



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

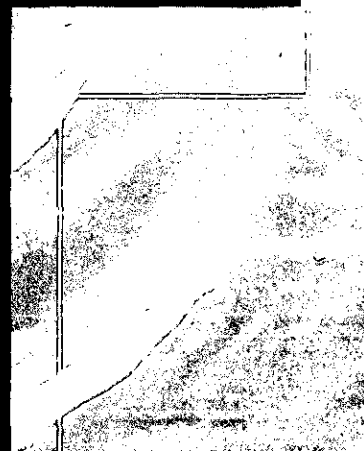
VOLUME 2

HJ Booysen • MF Viljoen

WRC Report No 690/2/99



**Water
Research
Commission**



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

VOLUME 2

URBAN AREAS

by

HJ Booysen

MF Viljoen

Report to the Water Research Commission

by the

Department of Agricultural Economics

University of the Orange Free State

Project Leader: Prof M F Viljoen

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LIST OF ABBREVIATIONS

ANU	Australian National University
ANUFLOOD	Computer program developed by the Australian National University to calculate flood damage
CRES	Centre for Resource and Environmental Studies
CSIR	Counsel for Scientific and Industrial Research
DAMCAL	Damage Reach Stage-Damage Calculations
DTM	Digital Terrain Model
EAD	Expected Annual Flood Damage Computation
FDA	Flood Damage Analyses
FHRC	University of Middlesex
GIS	Geographic Information System
HEC	Hydrologic Engineering Center
MAD	Mean Annual Damage
MAR	Mean Annual Rainfall
NED	National Economic Development
NFIP	National Flood Insurance Program
RMF	Regional Maximum Flood
RSA	The Republic of South Africa
SRK	Steffen, Roberts and Kirsten
TEWA	a computer model for Tangible Economical flood Water damage Assessment
UOFS	University of the Orange Free State
USA	United States of America

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 Upington 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.

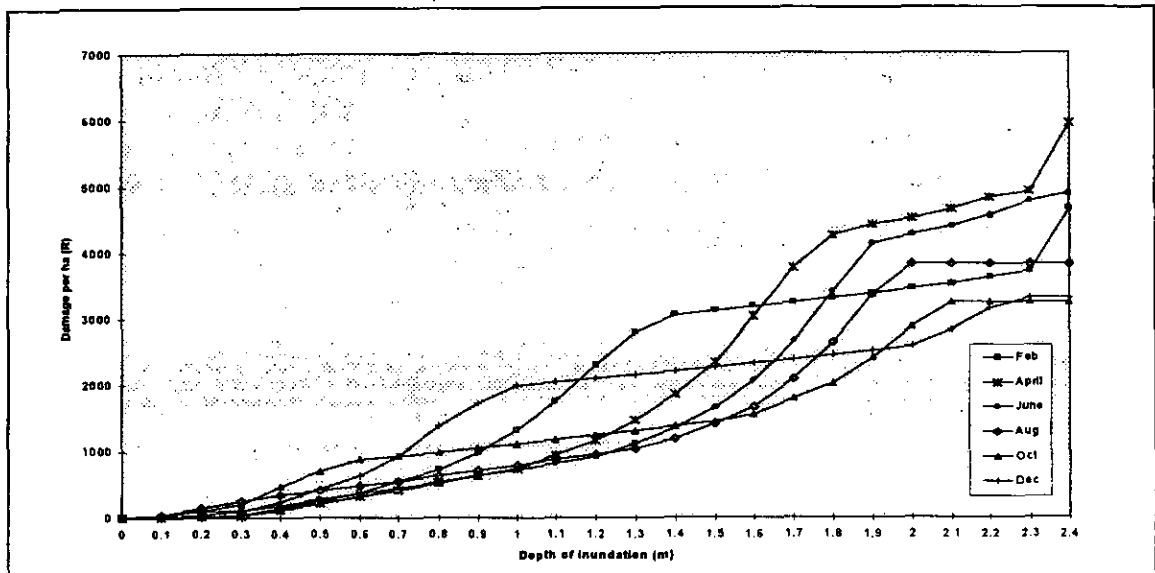


Figure 1: Loss functions to determine damage to the harvest of sugarcane in the Mfolozi floodplain, 1995

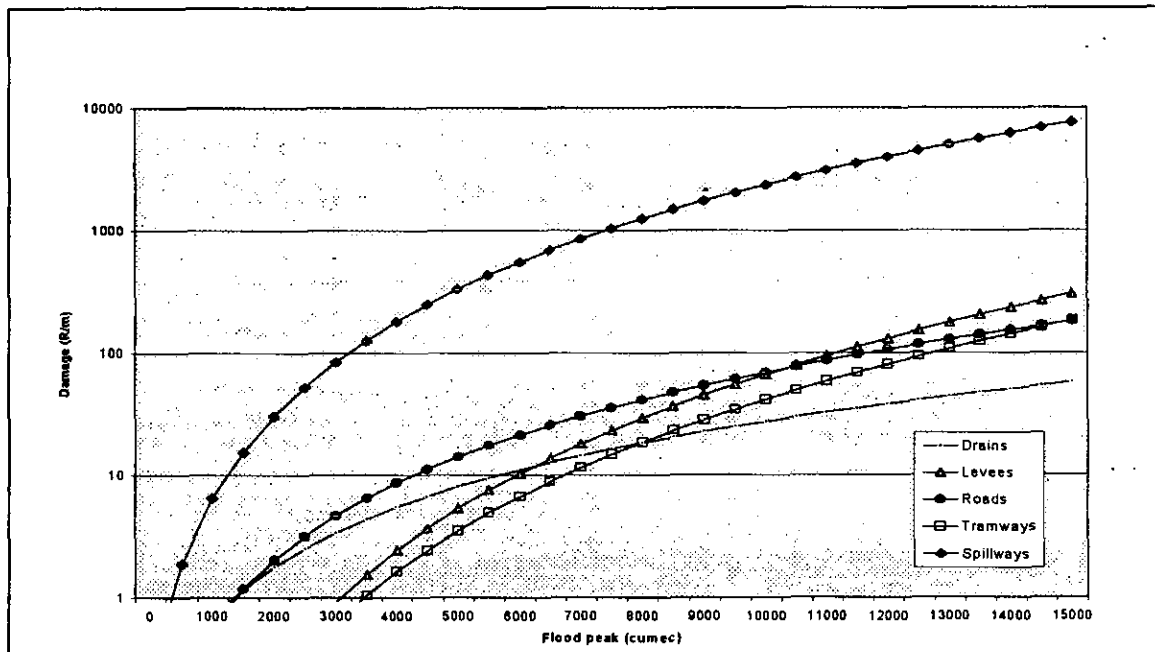
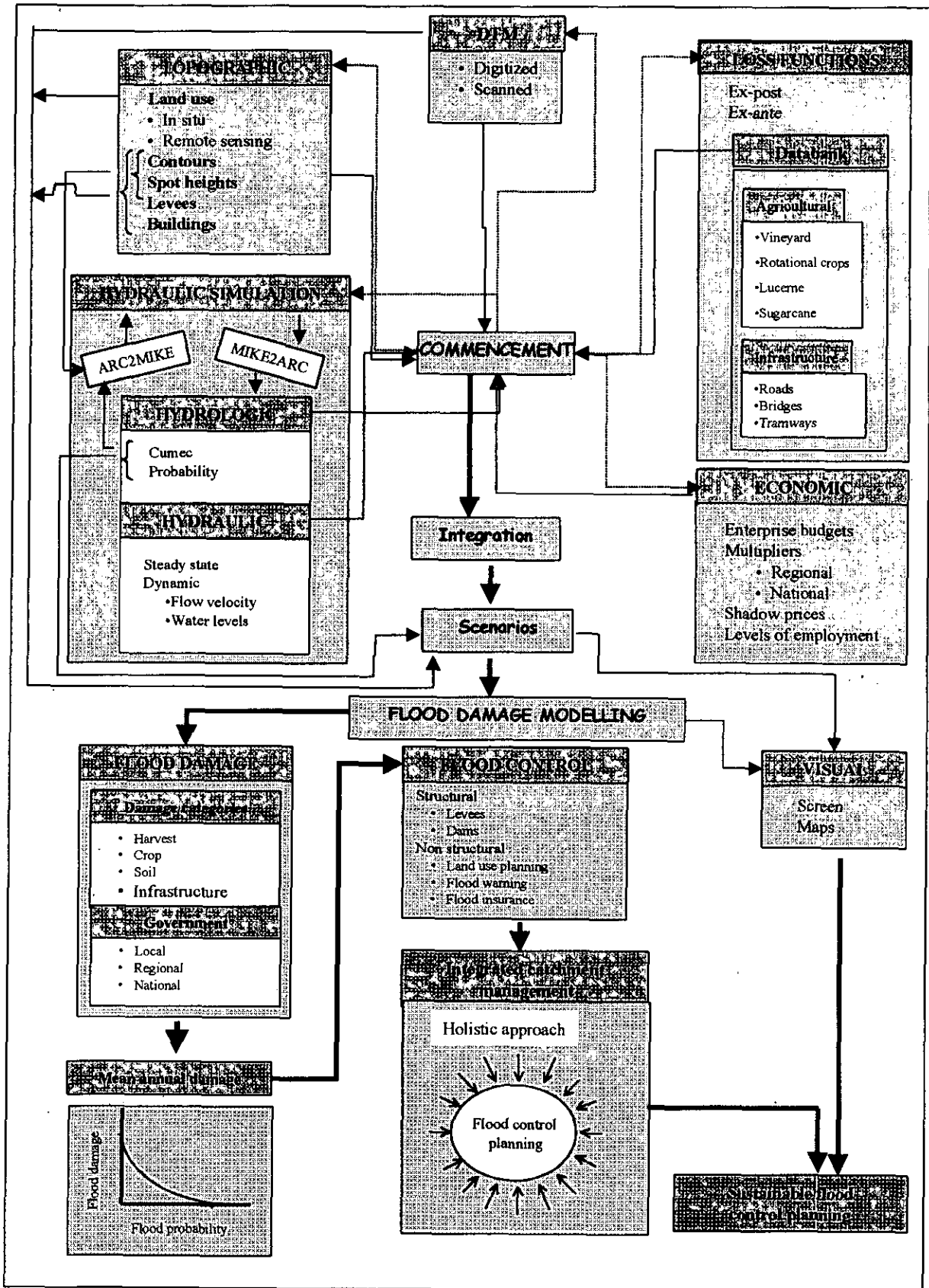


Figure 2: Stage damage curves (1995 values) for different infrastructure categories in the Mfolozi floodplain

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

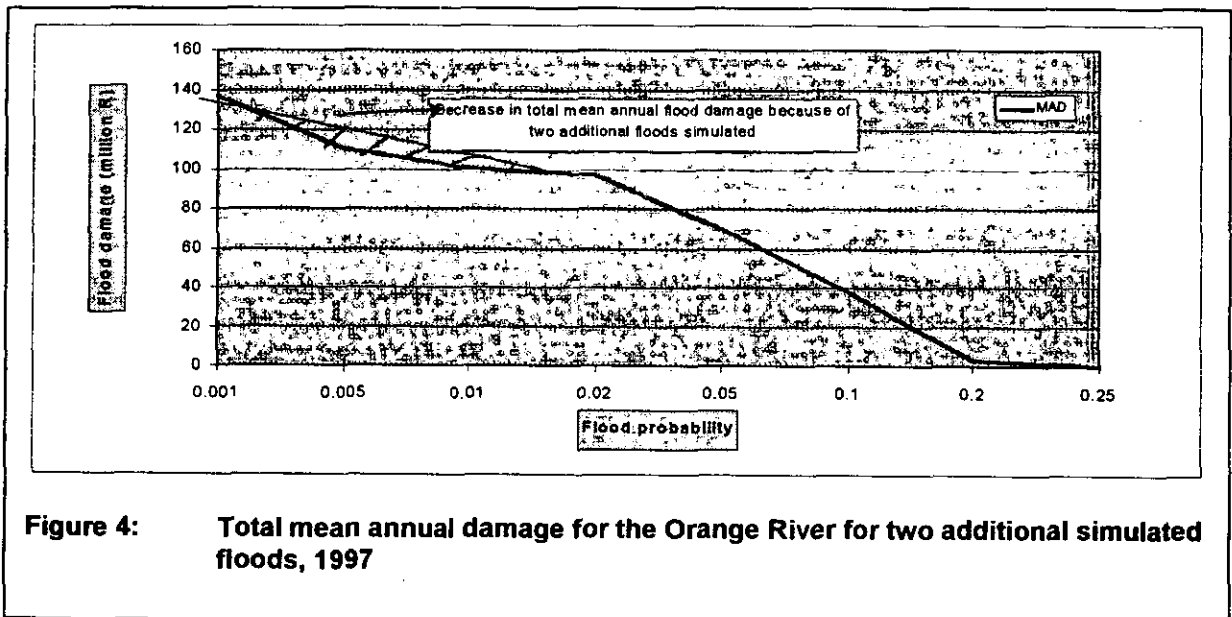


Figure 4: Total mean annual damage for the Orange River for two additional simulated floods, 1997

- 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.

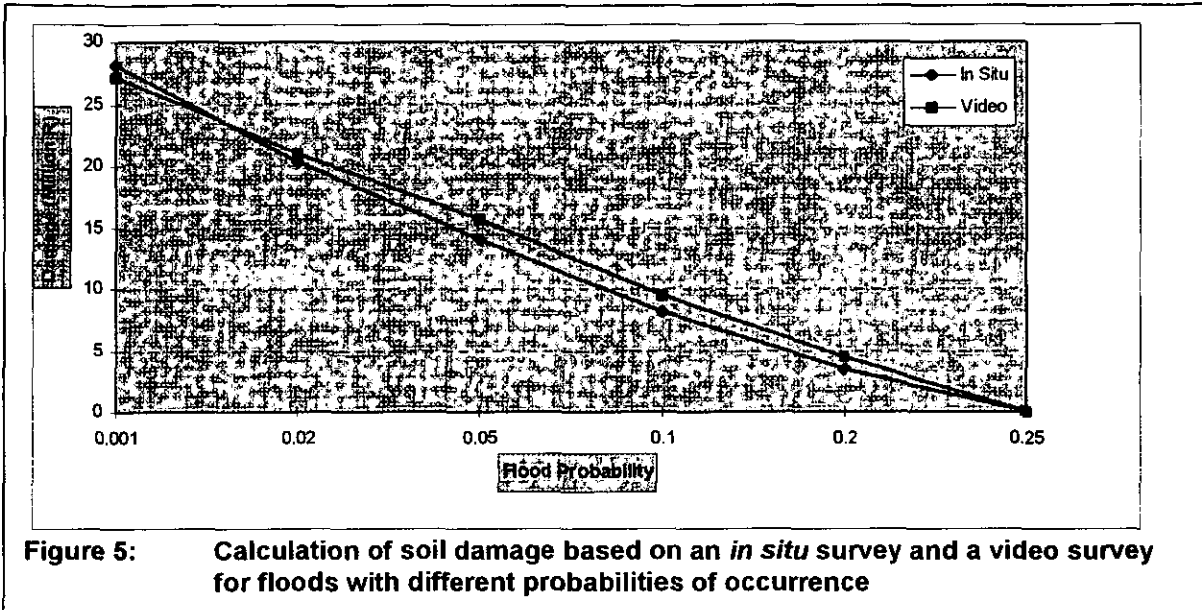


Figure 5: Calculation of soil damage based on an *in situ* survey and a video survey for floods with different probabilities of occurrence

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.

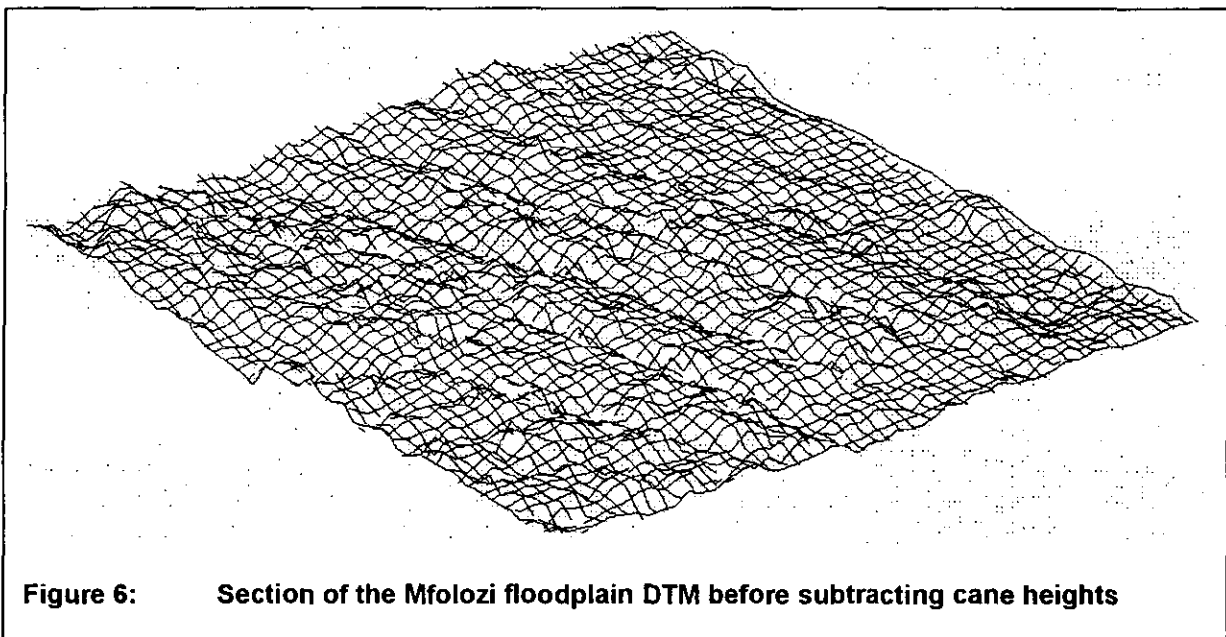
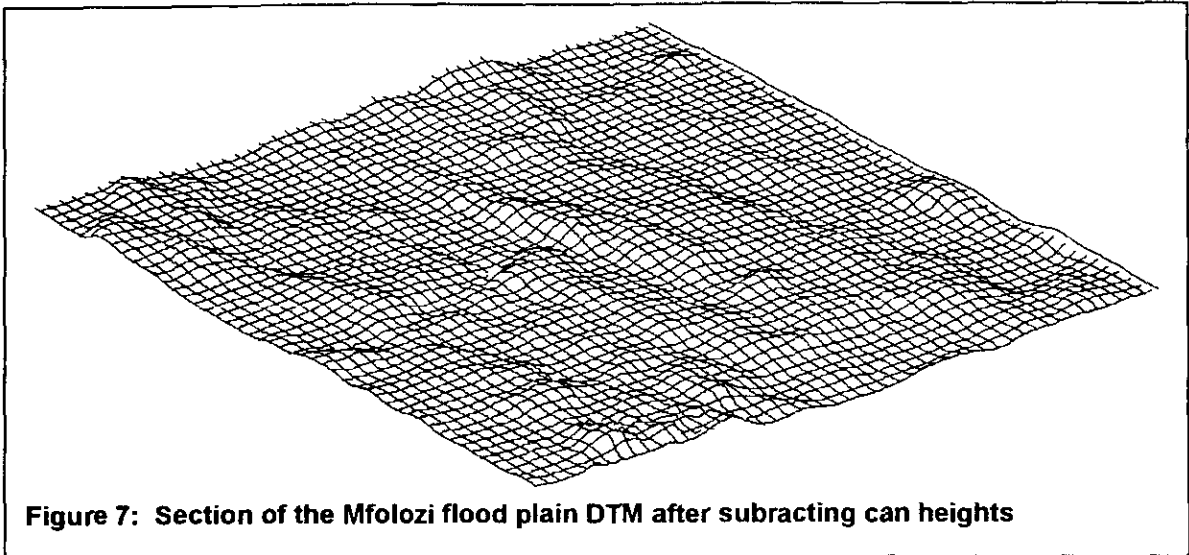


Figure 6: Section of the Mfolozi floodplain DTM before subtracting cane heights



- ☛ 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 the 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.

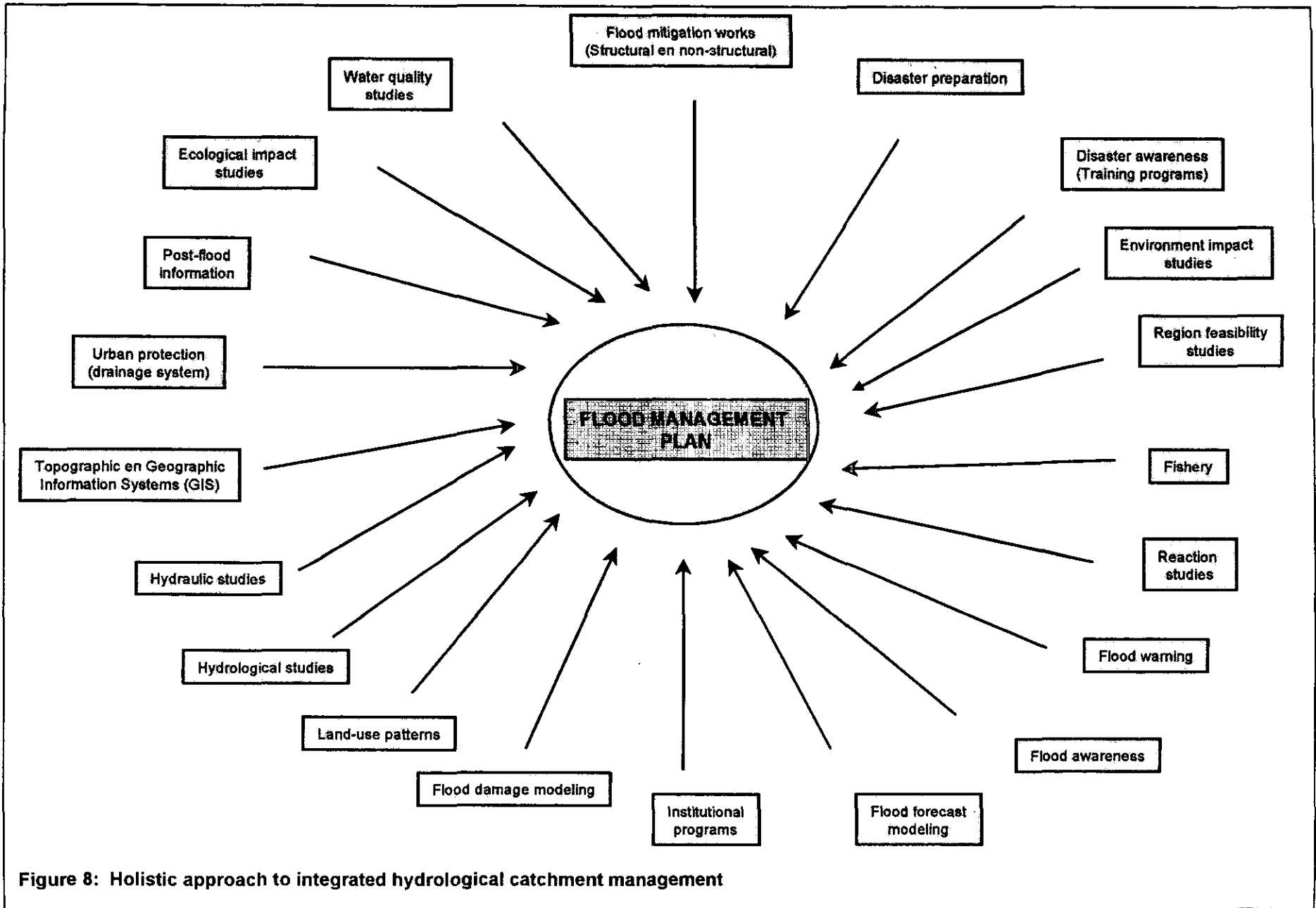


Figure 8: Holistic approach to integrated hydrological catchment management

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
Group 1	10 093	13 562	16 939	29 549	45 764	58 739	74 967	78 221	78 234	75 007
Group 2	4 783	8 212	11 554	24 050	40 179	53 169	69 734	73 309	73 746	71 044
Group 3	1 570	3 560	5 498	12 739	22 058	29 526	38 910	40 826	40 892	39 107
Group 4	187	1 775	3 324	9 150	16 768	23 041	31 554	33 793	34 688	34 238
Group 5	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
Group 1	Big luxurious houses
Group 2	Big - high economic class – houses
Group 3	Medium – high economic class – houses
Group 4	Medium/Big - medium economic class –houses
Group 5	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.

