer warning time or the greater accuracy with which floods are forecast, than the difference between maximum potential damage and the total true flood damage (Smith and Handmer, 1986).

The satisfaction of communities with regard to warning services can also be used to evaluate a flood warning system. Several problems arise with this approach. Floodplain inhabitants experience one or two floods in a lifetime and hence the satisfaction of inhabitants will only be measured in the course of one or two flood incidents. Consequently, public satisfaction with flood warning during smaller floods will not necessarily serve as a sounding board for public contentment during bigger floods. Where dwellers are poorly informed regarding the risk of floods, the possibility exists that high public satisfaction with a warning service may give rise to an underestimation of the danger of flooding and an overestimation of the effectiveness of a warning system.

Finally, the shortcomings of warning system can be evaluated by identifying, categorising and documenting the shortcomings of flood warnings. The advantage of this method is, *inter alia*, that a specific division of a system could easily be improved, while on the other hand the greatest problem posed to the approach is the gathering of suitable information after a flood, when other clearing works are enjoying priority.

Contrary to the approaches put forward by Parker and Neal (1990), Smith and Handmer (1986) and Krzysztofowicz and Davis (1983) discuss a methodology which could be used at micro level for evaluating an FFWRS. This methodology is built on two elements, namely a model of an FFWRS and a performance evaluation. The former encompasses a mathematical description of the physical aspects that occur during floods, while the latter renders a measurement of the behaviour of an FFWRS. Jointly the two aspects mentioned constitute an evaluation model. Simplified criteria are proposed by Smith and Handmer (1986) to evaluate the efficiency and effectiveness of an integrated FFWRS.

Parker and Fordham (1996) apply a specific methodology in the European Union, with specific attention to the Netherlands, the United Kingdom including Scotland, Northern Ireland, England, Wales, Germany, France and Portugal. This methodology entails a staged development model that has been developed to simplify an FFWRS over time. The model consists of five stages of development and depicts a prescriptive approach to FFWRS. In addition to the five development

stages, 14 criteria are established for evaluating an FFWRS and these differ from the evaluation procedures proposed by Krzysztofowicz and Davis (1983) and Smith and Handmer (1986). The level of development of a FFWRS is measured in terms of a five-point scale ranging from one (undeveloped) to five (advanced). The staged development model can be represented in table form and is now discussed briefly (Table 9.1).

**Table 9.1: Staged development model of flood forecasting, warning and response systems**

Criteria	Development states		
	1	2 and 3	4 and 5
1. Flood warning philosophy	Rudimentary	Intermediate	Advanced
2. Dominance of forecasting vs warning	Forecast dominant	Equal	Equal and improved accuracy
3. Application of technology to FFWRS	Model with manual	Mixture	Fully automated
4. Geographical coverage	<10%	>10% <50%	>50%
5. Laws relating tot FFWRS	No laws/ permissive	Laws	Laws with liability
6. Content of warning messages to public	'Blanket': general location	Mixed: Location/timing	'Target': seventy/location & timing
7. Methods of disseminating flood warning	General broadcast	Wardens/ agencies/police	Personal phone/fax/pager'
8. Attitudes to freedom of risk/hazard information	Little, request only	Restricted to general floodplain	Open specific property
9. Public education about warnings	Minimum	Some, e.g. colour codes	Fully informed
10. Knowledge of FFWRS effectiveness	Denial of failure	Recognise limitations	Research tested
11. Dissemination of lessons learned	Little	Partial	Full
12. Performance targets and monitoring	None	Key indicators	Accuracy/timely/ reliability
13. National standards	Parochial	National/regional variations	National/ International
14. Organisational culture	Independent	Agency liaison	Service level agreement with agencies

Source: Parker and Fordham (1996)

**Explanations of development stages:**

- 1: Basic-little development
- 2-3: Improved performance but some failures apparent
- 4-5: More advanced performance; failures reduced

In order to use the above-mentioned prescriptive approach, a country has to

formulate a clear philosophy regarding FFWRs. Should the philosophy be absent, the level of development will receive a value of 1 under criterion 1, while countries with a strong philosophy will receive a point of 4 or 5. Countries with underdevelopment will have virtually no FFWRs in use and will cover less than 10 per cent of a geographical area. In contrast herewith countries with an higher level of development (three and higher) have more than 50 per cent of the geographical area covered by an FFWRs. An improvement of FFWRs can be attained by investing in broadcasting and response systems of flood forecasting and warning methods. Where the FFWRs is poorly developed, low technology will be present and little if any attempt will be in evidence to improve warning-broadcasting methods. The legal support of an FFWRs (criterion 5) may possibly not exist at all, or is very poor, with the result that flood warning does not necessarily exist (criterion 6) and a crude manner of broadcasting (criterion 7) is therefore present. A fully fledged FFWRs is based on knowledge of an effective system (criterion 10) that is deduced from the performance (criterion 12) of an FFWRs. Criterion 11 is used to improve an FFWRs by means of post flood incidents and also to disclose lessons learned from the public. A well-developed and mature FFWRs is also founded on national standards and on a positive co-operative culture (criterion 13) with interactive agreements and commitments (criterion 14).

#### **9.5.6.4                      *Institutional aspects***

Australia has had various institutional problems. Uncertainties regarding the roles of various governmental institutions have led to serious financing and implementation problems in respect of an FFWRs at all government levels in Australia. Consequently, a central body, the State Emergency Services was founded (Smith and Handmer, 1986). In addition a centralised Commonwealth based system is employed in Australia which centres on the Meteorological Bureau. The Meteorological Bureau provides information to forecasting centres in regions. In England flood warning systems are handled on a regional basis within the system of the water authorities. In 1972 the Flood Forecasting and Warning Centre in Bangladesh came into existence as a permanent entity. Tasks such as data communication and distribution, updating of flood forecasting and formulating of

forecasting and distribution of forecasting messages are performed by the Flood Forecasting and Warning Centre. This centre functions in close co-operation with the Meteorological Department. Appropriate liaison exists between the centre and the Meteorological Department so that there is no limitation on data distribution (Dhake, 1995). Close liaison is also maintained with the Space Research and Remote Sensing Organisation in order to receive satellite images for flood forecasting purposes. Satellite images that point out the morphological changes in a river system and in the flooded areas, are requested from time to time. Co-operation is in place with the Disaster Management Bureau in order to determine the impact of flood disasters. Communication is set up with flood related project personnel for the guidance of floodplain inhabitants towards the desired response during natural disasters (Dhake, 1995).

In the Netherlands a disaster management organisation has been integrated with a national co-ordinating centre. A Disaster Act formulated in 1985 defines the roll and responsibilities of public authorities during disaster management (Parker and Fordham, 1996).

Case studies carried out by Parker and Fordham (1996), show that the Netherlands have acquired the philosophy of learning from past experiences. The result of this is that potential flood damage decreases with time. During floods, the FFWRS is managed also from three control rooms, namely the Department of Water Affairs, the Mayors office and the Police Communications Centre. Incoming information is automatically relayed to all three control rooms so that communication multiplies threefold in effect (Parker and Fordham, 1996). The daily activities of the centre are summarised by BANCID (1995) and can be consulted for more particulars. In contrast herewith the national river authorities in the United Kingdom are primarily responsible for flood protection and FFWRS initiatives.

The efficiency of an integrated FFWRS is best promoted by institutions that place an accent on local decision making, rather than focusing on centralised structures. According to Smith and Handmer a degradation of systems occurs when decision making is removed from the realm of local experience of a river system. Centralised structures not only lead to complex broadcasting methods, but also to

intensive co-ordinating systems which are aggravated by poor communications and inexperienced personnel (Smith and Handmer, 1986). In England many water authorities implement a flood forecasting and warning system which is based on a rainfall runoff model. Experiments have already been conducted in an attempt to prolong the warning time by making use of radar data. In this way data of the duration and intensity of rainfall can be used for simulation, in preference to river flow data. During the 1982 flood in York, England the flood warning system functioned very well, distinctly as a result of the fact that the public command sound flood experience, thus knowing how to respond to flood warnings (Parker and Neal, 1990).