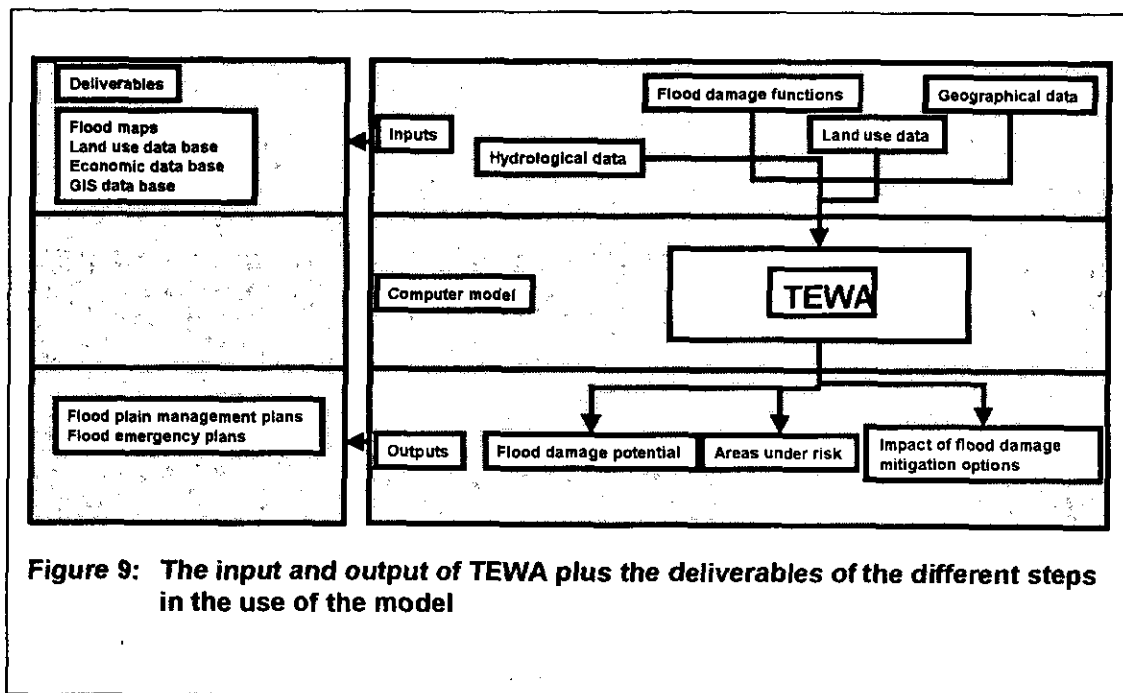


Figure 9: The input and output of TEWA plus the deliverables of the different steps in the use of the model

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

THEORETICAL AND METHODOLOGICAL FRAMEWORK

1.1 BACKGROUND AND MOTIVATION

Research in South Africa on the calculation of flood damage in urban areas started in 1975 by using the ex-post approach. With this approach the flood damage was calculated after a flood had occurred. Information was gathered with the help of questionnaires and interviews. The study areas were along the Orange and the Vaal Rivers. For these two areas, damage to both agricultural and urban sectors was calculated. Flood damage curves were also developed for different land uses.

During the late eighties and early nineties, the need arose to calculate damage according to the ex-ante approach. In 1993 researchers began to do research on *flood damage in the absence of a flood*. The *pro's and cons* of the ex-post and ex-ante approaches were discussed during the previous phase of the current research. The most important advantage of the ex-ante approach compared to the ex-post approach, was found to be the ability to gather information to evaluate flood damage mitigation options.

The ex-ante approach was used in two urban areas, Upington and Vereeniging. For the research an Australian computer program, Anuflood, was adapted to calculate flood damages for these regions. The adaptation included the development of flood damage curves, the drawing up of hydrological data and the collection of land use data. Flood damage curves were determined by using primary information that was gathered by means of questionnaires. Research reports from both England and Australia were also consulted. Measurement procedures for damage to different residential and commercial items were obtained from these reports. The firm of consultants, Chunnet, Fourie and Partners supplied hydrological data for the study

area. Together with this information, information from the Department of Water Affairs and Forestry was used to determine flood probabilities and flood lines.

1.2 PREVIOUS RESEARCH

During the previous phase (Booyesen, 1996), flood damage curves for the study areas were developed. Data was gathered by means of surveys. Firstly data concerning land use was gathered and the location of properties in towns determined by means of relative location as well as co-ordinates. Furthermore, information concerning the characteristics of properties was collected. Data regarding type of properties (residential or commercial), classification (socio-economic class/category of residential properties), address of property, elevation above sea level and the height of the building were gathered to form a database. This information, as well as hydrological data, is used in the model to calculate flood damage.

1.3 SHORTCOMINGS IN THE PROCESS

1.3.1 FLOOD DAMAGE CURVES

One of the shortcomings of existing research is that flood damage curves were developed for specific areas. This means that it is area specific and cannot be used with confidence in other areas. During the first phase flood damage curves were developed only for Upington and Vereeniging. The data set must be expanded to develop flood damage curves that can also be used in other areas in South Africa.

1.3.2 ANUFLOOD

The use of Anuflood in South Africa has two problems. The first is that Anuflood was developed in Australia. This has the consequence that little support can be given to possible users of the program. Anuflood is a text-based model, which means that maps cannot be produced. Therefore map information has to be produced as text.

New ideas and approaches cannot be tested with Anuflood. For example, this model cannot indicate the best site for an industry regarding flood damage. The possible impact on the environment can also not be tested by using Anuflood.

1.3.3 FLOOD DAMAGE MITIGATION OPTIONS

The former research came to a stop with the evaluation of some flood damage mitigation options. This was not taken further because a combination of measures could not be identified. Evaluation was also not proceeded by plans.

1.4 AIMS OF THE PROJECT

With the above information as background, the aims of the new project are to address shortcomings of the former research.

Main objective

The main objective of the project is the development and adaptation of flood damage functions, -models and -computer programs for agricultural and urban areas in South Africa.

Specific objectives

Objective 1

The development of flood damage curves for a few alternative land uses within flood plains in urban areas.

Objective 2

The further development of flood damage models and computer programs to be more generally applicable in urban areas. Beside the utilisation of new technology like remote sensing, the models will be adapted for three levels of decision-making (local, regional and national) and they will fall into line with the revised national flood-management policy. The drawing up and adjustment of guidelines (if necessary) to make the policy feasible on all three levels, will also receive attention.

Objective 3

The testing, validation and verifying of models and computer programs in terms of selected areas.

Objective 4

The presentation of workshops and seminars to demonstrate the application of flood damage curves, -models and -computer programs and to foster technology-transfer.

1.5 STUDY AREA

To achieve the objectives as set out above, the Despatch and Uitenhage municipal areas and Soweto-on-Sea were chosen to be the study area. These three areas are situated in the Eastern Cape. In Figure 1.1, an orientation map, the location of the study area in South Africa is shown. The fact that the land use composition of this district is prone to flooding makes it a well-chosen study area. Land uses vary from large industrial plants to informal settlements. In Despatch mainly formal residential and commercial areas are found, while Uitenhage is (beside the residential sections) also an industrial area. These two areas are situated along the Swartkops River. Soweto-on-Sea is an informal settlement along the Chatty River. In Chapter 2 these study areas will be discussed in more detail.

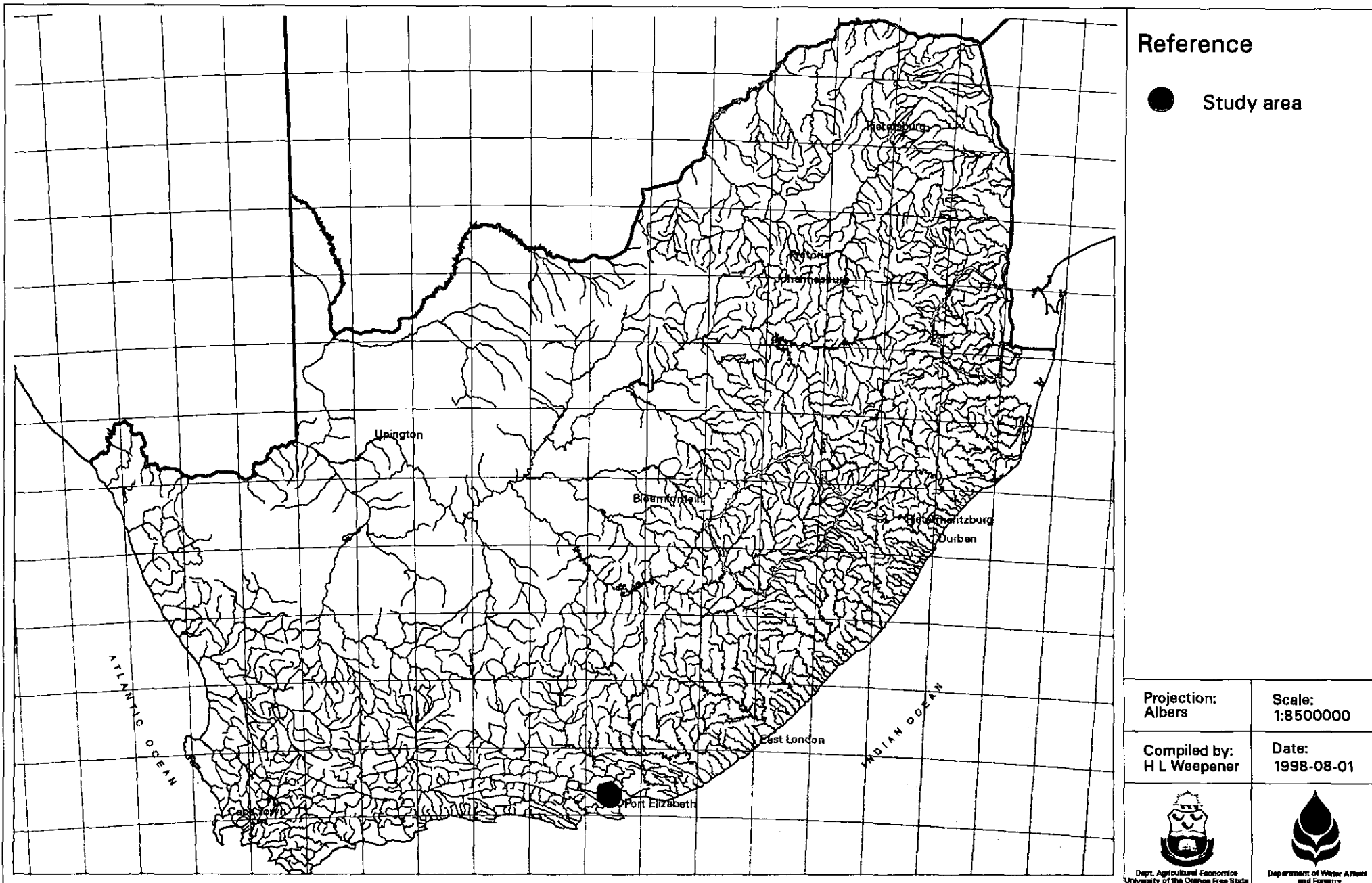


Figure 1.1: Orientation map of the study area

1.6 SUMMARY OF RESEARCH PROCEDURE

The research procedure is discussed with the objectives in mind, as set out earlier in this chapter. For each objective, the following aspects will be studied; relevant literature, phases of investigation, gathering and processing of data.

Objective 1

The development of flood damage curves for a few alternative land uses within the flood plains of urban areas.

For the development of flood damage curves, a literature study was undertaken during the former phase of the research (Booyesen, 1996). This literature study was continued during the present research. Old sources were re-evaluated, new literature was investigated continuously. After the literature study, the questionnaires that were used during the first phase were adapted. Before the survey was done, pilot visits to the three areas were made. People like city engineers and disaster managers who are concerned with floods in the area, were consulted and surveys were planned.

During the survey inhabitants of the study area completed questionnaires. Students were used to gather the information. A new aspect that received attention in this research was the development of flood damage curves for informal settlements. People of the local communities collected information for the survey. They were trained during one of the pilot visits to the area, and the questionnaires were supplied for the survey.

The collected data was processed with the aid of a computer. Firstly, a spreadsheet was used to develop 'n flood damage curve per unit (residential, commercial and industrial). After the units (except for the industrial land use) had been categorised, a regression-analysis was applied on the values of the different damage curves to obtain a flood damage function per category. As was mentioned in the former research (Booyesen, 1996), industries are not grouped into categories because of the large differences that exist between industries.

Objective 2

The further development of flood damage models and computer programs is to make them more generally applicable for urban areas. Beside the usage of new technology like remote sensing, the models will be adapted for the three levels of decision-making, namely local, regional and national, and put into line with the revised national flood management policy. The compilation and adaptation of guidelines (if necessary) to make the policy feasible will also receive attention.

ANUFLOOD, a computer model that was developed in Australia by the Australian National University, was used during the former research (Booyesen, 1996) to calculate the flood damage for two study areas: Upington and Vereeniging. A choice had to be made on the further development of Anuflood, or the development of a totally new model. As will be mentioned in later chapters, it was decided to develop a Geographic Information System (GIS) support model. The model TEWA (a computer model for Tangible Economical flood Water damage assessment) was developed. For the development of the model the experience, gained during the adaptation of Anuflood for South African conditions, was utilised. For the type of data required for the calculation of flood damage, ANUFLOOD's method of collecting input-data was exploited.

TEWA requires land use-data, hydraulic data and flood damage curves as input. Since TEWA is GIS-based, a fourth set of data was added. Graphic data was either digitised or obtained from a co-operative. The municipality of Uitenhage supplied digital charts, while charts for Despatch and Soweto-on-Sea had to be digitised. The data was linked in the model in order to do calculations.

The model was also developed in such a way that people from different sectors (from the government to the private sector) could make use of it. Industries in the Uitenhage flood plain can, for example, use the model to compile the optimal package of flood damage mitigation options for their plants. The municipality can, for example,

use the model to determine the effect of a new development in the flood plain on the potential for damage.

Objective 3

Testing, validating and verifying of models and computer programs for selected areas.

Die main objective of the research is to develop a model that can be used in urban areas of South Africa. This is the aim of Objective 3. A further aim of the study is to point out the influences of possible flood management scenarios. The study area that was selected for this purpose was the Despatch and Uitenhage municipal areas as well as Soweto-on-Sea. The first two regions are located along the Swartkops River and Soweto-on-Sea along the Chatty River.

The model was compiled to research different sectors in the area. Formal and informal residential, commercial and industrial functions land use were investigated. Several scenarios were also evaluated. Damage without as well as damage with mitigation were investigated.

Research on historical flood damage in the study area has not yet been done, therefore mathematical methods were used to validate and verify the model.

Objective 4

Presentation of workshops and seminars to demonstrate the application of flood damage functions, -models and -computer programs and to propagate technology-transfer.

Objective 4 is not discussed in the report, but during the course of the project seminars on the research were presented. One such presentation was done during the Emergency Disaster congress in Kroonstad. During the next phase of the research further presentations in the specific study areas will be held.

1.7 COMPOSITION OF THE REPORT

The composition of the report is shown in Figure 1.2. In Chapter 1, a theoretical and methodological framework for the report is given. Previous research is discussed, and shortcomings are identified upon which the new project's objectives will be based. Theory underlying the research is discussed separately in each chapter that deals with a specific subject. In Chapter 2 the study area is discussed more extensively. Land use, hydraulic, topographic and former flood experience is discussed in that chapter. Maps are used to depict specific characteristics of the area. A discussion on the development of flood damage curves follows in Chapter 3. Flood damage curves are developed for residential, commercial and industrial sections. What makes the exposition of this research different from the former research reports, is that an attempt was made to develop flood damage curves which can be applied on a national level.

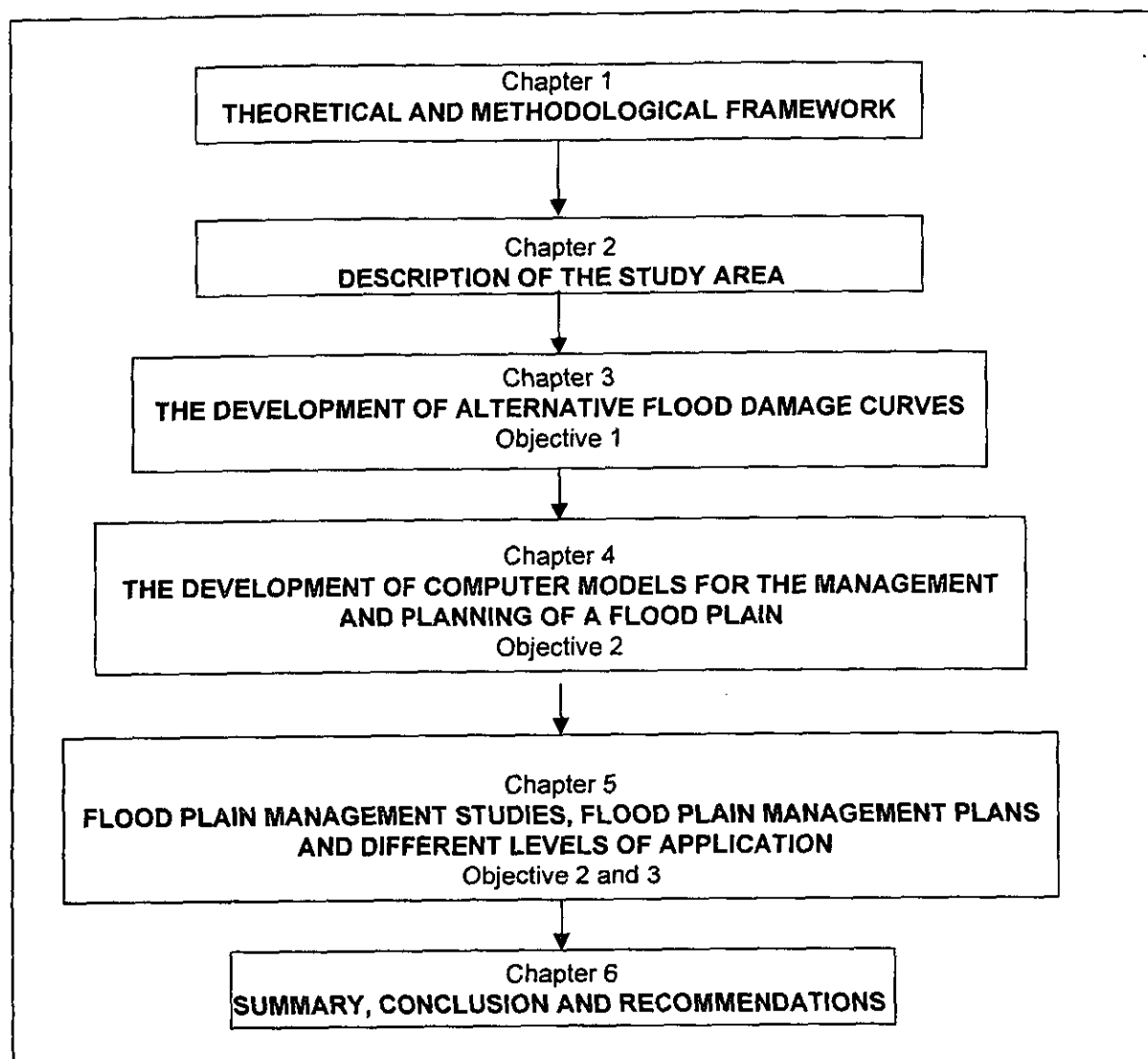


Figure 1.2 The composition of the report

As was mentioned in former research reports, standard flood damage curves were not developed for industrial properties. The same approach is followed here as was suggested by Smith in 1993. The method he uses is to visit each industry in a flood plain and to ask management to complete a questionnaire. In Chapter 4 the model that is used in the study, is discussed. The chapter starts by briefly evaluating Anuflood, which was used during the former research. After the shortcomings of Anuflood were discussed, TEWA was developed. TEWA is evaluated at the end of the chapter by calculating the damage potential for the whole study area. The damage value is verified by means of a mathematical method.

Flood level management-plans are discussed in Chapter 5. In this chapter the application of possible plans are discussed and the results fully described. The research report is concluded with Chapter 6 by a summary of the research. In this summary some conclusions are made. This chapter ends with some recommendations for the use of the results of this study and proposals for further research.

CHAPTER 2**DESCRIPTION OF THE STUDY AREA****2.1 INTRODUCTION**

In this chapter the reader will be acquainted with the study area. A description of land use, floods, flood characteristics, flood damage prevention measures, soil characteristics, etc. will be given for the different study areas. The study is taking place in three areas in the Eastern Cape. Two of the areas are along the Swartkops River. In these areas the accent falls on formal residential, commercial and industrial activities. The other area is situated along the Chatty River and is known as Soweto-on-Sea. Only informal housing is found in this area.

2.2 TOPOGRAPHIC CHARACTERISTICS OF THE SWARTKOPS RIVER AREA

Figure 2.1 shows the study area that stretches from the Nivens Bridge at Uitenhage. The land use include residential, commercial and industrial areas. In Uitenhage it is mainly residential and industrial, including well-known Volkswagen and Good Year industrial plants. The Despatch area is mainly residential and commercial. Figure A.1 shows that in Despatch it is mainly the most residential and commercial properties that are effected by floods. Figure A.2 shows the Industrial, commercial and residential properties in Uitenhage that are effected by floods of different magnitudes.

2.2.1 OCCURRENCE AND NATURE OF FLOODS

The Swartkops River area is prone to flooding. The river flows through the Kruis River area, residential, commercial and industrial sites. One of the potential dangers is that

the Kruis River area, which provides the largest volume of fresh vegetables for the local market, may be cut off from Uitenhage.

The following excerpt of the Swartkops River's flood history is from a report of Uitenhage's emergency-plan documentation:

1888 Whirling floodwater from Cuyler Street up to the wool-washer.

1893 Offices at the Bagshaw Giboud under water.

1912 Easter week-end. One house flooded, 2 houses at Cuyler Manor cut off, wool-washery swept away by flood waters, Despatch under water, Swartkops River plus minus 600m wide at Nivens Drift.

1917 June. Floods swept huts, shacks and animals away.

1922 Details not available.

1931 October. Old traffic route to Port Elizabeth cut off.

1932 January. Flood damage and disruption large in the Gamtoos.

1934 July. Nivens Drift and De Mist Bridge under water.

1951 January. Floods isolate Uitenhage from nearby farms and cities.

1968 September. Uitenhage cut off from outside world.

1971 August. Railway bridge at Despatch was damaged. Volkswagen under water. Swartkops reach its highest level in 18 years.

1978 Fire Brigade had to pump water out of Bosal.

1981 March. One factory inundated with water.

1983 Flash flood. Elands River and the Swartkops River came down simultaneously.

1988 The railway bridge on the section between Uitenhage and Glenconner swept away.

1996 More than 20 farms at Uitenhage cut off by rising water in the Kruis River.

Especially since 1965 attempts have been made to remove gravel and sand which impair the flow of the river. The riverbed has consequently been deepened and this, in combination with the strengthening of the wall of the Groendal Dam, will significantly lower the probability of floods.

2.2.2 FLOOD LINES

A firm of consultants, Steffen, Robertson and Kirsten (SRK), provided hydrological data for the project. Topocadastral information was gathered by SRK from different organizations. In the report of SRK these organizations are mentioned.

2.2.3 FLOOD PEAKS

Because the catchment area is so large, SRK used HDYPO1 and Kovac's models. The flood peaks in Table 2.1 were developed through the use of these models and were compared with those created by the CSIR.

Table 2.1 Flood frequency and flow in cubic metres per second for the Despatch and Uitenhage area according to different models

	Occurrence intervals (years)/ Flow (m ³ /s)					
	5	10	20	50	100	RMF
HDYP01	857	979	1345	1615	1868	8116
Concentric diagram of HRU 1/72	360	570	810	1350	1600	
Kovac's				2361	2937	5220
CSIR					1854	
Adjusted	400	600	800	1600	1850	5500

Source: Fitzpatrick *et al.* (1996)

2.2.4 METEOROLOGICAL DATA

The catchment of the study area stretches from Despatch in the east in a northwesterly direction for 60 km. It is confined to the Great Winterhoek Mountains in the north and the Elands Mountains in the south. The total area of the catchment is 1 120 km².

The mean annual rainfall (MAR) in the area varies between 250 mm and 830 mm. For the calculation of the MAR for the whole region, information about the spatial distribution of the rainfall of the region is necessary. An isohite map was used. Where an area was joined with isohite lines, it is accepted that the line represents the rainfall. For areas between two lines, the average of the two lines was taken as the rainfall. By using this method, 551 mm was calculated as the MAR. Flood peaks and levels were calculated by the consultants through the use of models.

In Figure 2.1 the positions of the different cross sections are indicated and Table 2.2 show the cross sections with different levels for different sized of floods. The cross sections and the 1:100 year flood and the regional maximum floods of Uitenhage and Despatch are indicated in Figure 2.2

Table 2.2 Hydrological information for the study area, Uitenhage and Despatch

Distance from the Swartkops River mouth (m)	Location of the cross sections	Flood elevation (m above sea level) for various flood frequency in years					
		1:5	1:10	1:20	1:50	1:100	SMV
21220		14.2	14.7	15.3	16.7	16.6	20.2
21960		16.5	16.8	17.1	18.1	18.3	20.6
22402		17.4	17.8	18.1	18.6	18.8	20.7
22990		18,7	19,7	20,0	20,5	20,7	21,5
23650		20.2	20.9	21.2	22.7	22.9	24.7
24350	Train bridge	21,8	22,2	22,6	24,1	24,3	27,9
24680		22.2	22.6	23.0	24.4	24.6	28.0
25440		22,2	22,6	23,0	24,4	24,6	28,0
26370		25.2	25.4	25.7	26.4	26.6	28.4
26500	Bridge at R75	26,0	26,3	26,6	27,7	28,0	29,7
27110	Frans Claasen bridge	30,2	30,4	30,5	31,0	31,1	32,3
27390		31.1	31.1	31.5	31.9	32.0	34.4
28890	Bridge	31,1	31,4	31,7	32,6	32,9	37,1
28910		31.1	31.4	31.7	32.6	32.9	37.1
29900		32,8	33,2	33,6	34,7	35,0	37,7
31080		36.1	36.3	36.6	37.6	37.8	40.2
31830	Niven's bridge	37,8	38,1	38,3	39,5	39,8	42,3
31870		37.8	38.1	38.4	39.5	39.8	42.4
32710		41.0	41.3	41.6	42.1	42.2	44.6

2.2.5 FLOOD DAMAGE CONTROL MEASURES

In the study area, the current flood damage control measures depend on the type of land use. Precautions vary from no measures at all by individual house owners, to flood-insurance of thousands of Rands by industries. No precautions are also being taken by commercial institutions in Despatch. The councils of Despatch and Uitenhage however have flood emergency plans at hand.