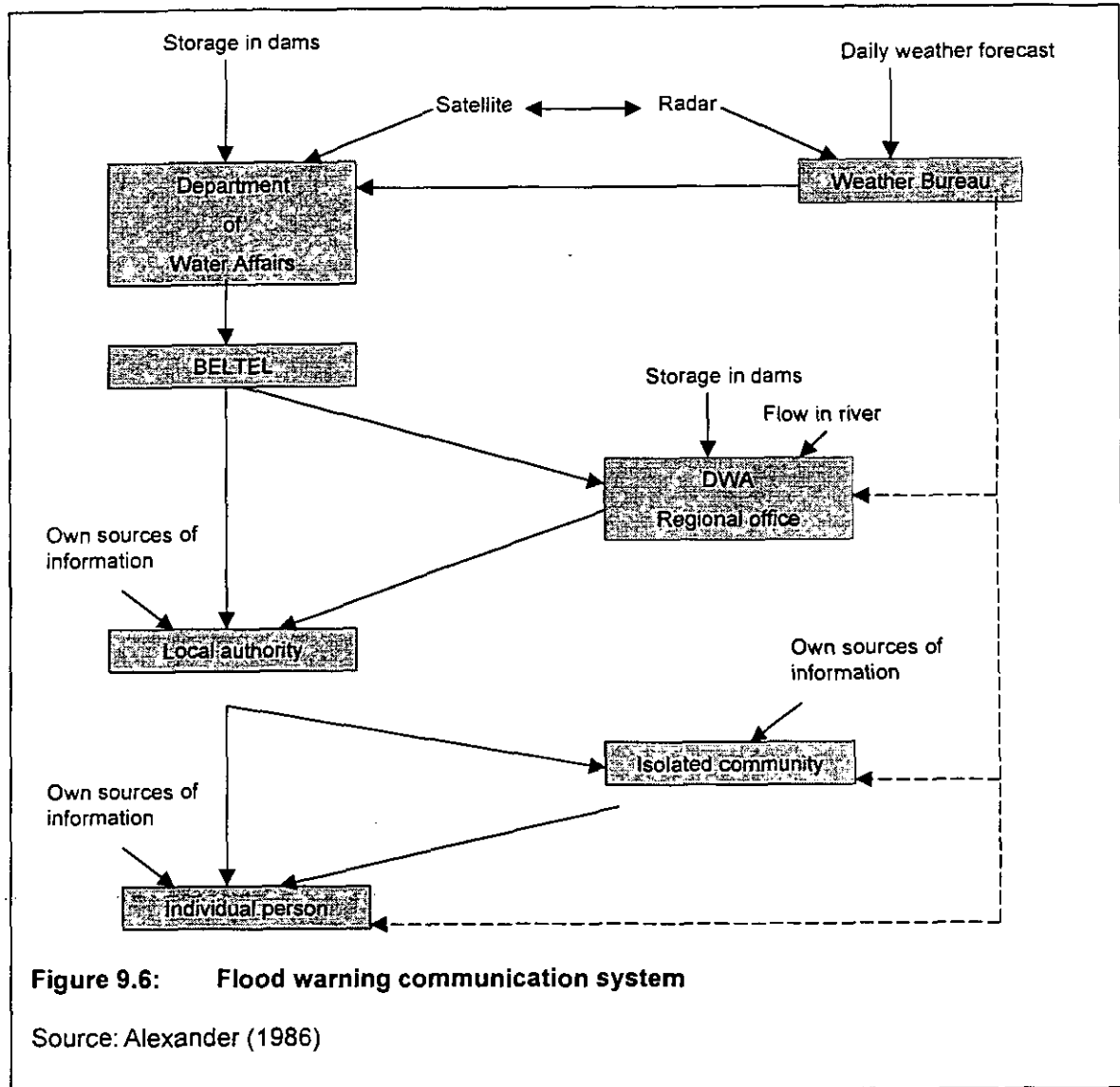
National governments ought to be primarily responsible for the monitoring of rainfall in the form of the collection and storing of data, the purchasing, installation, and maintenance of equipment and furthermore to distribute this data to provincial and local authorities. Provincial authorities should be more concerned with the gathering and storing of river level data. In other cases however, warning systems may be locally to totally privately orientated. Particularly with modern communication technology, the essentiality of central expertise is becoming less pronounced, with a greater need for local warning systems. Be this as it may, priorities must be clearly spelt out for an FFWRS at all government levels.

#### **9.5.6.5 *Flood forecasting, warning and response system for South Africa***

As far as the FFWRS in South Africa is concerned, there is very little, if any, formal flood warning available. A flood warning communication system based on a daily rainfall data and antecedent precipitation indices, was developed by Alexander and installed by the Department of Water Affairs and Forestry in June 1993. This system is depicted in diagram form in Figure 9.6; for more particulars Alexander (1993:172) can be consulted. Due to the various reasons this system has since fallen into disuse.

DWAF is operating and improving a relatively advanced FFWRS in the Vaal- and Orange River systems. A flood office is opened in Pretoria during floods in these rivers to co-ordinate dam operations and information dissemination.

On the local level, regularly flooded communities are keen to be part of flood warning systems. Examples are Alexandria on the Jukskei River and Ladysmith on the Klip River.



**Figure 9.6: Flood warning communication system**

Source: Alexander (1986)

The Weather Bureau is primarily responsible for the forecasting of flood producing rainfall. Three systems are used for this purpose, namely a mathematical weather model, geostationary satellite images and a radar observation station. Notwithstanding the occurrence of erroneous warnings which had been issued in the past, the mathematical weather models have managed to forecast major flood incidents correctly. Alexander (1993) mentions that various floods (Natal 1987) had been forecast 5 days ahead of occurrence by the Weather Bureau. Loss of

life did however still occur since there was not effective response to the aforementioned forecast. Radar equipment currently used is old and unsophisticated, and bad telephone communication between measuring stations and the Weather Bureau still features during floods (FMC, 1998). The communication system (Figure 9.6) is in itself not a flood warning system. Effective flood warning cannot be issued by national authorities since additional information is required for this purpose. Warning must be issued at local government level (Alexander, 1993). The Department of Water Affairs and Forestry does indeed issue warning to the public via the media and notifies specific civil defence units where it is in possession of relevant information. Existing civil defence services still have an important role to play with regard to flood warning and disasters (FMC, 1998).

For the purposes of a new flood management policy a new communication system should be developed for South Africa. While the MARNET communication system functioned well in the past, this system has now limited application possibilities. The reasons for this are limited funds (Green Paper, 1998) and the fact that the system is being moved to the Department of Constitutional Development, which at present does not have the expertise to maintain the MARNET System. In addition to the shortcomings mentioned it is found that members who have to staff the MARNET 24 hours every day are not always available when the MARNET is tested and in many instances not even during emergency events. To place this important function at a State Department can only have the effect of displacing the problems mentioned from one Department to another. The private sector can be used fruitfully in this regard. The latest development in cellular phones could be applied as an excellent communication system. When adequate satellites have been launched, virtually the whole surface of the earth will be covered by a communications blanket. Cellular phone operators are available 24 hours a day and are already engaged in providing aid in emergency situations.

Secondly, a formal national flood forecasting, warning and response centre must be established for South Africa. This centre must be able to receive, process and issue data in an intelligible way. The present Interim Disaster Management Centre can also be used for this purpose.

Thirdly, the new flood management policy must make provision for the installation of an appropriate national flood forecasting, warning and response system (FFWRS). Provincial and local authorities must be empowered in terms of this policy to install their own FFWRS which will be adapted to its own unique circumstances. In order therefore to reduce the social disruption and damage of floods, local authorities must promote flood awareness in communities by providing flood data and advice to owners, floodplain inhabitants, visitors, potential purchasers of land and investors. Research has shown that a high degree of carelessness is evident in the public concerning flood hazards. The FMC (1998) refers to this as follows: "A lack of specialist advice to smaller communities on how to deal with flood situations". Therefore appropriate flood and disaster awareness programs should be compiled for communities at local level.

Flood preparation measures are being instituted to empower communities with the objective of achieving a higher level of preparedness. Communities must therefore have the ability to react to flood forecasts, to compile proactive measures for floods, to respond timely and to keep pace with the advent of floods through effective and timely rescue actions, as well as the rendering of other suitable post disaster assistance (BANCID, 1995). Floodplain dwellers not only have the right to be informed of all possible risks of living in floodplains, but also have to be fully involved in the decision making process. Only when the aforementioned aspects and activities referred to in Figure 9.4 are in equilibrium will floodplain sovereignty be achieved. If a single aspect of Figure 9.4 is omitted in the planning of floodplains, a distorted image of sustainable integrated floodplain planning will result and floodplains will no longer be sovereign. Floodplain sovereignty can therefore only be achieved if all floodplain inhabitants are at the same level of disaster awareness. In this regard comprehensive standing orders for floods can be formulated in order to handle all flood crises. The orders mentioned must be designed to cope with situations before, during and after a flood. A disaster management centre should play a role during all three phases of the flood.

Task 7 of the FMC investigation was executed in order to investigate an appropriate flood forecasting system for South Africa. Task 12, which specifically investigates a

strategy for the education of individuals with respect to flood hazards, was executed as a sub-division thereof. The findings of Task 12 illustrate that relatively little research has been performed in this respect. Important aspects which do have to be considered are, *inter alia*, the value system of communities, lessons learned from the past, community involvement at attenuation and the credibility of both the institutions and the disaster message (Report: Task 12, 1994). Distinction is made between risk lowering and risk preparation. Risk lowering or attenuation is performed by means of structural flood control measures, while risk preparation is addressed through sociological aspects (Forster, 1980). In this regard the report on Task 12 (1998) puts it as follows: "If an event can be managed in such a way that the social structures are not disrupted, it will not become a disaster".

Disaster education normally includes the identification of leaders in communities. In this way the ability of the community to issue warnings and to respond effectively to them can be improved. Warning systems for a rainbow nation such as South Africa will differ considerably in relation to the value system of regions. The issuing of warnings for squatter camps will differ substantially from warnings in the metropolitan area. For more detailed information regarding the education of communities the report on Task 12 (1998) can be consulted.

Lastly, but not the least, appropriate institutions to be tasked with the implementation of an FFWRS in South Africa have to be identified. A well-developed FFWRS which is not implemented is of no value. The first step in ensuring that a national FFWRS can be developed, is to ensure that the required institutions in South Africa are in place. It is here where the new flood management policy can fulfil an important role. National, provincial and local authorities should be empowered through appropriate acts, ordinances and regulations to ensure floodplain sovereignty in South Africa. New and innovative thinking will have to be employed in the education of communities. Not only will new technology have to be used, but new training and education methods will have to be developed. To this end suitable research will have to be undertaken.