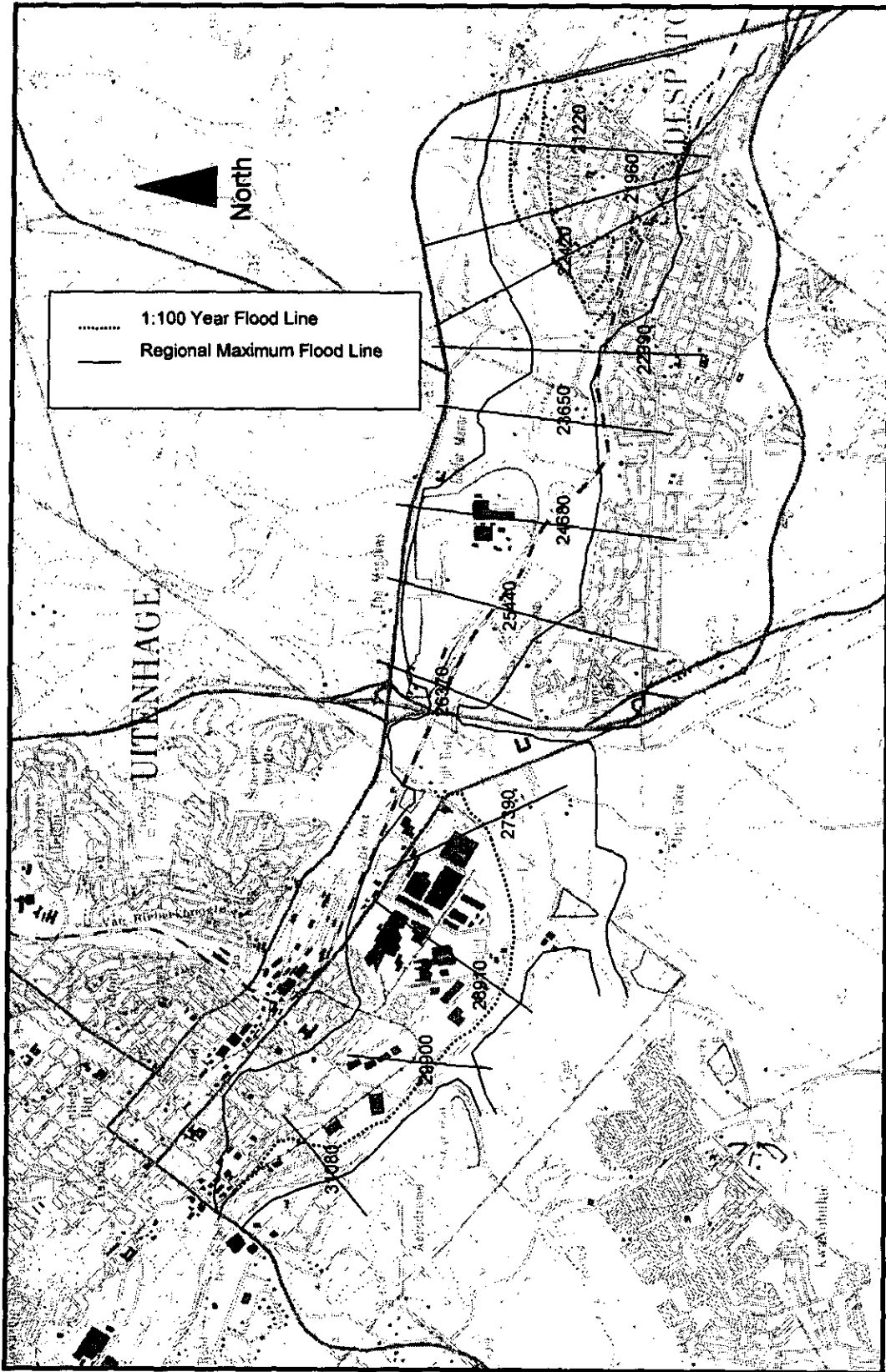


Figure 2.1 Uitenhage and Despatch with the cross sections used in the research

2.3 TOPOGRAPHIC CHARACTERISTICS OF THE CHATTY RIVER

The Chatty River originates in the Groenbosse-area of Port Elizabeth. Urban settlements in the catchment area are Booysen Park, Bethelsdorp, Kleinskool, KwaDwesi, KwaMagxaki, Zwide and Soweto-on-Sea. According to Mackay *et al.* (1994) there stayed plus-minus 80 000 people in approximately 15 000 squatters' shacks in Soweto-on-Sea during 1994. Many of them were unemployed and had no transport. Minimal services were being provided at that time: roads were not kept up, only 200 taps served the whole community, sewerage-removal consisted of weekly removal of buckets and no facilities for garbage-removal existed.

Because Soweto-on-Sea has initially developed with little control, 3 000 of the shacks were built under the 1:50 year flood-line of the Chatty River. This has the implication that 16 000 people are subject to flood danger.

2.3.1 FLOOD LINES

The basic characteristics of the catchment-area at the R75 and Swartkops/Redhouse road are given in Table 2.3. Van Bladeren (1997) compiled this table.

Table 2.3 Characteristics of the Chatty River catchment-area

Parameter	R75	Redhouse/ Swartkops road
Catchment area(km ²)	106	126
Slope (%)	2,8	2,8
Urban present (%)	16	29
Future (%)	65	71
Stream length (km)	19	27

Van Bladeren (1997) used the HEC-RAS package to determine the flood-lines. This package is a two dimensional, static flood-modeling program. Estimated flood-levels for different flood frequencies are presented in the SRK-report. Table 2.4 is a

summary of this delineation. For reference purposes, Figure 2.3 gives the position of some of the cross sections.

Table 2.4 Estimated elevation (metre above sea level) for different sized floods for the Chatty River

Cross section	Elevation (metre above sea level) for different flood frequencies (years)							
	1:2	1:5	1:10	1:20	1:50	1:100	1:200	SMV
590	9.6	10.1	10.5	10.8	11.2	11.5	11.7	12.1
790	9.3	9.5	9.6	9.7	9.8	10.0	10.1	10.5
970	8.9	9.1	9.2	9.2	9.2	9.4	9.5	10.4
1565	6.8	7.4	7.7	8.0	8.4	8.8	9.1	10.1
4900	4.8	4.9	5.0	5.1	5.2	5.3	5.3	5.5

2.3.2 WATER AND SOIL CHARACTERISTICS

The catchment of the Chatty River is relatively small. Consequently the Chatty has an intermittent flow with an average of $0,05\text{m}^3/\text{s}$ at the Redhouse Road. The salinity of the river varies from 10 to 14 parts per thousand. Due to the Faecal bacterium and mineral pollution the quality of the water is very low. According to Mackay *et al.* (1994), the Department of Agriculture, undertook a survey of soil types in the flood-plain of the Chatty River. The findings are discussed comprehensively in their report. The main features are the following:

- the subsoil has a high clay content which restricts drainage,
- the water table is very near the soil surface,
- the topsoil is sandy and erosion by wind can be very high and
- in many areas the topsoil has been spoilt by construction and/or the dumping of construction materials.

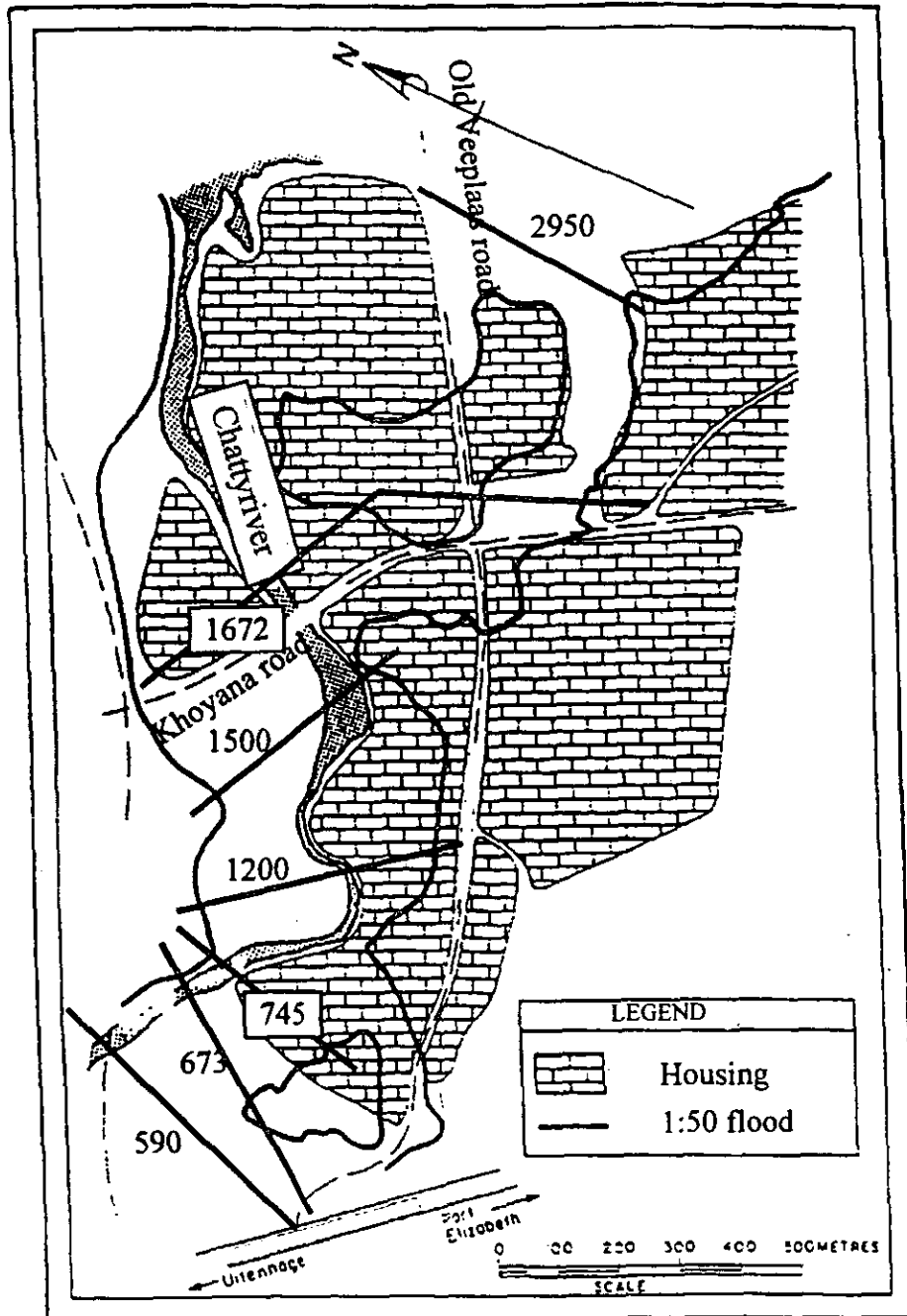


Figure 2.2 Soweto-on-sea with existing housing and the 1:50 year flood line

Source: Mackay et al. (1994)

2.3.3 LAND USE

The current land use pattern is depicted in Figure 2.3. It is mainly residential. Other land uses which occur but which are not indicated, include schools and recreational facilities.

2.3.4 FLOOD DAMAGE MITIGATION OPTIONS

MacKay *et al.* (1994) depicts land use-management as a suitable flood damage control measure for the Soweto-on-Sea area. Five land uses: schools, sports grounds, pastures, vegetable cultivation, swamps and the possibility of fish farming were investigated.

Schools

There is an urgent need for both primary and secondary schools. Locations have been identified where minimal filling is necessary to lift the school grounds above the 1:50 year flood level.

Sports grounds and recreation

Sports grounds are seen as appropriate use of flood plains. This lowers the potentials for damage and recreational facilities can also be of benefit to a large part of the community. The sports grounds also serve as a buffer between the river and the inhabited area and this can lower pollution levels.

Cultivation of vegetables

There is potential for the cultivation of vegetables, but it is restricted by the high salt content of the soil. Another aspect that should be born in mind concerning this, is the cost of irrigation that might vary between R3 000 and R5 000 per hectare. Protection

of the vegetables can also create a problem, because of theft and destruction by straying farm animals.

Grazing

Under normal conditions, the carrying capacity of the flood plains is one head of large stock or six head of small stock per 10 hectare. If this stocking rate were exceeded, it is likely that the area would quickly become over grazed, leading to soil erosion and loss of any ability of the land to sustain stock.

Swamp surfaces

The main reason for this kind of land use is to prevent other development. It supplies a storage capacity for water, a habitat for fish and an attractive urban area.

Although schools and sports grounds are the options with the highest benefits, all five options are feasible.

2.4 SUMMARY AND CONCLUSIONS

The study area is extremely suitable for flood damage research. The diversity of the land use is of such a nature that a complete survey, which covers the whole spectrum of land use, can be undertaken. The land use vary from informal settling, formal residential, commercial to industrial activities. From Paragraph 2.2.1 it is obvious that floods periodically pose problems for the area. A positive aspect is however that the inhabitants (from industrialists to squatters) are involved in attempts to lower their territory's potential for flood damages.

The hydrological information that has been obtained from the consultants is of high quality and can be used in the research. Flood lines are indicated on charts with accompanying tables that show the elevations for different sized floods.

CHAPTER 3

DEVELOPMENT OF FLOOD DAMAGE FUNCTIONS FOR ALTERNATIVE URBAN LAND USES

3.1 INTRODUCTION

During the previous research phase, area-specific flood damage functions were developed. Examples of these are the flood damage functions that were drawn up for Uppington and Vereeniging. There is, however, a need for more general applicable flood damage functions to be available for flood plain management throughout the country. The aim of this chapter is therefore to develop flood damage functions for alternative urban land uses that will be generally applicable on a national level.

Flood damage functions describe the relationship between flood characteristics like depth of inundation, velocity of floodwater, duration of flood and damage done. Flood characteristics affect different land uses differently. For residential areas, for example, the depth of the inundation is the more determining flood characteristic for the development up of flood damage functions, while the duration of a flood is the determining one for certain agricultural land uses (e.g. sugarcane). Figure 3.1 is a schematic presentation of a flood damage function.

Flood damage functions are the pillars upon which flood damage research were built over the past few years. White (1961) was one of the first researches to use the concept of flood damage functions. From then on this concept was used and applied world-wide. Penning-Rowse *et al.* (1977) in England, Viljoen *et al.* (1978) in South Africa, Smith *et al.* (1993) in Australia and the American Corps of Engineers in the USA are of the most important researchers to whom this

research relates. Flood damage functions are mainly used for the determination of flood damages and the evaluation of flood damage mitigation options.

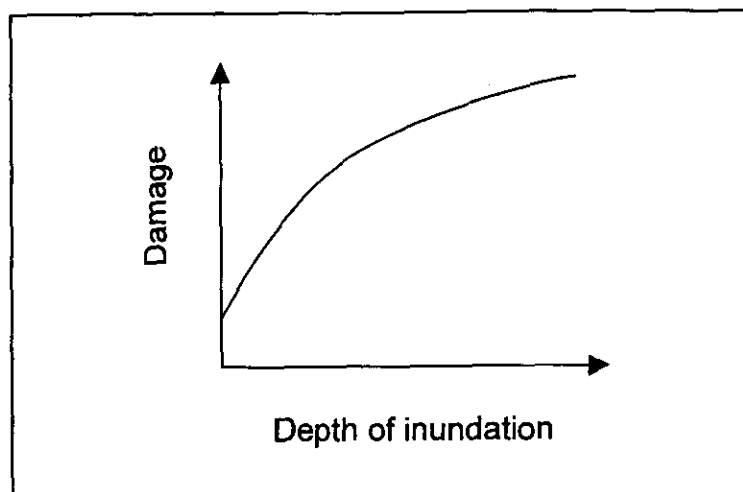


Figure 3.1 Example of standard depth/damage data (damage curves)

3.2 PROCEDURE TO DEVELOP FLOOD DAMAGE FUNCTIONS (GENERAL)

According to Parker *et al.* (1987) and Penning-Rowsell and Chatterton (1977) (as quoted by Booyesen, 1996), land use, characteristics of flood water and actions to limit flooding are the most important factors that have an influence on flood damage. Homan and Waybur (1960) regard depth and duration of floods, velocity of the water, sediment content, type and value of properties and flood precautions as the most important factors that determine the extent of flood damage. After research into these factors, it was found that depth-damage-relationships are statistically the most significant. The values of the structures and the contents are also very important. Vos (1982) sees depth of inundation as the most important independent variable that figures in the models he uses. McBean *et al.* (1988) also concludes that although time of year of flooding, velocity of flood waters, duration of flooding, sediment load and warning may be relevant to flood damage, most historical assessment procedures have focused on only one explanatory variable, depth of inundation. "Add on" or percentage factors have accomplished the incorporation of the other factors. McBean's conclusions was that for longer

duration floods (greater than 24 hours) the total damages should be increased by 6 percent and potential explanatory variables including flood area, exposure to previous flooding, family income, etc., did not explain significant percentage of potential flood damage with reliability.

From the above it can be concluded that the two most important independent variables in the assessment of flood damage and the drawing up of flood damage functions, are depth of inundation and the value of the property and improvements.

3.2.1 DEVELOPMENT OF FLOOD DAMAGE FUNCTIONS

For the development of flood functions, two approaches can be used. The one is based on projected damage and the other on historical damage. The first is a synthetic approach where the damage is projected by using different flood characteristics like depth and duration of floods. The second approach is to develop damage functions from information on actual flood damage.

For the application of the synthetic approach, it must be decided which types of damage to include and which not. Furthermore, a choice has to be made between depth/damage or depth/percentage approaches. With the depth/damage ratio damage is indicated in terms of money value, and with depth/percentage as a percentage of a value, for example the value of property or stocks.

The depth/percentage as well as the depth/damage ratio's were researched for this report. A few questions arose, especially with regard to the residential sector i.e. should the market value or the municipal value be used to determine the value of property? According to people who have knowledge of the residential market, there is a large variation in the prices of houses throughout the country. For example, this variation can cause that a 10 percent damage on a house in a specific part of the country, would not necessarily be the same as a 10 percent damage to a house of exactly the same category in another part of the country. To solve this problem, Smith (1993) used the depth/damage approach. He

identified categories by using the front views of houses [Booyesen (1996) in South Africa also used this method]. Depth/damage functions were drawn up for each category. In successive research (Despatch and Uitenhage) it was found that this approach can be applied successfully, and it was decided to use the depth/damage approach in the research.

3.3 PROBLEMS IN CONSTRUCTING STAGE DAMAGE FUNCTIONS

When flood damage functions are developed it is necessary to know the difficulties and problems involved. Smith (1994) identified five problems in constructing stage damage functions:

- what to include,
- what values should be allocated to items,
- how many building types should be used,
- scatter and error and
- interpolation and extrapolation.

What to include?

The important items that Smith (1994) excluded were vehicles and boats because they can be moved out of danger. McBean *et al.* (1988) also uses this approach. The most difficult category is the cost of clean-up. It is usual to incorporate it into overall stage damage functions for residential properties.

What values should be allocated to items?

The normal methodology is to use the concept of average remaining value. For convenience, flood damage surveys often assume that the average remaining value is 50 percent of a comparable new item.

How many building types?

There is no clear-cut answer (Smith, 1994); the number depends on time available and the variations in the area under study.

Scatter and error

Direct flood damage for individual properties differs markedly even when they are in a single class. It is clear that published stage damage functions involved considerable smoothing of the raw data, i.e. the scatter is large (Smith, 1994).

Interpolation and extrapolation

Having estimated the loss for a series of heights there remain the problem of interpolating between the data points. There is no correct solution to this dilemma (Smith, 1994). Common practice is to join the damage points with straight lines. Extrapolation is also problematic. The usual procedure is to extrapolate the data following the pattern of synthetic stage damage functions.

After he stated the problems Smith (1994) also made some recommendations for South Africa for the development of flood damage functions.

1. The need to develop agreed and consistent methodologies to predict flood losses. This requires the formulation of flood damage functions.
2. Flood damage functions are an essential step but are only the first stage in assessing flood losses. They must be combined with field surveys of property at risk and with hydrological information to predict flood damages.
3. In the urban sector the aim should be to use the experience from FHRC (University of Middlesex¹) and ANU (Australian National University) methodologies to produce synthetic flood damage functions.
4. Surveys of synthetic damage of a range of commonly occurring house types would form a national data base.

5. The use of synthetic data requires that information is available on how to convert these to reliable estimates of actual damage.
6. The opportunity afforded by the formulation of a national flood policy should incorporate:
 - the effects of severe floods on building failure and
 - the prioritisation of warning systems on the basis of cost-effectiveness.
7. For indirect losses the procedure is that it should be related to overall economic loss at regional or national level.

3.4 THE DEVELOPMENT OF RESIDENTIAL FLOOD DAMAGE FUNCTIONS

For the development of residential flood damage functions, the damage functions are divided into two parts. The process will be to determine damage functions for the structure and the contents of a house (Booyesen, 1996) and then to determine a combined damage function. Penning-Rowse and Chatterton (1977) divided a residential unit in two sub-categories, the building structure and the contents of the house. These categories are subdivided as follows: contents of the house into household items, warming devices, electrical appliances, furniture and personal items; building structures into building decorations, electrical wiring, plumbing, fences and gates. For each of the sub-categories a flood damage function is developed.

Lastly the contents and structure damage functions are combined to draw up an overall flood damage function for the different categories.

3.4.1 THE DEVELOPMENT OF FLOOD DAMAGE FUNCTIONS FOR FORMAL HOUSING

Booyesen (1996) discussed the development of residential damage in detail. Shortly, he developed separate functions for contents and structure. Properties

¹ Formerly Middlesex Polytechnic

were categorised and for each category a contents and structure damage function was developed.

3.4.2 THE DEVELOPMENT OF FLOOD DAMAGE FUNCTIONS FOR INFORMAL HOUSING

Flood damage functions for informal settlements were not determined during former research in South Africa. As such settlements are a reality in South African flood plains it is necessary to determine relevant flood damage functions. This is also necessary in the study area. As was referred to in Chapter 2, Soweto-on-Sea was used to develop flood damage functions for informal settlements. During pre-investigation, houses in this flood plain were categorised into two categories, namely Class 1: houses with only one room and Class 2: houses with more than one room. In Figure 3.2 the two classes are depicted.

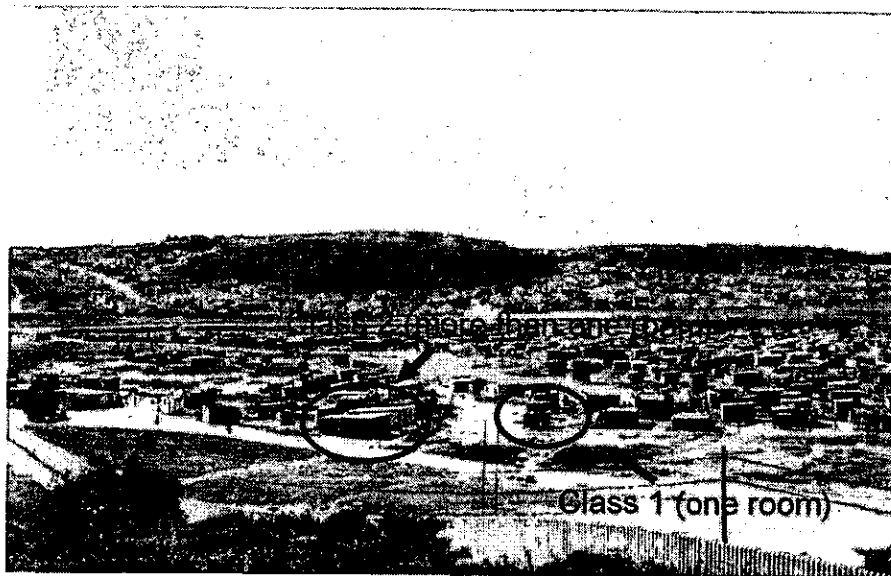


Figure 3.2 Examples of the different classes of houses which are to be found in Soweto-on-Sea

Although the social impact of a flood on a squatter camp has not been researched, such an impact can be quite extensive and it cannot be ignored.

Deaths like those during the 1996-floods in Mpumalanga (Beeld, 14.02.96) is a typical example of this. In this research however only the financial implications of floods are determined. The loss functions, which are developed in this chapter, were thus drafted with the aid of financial data.