### **9.5.7 INSTITUTIONAL, POLITICAL AND SOCIAL ASPECTS**

In the past, social development and income distribution had not been explicit objectives of water management objects (BANCID, 1995). Similarly in the past disaster management was viewed in the context of reaction or response to disaster and not as forming part of a long term planning and development program of the authority (Green Paper, 1998). It is now acknowledged that growth in agricultural production would give rise to increase in employment and income. In this way socio-economic benefits will be attainable (BANCID, 1995). It is important that the standard of living in a region shall be lifted so that social and environmental aspects could also be improved (Jacobs and Iwra, 1994). Employment opportunities, change in professional structures, income distribution and property ownership are social aspects which should be considered by water management planners. A paradigm shift is required in disaster management, one which not only entails the physical and technological measures, but also comprises a sociological and human resources approach (Green Paper, 1998). Other important aspects in project planning are local participation, avoiding social conflict and improvement of quality of life. One of the main difficulties in the prevention of flood damage, is that responsibilities of institutions are not adequately defined (Galloway, 1995). Flood protection can be carried out by means of a floodplain management plan and requires impressive changes in institutional structures as well as official attitudes (Dempster and Brammer, 1992). Ghosh (1991) states the following: "What we need, therefore, is to change our thinking".

In general, projects in South Africa are run by the "top down" approach. For this reason politicians and the state have largely dominated projects. With a new government in power since 1994 it is expected by the electorate that it will contribute to democratisation which will satisfy the needs of communities at grass roots level in terms of a "bottom up" project planning and implementing approach.

With increasing participation by South Africa in the international arena, international institutions should also be involved in the implementation of flood control and flood damage control measures, as well as water development projects, particularly where the developing communities are affected.

Due to the fact that the Bill of Human Rights has also been incorporated in the Constitution, the protection of the rights and property of the citizens of South Africa against extensive flood incidents will also come to the fore. Consequently, all future institutional, political and social development in South Africa should be addressed (FMC, 1998).

The lack of suitable institutions at all levels, generally leads to ineffective implementation of water management matters. Van Zyl states this as follows: "The lack of a proper institutional dispensation to ensure and facilitate effective integrated catchment management. This complicated the process in many ways". The key argument concerning the institutions in question is that there are more than one way of organisation such institutions effectively, each of these designed to be completely feasible and efficient for the specific local circumstances (Smith and Handmer, 1986).

Flood management focuses more actively on the affairs of communities than would be incumbent on pure water management. For this reason a multi-sectoral, interdepartmental body would be essential for flood management. In this way the Department of Water Affairs and Forestry can provide all technical flood management information to the aforementioned integrated institutions. Other water related aspects such as town planning, norms and standards and disaster management plans can be handled by other institutions or Departments which have the required expertise. A need exists for an institution which can receive technical information, process it and make it available to the public in intelligible format (Green Paper, 1998).

It is therefore understandable that a series of shortcomings exists in South Africa with regard to the allocation of flood management responsibilities. The reason is that no co-ordination and policy guidance exist to this end (FMC, 1998). Each tier in the hierarchy, from the central government down to the individual has a roll to play in flood management. The following institutions are currently involved in flood management in one way or another in South Africa (FMC, 1998).

### **9.5.7.1 State departments**

#### *Department of Water Affairs and Forestry:*

The Department has accepted a flexible water management strategy which includes measures to minimise life and property losses by the introduction of dam safety regulations and flood control measures. The department of Water Affairs and Forestry is also empowered to erect water works, specifically for flood control purposes.

#### *Department of Environmental Affairs and Tourism:*

The Weather Bureau, a Chief Directorate within the Department of Environmental Affairs, is responsible for the important function of preparing and issuing weather forecasts. Forecasts are published and forwarded, together with relevant satellite images, to institutions such as the Department of Water Affairs and Forestry. In October 1996 a Long Term Group Operational Information Centre (LOGIC) was established to relay timely information directly to the public.

#### *Department of Regional and Environmental Affairs:*

This Department derives its responsibility towards flood management from the fact that it administers the Civil Defence Act 1977 (Act 67 of 1997). A shortcoming of the aforementioned mentioned act is that the Minister of Political Development is empowered to declare an area a disaster area, but has no powers to activate other ministers for the purposes of disaster management. Funds which are collected in terms of the Fund Raising Act (Act 107, 1978) cannot be appropriated to the benefit of civil defence, since it resorts under a separate act as indicated above (Green Paper, 1998).

#### *Department of Health:*

The Department of Health is empowered to raise funds for flood victims.

#### *Department of Agriculture:*

This Department is primarily responsible for the reinstatement of flood damage to natural agricultural resources or earth reinstatement, by the allocation of subsidies.

#### *South African Police Service (SAPS):*

The SAPS, who have the necessary manpower, good equipment and communication facilities at their disposal during floods, have an important role to play in the issuing of flood warnings, rescue actions and maintenance of law and order.

#### *South African National Defence Force (SANDF):*

The SANDF manages basically the same functions as the SAPD, particularly as far as rescue actions are concerned. The role, composition and hierarchy of the SANDF are presently undergoing drastic changes as a result of the current transformation process (1998). Existing well developed structures which have been applied to disaster management purposes in the past will no longer be active. The new disaster management policy of South Africa will therefore make provision to mobilise communities to the extent that members will be trained to handle disasters in future. In this regard the Netherlands introduced a provision in their Water Act to the effect that members could enrol with a dike army, which can be mobilised during disasters. The aforementioned approach can form part of the present and future part-time forces of the SANDF. Solid structures were in operation in SANDF in the past, which ensured effective communication between various state departments. Communication systems which were used by the SANDF (MARNET) are now outdated and new structures will have to be developed in the wake of the transformation process.

#### **9.5.7.2 Provincial administration**

Responsibilities such as co-ordination, implementation of rescue actions, evacuations and protection during floods, and relief after floods are executed under the accountability of the provincial administrations. These actions are carried out by municipalities, district councils and civil defence units.

#### **9.5.7.3 Local authorities**

Metropolitan, Local and District Councils have a great responsibility of implementing flood control measures before and during floods, as well as the reinstatement of

flood damage after flooding. Land use planning, zoning and the compilation and implementation of contingency planning are also the responsibilities of local authorities.

#### **9.5.7.4 Community**

No guidelines presently exist for the organisation and mobilisation of communities, other than by Civil Defence (Green Paper, 1988). The National Management System (NMS), comprising the Town Clerk, Police, Commando, Civil Defence and other state departments at local level, used to meet on a regular basis in order to co-ordinate disaster management matters. In this way the community was directly involved with disaster management. When a specific emergency situation arose, a Joint Operation Centre (JOC) would be established which effectively stepped up communication threefold since the Commanding Officer of the Commando and of the Police, and the Chairman of Civil Defence operated the JOC jointly. It is in this area that the new disaster act of South Africa will have to think innovative in order to mobilise communities for disaster management. Members of the community must be identified and trained to take proactive action during any disaster.

#### **9.5.7.5 Individuals**

The responsibilities of individuals are not formulated *per se*, but individuals should display the responsibility of getting involved in appropriate institutions in order that they may be properly informed of the actions required during disaster situations. The new disaster management policy ought to make provision for this aspect so that individuals may join definite organisations to be able to act during disasters.

### **9.5.8 URBAN PROTECTION**

The quantity and type of property determines the total flood damage to developed areas. Urban type development in flood prone areas cause extensive damage to communities during flooding. In some cases certain areas should not have been developed for urban purposes. Regulations with regard to zoning and development are the best long term measure for ensuring that land use is planned in such a way

as to limit flood hazards and, secondly, to reduce the upward trend in flood damage extent. Land use such as residential, commercial, industrial, agricultural and special, are common occurrences in floodplains. Each land use type should be properly defined by the authority concerned in order that the risk of different land uses can be clearly pointed out. Special land uses include hospitals, schools, public halls, churches, police and fire stations, telephone exchanges and power substations (New South Wales Government, 1986).

Exposure to flood losses can be limited or minimised by means of rezoning where little or no expected demand or rights for development such as for urban areas exists. Local authorities should still maintain low development zones in floodplains in respect of substantial floods and must accept a development strategy which discourages demand for development in flood prone areas. The latter can be achieved more readily where sufficient flood free land exists for development. Where no alternative flood free land is available and a demand for additional ground is still active, an alternative strategy should be considered, which could include high density development, avoidance of even poorer areas, suitable conditions for development and structural control measures. Situations where existing and higher intensity zoning are in place are more complex. The principle of endeavouring to reduce the intensity of development or of not attempting to raise it at all, must be adhered to. Areas which do not afford safe access during floods have to be treated with great circumspection. In some instances rezoning is possibly the only alternative for ruling out areas for permanent development (New South Wales Government, 1986).

Proposed development works in flood prone areas in New South Wales are classified as either conciliatory or conditional development. Conciliatory development is suitable for the flood hazards at development works as well as the impact of development on existing flood heights and flood velocities. Conditional development results in unacceptable flood damage or has an unacceptable impact on flood heights and flood velocities. Conditional development is not necessarily prohibited but may be subject to extremely strict conditions. It would therefore be the responsibility of the developer or owner to prove to authorities that this development would not result in significant water levels, flow velocities, flood

damage and community disruption. Intensive studies by consultants may in some instances be required in order to obtain sufficient support for the aforementioned type of application. New South Wales Government (1986) provides comprehensive development guidelines under conciliatory and conditional classifications and can be consulted for further detail.

Flood control and flood damage control measures which are instituted in order to protect commercial areas should not only be implemented cost effectively but will also have to be sustainable. Projects conforming to the criteria in developed areas will not necessarily succeed in undeveloped areas. Thus for example expensive and exorbitant structural measures will place an additional burden on the tax payer in developing countries, who is barely able to afford it in any event.

In urban development it is important also to provide appropriate drainage systems. Drainage maps can easily be updated by means of the latest satellite data and must be used to augment national plans in order to exercise flood control at national, provincial and local level. In this way government plans can be drafted with special reference to the drainage system of a country. Flood control therefore has to be based on a combination of measures (Ghosh, 1991).

In South Africa the 1:50 year flood line for development was accepted when Section 169A of the Water Act 1975 was promulgated. In 1978 this flood line was amended to the 1:20 year flood for catchments larger than one square kilometre. The purpose of section 169A is two fold, namely:

- ☛ to warn authorities against flood hazard, and
- ☛ to empower the minister to control development in areas which may be specified.

The first goal was achieved by installing the 1:20 year flood line as the development line. To date parliament has not given any attention to the second goal (FMC, 1998).

Notwithstanding the fact that the aforementioned Act specifies the 1:20 year flood line as the development line, local governments continued to specify the 1:50 year flood line. Another method of controlling development is by accepting actual observed flood markings as reference. By this method inaccuracies inherent to hydrological and hydraulic information are eliminated. The determination of an acceptable level of risk is a political decision which is normally based on experience and socio-economic considerations and seldom, if ever, on economic optimisation studies or engineering calculations (FMC, 1998; Alexander, 1993).

The FMC report (1998) recommends that Section 169A of the Water Act be retained, but that the acceptable flood line be amended to the 1:100 year flood. The objectives of this Act should be defined more clearly and a fixed method of determining flood lines should be specified. The use of corresponding results in all cases can be ensured by this means. The term flood line should be replaced with development line (FMC, 1998).

Although flood lines are generally used for development control by authorities, also in countries abroad, this approach is considered rigid. Notwithstanding the fact that the Water Act recommends the 1:20 year flood line for development, local governments have decided otherwise. It is commonly known that morphological and hydraulic data not only differs between rivers but also substantially between trajectories within the same river. By imposing a rigid approach to floodplain development, unnecessary limitations will be placed on development in certain areas and economic development and growth will be unnecessarily hampered. River properties such as depth and duration of flooding may give rise to a decrease in flood damage as a result of distinctive morphological properties of the river, particularly when certain precautions are taken. An adapted approach which is used in Australia should be applied in South Africa supplementary to the aforementioned approach, namely that regions be subdivided in to zones and that development is not only determined on the basis of a flood line but also in terms of depth of inundation and flow velocities of the water. In this way a merit approach is followed as already discussed previously in this chapter. This approach will eliminate unnecessary limitations on floodplains, which are valuable resources, particularly for agriculture, and will simultaneously limit development in hazard zones.

### 9.5.9 LAND USE

Knowledge regarding land use is not only essential for the management of water resources in any country, but also for the determination of flood damage. Even during effective environmental studies at regional level accurate land use information is required (Turner *et al.*, 1996). For this purpose remote sensing and GIS techniques can be applied with great success. Remote sensing and GIS techniques have been applied successfully by Turner *et al.* (1996) to establish environmental changes in Australia. Remote sensing and GIS techniques have also been employed in South Africa to determine the average annual flood damage (Chapter 4).

In South Africa the CSIR has already commenced a survey of various land uses (agriculture, plantation and urban), but have not yet dealt with the respective land coverage (vineyards, corn, grazing and houses). The Institute for Land, Water and Climate can also provide the aforementioned information upon request. Where information is indeed available, the scale is not sufficient for flood damage simulation and is outdated in many instances.

The inputs to the new flood management policy of South Africa (FMC) do not mention the importance of land use. A national land use survey should be undertaken and maintained for South Africa. Information must be stored in the correct format and scale in order that local authorities can have easy access to the data. In this way floodplain management can be performed cost effectively. The Department of Agriculture could possibly play an important role in this exercise. In any event the flood management policy must spell out this type of responsibility.

### 9.5.10 FLOOD MODELLING

Flood modelling as implied herein does not only comprise the modelling of hydrological and hydraulic data but also entails the modelling of various flood damage categories. For this purpose appropriate flood damage simulation models are required. Hydrological and hydraulic simulation models are readily available

while only a few flood damage models, applicable to the agricultural sector, are obtainable. Suitable interfaces between models are required in addition to the above, to perform integrated floodplain management studies (Chapter 6).

A hydrodynamic mathematical model is in use in Bangladesh for flood forecasting and warning purposes. The model is based on MIKE 11 which simulates the flow in rivers. MIKE 11 software makes provision for river modelling for hydrodynamic calculations and NAM modelling which is used for rainfall runoff. An additional module, Flood Forecasting is used for flow forecasting purposes which simulates timely effects of the aforementioned two divisions (BANCID, 1995). In order that floods are simulated effectively, models which describe the hydraulic and morphological effects of rivers are required (Marchand *et al.*, 1995).

A general approach which is also being used by Australia, USA and England, is the approach of White who proposes a method of determining the potential flood damage by means of loss functions. This approach is particularly suitable for urban applications but has as yet not been used often in the agricultural sector. This can possibly be attributed to the fact that flood damage relationships in agriculture are not easily established. Task 9 of the FMC investigation has been formulated as follows: "Determination of loss functions and integrating these into the management system" (FMC, 1998). A flood damage research project aimed at performing the aforementioned was commenced in 1992 and is financed by the WRC. A report on Task 9 was compiled and finalised in 1994. This served as input to the new flood management policy of South Africa. The following main findings emanate from the report of Task 9 (Report: Task 9, 1994):

- ☛ Actual floods have been very poorly documented in South Africa and no useful loss functions for the estimating of potential flood damage is available.
- ☛ Against the background of the current political, economic and institutional circumstances in South Africa, it would not make sense to undertake a country wide project in order to develop a data bank for loss functions. Attention should rather be focused on specific problem areas so that an

appropriate flood management plan with the best available technology can be formulated.

- ☛ Very little work has been done in South Africa in terms of loss functions, particularly in the agricultural sector.

The findings referred to above deal mainly with research based on the ex-post approach and makes no mention of the progress made to date with the ex-ante approach. The first finding, namely that no useful loss functions for the estimating of potential flood damage is available, is contrary to findings of current research (Du Plessis *et al.*, 1995; Booysen and Viljoen, 1995). Good progress has been made to date with the compilation of loss functions for agriculture and urban areas. In addition to loss functions appropriate flood damage simulation models called FLODSIM (agriculture) and TEWA (urban) have been developed in order to integrate loss functions with a decision making management system as formulated by Task Group 9. These flood damage simulation models are at present being refined and adapted for user friendliness (Chapter 6).

Flood management plans as referred to in the report on Task 9 (Task 9, 1994), can only be prepared successfully and sustainable if suitable decision making systems such as FLODSIM and TEWA are available. Findings of Task Group 9, which serve as input to the national flood management policy of South Africa, do not put these aspects into perspective. Contrary to this, the Department of Agriculture (UOFS) have been doing flood research since 1974 and should be requested to give input to the national flood management policy. An agricultural economical perspective on certain aspects concerning the flood management policy should be provided by an economist.

#### **9.5.11 FLOOD DAMAGE INSURANCE**

Although flood insurance is considered a component of flood control measures and is not mentioned per se in Figure 9.4, it is nevertheless necessary to be addressed for policy purposes. It is indeed possible to establish the insurance premium for different land uses in irrigation areas by means of FLODSIM by equating the premium to the total mean annual flood damage (Du Plessis *et al.*,

1995). Additional administrative and levy costs must also be considered in premiums. Premiums estimated for land use in Uppington prove to be expensive and not affordable (Du Plessis *et al.*, 1995). Comprehensive flood insurance has not been applied in South Africa to date, on the one hand, since information on the extent of premiums was not readily available and on the other hand because the risk of floods cannot be spread as is the case with, for example, hail insurance, where hail storms effect individuals randomly in a community. The latter is the reason why flood insurance is not financially attractive to insurance institutions.

Insurance can in no way cause a direct decrease in flood risks (Alexander, 1993). A distinction is made between insurance which is carried by the individual himself and insurance which is supported by the state. Where the state contributes to premiums, insurance has a negative impact on flood control because the individual does not actually realise the risk of settling in floodplains. When the individual bears the premium himself inhabitants are aware of the extent of the risk of settling in floodplains. In both cases a semblance of security attached to living in floodplains is created (these aspects are fully covered in Du Plessis, 1994:198-199). For insurance to be practically plausible the premium and the risk have to be small (Alexander, 1993). In the case of present insurance in urban areas of South Africa, the risk is spread across the whole spectrum of disasters and not only floods. Risk of crop losses is indeed borne by Sentraoes but here also the insurance covers hail and fire only. Insurance against flooding is in fact provided on request (FMC, 1998). Insurance can only be affordable when all crops and land in all river floodplains of South Africa are covered by insurance. In this way the risk is distributed. The role of the state in terms of financial support in the past had an important influence on the attractiveness of insurance in the agricultural sector. This role of the state is rapidly changing and generally speaking central government will not in future afford any financial support to individual and private concerns (Green Paper, 1998).

The FMC (1998) recommends that flood insurance should play a greater roll in lowering flood losses although it fulfils a small role in flood management at present. A national flood insurance strategy for South Africa should be

formulated.

With the aforementioned discussion as background it would appear that flood insurance for South Africa does not constitute a feasible option to be considered. Premiums have already become unaffordable and flood insurance will place an additional burden on floodplain dwellers that cannot afford it at this stage (particularly squatter camps in floodplains). In order that insurance be made practically feasible, the state will have to subsidise premiums and this will lead to escalation of flood damage since false security will be created. The only way in which flood insurance may possibly succeed is if a national insurance strategy should find a way of spreading flood risks at national level.