3.4.2.1 Contents damage functions

For the development of content damage functions, 103 questionnaires were completed in Soweto-on-Sea by trained field workers. The same method which was used for formal housing (Booyesen, 1996), was also used for informal housing. In the formulae that were used to set up flood damage functions, two approaches were followed to determine remaining values. Firstly the value that was given by the respondent was used, and secondly, prices of new items (age taken into account) were used as residual values. Table 3.1 is the result of this exercise.

Table 3.1 Content flood damage functions (1996) as developed for informal housing in the Soweto-on-Sea flood plain

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

3.4.2.2 Damage to the structure

From a land use survey it was determined that the two main types of construction material are corrugated iron and wood. The methods that are used to identify property in the flood plain (Chapter 4), do not make it possible to determine the kind of building material of the houses. As a result of this, the assumption was made that the building material of all houses is corrugated iron and that the

damage to the structures is the replacement value thereof. The average price of a sheet of corrugated iron (0,61m x 1m) is R13,32 (1996). For a house of 40m² (the average in the study area) about 82 sheets of corrugated iron would be needed. The potential damage is estimated to be R1 092. This amount includes only the price of the corrugated iron, but the cost of labour and any other expenses are not included.

In the questionnaires the respondents were requested to make a calculation of the value of their houses, and the estimated averages vary between R955 and R1 016. These values compare quite well with the calculations in which the price of new sheets of corrugated iron was used. From discussions with farmers in the Orange River flood plain (Upington), it was determined that squatters' huts will be swept away if flood water reaches a depth of 0,5m to 1m.

In this study the assumption is made that, if squatters' huts are flooded to a depth of 0,5m or more, the damage to the structure will be approximately R1 000 per hut.

3.4.3 THE DEVELOPMENT OF RESIDENTIAL FLOOD DAMAGE FUNCTIONS WHICH CAN BE APPLIED NATIONALLY

In this section two methods which make it possible to draw up flood damage functions speedily, are reported. In the first case damage is expressed as a percentage of the overall value of the contents of a house. Secondly flood damage functions, which were developed for Upington, Vereeniging (Booyesen, 1996), Despatch and Uitenhage, are combined to construct standard flood damage functions.

3.4.3.1 Damage as percentage of total value

Contents of houses were categorised according to the rooms in a house (see Appendix 2 of Booyens' dissertation of 1994). Items were categorised into: Lounge, Dining room/Kitchen and Bedroom. Other categories are: Wall-

hangings, Ornaments and Other. Items like vacuum cleaners, washing machines and bedding are categorised as Other, and paintings as Wall-hangings.

The sum of the current value of the items in each room is used to calculate the percentage damage. Current value is the value of the items at the time of flooding and not the amount of a new item. Age and value reductions are thus taken into account.

In Table 3.2 an example of the results is given. The total value of the items in the room is R80 560.

Table 3.2 An example of determining the percentage damage to the contents of a house

Depth of inundation	0,1 m	0,3 m	0,6 m	1,2 m	1,5 m	2,4 m
Damage (R)	5 120	12 258	28 012	62 023	76 300	80 560
%	6	15	35	77	95	100

The percentage damage for each house of the four areas (Upington, Vereeniging, Despatch and Uitenhage) was calculated in this way. All the percentages of the same categories were put together and a regression-analysis was done. Equation 1 is the result of the analysis for the Lounge-category.

$$Y = 4,43 + 115,66x - 32,81x^2 \quad R^2 = 0,89$$

The others equations of the other categories are as follows:

Dining room/Kitchen

$$y = -1,258 + 110,00x - 28,86x^2 \quad R^2 = 0,93$$

Bedroom

$$y = 2,37 + 135,85x - 41,86x^2 \quad R^2 = 0,92$$

Ornaments

$$y = -4,17 + 66,70x - 8,83x^2$$

$$R^2 = 0,89$$

Other

$$y = 6,55 + 89,28x - 21,71x^2$$

$$R^2 = 0,83$$

Where y = percentage of total value per category
 x = depth of inundation in metre

Wall-hangings

Because the R^2 of the regression equation of damage to wall-hangings is too low (Vereeniging 0,386), it was decided not to construct a function for Wall-hangings. A separate section in a questionnaire should be provided to accommodate wall-hangings in a flood damage function.

In Figure 3.3 and Table 3.3 the flood damage functions which were developed by means of the above mentioned method, are depicted graphically.

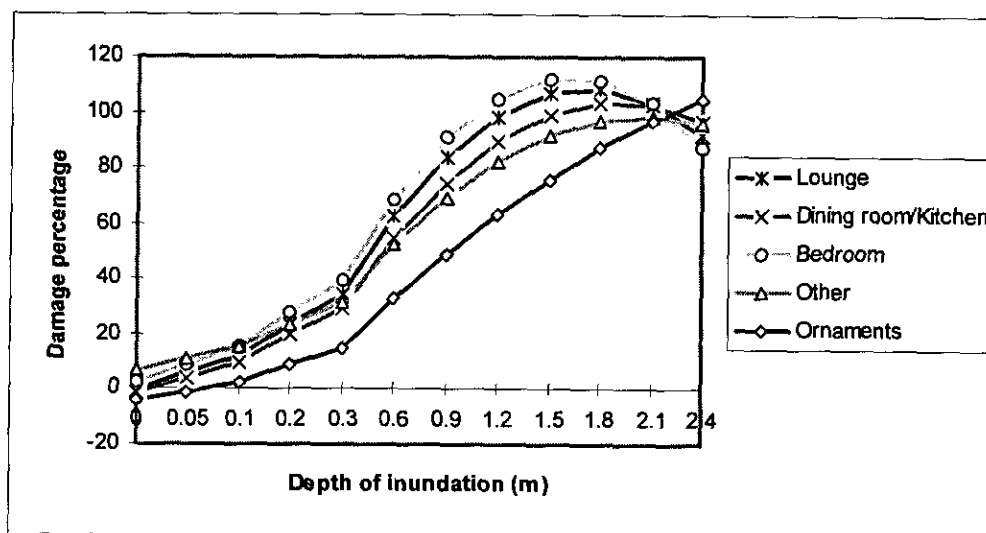


Figure 3.3 Damage to contents as a percentage of total current value of the contents of a category

Table 3.3 Content damage (1996) as percentage of total present value of a category

	Percentage damage											
	0	0,05	0,1	0,2	0,3	0,6	0,9	1,2	1,5	1,8	2,1	2,4
Lounge	0	6,2	15,7	23,7	34,5	62,5	83,8	98,6	100	100	100	100
Dining room/kitchen	0	4,2	9,5	19,6	29,2	54,4	74,4	89,2	98,8	100	100	100
Bedroom	2,4	9,0	15,5	27,9	39,4	68,8	90,8	100	100	100	100	100
Other	6,6	11,0	15,3	23,5	31,4	52,3	69,3	82,4	91,6	96,9	98,3	98,3
Ornaments	0	0,9	2,4	8,8	15,1	32,7	48,7	63,2	76,0	87,3	97,0	100

3.4.3.2 The development of standard flood damage functions

The first major application of standardised flood damage functions to buildings was for use with the National Flood Insurance Act in 1968 in United States of America (Smith, 1994). The flood damage functions were presented in terms of market values. Smith (1994) did not recommend this approach because there is a relative poor relationship between the market price and susceptibility to flood damage.

Standard flood damage functions are developed by examining a variety of housing units in different parts of the country. Categories that were identified for the different areas, can be combined to develop standard categories. Four areas in South Africa that have been researched, are Uppington, Vereeniging, Despatch and Uitenhage. The Uppington residential area was divided into eight categories, Vereeniging into 15, Despatch and Uitenhage into three each. The different categories for the residential areas of Uppington, Vereeniging, Despatch and Uitenhage are shown in Table 3.4 to 3.6.

Table 3.4 Housing unit categories for the residential area of the Uppington flood plain

Category	Description
Class 1	Small – low economic class – house
Class 2	Medium - medium economic class – houses
Class 3	Big - medium economic class – house
Class 4	Small - medium economic class – house
Class 5	Medium - high economic class – house
Class 6	Big - high economic class – house
Class 7	Medium - high economic class - house (two storey)
Class 8	Big - high economic class - house (two storey)

Table 3.5 Housing unit categories for the residential area in the Vereeniging flood plain

Category	Description
Class 1	Small flats
Class 2	Big/medium flats
Class 3	Small town houses
Class 4	Big/medium town houses
Class 5	Small houses
Class 6	Medium houses
Class 7	Big houses
Class 8	Luxury big houses
Class 9	Villas
Class 10	Big/medium flats (two storey)
Class 11	Big/medium town houses (two storey)
Class 12	Small houses (two storey)
Class 13	Big houses (two storeys)
Class 14	Luxury big houses (two storey)
Class 15	Villas (two storey)

* No respondents

Table 3.6 Housing unit categories for the residential area in the Despatch and Uitenhage flood plain

Category	Description
Class 1	Small – medium economic class – house
Class 2	Medium - medium economic class – house
Class 3	Big – medium economic class – house

After the residential flood damage functions of the four study areas have been compared, different categories were combined to form new categories.

Combinations were determined according to the house content flood damage functions of the various categories.

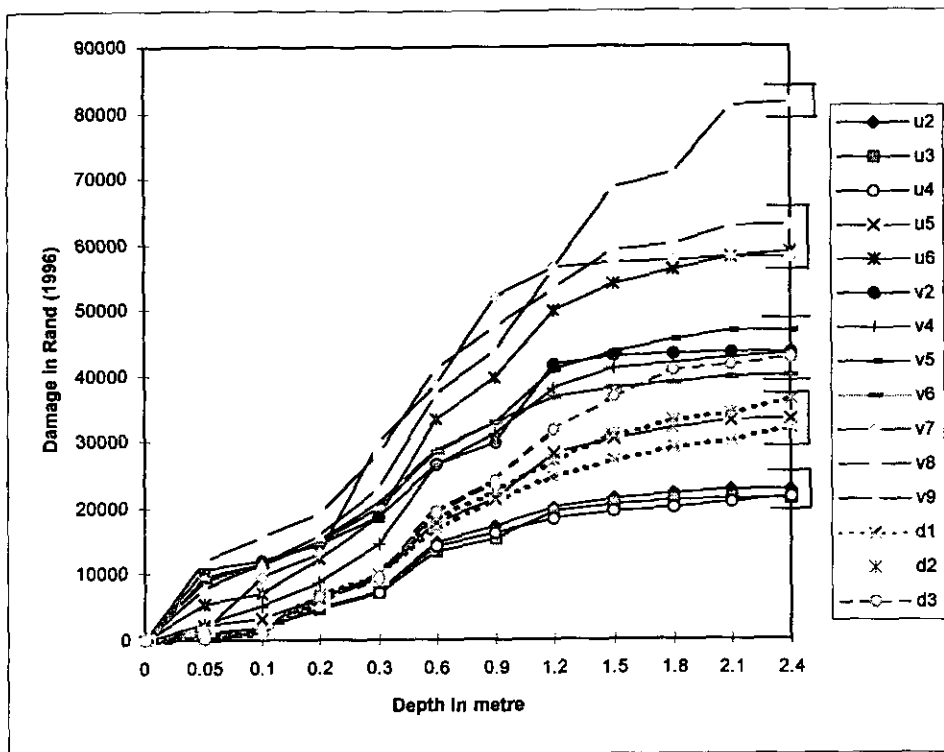


Figure 3.4 Content damage curves for single-storey home units in Upington, Vereeniging, Despatch and Uitenhage

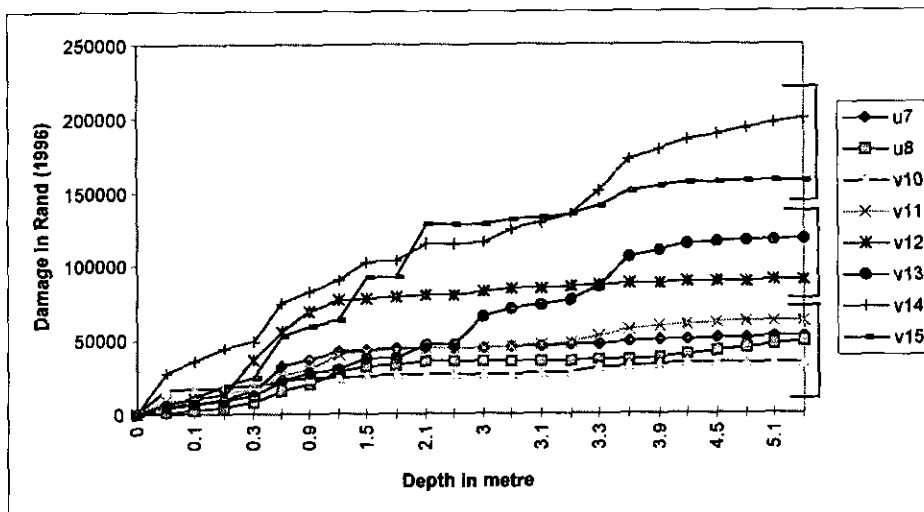


Figure 3.5 Content damage curves for double storey-buildings in Upington and Vereeniging

The categories, shown in Figure 3.4 and 4.5, are grouped in Table 3.7. Eight new categories were identified, of which five represented single-storey and three double-storey buildings.

Table 3.7 Categories in Uppington, Vereeniging, Despatch and Uitenhage, which were combined for the calculation of standard flood damage functions

Categories	Class (D= Despatch en Uitenhage, U = Uppington, V = Vereeniging)
Group 1	V9
Group 2	V7, U6, V8
Group 3	V2, V4, V5, V6, D3
Group 4	U5, D1, D2
Group 5	U2, U3, U4
Group 6	V19, V19
Group 7	V14, V12
Group 8	V11, U7, U8, V2

After grouping of the content flood damages functions of the individual houses in the new categories regression functions were fitted.

The results are:

Group 1

$$y = 10\,093,38 + 70\,251,11x - 18\,001,60x^2 \quad R^2 = 0,66$$

Group 2

$$y = 4\,782,96 + 69\,454,84x - 17\,435,90x^2 \quad R^2 = 0,63$$

Group 3

$$y = 1569,61 + 40\,316,22x - 10\,281,60x^2 \quad R^2 = 0,49$$

Group 4

$$y = 187,36 + 32\,116,80x - 7\,470,50x^2 \quad R^2 = 0,54$$

Group 5

$$y = 280,59 + 22\,520,86x - 5\,929,36x^2 \quad R^2 = 0,69$$

Group 6

$$y = 20\,150,38 + 51\,663,61x - 4\,022,97x^2 \quad R^2 = 0,291$$

Group 7

$$y = 29\,264,18 + 8\,337,7x + 2\,064,17x^2 \quad R^2 = 0,25$$

Group 8

$$y = 10\,251,97 + 18\,205,6x - 1\,908x^2 \quad R^2 = 0,26$$

Where y = 1996 R-values of damage
 x = depth of inundation in metre.

In Table 3.8 the new combined categories are described, and in Tables 3.9 and 3.10 the flood damage functions are presented in tabular form. In Appendix D the categories are visualised by photo's of the houses.

Table 3.8 Categories of home units according to which standard flood damage functions are grouped

Categories	Description
Group 1	Big luxurious houses
Group 2	Big - high economic class – houses
Group 3	Medium – high economic class – houses
Group 4	Medium/Big - medium economic class –houses
Group 5	Small/medium - medium economic class – houses
Group 6	Big luxurious - high economic class – houses (two storey)
Group 7	Big -high economic class – houses (two storey)
Group 8	Big/medium high economic class - houses (two storey)

Table 3.9 Standard house 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
Group 1	10 093	13 562	16 939	29 549	45 764	58 739	74 967	78 221	78 234	75 007
Group 2	4 783	8 212	11 554	24 050	40 179	53 169	69 734	73 309	73 746	71 044
Group 3	1 570	3 560	5 498	12 739	22 058	29 526	38 910	40 826	40 892	39 107
Group 4	187	1 775	3 324	9 150	16 768	23 041	31 554	33 793	34 688	34 238
Group 5	281	1 392	2 473	6 503	11 659	15 747	20 721	21 607	21 426	20 178

Table 3.10 Standard house content flood damage functions for general application (double-storey)

	Damage in Rand (1996) for depth of inundation (m)									
	0	0.6	0.9	1.5	2.1	3	3.6	4.5	5.1	5.4
Group 6	20033	58540	77793	116300	154809	212573	251084	308851	347364	366620
Group 7	36352	43489	47750	57657	69409	90500	106868	134881	155865	167049
Group 8	12735	25450	31168	41322	49769	59239	63418	66486	66397	65713

Finally the structure damage functions must be added. The damage functions that were developed in 1993 (Booyen, 1996), were adapted for inflation after 1996 and presented in Table 3.11.

Table 3.11 Structural flood damage functions for general application

	Damage in Rand (1996) for depth of inundation (m)										
	0	0.05	0.2	0.3	0.6	0.9	1.2	1.5	1.8	2.1	2.4
Class 1	0	5 005	5 005	5 005	12 634	12 634	12 909	12 909	12 909	12 909	38 810
Class 2	0	5 005	5 005	5 005	23 354	23 354	23 863	23 863	23 863	23 863	24 908
Class 3	0	10 879	10 879	10 879	38 286	38 286	39 118	39 118	39 118	39 118	57 926

Class 1 (structural damage function) is used with Group 5 (house content damage function), while Class 2 is used with Groups 4 and Class 3 with Groups 1 to 3, 6 - 8. Class 1 of the structural flood damage functions represents low, Class 2 medium and Class 3 high economic class houses.

3.5 THE DEVELOPMENT OF COMMERCIAL FLOOD DAMAGE FUNCTIONS

In this section flood damage functions for Despatch and Uitenhage are developed, after which these functions are combined with functions developed for Vereeniging in 1993 to create standard functions. As was mentioned in Chapter 2, mainly commercial land uses occur in Despatch, but these land uses are also found in the Uitenhage flood plain. The method that was used for the development of flood damage functions, is the same that was applied by Booysen (1996). A short summary is given of the method that had been used:

3.5.1 THEORETICAL BACKGROUND FOR THE DEVELOPMENT OF COMMERCIAL FLOOD DAMAGE FUNCTIONS

3.5.1.1 Damage functions for different businesses

Booyesen (1996) calculate damage in terms of damage to stock, building structure, equipment and loss in income. The method used to calculate the damage was developed by Penning-Rowsell and Chatterton (1977) and refined by Parker *et al.* (1987). Damage to stock is a function of value and susceptibility for damage. The value of the stock is given by the respondent and the susceptibility for damage is the percentage of the stock that will be damaged should it come into contact with floodwaters. The first step is to calculate damage, should all the stock be inundated. This is done with the following equation:

$$TD = V \times S$$

Where

TD = total damage

V = value of stock

S = susceptibility for damage.

The value of the stock is obtained from the questionnaires that were completed by the owners of businesses. The percentage figures that is used for susceptibility for damage, is obtained from Booyesen (1996). In the previous calculations only the total damage was determined, should the stock be inundated totally. To present a damage function for stock, it is necessary to calculate the damage per height intervals. The total damage is multiplied with the height distribution of the stock.

Damage to the equipment is calculated by multiplying the susceptibility for damage of the type of equipment with the total residual value of the item. To calculate the susceptibility for damage, the values developed by Penning-RowSELL and Chatterton (1977) were used.

Indirect flood damage (loss in income) has two variables that determine the extent of the damage (Penning-RowSELL, 1977): the turnover of the business and the length of the disruption.

The loss in income is calculated by multiplying the gross margin with the number of days that the business could not do any trading. Gross margin is gross income minus variable costs like electricity and transport. Fixed costs are not calculated. Gross margin in this case is calculated by multiplying the gross turnover per day with the added value.

One of the possibilities to project structural damage to businesses is to do a survey of the different enterprises. In the questionnaires, questions can be asked the kind of floor covering, electrical works and decorations. To attach value to these damaged items is a difficult task.

After discussions with Smith (1993) and other experts it was decided to use residential structural damage for the different commercial premises in this survey. "It can be assumed that damage to these items in retail premises is similar to that in residential properties, although in the larger retail properties redecoration and repair costs may be proportionately lower" Penning-RowSELL en Chatterton (1977).

3.5.1.2 Damage functions for different categories of business-enterprises

To develop damage functions for commercial land uses, the different business-enterprises must be categorised. The variables, according to which the categorisation is done, are the value of the stock and the floor area. The approach that was used was recommended by Smith (1994) and was also used in South Africa (Booyesen, 1996). There are three sizes categories and five value classes. Size categories vary from small (size group 1, less than 186m²), medium (size group 2, 186 - 650m²) to large (size group 3, larger than 650m²) floor area. Value classes are divided according to the value of stock of businesses in the study area. In this study the categories for the different study area (Vereeniging, Despatch and Uitenhage) differ. In Section 3.5.3 a general categorisation is presented. This categorisation can be used as a standard in other parts of the country.

3.5.2 THE DEVELOPMENT OF FLOOD DAMAGE FUNCTIONS FOR COMMERCIAL AREAS OF DESPATCH AND UITENHAGE AREA

The first step was to identify businesses situated in the flood plain. Information on these businesses was obtained by the completion of questionnaires (developed by Booyesen, 1996) by the owners. The collected data was used to determine a damage function for each business. A damage function was also determine for stock, equipment, structure and loss of income. To obtain an overall flood damage function for a business, the damage to the different components was summed. For the incorporation of commercial structural damage, the structural damage of group 1 of the residential classification was used.

After flood damage functions for the different businesses were developed, the businesses were categorised. By calculating the average damage per depth of inundation the flood damage functions for the categories were developed. The flood damage functions developed for Despatch and Uitenhage are shown in Table 3.12. The damage to a business-enterprise with high value stock (like

expensive clothing shops) and a floor surface area of more than 650m², is more or less R100 000 with a depth of inundation of 0,9m.

Table 3.12 Commercial flood damage functions (1996) developed in Despatch and Uitenhage (without structural damage)

Size	Value	Damage in Rand cause by depth of inundation in metres							
		0.3	0.6	1.2	1.5	1.8	2.1	2.4	2.7
1	1	6643	14850	21362	22504	23371	23829	44848	44890
1	2	19593	44455	83928	96605	106230	111316	140228	140697
1	3	139021	309506	697454	871498	1003643	1073476	1140239	1146685
2	1	38269	86801	179411	213836	239974	253786	287800	289075
2	2	14081	31724	55204	60907	65236	67524	94800	95011
2	3	34495	76207	153118	173338	188690	196802	227483	228232
3	1	18,96	43,49	82,54	96,15	106,48	111,94	139,96	140,46
3	2	42,55	87,61	180,74	194,19	204,41	209,81	233,71	234,21
3	3	28,72	65,15	127,61	130,62	132,90	134,10	146,91	147,02

Size		Value
1	=	Small (less than 186m ² floor area)
2	=	Medium (186 - 650m ² floor area)
3	=	Large (larger than 650m ² floor area)
		1 Low contents value
		2 Medium contents value
		3 High contents value

3.5.3 THE DEVELOPMENT OF STANDARD FLOOD DAMAGE FUNCTIONS FOR COMMERCIAL AREAS

This research indicated that it is more difficult to develop standard flood damage functions for the commercial than for the residential sector. By using Smith's (1993) approach, it is possible to develop such functions. Information from areas that have already been researched (Vereeniging, Despatch and Uitenhage) was compiled and an attempt was made to draw up a standard functions for the commercial sector. These flood damage functions are the overall flood damage functions, which include structural damage.

Since the same approach (as discussed above) was used for the flood damage functions of the three areas, it was decided that the data could be combined to develop a standard flood damage function. Seeing that Vereeniging's survey was done in 1993, the values were adjusted to that of 1996. This adjustment was

done with a factor of 0,242 (increase in consumer price index between 1993 and 1996). In Table 3.13 the adjusted values are shown.

Table 3.13 Commercial flood damage function developed for Vereeniging (1996) without structure damage

Size	Value	Damage in Rand cause by depth of inundation in metres							
		0.3	0.9	1.2	1.5	1.8	2.1	2.4	2.7
1	1	17775	38943	64922	66827	66827	66827	92728	92728
1	3	13958	38096	53371	61885	67198	69933	97433	97686
1	4	21783	60604	90493	106252	115833	120896	149757	150225
1	5	58250	167893	265127	306250	334195	348963	383497	384861
2	1	13685	25109	39758	46744	46744	46744	72645	72645
2	2	27433	52857	92429	119075	122730	124661	151691	151869
2	3	25380	76870	112227	134387	148520	155989	186256	186946
2	4	41891	125813	188872	221576	245389	257972	291230	292392
2	5	169206	592908	844560	1054634	1211854	1294938	1369412	1377081
3	2	23.16	66.43	102.35	115.85	125.52	130.53	155.93	156.30
3	3	61.02	187.68	297.39	344.76	381.24	400.24	415.84	417.59

* Damage per square metre

Size	Value
1 = Small (less than 186m ² floor area)	2 Low contents value
2 = Medium (186 - 650m ² floor area)	2 Medium contents value
3 = Large (larger than 650m ² floor area)	3 High contents value

For the development of standard flood damage functions, the original data sets were brought into account (Vereeniging, Despatch and Uitenhage), and all the individual flood damage functions were sorted according to value of stock and floor area of the property. Value of the stock were categorised into five groups:

- | | |
|---------------------------|--|
| 1. R0 (no stock) | Commercial banks |
| 2. Smaller then R50 000 | Hair dressing saloons and small cafe's |
| 3. R50 000 - R200 000 | Butcheries and clothing shops |
| 4. R200 000 - R1 000 000 | Liquor stores and motor sales |
| 5. Larger than R1 000 000 | Hardware and video shops. |

It is important to note that the above examples were taken from the study areas and that some of the business enterprises in other areas may fall in other categories. It will all depend on the value of the stock. After the categorisation according to stock value, the set was further divided according to the floor area categorisation as in section 3.5.1.2. The average damage per depth of inundation was calculated for each category and is summarised in Table 3.14.