## **9.6 POLICY IMPLICATIONS OF CURRENT RESEARCH**

As far as can be ascertained no mention is made of integrated management concepts in the flood management policy. The concept of integrated catchment management should be incorporated in the new flood management policy of South Africa, in order that complex water management problems can be solved in future.

Due to a shortage in quantitative information concerning integrated catchments for South Africa, as well as considerable differences in hydrological and hydraulic answers coming from state institutions and consultants, the new flood management policy of South Africa should introduce an appropriate methodology so that comparable studies in floodplains can be performed. In order to comply herewith applied research should be undertaken. Apart from shortcoming with regard to hydrological and hydraulic data, little topographical data in the required format and scale is available for flood and flood management studies, which leads to unsatisfactory flood damage modelling. Applicable national projects should be undertaken to this end, which will enable local authorities to achieve better and more accurate flood damage modelling.

Despite applicable environmental and water quality legislation of the past, at least 50 per cent of South Africa's wetlands have been destroyed. For this reason the new

flood management policy for South Africa should take a stronger stand concerning water quality and ecological sustainability. As a point of departure the flood management policy of South Africa should be integrated with relevant policies. Historical flood records of South Africa are very poorly documented (Report: Task 9, 1994) which has the effect that various simulation models (hydraulic and flood damage models) cannot be properly calibrated. The most important cause hereof is that no institution in South Africa is responsible for the collection and maintenance of scientific flood records and no concern accepts ownership for the documentation of the information mentioned. The new flood management policy of South Africa should clearly spell out flood responsibilities at all levels but particularly for the documentation of post flood information.

No normal flood warning system exists presently (1998) for South Africa. A national forecasting, warning and response system (FFWRS) and a national communication system will have to be instituted for South Africa. In addition hereto an implementing strategy should also be formulated by the flood management policy. In this way local authorities can be empowered to draft their own FFWRS, which will thus comply fully with the demands of the unique local circumstances. A flood warning system was indeed developed by Alexander and installed by the Departement of Water Affairs and Forestry in 1993.

The present development control in floodplains as proposed by the FMC (1998), is rigid and will unnecessarily limit development in floodplains. An adapted approach, which will divide areas into zones and which will determine development not only in terms of flood line but also on the basis of flooding and flow velocities of the water, should be incorporated into the flood management policy. In this way a merit approach which revokes unnecessary limitations on floodplains but which limits development in hazard areas by the same token would be followed.

It is not true that no progress has been made with respect to appropriate loss functions particularly in the agricultural sector. Good progress has been made to date with the preparation of loss functions for both agricultural and urban areas. Appropriate simulation models namely FLODSIM (agriculture) and TEWA (urban) have already been developed in order to integrate loss functions with the decision

making management system. The flood damage simulation models can be used to formulate appropriate sustainable flood management plans for flood prone areas. These aspects have not been dealt with in perspective in the report of Task Group 9 and should be rectified for policy purposes.

Little quantitative data is available in South Africa. A national strategy ought to be formulated in order to make available appropriate land use data of the correct format and scale for local authorities in order to execute floodplain management studies.

In conclusion, it is contended that an appropriate National Flood Management Centre should be instituted for South Africa, which must be able to receive and process technical data and make it available to the public in intelligible format. The present Interim Disaster Management Centre can handle these functions in the interim.

## 9.7 SUMMARY

Traditionally, only structural and non-structural control measures are implemented in the planning of a floodplain, despite the fact that authorities are reluctant to accede to the critical issue, namely that non-structural control measures are also required. When only structural and non-structural control measures are applied in floodplains the potential flood damage continues to rise notwithstanding the evidence of a positive cost benefit ratio. The result of this is the escalation of flood damage over time. An adapted approach was therefore discussed in this chapter which in a sense gives rise to a new dimension in floodplain management planning. A sustainable floodplain policy, which advocates the approach of *living with* floods and other natural disasters and processes, is proposed for South Africa as a solution to the problems referred to. Consequently the flood damage simulation model (FLODSIM) has been expanded to the extent that sustainable flood management plans can be formulated for authorities. A holistic approach to integrated catchment management is therefore proposed for South Africa. "A holistic co-operative approach is necessary which would ensure in achieving a sustained minimal standard human life for the people and protection of the environment. There is no other alternative for the survival and betterment of the people of the region" (BANCID, 1995).

Various flood management systems exist in the world today. An integrated system can best be instituted by formulating an appropriate management policy. Subsequent to the formulation of a flood management policy the implementation of this policy can best be facilitated and co-ordinated by the formulation and implementation of the floodplain management plan (FPMP). This objective can most easily be achieved by the appointment of a floodplain management committee by local authorities. This committee has various responsibilities, namely the execution of flood studies and floodplain management studies, the choice of a suitable flood standard and the formulation and implementation of the flood management plan.

In order to be able to solve the complex water resources management problems in future, South Africa should formulate a much stronger philosophy with regard to integrated catchment management. Little quantitative information exists for integrated catchments in South Africa at present. Therefore research should be undertaken to develop an appropriate methodology to obtain suitable hydrological and hydraulic data, so that comparative studies can be undertaken in floodplains.

In spite of appropriate environmental and water quality laws in the past, the ecology is still being destroyed. For this reason the new flood management policy of South Africa should express a more forceful philosophy regarding water quality and ecological sustainability.

Historical flood records are poorly documented in South Africa, and this is the cause that various simulation models (hydraulic and flood damage models) are not properly calibrated. The reason for this is that no institution in South Africa is responsible for the collection and maintenance of scientific flood records and no ownership of the documentation of the flood information mentioned is acknowledged. Flood responsibilities at all levels will have to be spelt out unequivocally.

No formal flood warning system exists at present (1998) for South Africa. A national flood forecasting, warning and response system (FFWRS) and a national communication system have to be instituted for South Africa. New technology and approaches should be investigated to this end.

Development control in floodplains traditionally takes place in terms of flood lines or development lines. Such an approach is rigid and will unnecessarily restrict development in floodplains. An adapted approach which divides areas into zones and which terminates development not only on the basis of flood lines but also in terms of the depth of flooding and flow velocities, should be investigated for South Africa. In this way room will be made for a merit approach which will revoke unnecessary limitations on floodplains but also limit development in hazard zones by the same token.

The loss function approach is a development which is also supported in countries abroad for the determination of potential flood damage in floodplains. Applicable flood damage simulation models, namely FLODSIM (agriculture) and TEWA (urban) have been developed in the course of this research in order to integrate loss functions with a decision making model. Flood damage simulation models can be used to formulate sustainable flood management plans for flood prone areas.

Little quantitative land use data is available for floodplains in South Africa and a national strategy should be formulated to make appropriate land use data available in the right format and scale to local authorities in order that floodplain management studies can be executed.

In conclusion, it is contended that an appropriate national flood management centre should be instituted for South Africa, which should be able to receive and process technical data in an intelligible format for public consumption. The present Interim Disaster Management Centre could execute these functions in the interim.

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# CHAPTER 10

## SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

### 10.1 INTRODUCTION

In this chapter the summary, conclusions, and recommendations for future research are presented. The overall goal of this research was to develop a user-friendly flood damage simulation model (FLODSIM), which can be applied cost-effectively in flood sensitive irrigation-areas in South Africa to determine economic benefits of different combinations of flood and flood damage control-measures. In this way, more effective flood management plans can be formulated and implemented. As a starting point a theoretical framework was formulated and used as the building block of this research. During the first research phase the shortcomings of the methodological framework were identified. A procedure was developed during this phase to address the shortcomings.

The specific aims of the project formulated in the report are the following:

- ☞ To develop an applicable user-friendly flood damage simulation model.
- ☞ Development of loss functions for the different land use that occur in irrigation areas.
- ☞ Adaptation of FLODSIM to be applicable in other flood prone irrigation areas of South Africa.
- ☞ To apply FLODSIM in a flood prone area of South Africa to determine the total average annual flood damage.
- ☞ To show how FLODSIM can be used to provide guidelines for flood management policy and flood management plans to authorities, in

order to apply and maintain total integrated floodplain management within catchment areas.

First a summary regarding each aim as it unfolds in the different chapters are presented.

## **10.2 SUMMARY**

### **10.2.1 DATA ACQUISITION**

Alternative methods to identify the land use pattern in floodplains, were investigated. Remote sensing was taken as a point of departure and satellite-, radar- and video remote sensing were investigated *inter alia* for cost effectiveness.

In Europe satellite remote sensing is especially used to control arable and grazing land on which a subsidy benefit is payable on a per hectare basis. Crop statistics are also collected by means of satellite remote sensing. At a regional and local level there is an increase in the use of satellite remote sensing for the purpose of collecting information concerning the changes in land use and with a view to making production forecasts. The accurate identification of crop types depends on the timely availability of images during the crop growth period. Images obtained at a specific time of the year can also be used to determine the yield of different crops (European Space Agency, 1995). A too high image resolution (80 m) and poor images, especially due to overcast conditions result in satellite remote sensing not always being a suitable operational decision-making mechanism. Radar satellites such as ERS-1 and ERS-2 were launched in July 1991 and help to surmount the problem of poor images during overcast conditions. Synthetic Aperture Radar (SAR) transmits microwave energy to the surface of the earth and records the variation in the strength of the reflected signal. Images are obtained irrespective of overcast and even daylight conditions. Radar is sensitive to the structure and humidity conditions of vegetation and also to the roughness and moisture levels of

the soil surface (European Space Agency, 1995). However, SAR cannot serve as a replacement for LANDSAT MSS, FCC, TM and SPOT images. Each of the aforementioned images has its advantages and disadvantages and they should therefore not be used separately and in isolation, but should rather supplement one another. Inggs (1996) developed a refined procedure for using SAR images to create DTMs. Instead of a satellite, an aircraft is used as the platform. Although the cost involved in using this technique as an operational decision-making mechanism is still high, the possibility of using this technique for the identification of land use and the creation of DTMs should definitely be researched.