Table 3.14 Standard commercial flood damage functions (1996) for general application (without structural damage)

Value	Size	Damage in Rand caused by depth of inundation in metres							
		0.3	0.9	1.2	1.5	1.8	2.1	2.4	2.7
1	1	19865	45547	73545	81176	83807	85197	111907	112035
1	2	30378	83828	129942	148461	160761	167261	196979	197579
2	1	9842	25311	34054	38100	40355	41547	65999	66109
2	2	24621	59925	91833	113044	121706	126283	154877	155300
2	3	33,39	92,10	151,25	165,19	175,77	181,36	205,57	206,08
3	1	26172	75715	113987	132989	145475	152074	181848	182457
3	2	24314	72963	105216	123428	136637	143537	173483	174120
3	3	51,03	126,84	185,74	197,67	206,73	211,52	238,47	238,91
4	1	67285	194469	315396	354453	383679	399123	434063	435488
4	2	19646	103698	154451	197479	231102	253955	281884	298158
4	3	39,55	101,91	182,37	191,72	199,08	202,89	217,73	218,08
5	1	155186	647542	927925	1189018	1394693	1513970	1598848	1626764
5	2	129796	448272	644737	796353	910660	971066	1032291	1037867
5	3	41,22	126,59	200,01	231,72	256,13	268,85	281,33	282,51

Value	Size
1. R0 (no stock)	1 = Small (less than 186m ² floor area)
2. Lower than R50 000	2 = Medium (186 - 650m ² floor area)
3. R50 000 - R200 000	3 = Large (larger than 650m ² floor area)
4. R200 000 - R1 000 000	
5. Higher than R1 000 000	

*** Damage per square metre

In Chapter 4 these flood damage functions are being used in computer models to calculate flood damage.

3.6 THE DEVELOPMENT OF INDUSTRIAL FLOOD DAMAGE FUNCTIONS

From the literature Booyesen (1996) found that industrial flood damage functions cannot be categorised like residential and commercial flood damage functions. The reason for this is that the industrial plants differ too much. Some of the differences lie in the methods of production, management differences and size of the plants. For the calculation of industrial flood damages, the procedure is thus to let questionnaires be completed at each plant in the study area and to draw up a function for each. During the research in Uitenhage the co-operation of the industrialists differed to a large extent. Some of the industrialists were immediately supportive and completed the questionnaires while others allowed an interview and promised to complete the questionnaires themselves but never returned it. Only six questionnaires were processed.

3.6.1 THEORY FOR THE DEVELOPMENT OF INDUSTRIAL FLOOD DAMAGE FUNCTIONS

Penning-Rowsell and Chatterton (1977) divided the questionnaire to calculate industrial damage in 11 sections. In Figure 3.6 this division is shown.

1.	Name of industry	
2.	Type of business	
3.	Total area of premises	
4.	Total area of ground floor	
5.	Height of ground floor	
6.	Site and equipment	<ul style="list-style-type: none"> (a) vertical distribution (b) current net value (c) susceptibility for flood damage
7.	Raw materials and in-complete goods	<ul style="list-style-type: none"> (a) vertical distribution (b) current net value (c) susceptibility for flood damage
8.	Completed goods	<ul style="list-style-type: none"> (a) vertical distribution (b) current net value (c) susceptibility for flood damage
9.	Total physical damage	Expected damage of flood for different depths of flooding
10.	Average weekly turnover	
11.	Capacity to transfer production	

Figure 3.6 Information needed for the calculation of potential industrial flood damage

From information gained from the questionnaires, flood damage functions could be developed. Sections six to ten in questionnaires were used to developed flood damage functions. Question six concerns current value of the plant and equipment, question seven raw materials and incomplete goods that are stored on the premises, question eight completed goods, question nine total physical damage and question ten average weekly turnover. Weekly turnover or loss in income is not immediately calculated in the flood damage function, but can be added later when it can be determined for how long the plant has been out of production.

The respondents gave values for damage to plant, equipment, raw materials, incomplete goods, completed goods and the building structure. Respondents also supplied other information, like potential for damage. Penning-Rowse *et al.* (1977) and Smith (1993) recommended this approach. Table 3.15 is an example of the questions in the questionnaires. This specific question concerns damage to plant and equipment. Respondents were asked to indicate the value of the equipment, what percentage of equipment occurs at the different levels and what

percentage of equipment value will be damage with different floods. From this information a flood damage function is set up for the three components (plant and equipment, raw materials and incomplected and completed goods), which are combined to develop a damage function for the plant.

Table 3.15 Example of a questions used during a survey among Uitenhages' industrialists

8.a	Wat is die totale huidige waarde van die aanleg en die toerusting (geboue uitgesluit)/What is the total present value of this plant an equipment (buildings excluded)?	R.....				
8.b	Watter persentasie van die aanleg en toerusting (gebou uitgesluit) word by die volgende hoogtes aangetref/What percentage of plant and equipment (buildings excluded) is kept at the following heights?	0m- 0,5m	0,5m - 1m	1m - 2m	2m - 3m	+3m
		%	%	%	%	%
8.c	Watter persentasie van hierdie waarde sal verlore gaan deur vloedskade/What percentage of this value would be lost through flood damage?	%	%	%	%	%
		R	R	R	R	R

indirect damage is more difficult to project and it was decided to adapt Parker's *et al.* (1987) approach for use in the research in Uitenhage. After his criticism of existing methods and the adaptation of Penning-Rowell and Chatterton's (1977) approach, Parker decided on the following approach: The correct measurement of loss of production is the loss of added value (the value of the company's addition to the economy). Additional costs caused by the lower productivity as a result of the flood, must be added to the loss of added value. Additional costs include overtime payment, increase in electricity costs or costs of the shifting of production within the business. Booyen (1996) discussed in detail how direct as well as indirect damage can be calculated.

3.6.2 FLOOD DAMAGE FUNCTIONS FOR INDIVIDUAL INDUSTRIES IN THE UITENHAGE FLOOD PLAIN

The following tables were compiled from information supplied by industrialists in the Uitenhage flood plain. Damage to different components are given in the tables and summed to calculate the total flood damage function for the plant. After the compilation of the table, a table is drawn up that shows the effect of warning time on the flood damage function. Different warning times, varying from two hours to two days, were given to the respondents. The question was: what percentage of the raw materials, products and loose equipment will be removed with different warning times. The tables show the damage that is caused by floods but the structural damage is not included.

In the following section, the flood damage functions of the different industries are given in tabular form. For confidentiality reasons the industries are referred to as Industry 1, 2, etc.

Industry 1, with a floor area of 7886 m², manufactures wire for tyres.

Table 3.16 Flood damage functions for Industry 1 in the Uitenhage flood plain, 1996

Damage to:	Damage in Rand for different depths of inundation in metre			
	0.5	1	2	3
Plant and equipment	2000000	5000000	3600000	4000000
Raw materials and incompletd goods	864000	1620000	1800000	1800000
Completed goods	240000	720000	1080000	1200000
Structure				
Total	3104000	7340000	6480000	7000000
Damage in R/m²	394	931	822	888

The respondent could not give an indication of what the damage to the structure would be. It is expected that the damage-potential could be much higher.

Table 3.17 The residual flood damage function for different warning times for Industry 1, 1996

Warning in hours	Percentage of movables that can be removed	Percentage that remains	Damage in Rand for depth of inundation in metre (structural damage excluded)			
			0.5	1	2	3
2	10	90	2793600	6606000	5832000	6300000
4	20	80	2483200	5872000	5184000	5600000
12	25	75	2328000	5505000	4860000	5250000
24	30	70	2172800	5138000	4536000	4900000

If the company can extend the warning time to two hours the company can save up to R734 000 and if the warning time can be extended to four hours the savings are R1 468 000 with an inundation of 1 metre.

Industry 2 with a floor area of 17 000m² manufactures crankshafts and steering mechanisms. Flood damage functions are presented in Tables 3.18 and 3.19.

Table 3.18 Flood damage function for Industry 2 in the Uitenhage flood plain, 1996

Damage to:	Damage in Rand for different depths of inundation in metre			
	0.5	1	2	3
Plant and equipment	3200000	16000000	16000000	16000000
Raw materials and incompletd goods	283000	1415000	2122500	2122500
Completed goods	250000	250000	250000	250000
Structure	785000	2355000	3925000	4710000
Total	4518000	20020000	22297500	23082500
Damage in R/m²	220	1039	1081	1081

Table 3.19 The residual flood damage function for different warning times, 1996 for Industry 2

Warning in hours	Percentage of removable that can be removed	Percentage that remains	Damage in Rand for depth of inundation in metres (structural damage excluded)			
			0.5	1	2	3
2	1	99	3695670	17488350	18188775	18188775
4	1,5	98,5	3677005	17400025	18096913	18096913
12	2	98	3658340	17311700	18005050	18005050
24	2,5	97,5	3639675	17223375	17913188	17913188
2	6	94	3509020	16605100	17270150	17270150

Industry 3 with a surface of 16 000m² manufactures motor car components. The flood damage functions are given in Tables 3.20 and 3.21.

Table 3.20 Flood damage function for Industry 3 in the Uitenhage flood plain, 1996

Damage to:	Damage in Rand for different depths of inundation in metre			
	0.5	1	2	3
Plant and equipment	0	67500000	150000000	175000000
Raw materials and incompletd goods	0	1197000	1995000	2660000
Completed goods	0	22500	112500	250000
Structure	1000000	50000000	150000000	200000000
Total	1000000	118719500	302107500	377910000
Damage in R/m ²	0	4295	9507	11119

Table 3.21 The residual flood damage function for different warning times, 1996 for Industry 3

Warning in hours	Percentage of moveables that can be removed	Percentage that remains	Damage in Rand for depth of inundation (structural damage excluded)			
			0.5	1	2	3
2	10	90	0	61847550	136896750	160119000
4	20	80	0	54975600	121686000	142328000
12	25	75	0	51539625	114080625	133432500
24	35	65	0	44667675	98869875	115641500
48	50	50	0	34359750	76053750	88955000

Industry 4 with a floor area of 450 m² manufactures exhaust systems. The damage functions are shown in Table 3.22.

Table 3.22 Flood damage function of Industry 4 in the Uitenhage flood plain, 1996

Damage To:	Damage in Rand for different depths of inundation in metre			
	0.5	1	2	3
Plant and equipment	72000	600000	600000	600000
Raw materials and incompletd goods	25000	100000	100000	100000
Completed goods	49500	110000	110000	110000
Structure	360000	600000	600000	600000
Total	506500	1410000	1410000	1410000
Damage in m²	326	1800	1800	1800

Industry 5 with a floor area of 162 m² manufactures number plates with the flood damage functions given in Table 3.23.

Table 3.23 Flood damage function of Industry 5 in the Uitenhage flood plain, 1996

Damage to:	Damage in Rand for different depths of inundation in metre			
	0.5	1	2	3
Plant and equipment	7600	47500	190000	190000
Raw materials and incompletd goods	3750	15000	48600	60000
Completed goods	0	0	0	0
Structure	0	0	0	0
Total	11350	62500	238600	250000
Damage in m²	70	386	1473	1543

When one look at the different industries' damage components, it is evident that the values differ significantly. Damage to plant and equipment inundated by 2m, varies from R0,19 million (Table 3.23) to R175 million (Table 3.20). This difference accentuates the great variation that exists between the industries, which makes it quite impossible to develop a standard function. Warning time can make a big difference to flood damage. For Industry 3 for example the savings for a two hours warning time is R56 871 950.

3.7 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Damage functions for three land use types were developed in this chapter. Firstly, flood damage functions for residential uses were developed. Residential includes formal as well as informal housing. Flood damage functions were first developed for Despatch and Uitenhage (formal housing). Subsequently these functions were combined with functions that were developed for Upington and Vereeniging during 1993 to develop combined flood damage functions. In this combined function a percentage as well as a standard flood damage function approach were applied.

Flood damage functions for informal housing were developed in the same way as those for formal housing. Content damage functions were developed and then combined with structure damage to obtain total flood damage function.

With this research completed, there are three approaches/methods to develop flood damage functions for a specific study area. The first method comprises a comprehensive survey where the whole inventory of say a specific house is recorded and a flood damage function developed according to it. Secondly a shortened questionnaire can be used. In this questionnaire, the type of question to be asked can e.g. be: what is the value of the items in the lounge (ornaments and wall-hangings excluded)? This value is multiplied by a percentage to included calculate damage per room. This value is then included into a total flood damage function per house. In the third approach standard flood damage functions can be used. These functions can be adapted as flood damage data increases. The required grade of accuracy will determine which of the three approaches are going to be implemented. The first method will provide more accurate information than the second and third methods, but the advantages of the last two methods are inter alia the saving in time and costs.

Commercial flood damage functions were also developed for Despatch and Uitenhage. Potential damage functions were developed for individual business enterprises. Damage to stock, equipment, building structure and loss in income

were combined to complete the damage functions. The completed loss functions were combined with loss functions developed for Vereeniging to draw up standard commercial flood damage functions. Lastly flood damage functions for five industries in the Uitenhage flood plain were developed. From these functions the difference in flood damages for the different industries became evident. These differences make it impossible to develop standard flood damage functions for industries.

In Chapter 3, the different standard flood damage functions that were developed in this chapter, will be used in combination with the area-specific damage functions to project potential damage. The applicability of the standard functions will also be evaluated.

CHAPTER 4

THE DEVELOPMENT OF COMPUTER MODELS FOR THE MANAGEMENT AND PLANNING OF A FLOOD PLAIN

4.1 INTRODUCTION

There are six basic options available for reducing the risk of loss of life of persons living in flood prone areas (Alexander, 1993).

- Do nothing.
- Move residents to higher ground.
- Build flood damage mitigation works.
- Install passive flood warning systems.
- Operate active flood warning systems.
- Develop community river watch systems.

The identifying of the different solutions is essential but what is also as important is the evaluation of these options to determine the best in terms of cost benefit ratio, cost effectiveness or other criteria. To do this fast and effectively by computer models are an excellent tool. Two well-known models are the Flood Damage Analyses (FDA) Package developed by the Hydrologic Engineering Center (HEC) of the US Army Corps of Engineers in the United States of America and an Australian model that was developed by the Centre for Resource and Environmental Studies (CRES). The FDA package enables a variety of flood damage computations to be performed using linked hydrologic and flood damage computer programs developed by HEC. Anuflood is an interactive computer model that calculates tangible urban flood damage and evaluates

flood mitigation options. The program needs three inputs to function: land use data, flood damage functions and hydrological data.

The aim of this chapter is to develop computer models for the management and planning of a flood plain. Firstly the adjustments of an Australian developed computer model (Anuflood) for South African situations and secondly the development of a GIS based model (TEWA) will be discussed. With knowledge that was obtained by adjusting ANUFLOOD for South African situations and by studying the FDA package a new flood plain management tool TEWA was developed. TEWA is the acronym for "a computer model for Tangible Economical flood Water damage Assessment", and thus is a computer model that calculates tangible flood damages. Furthermore the model can also evaluate different flood damage mitigation options. With this facility the model will also be able to determine the optimal location of new development on a floodplain.

4.2 THE FLOOD DAMAGE ANALYSIS (FDA) PACKAGE

4.2.1 DAMCAL

4.2.1.1 Overview

DAMCAL (damage reach stage-damage calculations) is part of a package of computer programs that make up the Spatial Data Management and Comprehensive Analysis System that was developed by the U.S. Army Corps of Engineers (1979) for flood plain management. The DAMCAL program is developed to access data and information stored in a grid cell data bank.

The DAMCAL computer program accesses the geographical information stored in a grid cell data bank for evaluation of the existing land use and any number of future land use. "A powerful analytical capability in DAMCAL is the ability to evaluate

nonstructural alternatives such as flood plain management policies, flood proofing alternatives, permanent evacuation, temporary structural protection and content removal in response to flood warning and any combination of the preceding" (U.S. Army Corps of Engineers, 1979).

4.2.1.2 Computational procedures

Methods of computing flood damage potential require the development of flood damage functions at selected damage reach index locations throughout the river system. The flood damage functions are then combined with hydrological data to calculate expected annual damage. Damage reaches (zones) are defined to capture the economic and hydrological variation in a flood plain. Usually flood damage functions are developed for each individual structure in the flood plain. The damage functions are then aggregated to an index location by adjusting elevation related data to account for slope of the water.

The methodology consists of constructing a unique flood damage function for each grid cell within the flood plain and then aggregating the damage potential of all grid cells assigned to a particular damage reach to an appropriate index location.

Since flood profile yields different water surface elevations throughout a damaged reach, a representative flood event is required to properly adjust the topographic elevation of each grid cell. Historic flood events are often used as reference floods.

A composite damage function is defined as a stage-damage function for a specified area within each adopted land use category that has significant damage potential.

4.2.1.3 Aggregation of damage functions

The DAMCAL computer program accesses the data bank and for each grid cell in the flood plain manipulates the appropriate data in the following manner:

1. The land use of the cell is determined and the corresponding composite flood damage functions is placed at the grid cell.
2. The stage axis of the function is converted to elevation.
3. Transfer the grid cell elevation-damage function to the index location.
4. The resulting grid cell aggregated elevation-damage function is then combined with the elevation-damage functions of other grid cells to calculate the total elevation damage.

4.2.2 EAD (EXPECTED ANNUAL FLOOD DAMAGE COMPUTATION)

This program was developed to help in economic evaluation of flood plain management plans (U.S. Army Corps of Engineers, 1989). EAD computed inundation reduction benefits. Damage may be computed in three different modes:

1. the damage associated with a specific flood,
2. the expected annual damage associated with a specific year or several selected years and
3. the equivalent annual flood damage associated with a particular discount rate and period of analysis.

4.2.2.1 Program principles

This program is based on the principle that flood damage to an individual structure, group of structures or flood plain reach can be estimated by determining the dollar value of flood damage magnitudes of flooding and by estimating the percent change of exceedance of each flood magnitude (U.S. Army Corps of Engineers, 1989).

The damage caused by a single flood is calculated by using flood damage functions. When the mean annual damage (damage which can be expected in any year, U.S. Army Corps of Engineers, 1989) are calculated, then the damage of each magnitude of flooding is weighted by percent change of each flood occurring. The sum of the weighted damage represents the expected annual flood damage.

To compare alternative plans or to compare damage with costs, an equivalent annual value is computed. This equivalent value represents a uniform distribution of annual values and is computed by discounting and amortizing each year's expected annual damage value over a period of analyses.

In the EAD the water surface descriptors are **stage** and **depth**. Stage is used as a term to represent both the situation in which a local datum is used for each location and also for a more general case of common datum for the entire study area. The frequency is referred to as exceedance frequency.

There are several different combinations in which the stage, flow damage and frequency data can be expressed to develop the damage-frequency matrix. The simplest way is to relate stage or flow to damage and stage or flow to frequency. The common parameter, stage or flow, can be used to relate damage to frequency (U.S. Army Corps of Engineers, 1987).

Because stage, flow, frequency and damage vary along a river, it is common practice to divide the river into reaches or zones and let a set of data represent the stage, flow frequency and damage data for a zone. An index location is selected within the reach and a single stage or flow-frequency matrix and stage-flow matrix are applied at that location and considered representative of these variables for the entire zone. Generally hydraulic and hydrologic factors govern the selection of the index location.

The main reason for computing flood damage is to determine the effectiveness and benefits of different flood plain management plans in reducing damage. Different management plans change the stage, flow, frequency and/or damage functions in different ways.

4.3 THE ADAPTATION OF ANUFLOOD FOR THE SOUTH AFRICAN SITUATION

Smith and Greenaway (1993) stated that ANUFLOOD is based upon the stage-damage function concept first outlined by White in 1945.

Three sets of data are needed to do calculations with ANUFLOOD. The data sets are land use data, flood damage functions and hydrological data. **Land use data** is about the location of the properties, street name, street number, number of storeys, buildings raised or not, height raised, grid co-ordinates, building material, ground height, floor height and damage class. Some of the data are obtained from a survey of the exterior of all buildings in the flood plain. Other data are obtained from different kinds of maps.

The information from the survey can be used in four different ways:

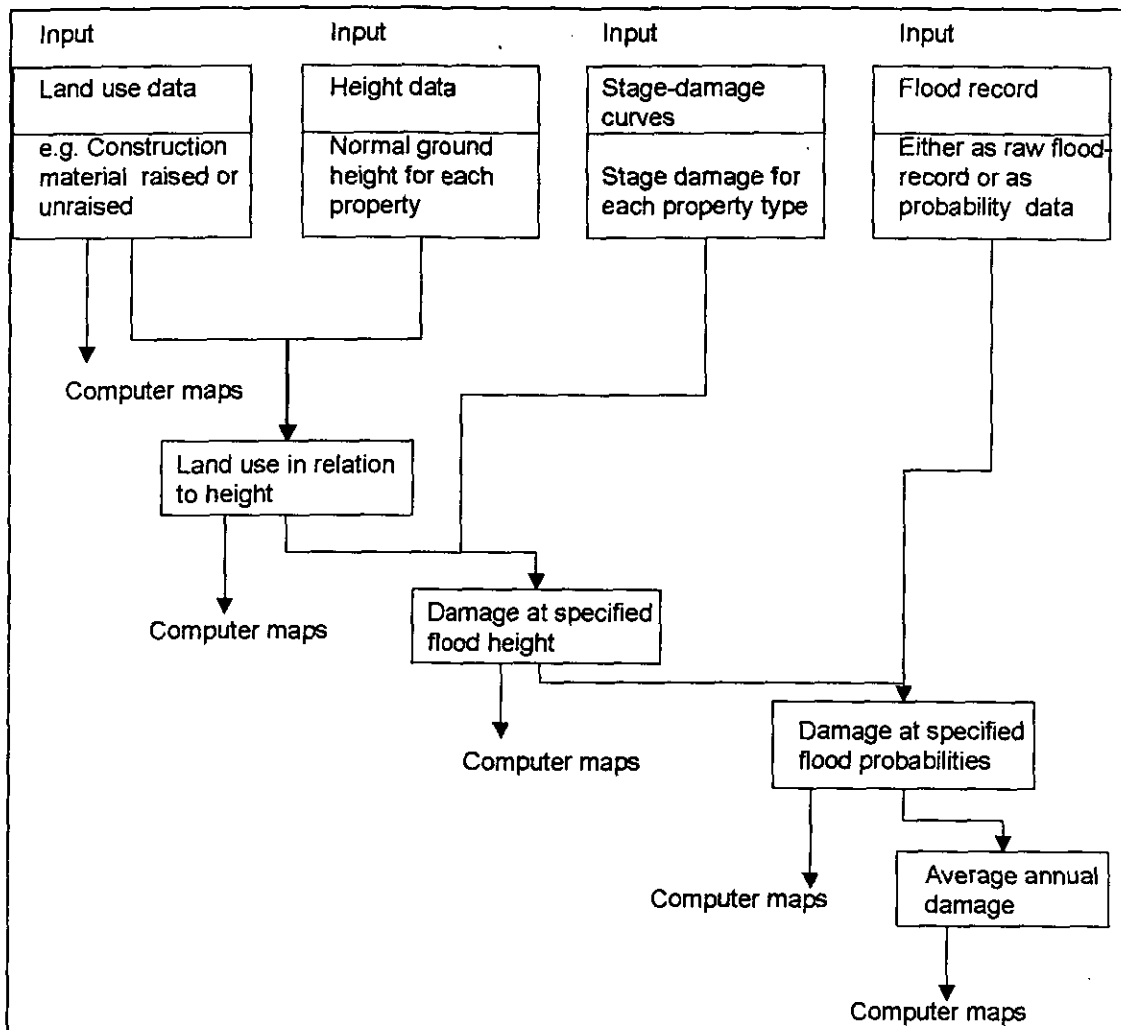
- to supply a statistical summary of the characteristics of the properties on the flood plain,
- to classify damage classes,
- to supply computer maps of flood damage and

- to give information to emergency agencies.

It is possible to subdivide the flood plain into a maximum of hundred subregions. The initial location subdivision depends on local circumstance or can be based on the form of available information on river slope.

The **flood damage functions** used with Anuflood are normally for potential direct damage. They represent the worst cases where no allowance is made for the reduction in damage by moving or lifting contents and damage includes that from water and silt. These functions represent damage to both the structure and contents of buildings.

Hydrological data for Anuflood includes flood frequency, slope and velocity of the flood water. The flood frequency is being referred to as flood height in terms of the probability of flood occurrence. The flood slope is the spatial difference in the maximum water levels. There are two ways for the incorporation of flood slopes in urban flood studies. A geometric surface can be fitted on the water surface or the urban areas can be divided into zones. Different probabilities vs. height are then used for each zone. In this instance it is assumed that the water surface is flat.