It is also possible to scan images by means of video cameras (Jensen 1986). Aerial video photography as a remote sensing mechanism developed extremely rapidly over the last five years, although video cameras have been used for remote sensing for the past decade (Mausel *et al.*, 1992). The ability to observe live images cost-effectively during data capturing, the fact that analogue images can be interpreted manually from the screen, after which images can be converted to digital values by means of image processing, are a few of the most important benefits which can be obtained by using video remote sensing. The greatest disadvantage of VRS is the relatively low image resolution when compared to a photograph (Mausel *et al.*, 1992). Consequently it would prove difficult to distinguish between certain crop types during land use surveys. Problems pertaining to lens distortion and georeferencing are encountered when using VRS and are carried over to the data, resulting in geometric distortion. In spite of the above-mentioned disadvantages, video remote sensing systems have already proved to be an effective research mechanism in various fields of application (Vleck, 1983, Nixon *et al.*, 1985, Everitt *et al.*, 1986 and 1989, as quoted by Marsh *et al.*, 1990).

After the various remote sensing techniques had been evaluated, especially for cost-effectiveness, VRS was chosen to map land use in the Lower Orange River Area between the Gifkloof Weir and the Manie Conradie Bridge at Kanon Eiland.

VRS was used five years after the *in situ* survey (1992). Consequently it must be accepted that land use in the research area could have changed. The primary purpose of the study was however not to determine the level of accuracy with which VRS classifies land use, but rather to determine the difference between the total mean annual damage as calculated on the basis of the VRS and that calculated on the basis of the *in situ* survey. The reason for this was to determine the value of VRS as an operational management tool, which can be used for the purpose of sensible floodplain management.

In the evaluation of VRS a distinction was made between vineyards, rotational cropping and lucerne. Flood damage was subdivided into harvest, crop and soil damage. It was found that the video survey indicated more extensive damage in the case of lower flows. In contrast the video survey indicated less extensive damage in the case of higher flow. The reason for this is that certain vineyards were inaccurately classified as rotational cropping. Consequently the survey indicated more extensive flood damage at a lower inundation depth. With regard to harvest and soil damage, VRS and the *in situ* survey indicated a difference of 11 and 12 per cent respectively in the case of individual floods. In the case of damage to harvests, the MAD as indicated by the two above-mentioned methods corresponds 97 per cent, while the MAD with regard to soil damage corresponds 94 per cent. More significant differences are, however, encountered in the case of crop damage, in which case VRS and the *in situ* surveys indicate a difference of up to 30 per cent in the case of individual floods, although there is an 87 per cent agreement between the MAD as calculated on the basis of VRS and that calculated on the basis of the *in situ* survey. If the aforementioned damage categories are combined, there is a difference of only four per cent in the MAD.

### 10.2.2 HYDRAULIC SIMULATION

In Chapter 5 hydraulic simulation is discussed. During the first phase of the

research a steady flow simulation program was used to obtain hydraulic data. Shortcomings such as constant flow when moving downstream, no time dimension, simulation of only single open channel condition and constant water flow during the manipulation of levees resulted in the emphasis being shifted from steady flow simulation to dynamic flow simulation. Thus it was decided to link a dynamic hydraulic simulation model to FLODSIM. In this way it was possible to obtain dynamic hydraulic data for floodplain planning and management.

Flow modelling techniques that are used at present vary from simple qualitative calculations based on historical flood events, to the calculation of backwater curves and to sophisticated one- and two-dimensional modelling techniques (Anderson and Bates, 1994).

Three approaches for the simulation of flow in rivers and channels were researched, namely steady flow hydraulic simulation, one-dimensional hydraulic simulation and two-dimensional hydraulic simulation. Steady flow programs such as the Channel Flow Profile program (CFP) are fully interactive simulation programs for the analysis of steady flow profiles in open channels, rivers, spillways and watercourses. The CFP approach is a well-known step-by-step method for the calculation of backwater curves, that is to say water level profiles (Chunnett, Fourie and Partners, 1993).

In contrast to this a dynamic hydraulic simulation model such as MIKE 11 is a numeric flow model that reflects information on flood levels, flow speeds and even the impact of proposed floodplain, flood control and flood damage control measures on simulated flood levels and flow speeds (Muller and Rungoe, 1996). In addition to the above-mentioned, simulation of simultaneous run-off in more than one flow path, water quality and sediment transportation in rivers and irrigation channels can also be handled by MIKE 11.

The largest difference between CFP and MIKE 11 lies in the time aspect involved in

MIKE 11. Flow is no longer steady, but is simulated dynamically. Consequently the run-off in all the sections along the channel will change over time and the duration of flooding is also taken into account.

Anderson and Bates (1994) points out that one-dimensional approaches are not always able to provide all the information such as flood (inundation) zones in areas with complex topographic conditions and floodplain characteristics. A two-dimensional flow simulation model (such as MIKE 21) was used and applied successfully by the above-mentioned authors. MIKE 21 is a typical two-dimensional flow simulation model and can also handle wave modules and more advanced cohesion sediment transportation (Department of Water Affairs and Forestry, 1997).

As a result of problems such as the hydraulic complexity, the variety of geomorphic conditions in the Orange River and a need for more detailed simulation information, it was decided to use a dynamic hydraulic simulation model to simulate the water level profile of the Orange River between the Gifkloof Weir and the Manie Conradie Bridge at Kanon Eiland. The Department of Water Affairs and Forestry was approached because this flood simulation model is frequently used (also in overseas countries) (Nielsen *et al.*, 1991; Woltemade and Potter, 1994; Havno *et al.*, (1995). Singh, 1995; and Muller and Rungoe, 1996) and because the Department of Water Affairs and Forestry had already acquired the MIKE 11 simulation program and is also using it at present in the Division Hydraulic Studies. Moreover MIKE 11 has ideal application possibilities in respect of the research area where there are different flow paths, especially in the case of low flows.

In order to be able to use FLODSIM and MIKE 11 meaningfully, the two above-mentioned models had to be linked. Appropriate interfaces between MIKE 11 and FLODSIM were developed.

The river channel is defined by carefully pinpointing the centre line of flow for flows with different probabilities of occurrence. The centre line is a line connecting points

of maximum flow speed of the water between different cross sections. If the water can flow in more than one channel, especially in the case of low flows, such channels must also be defined by means of a center line. In addition to the center line the river morphology was also defined by means of cross sections obtained from ARC/INFO, something which was not possible before. This information has great value and implies a considerable saving of time. Lastly MIKE 11 was calibrated for the research area by making use of historical flood event data, observed flood marks and existing flow simulation data.

Various scenarios were compiled for MIKE 11. As a starting point the same cross-sections which the consultant used during steady flow simulation, were also used for MIKE 11. No significant differences in water level heights could be found between the above-mentioned simulations. In general flood damage is calculated more conservatively when using MIKE 11 than when using CFP. The MAD amounts to R12,080 million when CFP is used as opposed to R10,659 million when MIKE 11 is used.

Secondly the river morphology was defined by taking cross sections from the digital terrain model (DTM) created by means of ARC/INFO. In this case flood damage caused by the once-in-five-years flood decreases drastically from R18,6 million to a mere R3 million. With the exception of the Once-in-twenty-years flood, the flood damage caused by all the remaining floods decreases, and the MAD also decreases further from R10,659 million to R9,612 million.

Lastly three levee scenarios, namely the increasing of the height of specific levees, the removal of two levees and the erection of two new levees at strategic places were compiled. If the height of the levees is increased the flood paths are restricted and water levels rise. The MAD therefore increases from R9,398 million to R9,440 million. The opposite applies when levees are removed. In this case the MAD decreases to R9,351 million. A net benefit is obtained if no maintenance is done on

the levees and if the repair cost is lower than 10 per cent of capital cost. The erection of the two above-mentioned new levees causes the MAD to increase to R9,402 million. If maintenance costs amounting to two per cent and repair costs after a once-in-ten-years and a once-in-twenty-years flood to 10 and 20 per cent of capital cost respectively are taken into account, at a 12 per cent discount rate the cost of erecting the levees exceeds the benefits.

It can be concluded that MIKE 11 has meaningful refinement benefits and the use thereof is consequently recommended. It will be of special benefit to local authorities to be able to determine the effect of individual floods and the benefits attached to various flood protection measures. Steady flow simulation can however still continue to be used by regional and national authorities in order to determine the MAD.

### **10.2.3 IMPLEMENTATION OF FLODSIM**

After solving problems with identifying the land use pattern cost-effectively and shortcomings with steady flow simulation, FLODSIM was refined and implemented in another flood prone area of South Africa. The Mfolozi floodplain was chosen for this purpose. First the necessary loss functions had to be determined and FLODSIM adapted.