Source: Smith and Greenway (1988)

Figure 4.1 Inputs and Outputs of ANUFLOOD

Figure 4.1 is a diagrammatic representation of the inputs and outputs of ANUFLOOD. It shows land use data, height data, stage damage functions and flood record as inputs for ANUFLOOD. After each combination of input data, output can be produced. For example if land use data, construction material raised, is combined with height data computer maps can show floor height by grid square.

4.3.1 PREPARATION - THE INPUT DATA

After acquisition of data it is stored in Anuflood in specific FORTRAN I/O data sets.

Flood damage functions

Specific formats exist in which the files must be stored in ASCII. These formats consist of columns and rows that is set-up in a certain way. An example is given for illustration purposes. These loss functions were used during a research project in Uppington.

Firstly specify the number of flood damage functions (two)	2
Specify total underhouse ¹ damage	0.0
Specify damage (R) for each depth of inundation (m) ²	0.0 0.0
	0.2 420
	0.3 510
	0.6 990
First flood damage function	0.9 1040
	1.2 1050
	1.5 1060
	1.8 1060
	2.1 1060
Terminator for the end of the loss function	99.9
Total underhouse damage	3055
	0.0 270
	0.2 9280
	0.3 11560
	0.6 23730
Second flood damage function	0.9 28520
	1.2 32280
	1.5 34590
	1.8 35660
	2.1 35480
	2.4 54920
Terminator	99.9

¹ Underhouse damage is the damage in Rand caused by floodwater under floor level.
² First column is depth of inundation in meter and second column is damage in Rand.

Hydrological data

Consultants provided hydrological data for the study area. The data is presented in the form of tables and maps with flood lines. In the computer model the data are presented as follow in the data file:

Height of flood above sea level (m)	Probability of flood occurrence
791.31	0.20
791.96	0.10
792.64	0.05
793.48	0.02
795.68	0.001

Land use data

Land use data are also stored in rows and columns. The land use data are divided into seven fields. Field 1 represents the zones in which the study area is divided into and field 2 the address of the property. It can include the street number and name. Field 3 contains the characteristics of the house. Field 4 is the location of the property in terms of xy co-ordinates. Field 5 contains the characteristics of building material, size of the house, size of the plot, the condition of the house and the age of the house. Field 6 represents the ground height and the floor height of the property. Lastly field 7 contains the damage category. Following is an example of the format the data is stored in.

Fields						
1	2	3	4	5	6	7
04 94	48	1 1 1	1.00	2888-4703	4 2 0 2 2	794.0 0.0 5
04 0	88	1 1 0	0.00	2833-4713	4 0 0 0 0	796.5 0.0 5
04 54	121	1 1 0	0.00	2764-4703	4 2 0 2 2	797.8 0.0 5
04 56	124	1 1 1	2.00	2759-4692	4 2 0 2 2	798.3 0.0 5

4.3.2 RUNNING THE PROGRAM

Table 4.1 ANUFLOOD's fourteen different calculations

Processor	Description	Explanation
1 and 2	Statistical analysis of residential and commercial data	These options can do frequency, cross-tabulated and multi-parameter frequency analysis.
3 and 4	Generate a subset of the residential and commercial data	The purpose of these processors is to generate a data set of houses and commercial properties that can be used apart from the total data set.
5	Total mean annual damage to residential property	This processor calculates the total average annual damage to residential property for the entire data set or a subset thereof.
6	Total damage to residential property	The processor evaluates the theoretical damage sustained at a particular flood height.
7	Read the contents of a data file	This processor allows data files to be accessed without having to cease program execution.
8	Total mean annual damage to commercial property	This processor calculates the total average annual damage to commercial property for the entire data set or a subset thereof.
9	Total damage to commercial property	The processor evaluates the theoretical damage sustained at a particular flood height.
10	Evaluate residential flood mitigation strategies	This processor allows four possible strategies to be evaluated. They are levee constructions, flood proofing, house raising and house clearing.
11	Evaluate commercial flood mitigation strategies	This processor operates in a similar fashion as Processor 10.
12	Evaluate mitigation strategies by height	Processor 12 provides damage estimates at a specific height or heights remaining after the implementation of a particular mitigation measure.
13	Flood slope/ trend surface/ height Adjustment	Processor 13 permits three different styles of available information to be used as a basis for the processing of the height data. It modifies ground and floor heights to allow for flood slope or other causes of spatial height variation.
14	Spatial distribution	This processor presents data on a grid square basis. The output consists of a nominated output file containing values for each grid square, plus a grid map of that data.

4.4 THE DEVELOPMENT OF TEWA

Two factors motivated the development of TEWA. The first is the benefit that Geographical Information Systems (GIS) provides. GIS provides map generation and manipulation; the study area can be shown visually on the computer screen and the impact of changes can immediately be seen. Questions also can be answered, such as the determination of areas that fit certain criteria. The second reason is that user support for Anuflood that was developed in Australia is not available in South Africa.

4.4.1 FUNDAMENTAL PRINCIPLES

Like EAD (U.S. Army Corps of Engineers, 1989) TEWA is based on the principle that flood damage to an individual structure/property, groups of properties or flood plain zone is determined by the monetary value of flood damage for different magnitudes of flooding. Damage caused to a property or a number of properties by a single flood event is calculated directly from a flood damage function. Mean annual damage is determined by calculating the integral of the graph of flood damages of a number of floods of different magnitudes.

Flood damage functions are a fundamental corner stone of the working of TEWA. Depth is plotted against potential damage and used to calculate damage to the particular property.

Because of the scattering of hydrological data along a river, for example cross sections every 100 meters, and economic activities the flood plain is divided into zones. All the properties in a particular zone have the same hydrological data but the properties in the zone are grouped into different categories.

The main reason for calculating flood damage is to evaluate different flood plain management options. The plans are compared with regard to costs and benefits. To

do this it is necessary to determine the present value of costs and benefits spread over a period of time.

GIS is another important part of the model. It is used to store geographical and attribute data, to combine data from different sources, do analyses and represent the results of the analyses.

In Figure 4.2 the main principles of the three models DAMCAL, EAD and ANUFLOOD are shown and combined to form the background from which TEWA was developed.

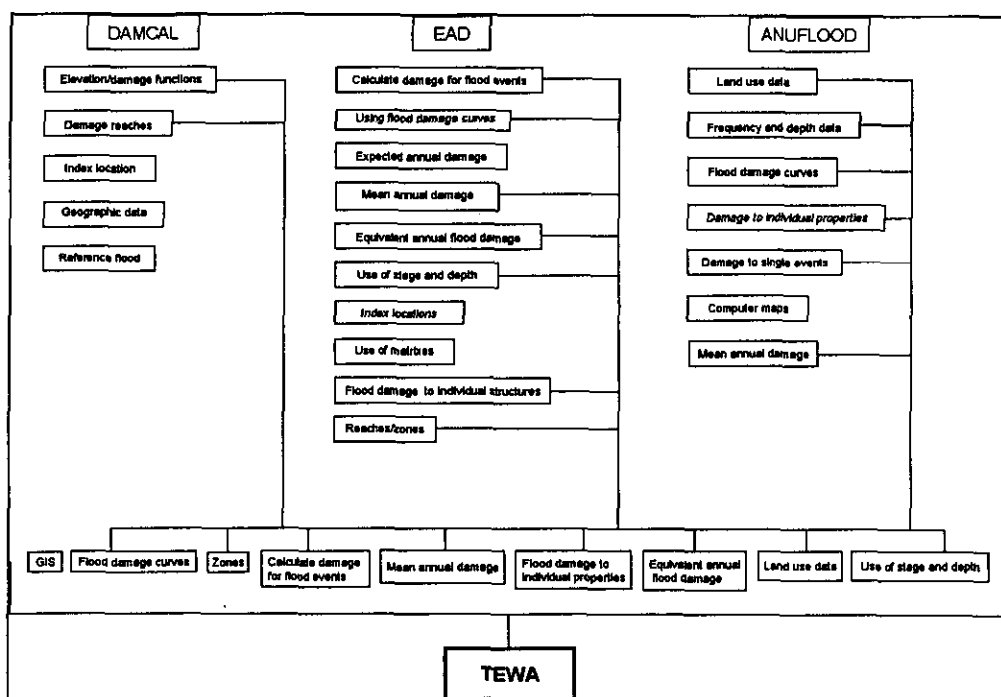


Figure 4.2 Aspects from DAMCAL, EAD (Both part of the US Army Corps of Engineers' package of flood damage computer programs) and ANUFLOOD that was used in the development of TEWA

4.4.2 THE DEVELOPMENT OF TEWA

The GIS-program used to develop TEWA was AllyMap, a GIS program distributed by Allyson Lawless in Johannesburg. The database program used for the calculations and data management was dBase III Plus.

4.4.2.1 AllyMap

AllyMap is a full featured GIS that runs on Intel based PC's (Light year computer systems, 1995). It uses the file structure of dBase (III or IV) for alphanumeric files and the file structure of AllyCad for graphics files. By using AllyMap you can:

- query any graphical object (road, land parcel, etc.),
- from a database record, show where any object is on the map,
- do queries on database records and produce resulting maps,
- do polygonal queries and zones changes and
highlight demographical trends using a (three dimensional) surface model.

4.4.2.2 dBase III Plus

dBase III Plus is a relational database management system. The program is designed for creating, maintaining and manipulating relational databases (Tsu-der Chou, 1986). Information in the database can be processed in two ways. One way is interactive command processing. With this method, information in the database is manipulated by means of commands entered interactively from the keyboard. After each command is entered, results are displayed on an output device such as a monitor or printer. The other method is batch command processing. Processing tasks are defined in a set of command procedures. The collection of commands is stored in a command file, which can be considered a computer program.

4.4.2.3 TEWA

Firstly the input data will be discussed, the different types of data that are being used in the simulations, plus the methods used to get the data in the appropriate form so that the computer can use it in analyses.

Data input

The input for the GIS model includes geographical and attribute data. Geographical data used in the study are the properties on the flood plains that must be represented in the databases. It includes residential, commercial and industrial land use. The phenomena of the real world (properties) are represented as area objects in the database. The erf or plot on which they are situated identifies the properties (buildings). An example of plots can be seen in Figure A.1 (Appendix A). Information from the attribute tables is linked to these plots.

The geographical data (maps) were obtained by using two approaches. First by maps in digital form were obtained from the municipality of Uitenhage. The municipality obtained their maps from digitising itself or from the Surveyor-General. These maps were in dxf-format and were imported into the AllyMap data structure. In the second approach a map of Despatch was digitised. On all the maps, plot-numbers were used as identifiers and were put manually on the maps. It was done by viewing the map on computer screen and used the mouse to put the plot-numbers on the map. With an operation in AllyMap these plot-numbers were incorporated into the maps' databases.

Characteristics of properties in the floodplain are necessary to do the analyses. From these characteristics, it is possible to link the properties to other information like flood damage functions and hydrological data. Information like type of properties, height above sea level and location of the property are be used to calculate flood damage. This procedure will be discussed later on. Additional information like the

address of a property that can be used in emergency planning is also included in attribute data.

Properties in the study area were classified according to the differences between land use on the floodplain. The land use were mainly residential, commercial and industrial. These different land uses were also divided into categories. Residential properties were divided into three classes and the commercial properties into nine. Because of reasons given in Chapter 3 the industrial sites were not grouped into classes.

Information collected

In the case of Uitenhage, two approaches were followed. With the first, the residential houses were classified by using aerial photography and ortho-maps. After the houses on the photos were compared with each other, they were categorised into three classes: small, medium and large. In the second approach the land use were classified by driving through the study area and noting the different characteristics on a matrix. During these surveys, information about the properties were collected. Information that were gathered for **residential land uses** were general location of the property, street names en -numbers, height raised, number of storeys , building materials and socio-economic classification. Other information that was retrieved from maps was the height above sea level of the houses. Although the information can be obtained from a DTM, the GIS program that was used in this research does not support this function and therefor the elevation information that was gathered from ortho-maps was read into the computer database manually. The same type of data as for the residential properties: general location, street names and -numbers, height raised, building materials and commercial classification were gathered for **commercial land use**. Information about **industrial sites** was more specific. For Despatch only the second approach was used.

All this data and information were read into records in dBase data files and combined with the geographic database files. The plot numbers were used again as identifiers. A main file for land use information, i.e. the height above sea level and for different categories of houses was created. Other information like flood damage functions and hydrological data were put into separate files.

4.4.2.4 Program description

The main aim of this program is to calculate tangible economical flood damage and by using this information the program evaluates flood damage mitigation options. Figure 4.3 is a diagrammatic outline of the different steps in the program for calculating flood damage. The program first calculates the depth of inundation. After this the damage is determined. The damage class determines the loss function to be used. It further determines the depth of inundation and reads the corresponding damage from the loss function data file.

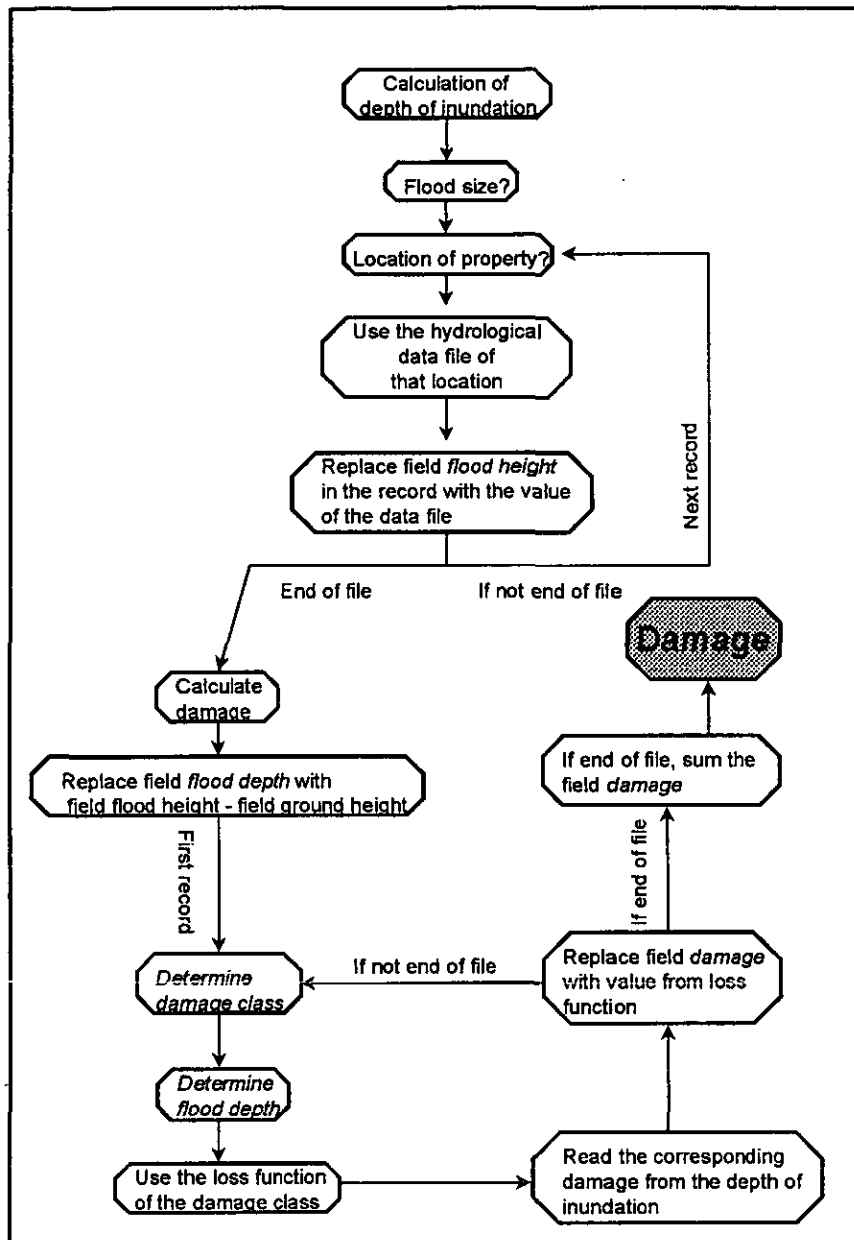


Figure 4.3 A flow diagram of the procedures of TEWA

Figure 4.4 is a visual representation of the process. (1) The program looks at the location, (2) the location determines the hydrological data that must be used, (3) flood depth is replaced by flood elevation minus ground height, (4) Class and flood depth determine the potential damage to the property, (5) damage in the main file is

replaced by the flood damage function's damage and all the damages are summed to get the total damage for the particular scenario.

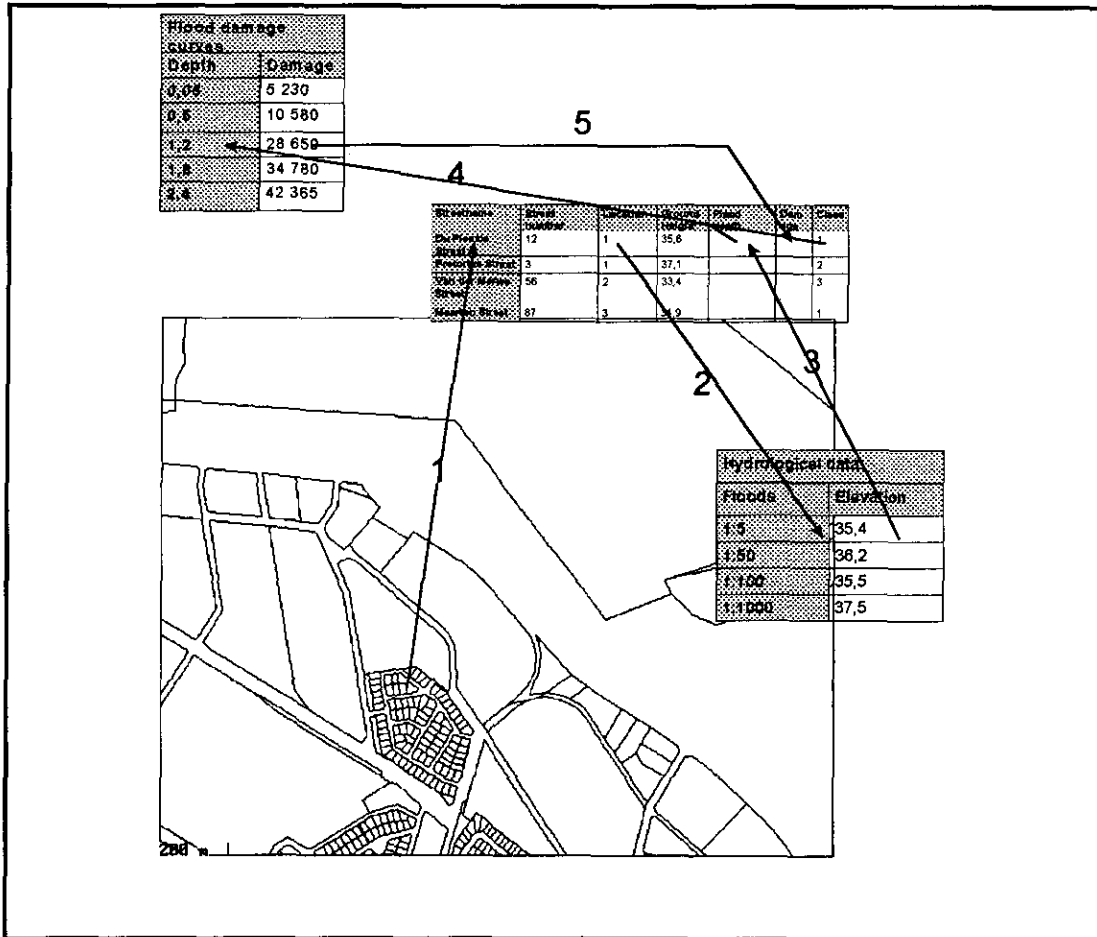


Figure 4.4 A visual description of the processes in TEWA

These calculations are the core of the model and all the other scenarios and calculations use this approach. Specific scenarios will be discussed when the different scenarios are evaluated in a later chapter.

4.4.3 THE USE OF TEWA IN THE STUDY AREA

4.4.3.1 Calculation of depth of overflow

A problem that has been identified is that the lower areas in the flood plain of the study area form islands. At Despatch, for example, there is an area in the middle of the town that is lower than the surrounding areas. Because these areas are lower than the flood elevation, it is possible that they might be flooded. Higher surrounding areas however will prevent these areas from being flooded during certain floods. AllyMap could not handle this problem and an alternative solution had to be found. The following approaches and assumptions were used:

Despatch

1:5 to 1:20 year floods

After calculating depth of inundation (1:5 year flood) with the original data set, it is evident that a section in the middle of the study area will be inundated (Figure 4.5), but in practice it is unlikely that this area will be flooded. Higher located areas surround the area and the flood profile shows that no water will flow into this area. It is assumed that no water will flow into the area and the ground height is adapted to reflect this. The reason for this adaptation is because the model cannot take the island effect into account. This adaptation has to be made by hand. For the 1:10 and 1:20 year flood, the same effect as for the 1:5 year flood apply.

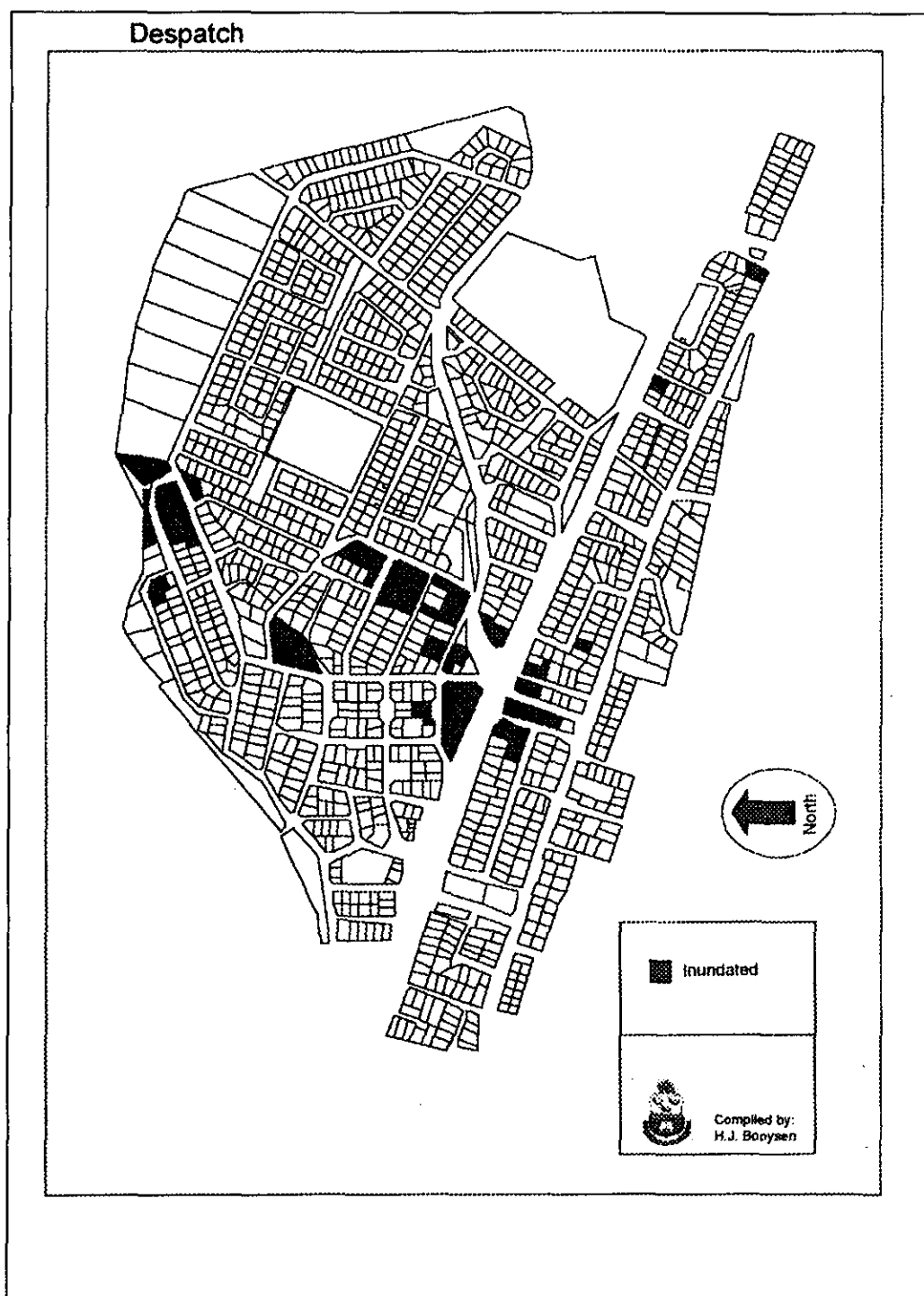


Figure 4.5 Areas that are below the 1:5 year flood line

1:50 and 1:100 year floods

The 1:50 year flood is an interesting case. The cross section at "chainage" 22420 shows that the water flows through at point A, which causes the region behind the higher areas to be flooded. No adaptations are being made to the original ground heights. The same applies for the 1:100 year flood.

Regional Maximum Flood (RMF)

The extent of the RMF is of such a nature that the whole region that falls within this flood line, will be flooded. No adaptation is therefor being made.

Uitenhage

Only the RMF of the known floods (1:5, 1:10, 1:20, 1:50 1:100 and RMF) will cause floods in the residential areas. Even if one observes the charts provided by SRK (Sketch 207878/2 and page - 7 of 9), only the areas next to the Swartkops River will be flooded. No adaptations are there for made to the original ground heights.

Soweto-on-Sea

Two methods had been used to project the potential for financial losses in the Soweto-on-Sea informal settlement. Firstly each house was dealt with separately. Secondly the area was grouped into 94 zones, and an estimate was made for damages for each separate zone.

The data inputs, which were necessary to do the estimation, were the same as those that were used for the formal settlements. As was discussed in Chapter 3, two flood damage functions were drafted for informal housing: one for a one-roomed house and a second for a house with more than one room. For the calculation of damages, two methods were used. Firstly the site of the house is determined. That determines

the cross section and thus also the hydrological information which will be used. The region is divided in 23 areas and each area has its own cross section. After the depth of the flood is calculated, the damage for each flood is determined. The site of each house was drawn from maps (1994) provided by the consultants. Each house in the flood plain was marked with a number, and from the maps it was determined if each house has one or more rooms. Because only the maps had been used to gather information, it is possible that mistakes could have been made with regard to the number of rooms. It is assumed that this fault will be cancelled. In one case a one-roomed house might be marked as one with more rooms, but in another case a more-than-one-roomed house might be marked as a one-roomed one. Figure 4.6 is an example of how the houses were marked.

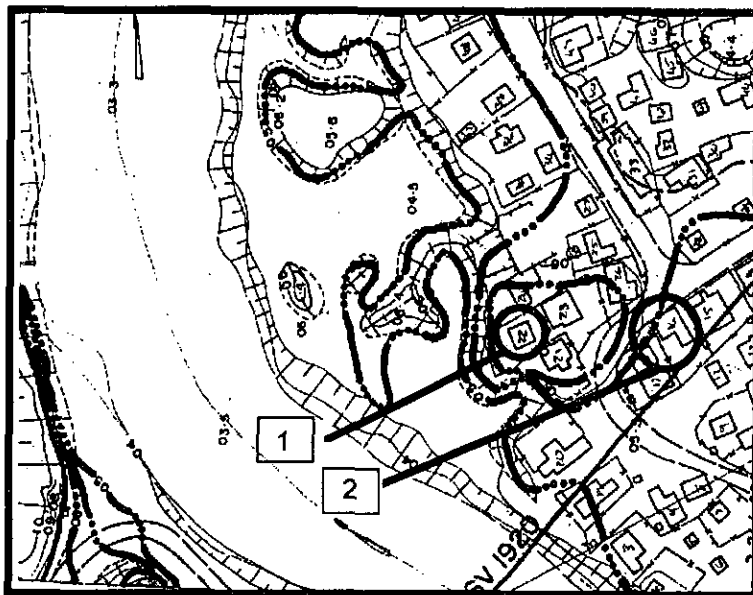


Figure 4.6 Part of Soweto-on-Sea along the Chatty River with two classification of houses

Number 1 is an example of a house which has been classified as one with one room only, and number 2 is an example of a house with more than one room. Both houses have been allocated to cross section 1920.

In the second method the previous two flood damage functions have been reduced to one. The reason for this is because identification and classifications had been made from air photos. Although the R^2 (coefficient of determination) is low, the damage function was still being used. Air photos were scanned and on them zones were drawn. Figures 4.7 and 4.8 portrayed this process. Figure 4.8 also shows the cross sections, which were used for the different zones.

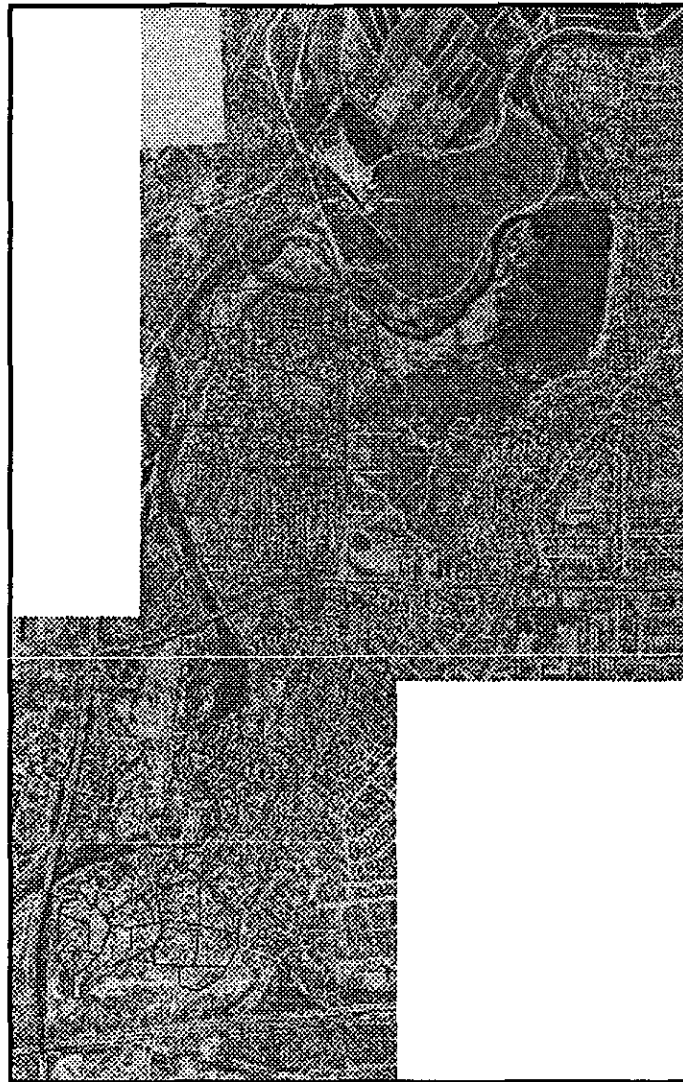


Figure 4.7 Soweto-on-Sea near the Chatty River classified in zones for calculation of flood damages

The number of houses in the different zones was counted from the photos. The sketch made on the scanned photo was stored in a format for retrieval by AllyMap. In AllyMap this sketch was converted into a database which contains height above sea level and number of houses in a zone.

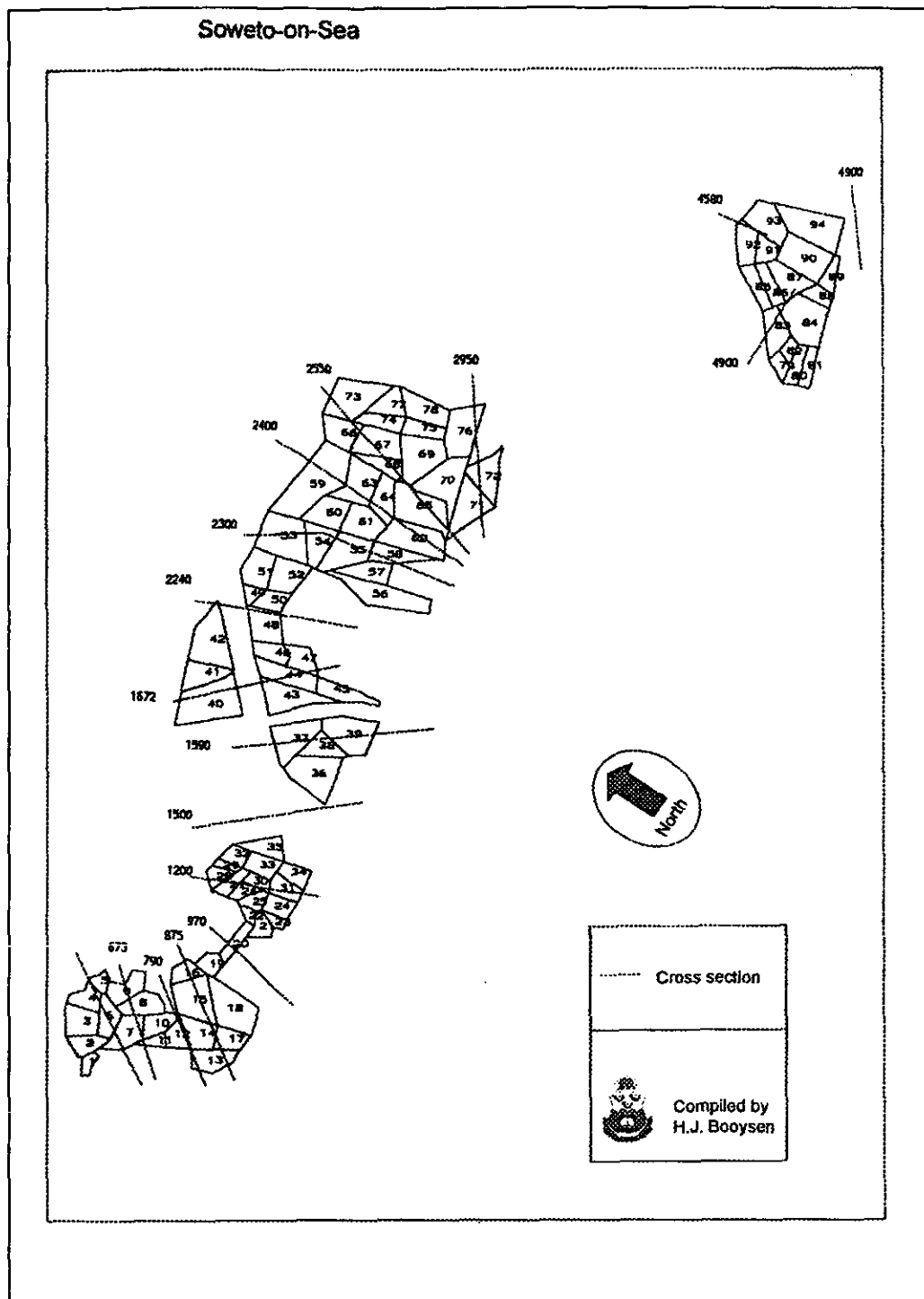


Figure 4.8 Zones in Soweto-on-Sea used for flood damage calculation in TEWA

Depth of inundation was calculated in the same way as indicated in Figure 4.4. Firstly it was determined to which cross section the zone should be linked. Ground height was subsequently subtracted from the cross section's flood height to determine the depth of the inundation of the zone. It is assumed is made that all the houses in the zone will be flooded with the same calculated flood depth of the zone. Damage from the flood damage functions is multiplied with the number of houses in the zone to determine the total damage per zone. The sum of the damages per zone is taken as the damage figure for the study area.

4.4.3.2 Calculation of damage for different zones

TEWA was used to determine potential damage to different sectors in the study area. Firstly the residential damage of the three areas, Despatch, Uitenhage and Soweto-on-Sea, was determined. Then damage for the commercial and industrial sectors was calculated. Potential damage was determined according to flood occurrence and set out in tables.

Residential area:**Despatch****Table 4.2** Potential total damage calculated in Rand for the Despatch residential sector, 1996

Zone	Flood frequency in years					
	1:5	1:10	1:20	1:50	1:100	RMF
Zone 6	0	0	16 191	3 600 541	3 849 491	10 858 798
Zone 7	767 213	1 102 260	1 413 534	8 926 308	9 370 228	14 889 071
Zone 8	0	0	66 264	12 261 198	11 962 382	23 027 865
Zone 9	0	0	0	307 217	407 884	7 182 399
Total	767 213	1 102 260	1 495 988	25 095 266	25 589 986	55 958 135

In Table 4.2 it is clear that Zone 8 has the most potential for flood damage. In Figure A.3 the different zones are shown.

Uitenhage**Table 4.3** Potential total damage calculated in Rand for the Uitenhage residential sector, 1996

Zone	Flood frequency in years						
	1:5	1:10	1:20	1:50	1:100	RMF [*]	RMF ^{**}
Zone 1	0	0	0	0	0	0	0
Zone 2	0	0	0	0	0	6 582 346	6 069 237
Zone 3	0	0	0	0	0	4 456 869	3 685 986
Zone 4	0	0	0	0	0	2 917 476	2 114 259
Zone 5	0	0	0	0	0	1 058 866	615 944
Total	0	0	0	0	0	16 517 114	12 485 426

Total damage includes damage to contents as well as structure

* Method 1 as discussed in Section 4.4.2.3.2

** Method 2

From Table 4.3 it is obvious that only the Regional Maximum Flood will cause damage to the residential areas. The damage value of Method 2, which is the more accurate calculation, is lower (average 17,21 percent for the zones) than the calculations of Method 1. The total damage calculation of Method 2 is 17,21 percentage lower than those of Method 1. Figure A.4 shows the different zones that was used in the calculations.

Soweto-on-Sea

Table 4.4 Potential total damage in Rand calculated for the Soweto-on-Sea residential sector, 1996

Flood frequency	Method 1	Method 2	Difference (Method 2 – Method 1)	Percentage difference
1:2	2 703 828	2 636 287	- 67 541	-2.5
1:5	3 596 638	3 601 000	4 362	12
1:10	4 067 300	4 259 367	192 067	4.5
1:20	4 371 739	4 647 895	276 156	5.9
1:50	4 916 137	5 301 055	384 918	7.3
1:100	5 181 393	5 798 550	617158	10.6
1:200	5 381 109	6 113 356	732 247	12
RMF	6 026 094	7 569 469	1 543 375	20.4

Damage for Soweto-on-Sea varies from R2,7 million (1:2 year flood) to R6 million (RMF) according to Method 1. The high damage figures show that, although Soweto-on-Sea is an informal settlement, the potential for damage to informal settlements cannot be underestimated. Although Method 1 is more accurate than Method 2, the two values do not differ very much. This means that Method 2 can also be used for the calculation of flood-damage.

Commercial sector:**Despatch****Table 4.5** Potential total damage in Rand calculated for the Despatch commercial sector, 1996

Zone	Flood frequency (years)					RMF
	1:5	1:10	1:20	1:50	1:100	
Zone 6	0	0	0	0	0	647 094
Zone 7	0	0	0	0	0	265 133
Zone 8	0	0	0	0	0	0
Zone 9	0	0	0	0	0	0
Total	0	0	0	0	0	912 227

According to these calculations, the potential for damage in the Despatch commercial sector is not high, especially when it is compared to that of the residential areas.

Uitenhage**Table 4.6** Potential total damage in Rand calculated for the Uitenhage commercial sector, 1996

Zone	Flood frequency (years)					RMF
	1:5	1:10	1:20	1:50	1:100	
Zone 1	0	0	0	0	0	0
Zone 2	0	0	0	0	0	0
Zone 3	0	0	0	0	0	190 073
Zone 4	0	0	0	27 658	104 702	677 465
Zone 5	0	0	0	0	0	1 776 831
Total	0	0	0	27 658	104 702	2 644 369

Damage occurs only from the 1:50 year flood and larger and it is only the RMF, which will cause considerable damage in Uitenhage's commercial sector.

During a 1:50 year flood damage of nearly R28 000 can be expected, while the Regional Maximum Flood can cause damage of almost R2,7 million.

Industrial area:

Uitenhage

The development of industrial flood damage functions was discussed in Chapter 3. From this discussion it was evident that a standard flood-damage function cannot be constructed up for industries. The best alternative is to complete a questionnaire at every industry in the flood plain. In the case of Uitenhage this was not possible, because problems were experienced to get the co-operation of all the manufacturers.

Because the aim of this research is to develop a computer model with which damage can be calculated and mitigation options be tested, it was decided to calculate potential industrial damage for the area. Potential damage was calculated for the five industries for which there exist flood damage functions. The flood damage of five of the estimated 18 industries in Uitenhage's flood plain is shown in the following tables.

Table 4.7 Potential damage in Rand calculated for Uitenhage industrial sector, 1996

Flood frequency (years)	Zones						Total
	1	2	3	4	5	6	
1:5	0	0	0	0	0	0	0
1:10	0	0	0	0	0	0	0
1:20	0	0	0	0	0	0	0
1:50	3 664 000	0	0	0	0	0	3 664 000
1:100	7 040 000	0	0	0	0	0	7 040 000
RMF	7 040 000	0	0	0	0	19 207 500	26 247 500

Damage to the five industries varies from R3 664 000 for a 1:50 flood to R26 247 500 for the Regional Maximum Flood. If it is taken into account that this constitutes 28 percent of the industries, it can be accepted that the potential for damage in the Uitenhage area will be significant.

4.4.3.3 Total damage for the whole study area

In Table 4.8 and 4.9, the different damage components of Despatch and Uitenhage are being added to get a total damage figure for the towns.

Table 4.8 Potential damage in Million Rand for Despatch, 1996

	Flood frequency (years)					
	1:5	1:10	1:20	1:50	1:100	RMF
Residential	0,77	1,10	1,50	25,10	25,59	55,95
Commercial	0	0	0	0	0	0,91
Industrial	0	0	0	0	0	0
Total	0,77	1,10	1,50	25,10	25,59	56,86

The largest damage component in Despatch is the residential sector. The commercial sector constitutes 2,9 percent of the total potential damage.

Table 4.9 Potential damage in Million Rand for Uitenhage, 1996

	Flood frequency (years)					RMF
	1:5	1:10	1:20	1:50	1:100	
Residential	0	0	0	0	0	12,49
Commercial	0	0	0	0,02	0,10	2,64
Industrial	0	0	0	3,66	7,04	26,48
Total	0	0	0	3,68	7,14	47,21

Although only five of the 18 industries were in the researched flood plain, the industrial damage is still the largest component of the total damage. If these values are compared to the total damages, industrial damages constitute 99 percent for a 1:100 year flood and 56 percent for the RMF of the total damages. In Chapter 5 it will be discussed how this phenomenon can make an impact on the flood damage mitigation options.

The calculation of Mean Annual Damage (MAD)

MAD is the integral under the function of the flood frequencies and damage.

To determine the real value for average yearly damage, the floods with the low occurrence probabilities must also be taken into account. Information of damages of such floods is scarce. Hypothetical point B (Figure 4.9) is the largest flood (with the lowest probability) of which flood damage is known. In such cases the average yearly damages are calculated as area AEDC in stead of KAC.

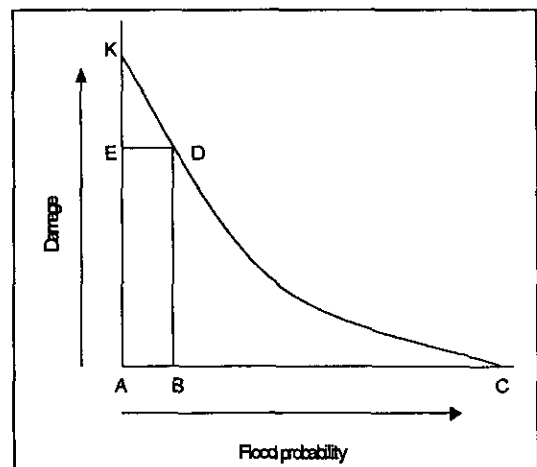


Figure 4.9 Calculation of mean annual damage
Source: Smith and Greenaway (1993)

To determine the mean annual damage for the study area, it is accepted that floods larger as the 1:4 year will cause flood damage. The annual damage is calculated by determining the surface under the damage function. This was obtained by calculating the surfaces of the triangles and rectangles under the different line segments and then by adding it.

Table 4.10 Mean Annual Damage in Rand for the study area, 1969

	Uitenhage	Despatch	Soweto-on-Sea (Method 2)
Residential sector	35 706	872 245	925 753
Commercial sector	15 676	5 017	0
Industrial sector	229 561	0	0
Total	280 943	877 262	925 753

From Table 4.10 it is evident Soweto-on-Sea has the highest mean annual damage (the number of industries that were researched must be remembered). One of the reasons can be that floods with a low frequency can cause damage in Soweto-on-Sea but only higher frequencies floods can cause damage in Despatch and Uitenhage. For example Table 4.8 shows that a 1:50 year flood can cause damage in Despatch and also Uitenhage. In the case of Uitenhage (Table 4.9) is the damage caused by a 1:50 year flood almost the same as the damage by a 1:5 year flood in Soweto-on-Sea.

4.4.3.4 Validation of the model (TEWA)

No damage figures of previous floods to validate the model exist for the study area. The following method was used to evaluate whether the results of the model were of the right size. The damage caused by RMF was evaluated.

Despatch

After the depth of inundation of the houses subject to the RMF has been determined, it was found that the median depth is 3,21 m. Next the houses were counted and it was found that 55 Category 1, 855 Category 2 and 171 Category 3 houses will be flooded. Because the Category 2 houses form such a large component of the flooded houses, it was decided to use this category's flood damage functions. With inundation of 3,21m the damage will be R59 928 per house. The number of houses which are flooded (913) are multiplied by R59 928, which gave a damage figure of R54 714 264. Damage as estimated by TEWA is R55 958 135.

Uitenhage

The same was done with Uitenhages' residential sector and it was found that the median depth of flooding was 0,9m. 223 Houses of Category 1, 275 of Category 2 and 2 of Category 3 will be flooded. Since the number of houses of Categories 1 and 2 is so near to each other, an average of the flood damage functions of the two categories was used. With a RMF 347 houses will be flooded, which gives a damage figure of R13 751 957 (347 x R39 631). TEWA estimated a damage of R12 490 000.

In both towns the difference is approximately R1,2 million; for Despatch, the value constitutes 2 percent, while for Uitenhage it is 10 percent.

4.5 SUMMARY

Three models were discussed in this chapter. One (FDA Package) is a American developed model, Anuflood, an Australian developed model that was adapted for South African situations and TEWA. TEWA is the abbreviation for "a computer model for Tangible Economical flood Water damage Assessment". Two of these models (ANUFLOOD and TEWA) were used in South Africa mainly to calculate tangible flood

damage. They can however also be used to evaluate flood damage mitigation options for the management and planning of a floodplain.

TEWA was developed from scratch by using a GIS program, AllyMap and a database program dBase III Plus. AllyMap is a full featured GIS that runs on Intel based PC's (Light year computer systems, 1995) and dBase III Plus is a relational database management system. dBase III Plus is designed for creating, maintaining and manipulating relational databases (Tsu-der Chou, 1986). TEWA first determines the location and category of a property and then use the corresponding data files (hydrological data and flood damage functions) to calculate flood damage. The procedures Anuflood uses to calculate flood damage were not discussed but the manner in which data are input into the program was. After data acquisition, it is stored in Anuflood in specific FORTRAN I/O data sets. A specific format exists in which the files must be stored in ASCII. This format consists of columns and rows.

ANUFLOOD was used during previous research (Booyesen, 1996) to calculate potential flood damage for Upington and Vereeniging and TEWA during this phase in Despatch, Uitenhage and Soweto-on-Sea. The main advantage of TEWA is that it is a GIS-application. Chart development is thus much better. The maps of Anuflood consisted of letters and figures compared to the more complete chart of TEWA - Figure A.1. Changes can immediately be input on the computer screen. At the same time the results of the changes can be shown on the screen.

Different methods were used to determine the potential damages for Uitenhage and Soweto-on-Sea. One method (in the case of Soweto-on-Sea it is Method 1) is more accurate, but more money and time is needed. One has to choose between a less accurate but cheaper method, and a more expensive but more accurate one. In the case of Soweto-on-Sea the difference between the results of the two approaches is small. It can thus be recommended that the same method (study area is divided in zones and the number of houses in each zone counted) being used in other areas

with the same characteristics as Soweto-on-Sea. In the case of Uitenhage, Method 2 is more accurate, but the user of the data must decide on the accuracy level required before deciding on a method.

In the chapter the high potential of an industrial area for flood damage is also discussed. Special attention has thus to be given to such an area. In particular, the planning and safeguarding of an industrial area are of utmost importance.

CHAPTER 5

FLOOD PLAIN MANAGEMENT STUDIES, FLOOD PLAIN MANAGEMENT PLANS AND DIFFERENT LEVELS OF APPLICATION

5.1 INTRODUCTION

As the majority of damage appeared to result from unwise use of flood plains, it became increasingly clear that careful land use planning, in combination with engineering, architectural and hydrologic measures, could be employed to avert local flood damage (Miller et al., 1996). Today, flood plain management is widely accepted and implemented throughout the United States. Flood plain management is defined as "... a decision making process whose goal is to achieve appropriate use of the nation's flood plains. Appropriate use is any activity or set of activities compatible with the risk to natural resources (natural and beneficial functions of flood plains) and human resources (life and property)...". The basic challenge of the flood problem is the development of a set of management strategies which can permit more intensive use of flood plains and yet minimise potential damages (Milliman, 1984). On what the economic and socially efficient level of flood hazard mitigation is, Milliman said that the realistic goal should be efficient flood plain management and not flood control *per se*.

According to the "Flood plain Development Manual" which was published by the New South Wales Government in 1986, it is being accepted that - except for the building of structural works for existing development - an increase in flood damage can be limited by making sure that with new developments the area's capacity to be inundated is taken into account. An integrated approach to area planning and management is thus necessary. This approach must take the total extent of floods into account in combination with other relevant planning factors (like zoning, land and environmental plans). In 1977 Dingman et al. remarked that flood plain regulation is

a rational way to limit the increase of flood damage, but the implementation thereof is a slow process. Smith *et al.* (1984) stated that there was a shift in emphasis in Australia with regard to water resource (and flood) policy. In the water industry there is a shift taking place from a construction phase to a management phase.