#### **10.2.3.1 Loss Functions**

Damage to sugarcane and infrastructure in the Mfolozi floodplain constitutes the greatest part of flood damage; thus loss functions were developed for the different damage categories of sugarcane and infrastructure respectively (Chapter 6). The loss functions were included in a flood damage simulation model for estimation of ex ante flood damage. Loss functions curves for sugarcane were developed to estimate damage to harvests and crops. In the case of damage to the harvest,

depth and duration of inundation were identified as the main determinants of the percentage of the total area of sugarcane that will be destroyed during a flood. Destroyed sugarcane also represents a saving in terms of a decrease in harvesting and marketing cost. In the case of damage to the crop (vegetative part of the sugarcane plant), potential future yields were 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.

The well-developed infrastructure in the Mfolozi floodplain effectively mitigates flood damage to sugarcane, especially during smaller floods, but annual maintenance and repairs after destructive floods amount to a considerable sum. It was found that there is a higher correlation between the extent of flood damage to infrastructure and the size of a flood than between damage to infrastructure and depth and duration of inundation. With regard to drains, levees, roads, tramways and spillways, the distance of each within the floodplain were determined for different flood peaks, making it possible to calculate damage per meter. The latter was used to determine the loss functions, which took the form of a Cobb Douglas function with flood peak as the only independent variable. Since loss functions were calculated per meter, they can be used to determine potential flood damage if additional infrastructure should be constructed in the floodplain.

### **10.2.3.2      *Adaptation of FLODSIM***

After appropriate loss functions were developed for the research area, the flood damage simulation model (FLODSIM) was adapted specifically for the Mfolozi floodplain (Chapter 7).

In Chapter 8 the application of the flood damage simulation model (FLODSIM) in the Mfolozi floodplain was discussed. Topographical data was digitised from

1:10 000 ortho photos (1979) and was updated with 1996-air photography and digital data obtained from Bosch and Associates. Two methods were applied to obtain a DEM for the Mfolozi floodplain. With the first method digital photogrammetry was used. The results from this method were unreliable due to the dense vegetation. A second DEM was created with an analogue stereoplotter. With this method points within cultivated fields could be ignored.

Hydraulic data was supplied by the Division Hydraulic Studies of the Department of Water Affairs and Forestry. The MIKE 11 hydraulic simulation model was used for this. Besides damage to harvest and crops, damage also occurs to infrastructure like roads, bridges, levees, railways and the spillway. Crop budgets for sugarcane and lucerne were drawn up and multipliers for Region E were calculated from Input-Output tables and saved in the economic database.

A budget for sugarcane in the Mfolozi floodplain was drawn up. Besides this budget, regional and national multipliers were calculated for this region to calculate secondary effects of the floods. Above-mentioned data were stored in the economical databases.

Flood damage was calculated with different discount rates. Meaningful variation in damages occurred between different floods for the different discount rates, with only small deviations in the total average annual flood damage. A discount rate of ten per cent was subsequently used to calculate damage to crops in the Mfolozi floodplain. Damage for 12 months of the year was calculated and a clear distinction between summer and winter floods was prominent. Damage during April is the highest (R2,824 million), in comparison with damage in June (R1,562 million) with damage to infrastructure not included.

#### **10.2.4 SUSTAINABLE INTEGRATED FLOOD MANAGEMENT PLANS**

Traditionally, only structural and non-structural control measures were implemented

in the planning of a floodplain. Therefore the potential flood damage continues to rise notwithstanding the evidence of a positive cost benefit ratio. The result of this is the escalation of flood damage with time. An adapted approach was therefore discussed which in a sense gives rise to a new dimension in floodplain management planning. A sustainable floodplain policy, which advocates the approach of living with floods and other natural disasters and processes, is proposed for South Africa as a solution to the problems referred to. Consequently the flood damage simulation model (FLODSIM) has been expanded to the extent that sustainable flood management plans can be formulated for authorities. A holistic approach to integrated catchment management is therefore proposed for South Africa. "A holistic co-operative approach is necessary which would ensure in achieving a sustained minimal standard human life for the people and protection of the environment. There is no other alternative for the survival and betterment of the people of the region" (Bancid, 1995)

Various flood management systems exist in the world today. An integrated system can best be instituted by formulating an appropriate management policy. Subsequent to the formulation of a flood management policy the implementation of this policy can best be facilitated and co-ordinated by the formulation and implementation of the floodplain management plan (FPMP). This objective can easily be achieved by the appointment of a floodplain management committee by local authorities. This committee has various responsibilities, namely the execution of flood studies and floodplain management studies, the choice of a suitable flood standard and the formulation and implementation of the flood management plan.

### **10.3 CONCLUSIONS**

The main findings regarding the specific aims of the research now follows.

### 10.3.1 REMOTE SENSING

The hypothesis formulated initially, namely that video remote sensing can be used as an operational management aid for the purpose of determining flood damage for floodplain management planning, cannot be rejected. The best results can be obtained by integrating available data, such as the results of *in situ* surveys, cartographic maps, aerial photography and satellite images. Great care should be taken in planning VRS in order to ensure that surveys are conducted at the right time of the year. In the case of the present research area surveys should be conducted before the growth season of winter wheat. Surveys can also be conducted at lower heights, especially in cases where digital land use information is already available. A middle course between the highest possible image quality and the lowest possible operational cost should be followed in determining flying heights.

### 10.3.2 DYNAMIC HYDRAULIC SIMULATION

In order to be able to conduct meaningful flood damage studies and develop simulation models, reliable and accurate hydraulic and hydrological data are *inter alia* required. As a first round, steady flow data was obtained from a consultant. During further refinement of FLODSIM and also as a result of the hydraulic complexity of the Orange River, a need for dynamic hydraulic data arose. Consequently it was decided to link FLODSIM and a dynamic hydraulic model in order to get more reliable information.

During initial comparison of the results obtained with steady flow and dynamic flow, it was found that the water level forecasts arrived at by these two approaches did not differ significantly. The hydraulic data received from the consultant proved to be reliable and accurate and that it can be used to calculate the MAD at national and regional level. It is only when a dynamic hydraulic simulation model is compiled in such a way that it makes specific provision for river morphological conditions unique

to an area, that steady flow and dynamic flow data differ. More realistic and accurate answers are obtained by means of dynamic hydraulic simulations, making it possible to engage in more reliable planning and management of floodplains and integrated catchment areas.

Where more complex river morphological conditions exist, one could even use two-dimensional hydraulic simulation models such as MIKE 21. The latter has already been used in many studies overseas, but is not yet readily available in South Africa.

### **10.3.3 FLOOD DAMAGE SIMULATION MODEL**

A GIS-approach was used to develop FLODSIM. In this research it was demonstrated how a GIS-approach could be used to integrate various databases for more useful floodplain management. To give attention to this approach, appropriate interface programs was written to link FLODSIM and MIKE 11. Therefore it was possible to simulated dynamic hydraulic data with MIKE 11 to be used within FLODSIM to calculate the mean annual damage. Accept flood control and flood damage control measures that could be evaluated traditionally by FLODSIM, integrated sustainable flood management plans can also be formulated and implemented.

### **10.3.4 ADAPTATION OF FLODSIM**

The total average annual flood damage for the Mfolozi floodplain, when damage to infrastructure is included, is R3,27 million during the summer months. This is more or less R450 000 more annually than when damage to infrastructure is not included. Damage to various infrastructure categories was also calculated, and the largest damage is to levees (an average of R105 000 per annum). This is followed by damage to railways with the smallest damage to bridges.

Traditionally flood damage is presented in terms of the total average annual damage, especially where flood control measures are compared from a benefit-cost point of view. One of the disadvantages of this method is that it does not explicitly point out the risks of floods. Subsequently an adapted method was used to show the risks of flood damages for communities. It was shown that it could be assumed with an 81 per cent assurance that no damage in the Mfolozi floodplain can occur in any year. Although there does exist the possibility of smaller floods, as a result of existing flood control measures that control such smaller floods, no damage occurs. It can also be assumed with a 98 per cent certainty that flood damage in any year will not exceed the amount of R27 million, or that flood damage will not exceed R16,6 million should floods occur during June. From this can be concluded that the damage risk of an April flood is 39 per cent higher than that of a June flood.

Several scenarios were evaluated as an exercise for the Mfolozi floodplain. Due to incomplete hydraulic data, it was decided not to calculate the economic benefit of the spillway. An option was investigated where the expropriated area after Domoina was hypothetically planted with lucerne, and where the area where the Mfolozi River flow into the sea, was deforested. This option offers the largest benefit for the Mfolozi floodplain and lowers the total average annual flood damage from R3,122 to R2,43 million. Consequently the risk of flood damage could be lowered when these options are applied in this area. Other aspects should however also be taken into account before any practical recommendations can be made.

### **10.3.5 POLICY IMPLICATIONS**

As far as can be ascertained no mention is made of integrated management concepts in the flood management policy. In order to be able to solve the complex water resources management problems in future, South Africa should formulate a much firmer philosophy with regard to integrated catchment management. Therefore the concept of integrated catchment management should be incorporated

in the new flood management policy of South Africa. In this regard the new National Water Act (No 36 of 1998) makes provision for the establishment of Catchment Management Agencies, which will be funded from the catchments which they serve. It is envisaged that these Agencies will fulfil a very important co-ordinating role with regard to holistic and integrated catchment management, encompassing both flood and drought management. In this regard the provisions of Section 145 of this Act are very exciting, viz.:

**"Duty to make information available to public**

145. (1) A water management institution must, at its own expense, make information at its disposal available to the public in an appropriate manner, in respect of -

- (a) a flood which has occurred or which is likely to occur;
- (b) a drought which has occurred or which is likely to occur;
- (c) a waterwork which might fail or has failed, if the failure might endanger life of property;
- (d) any risk posed by any dam;
- (e) levels likely to be reached by floodwaters from time to time;
- (f) any risk posed by the quality of any water to life, health or property, and
- (g) any matter connected with water or water resources, which the public needs to know.

(2) The Minister may, where reasonably practicable, establish an early warning system in relation to the events contemplated in subsection (1)."

Good progress has been made with respect to disaster management in a broader context in South Africa. In this regard a Green Paper which embodies a draft framework for disaster management has been passed to provinces and the public for comment (1998). The Green Paper highlights possible management strategies for improved management of different types of calamities. Therefore the objective of the Green Paper on Disaster Management is to develop an effective disaster

management system and to implement it by means of an appropriate policy, which will be embodied in legislation.

Due to a shortage in qualitative information concerning integrated catchments for South Africa, as well as considerable differences in hydrological and hydraulic answers coming from state institutions and consultants, the new flood management policy of South Africa should introduce an appropriate methodology so that comparable studies in floodplains can be performed. In order to comply herewith applied research should be undertaken. Apart from shortcoming with regard to hydrological and hydraulic data, little topographical data in the required format and scale is available for flood and flood management studies, which leads to unsatisfactory flood damage modelling. Applicable national projects should be undertaken to this end, which will enable local authorities to achieve better and more accurate flood damage modelling.

Despite applicable environmental and water quality legislation of the past, at least 50 per cent of South Africa's wetlands have been destroyed. For this reason the new flood management policy for South Africa should take a stronger stand concerning water quality and ecological sustainability. As a point of departure the flood management policy of South Africa should be integrated with relevant policies. Historical flood records of South Africa are very poorly which has the effect that various simulation models (hydraulic and flood damage models) cannot be properly calibrated. The most important cause hereof is that no institution in South Africa is responsible for the collection and maintenance of scientific flood records and no concern accepts ownership for the documentation of the information mentioned. The new flood management policy of South Africa should clearly spell out flood responsibilities at all levels but particularly for the documentation of post flood information.

No normal flood warning system exists presently (1998) for South Africa. A national forecasting, warning and response system (FFWRS) and a national communication

system will have to be instituted for South Africa. In addition hereto an implementation strategy should also be formulated by the flood management policy. In this way local authorities can be empowered to draft their own FFWRs, which will thus comply fully with the demands of the unique local circumstances. Only a flood communication system was developed by Alexander and installed by the Department of Water Affairs and Forestry in 1993.

The present development control in floodplains as proposed by the FMC (1998), is rigid and will unnecessarily limit development in floodplains. An adapted approach, which will divide areas into zones and which will determine development not only in terms of flood line but also on the basis of flooding and flow velocities of the water, should be incorporated into the flood management policy. In this way a merit approach which revokes unnecessary limitations on floodplains but which limits development in hazard areas by the same token will be followed.

Good progress has been made to date with the preparation of loss functions for both agricultural and urban areas. Appropriate simulation models namely FLODSIM (agriculture) and TEWA (urban) have already been developed in order to integrate loss functions with the decision making management system. The flood damage simulation models can be used to formulate appropriate sustainable flood management plans for flood prone areas.

Little qualitative data is available in South Africa. A national strategy ought to be formulated in order to make available appropriate land use data of the correct format and scale for local authorities in order to execute floodplain management studies.

In conclusion, it is contended that an appropriate National Flood Management Centre should be instituted for South Africa, which must be able to receive and process technical data and make it available to the public in intelligible format. The present Interim Disaster Management Centre can handle these functions in the interim.

## 10.4 RESEARCH RECOMENDATIONS

Problems experienced during the first phase of the research was solved in the second phase, mainly because of new technology development and better insight in the flood problem. In the technology explosion era we are living in today, problems experienced today, will probably be solved by better technology and equipment in the future. As time passes, better and more insight is obtained and it would be lamented if flood research lags.

The following problems *inter alia* remain and should be given attention in future research:

- ☞ Problems to create digital terrain models (DTMs) for research areas still remain. This is more than just a technology problem. Only limited topographical data, and of an appropriate scale, does exist for floodplains of South Africa. If more data in digital format and of an appropriate scale becomes available, FLODSIM can be implemented much easier in flood prone areas.
- ☞ Various differences exist in hydrological and hydraulic data between institutions. Research should be undertaken to develop and refine an appropriate methodology to calculate hydrological and hydraulic data. The disposal of hydraulic data and historical flood records will also help calibrating simulation models.
- ☞ A major shortcoming in South Africa is a lack in appropriate institutions with well-defined responsibilities. By establishing appropriate institutions, an institution should also be founded that could implement the FLODSIM-approach in flood prone areas.
- ☞ Possible adaptation of FLODSIM for a personal computer could be investigated. This aspect depends mainly on the development of the

level of computer technology.

- ☞ Research should also be undertaken to identify short cut methods for the ex ante approach in flood damage determination. More specific can the loss function approach be refined.
- ☞ More and bigger interdependency between results of the ex post and ex ante-approach must be established. Operational decision management could be developed.
- ☞ Because of various new modules which has been developed for FLODSIM in this phase of the research, little attention was given to the user friendliness of FLODSIM. This aspect needs further attention.

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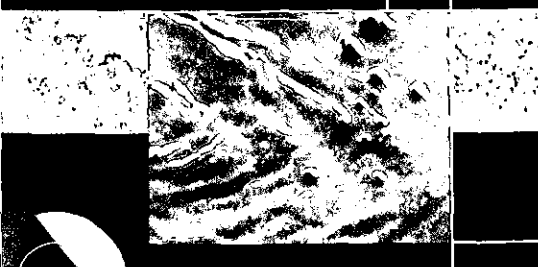
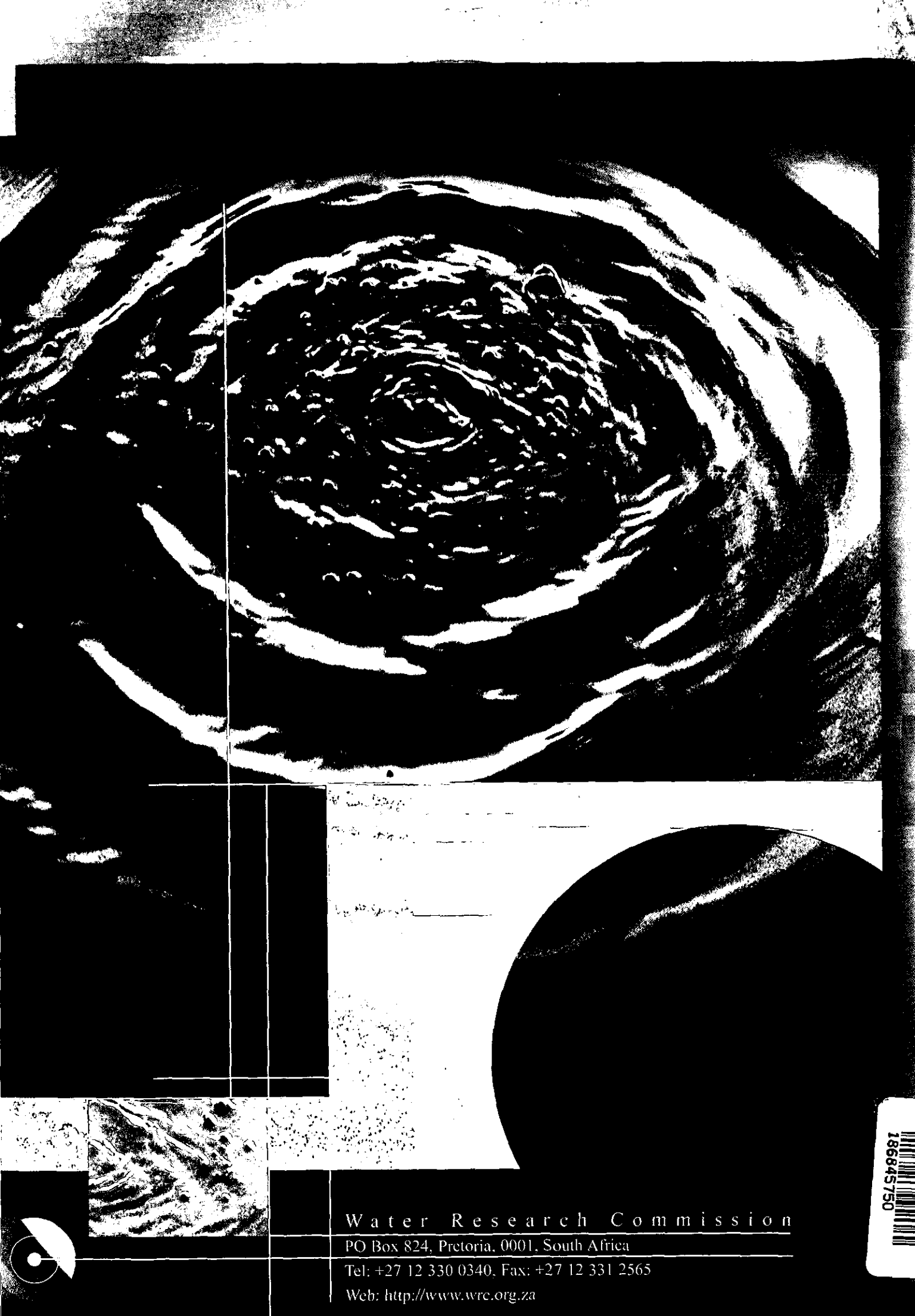
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