Separate measures for flood damage management have been tested in South Africa (Booyesen, 1996), but these measures have not been evaluated simultaneously. In this chapter flood policies and views of different countries in this regard are first considered. After this, the characteristics of a flood plain management system are discussed and the chapter is concluded with a hypothetical exercise in which a flood damage reduction plan is drawn up for the study area.

5.2 FLOOD POLICIES

South Africa

In Article 169A of the Water Law of 1956 it is stated that no town can be founded or expanded without flood lines - which is related to events of a specific recurrence period - being shown on the development plans to the satisfaction of the authority which is authorised to endorse such a foundation or expansion. (Department of Water Affairs, 1986).

The relevant part of the act reads:

"196A. Insertion of certain lines on certain plans, and approval by the Minister in respect of establishment or extension of townships in certain areas. – (1) No township shall, after the commencement of the Water Amendment Act, 1978 be established or extended under any law on any land unless –

- (a) the following particulars have been inserted on relevant lay-out plans in a manner to the satisfaction of the authority empowered under the relevant law to approve of establishment or extension in question –
- (i) in respect of any water course with a known and defined channel and with a catchment area exceeding one square kilometre, the line indicating the maximum level likely to be reached on an average every twenty years by flood-waters on the land in question, and
 - (ii) in respect of any low lying land without surface drainage on which water from an area exceeding five square kilometres collects naturally, the lines indicating the maximum level likely to be reached on an average every fifty years by such water on the land in question; and
- (b) if the land in question is situated in an area which, in the opinion of the Minister, is likely to be inundated by flood-water and which he has defined by notice in the Gazette, the Minister has, subject to subsection (2), previously approved of such establishment or extension, and the establishment or extension in question is effected in accordance with the conditions which the Minister may have deemed fit to impose on giving the said approval.

[Sub-s (1) amended by s. 7 of Act No. 27 of 1976 and substituted by s 18 of Act No. 73 of 1978]

- (2) If the whole or any portion of an area which the Minister has defined under subsection (1) (b) is situated within any guide plan area as defined in section 1 of the Environment Planning act, 1967, the Minister shall only grant the approval referred to in subsection (1) (b), in consultation with the Minister of Planning and the Environment.

[S. 196A inserted by S, 25 of Act No. 42 of 1975].”

The intention of Section 169A is twofold:-

1. to alert the relevant authority to the damage of flood and

2. to empower the Minister to control development in areas which he may specify (Alexander, 1993).

In 1989 the Municipal Engineer published an article in which the revision of the national flood management policy is briefly discussed. In this article, some aspects of the current policy are discussed in short. Under the heading 'control of urban development on a flood plain' it is mentioned that taking unknown risks into account, local authorities should therefore zone each area intelligently and plan for emergency measures. 'Expert interpretation of the particular circumstances in each case is essential, rather than mere routine application of the rules. Instead of simply fixing the developments boundary at the flood line associated with a given recurrence interval, other factors including river characteristics, possible upstream and downstream change and development, evacuation routes and the effects of structures and natural obstacles on flood flows must also borne in mind'.

Australia

Concerning urban flood plain management in Australia, it must be borne in mind that the government and regional authorities determine the basic policy, but that the primary responsibility for the implementation of the policy resides with the local government. From the seventies, there was a shift in emphasis in water resource policy (which includes floods), from an era of development (construction) to one of management. This is the result of changes in a wide range of social, economic and environmental matters. Other reasons include the escalating costs of construction and maintenance. The new approach can be observed in policy, legislation and institutional changes with regard to government. This change moves the emphasis from only structural strategies to a balance between structural and non-structural strategies.

Four factors are identified as causes for the failure of the implementation of flood plain management, with regard to land use measures, in the past. Three of these factors are under control of the federal and provincial authorities:

- funding that is to the benefit of structural measures,
- doubt in the legal base for strict land use control and
- the fragmentation of functional and geographical jurisdiction by different authorities.

The fourth factor is the selfish nature of organisations. Organisations with a construction mission and personnel who exist mainly of engineers, tend to give more weight to structural measures to the detriment of non-structural measures.

England and Wales

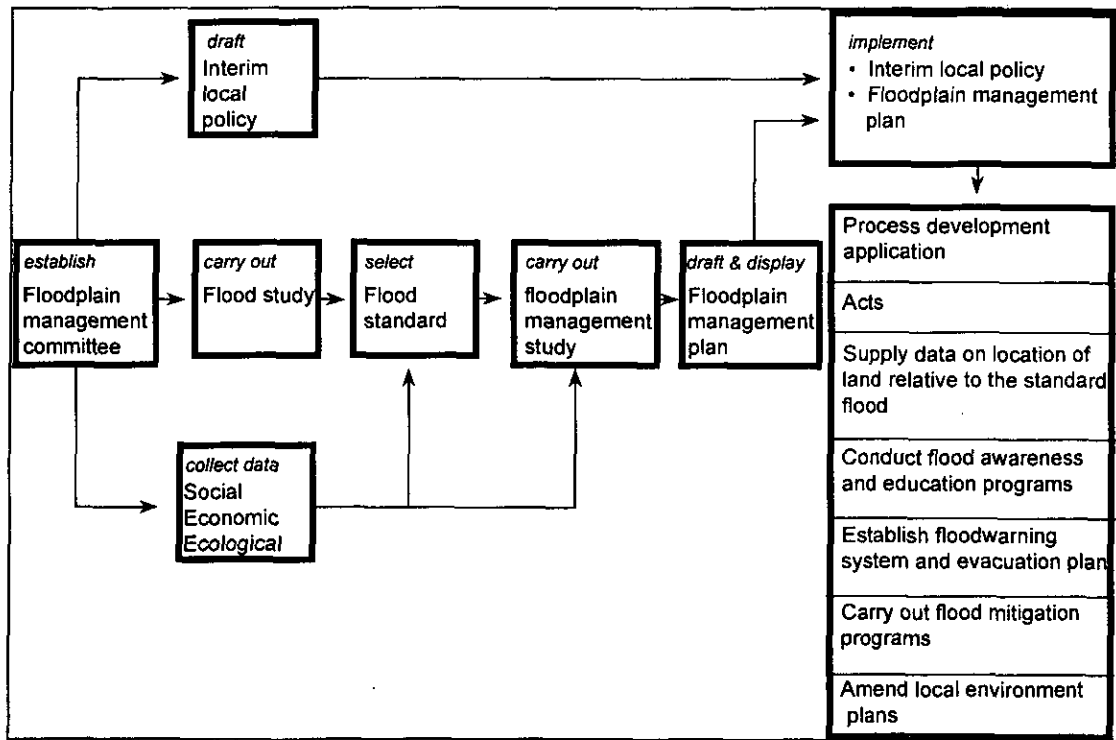
'The principal form of non-structural flood hazard reduction is regulation of flood plain development, although flood warning and flood insurance are also important' (Parker, 1995).

A central controversy throughout the research literature has been the economics and planning impact of structural flood defence projects. The traditional governmental approach to floods has been protective. "Escalator effect" is a term used by Parker (1995). It is the progressively higher levels of structural flood defence need to protect against progressively increasing flood damage potential, which is mainly caused by past-defence development of flood plains. This occurs when flood plain development controls are absent or ineffective. Flood defences are usually only constructed to the design standard warranted by the amount of flood plain development in the area to be protected before the defences are installed.

5.3 FLOOD PLAIN MANAGEMENT SYSTEM

For the effective management of a flood plain, a flood plain management system is necessary. The system exists of different actions that together form a structure to

manage a flood plain. "Flood plain Development Manual" which was published by the New South Wales Government in 1986, presents a management system as is shown in Figure 5.1.



Source: Flood plain Development Manual, New South Wales Government (1986)

Figure 5.1 A Flood plain management system

This system exists of different components, which is set up with the founding of a "flood plain management committee". The main aim of such a committee is to assist a town council in the development and implementation of a flood plain management plan. A flood study is the formal starting point in the process to describe the management options for flood plains.

An important part of the system is choosing a flood standard. It is important because it is a reference point for the development of flood management plans. "The Flood plain Management Web Site" describe a base flood as the selected flood frequency

for regulation purposes. The National Flood Insurance Program (NFIP) of the USA uses the 100-year flood as base flood. Smith (1996) states that the 1:100 year-flood line is used as the basis for urban flood plain management. It results usually from coping of other projects. There is no scientific or economical rational behind it. In South Africa the 1:50 year flood line was specified when Section 169A of the Water Act was introduced in 1975. In 1978 the act was amended and the designated flood line was reduced to 1:20 years (Alexander, 1993). For evaluation purposes the 1:100 year flood line is used in this chapter as a standard flood line to develop possible flood damage mitigation options.

5.3.1 FLOOD PLAIN MANAGEMENT STUDIES

Flood plain management studies are undertaken to identify and evaluate the effectiveness of suitable measures. Wood et al. (1985) recognised that conventional flood control planning should be based on balanced consideration of structural and nonstructural approaches. Furthermore, Woods et al. (1985) subdivides measures in levels, which reduce floods, and measures that reduce the capacity for flood damage. He classified the first as structural and the latter as non-structural measures.

Table 5.1 Examples of structural and non-structural measures for the reduction of flood damage

	Water control Measures	Land use control	Financial relief	Disaster avoidance
Structural measures	•			
Flood mitigation dams	•			
Levees	•			
By-pass floodways	•			
Channel improvements	•			
Retarding basins	•			
Non-structural measures				
Flood proofing of buildings		•		
Zoning		•		
Building & development controls		•		
Voluntary purchase		•	•	
Flood insurance			•	•
Public information & education				
Flood forecasting, warning & evacuation planning				•

Source: Flood plain Development Manual, New South Wales Government (1986)

In Table 5.1 examples are given of structural and non-structural measures for the reduction of disruption and damage caused by floods.

5.3.2 FLOOD PLAIN MANAGEMENT PLANS

Before a flood plain management plan can be drawn up, it must be assured that the plan measures up to specific criteria. According to New South Wales' "flood plain Development Manual" of 1986, a flood plain management plan must ensure the following:

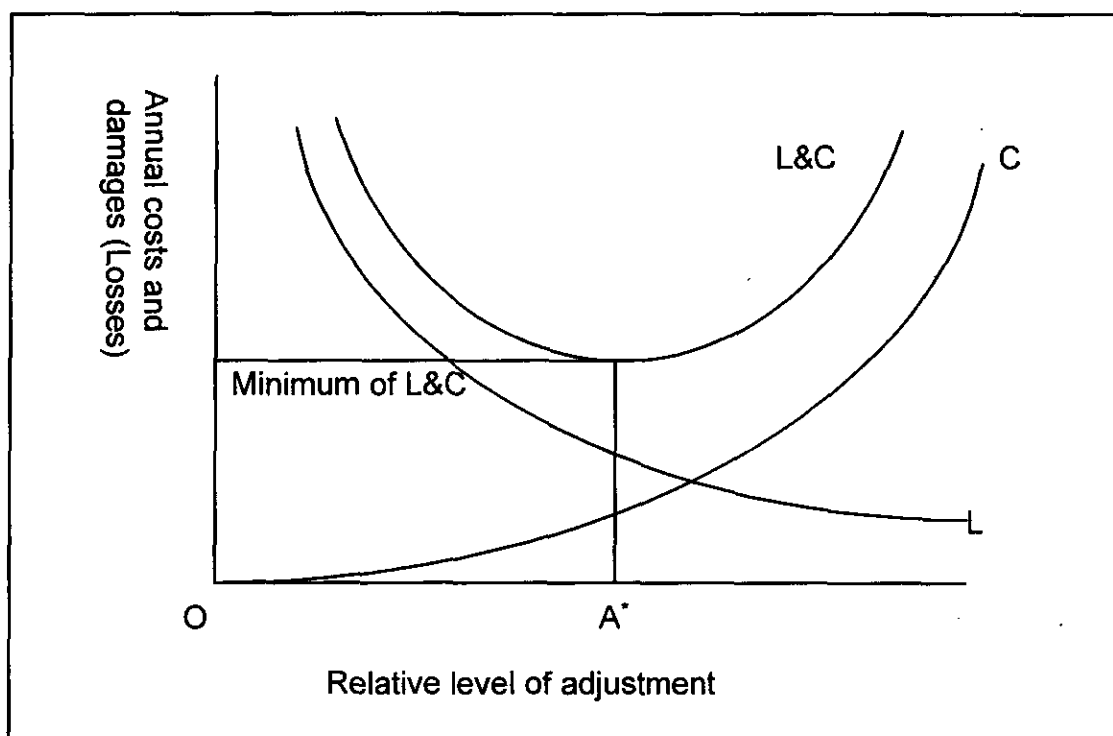
- the use of land that is prone to floods must be planned and managed in such a way that it is compatible with the calculated frequency and extent of floods,

- land that is prone to floods must be managed in such a way that social, economic and ecological costs and benefits are taken into account,
- flood plain management must also take the safety, welfare and health of the community into consideration,
- information concerning the extent of possible future floods must be available to the public,
- every possible action must be taken to reduce the danger and damage potential that can develop as a result of the development of flood plains,
- there should be no considerable growth in danger and damage potential as a result of new developments on the flood plains and
- suitable and effective flood warning systems should be in place and emergency services must be available for future floods.

5.3.2.1 Goal specification

The two approaches that are under discussion in this section indicate two possible goals for flood plain management plans. The first is the most effective level of adaptation and the second the maximum contribution to national economic development. These two are discussed, both are used in the research.

During the middle eighties, not much attention was given to an effective level of flood hazard reduction, according to Milliman (1984). Russel (1970) was (according to Milliman) one of the first to describe the optimum adjustment for natural disasters (Figure 5.2). The relative level of adjustment (A) for natural disaster is on the horizontal axle. The vertical axle measures the annual money value. In the graph curve C is the annual costs to create a specific level of adjustment. Curve L shows the expected total losses for a specific level of adjustment. The effective level is the level where the total of L and C is a minimum (A).



Source: Milliman (1984)

Figure 5.2 The optimal adjustment for natural hazards

According to Ford et al. (1989), the second method comprises the determination of an optimal plan that contributes maximally to national economic development (NED). The NED contribution of a flood plain management plan is the net benefit of the plan.

$$NB = (B_L + B_I + B_{IR}) - C$$

Where

NB = net benefit

B_L = location benefit

B_I = intensification benefit

B_{IR} = inundation reduction benefit

C = total cost for implementing and maintaining the plan.

Location benefit is the rise in net income that is brought about by additional flood plain development. Intensification benefit is the rise in net income brought about by the existing development. The flood mitigation benefit is:

$$B_{IR} = (D_{exc} - D_{plan})$$

Where

D_{exc} = flood damage for existing development

D_{plan} = damage after the plan was implemented.

Damage are measure as mean annaul damage. The function changed to :

$$NB = (B_L + B_I + [E(D_{exc}) - E(D_{plan})]) - C$$

5.3.2.2 Demarcation of areas in the flood plain

"Flooding and its effects vary both in time and place; even the problems incurred on a single flood plain vary across that flood plain for a given flood. Therefore, to achieve a merit approach to flood plain management it is necessary to divide the flood plain into categories descriptive of the impact that development may have on

floodwater and the impact that floodwater may have on development" Wood *et al.* (1985). Wood *et al.* used this approach in their development of a flood management plan for the Keene (New England) flood plain.

For planning and management, New South Wales classifies areas in flood plains in different hazard levels. These levels determine the kind of measures that can be applied in specific areas. The level of hazard is determined by hydraulic factors. If the flood velocity is 1 m/s and the depth of inundation 0,4m, the zone lies in a low hazard area. If the velocity is 1,4 m/s and the depth of overflow 1,2 m, it is a high hazard area (see Figure 5.4).

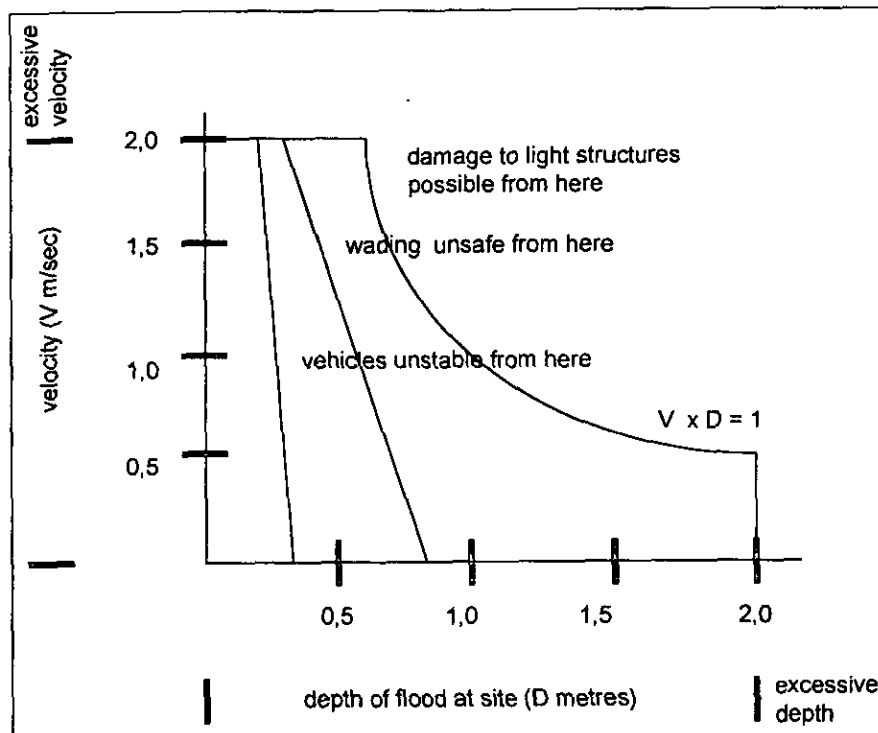
Furthermore, the flood plain is subdivided in hydraulic categories: flood way, flood storage area and flood fringe. **Flood ways** are those areas where a significant volume of water flows during floods. **Flood storage areas** are those parts of the flood plain that are important for the temporary storage of floodwaters during the passage of a flood. **Flood fringe** is the remaining area of land affected by flooding. In the absence of an hydraulic model capable of measuring impacts, flood ways and flood storage areas can be defined initially as follows.

Flood ways are those areas where the product of depth (m) and velocity of flow (m/s) is greater than 1,0 and/or those areas where removal of the cross section area available to pass flood flows will cause adjacent upstream flood levels to increase by more than 0,1m during major flooding.

Flood storage area are those areas outside flood ways that if completely filled with solid material would cause peak flood levels to increase anywhere by more than 0,1m and/or would cause the peak discharge anywhere downstream to increase by more then 10 percent.

The flood hazard resulting from depth and velocity of floodwater is summarised in Figure 5.3. This information forms the basis for the Provisional Hazard Categories

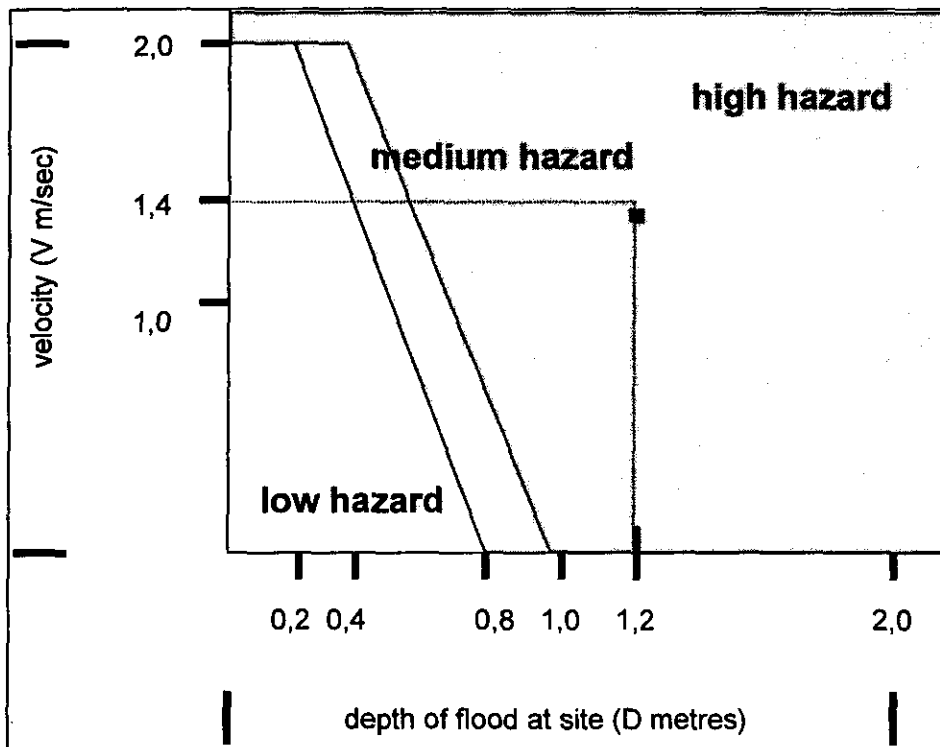
shown in Figure 5.4, which can be used initially to assign a hazard category to a particular area or site.



Source: Flood plain Development Manual, New South Wales Government (1986)

Figure 5.3 The relationship between velocity and depth of flooding with a certain level of hazard as a result

In Figure 5.3 the relationship between velocity and depth is depicted. These relations were derived from laboratory tests and flood circumstances that cause damage (Flood plain Development Manual, New South Wales Government, 1986). Should the velocity of the water be 1,5 m/s and the depth of overflow 1m, there can be damage to lighter type structures. In Figure 5.4 these relations are linked to hazards. When the velocity is 1,4 m/s and the depth of inundation 1,2 m, this area is a high hazard one.



Source: *Flood plain Development Manual, New South Wales Government (1986)*

Figure 5.4 Tentative hazard categories for flood plains

In the manual of New South Wales various tables are given that indicate the kind of policy measures that fit different circumstances. For example: when an area lies in a danger zone and in a flood storage area, the following policy is applicable:

- Any portion of a building or structure subject to inundation should be built from floodcompatible materials.
- Flood proofing above the standard flood should be required of new residences, including those associated with commercial and industrial development and of special use developments. Whilst this condition would generally apply to major residential extensions, the merits of the case should determine the need.

- The need to flood-proof commercial and industrial development should be determined on merit.
- Special consideration should be given to caravan parks as they are difficult to evacuate a fact which can be compounded by permanent vans and visitors lacking flood awareness. Also, caravans are easily damaged and can float.
- The developer or property owner should demonstrate that any building or structure can withstand the force of flowing floodwater, including debris and buoyancy forces as appropriate.
- A detailed report from an appropriate consulting engineer should be required in support of a development or building application.

The next step is to combine the different measures into a plan. Different methods have been used for this, and the one that is used in this study is discussed briefly.

5.3.3 METHOD FOR THE DEVELOPMENT OF AN OPTIMAL FLOOD DAMAGE REDUCTION PACKAGE: BRANCH-AND-BOUND ENUMERATION PROCEDURE (B AND B)

This strategy attempts to determine the lowest-cost plan. Experts identify areas where plans can be implemented. For each area the experts can propose 1. the status quo 2. levees 3. reservoirs and 4. canal improvements.

To determine the lowest cost plan, the B and B-procedure starts off with a set of plans, and subsequently the set subdivides in smaller subsets. A plan is executable when it can protect the specific area against a flood. If the plan is not feasible or the lower cost limit is higher than the costs of the best plan thus far, the plan is scrapped. Otherwise, the procedure divides the set further and the evaluation is repeated.

This procedure can analyse several measures. It uses the maximum net benefit as criteria and take hydrological risks into account by using expected-value analysis. The activities of the procedure can be explained as follows:

1. divide the plans into subsets for evaluation and choose one of the subsets,
2. determine the maximum net benefit,
3. determine the feasibility of the plans in the subsets and
4. if possible, divide the subset further and start again with no 2.

In Figure 5.5 the "branch and bound procedure" (Ford et al. 1989) is presented. From the figure it is evident that measures can be established at two locations (1 & 2) to safeguard two areas (A & B). A list of all the plans that can be executed is set up. At Site 1 a reservoir is built and the assumption is made that the option at Site 2 is optimal. It is optimal because the measure safeguards B totally without any costs. Because it is assumed that the measure at Site 2 is optimal, the net benefit calculated for Site 1, is accepted as optimal. Other options (like canal improvements) can also be evaluated for Site 1. The option with the largest net benefit is chosen.

We assume that the option with a reservoir at (1), with a net benefit of R20 000, represents the largest benefit. The plan is subdivided further to include a diversion at Site 2. The calculated net benefit for this measure is estimated as R10 000. This is tentatively regarded as optimal. Since the plan cannot be subdivided any further, one must back track in the plan up to the point that has not been divided. In this example it will be at the reservoir at Site 1. A levee at Site 2 is now being evaluated. The net benefit of R15 000 is determined for this measure. This value is larger than the previous one (diversion) and is thus the chosen one.

The plan cannot be subdivided any further and therefore one must go back to the point that has not been yet divided, and in the example this is up to the canal improvements at Site 1. Once again it is accepted that the option at Site 2 is optimal. The net benefit of this option is R7 000, which is smaller than the former packages, and it is thus not preferred aside.

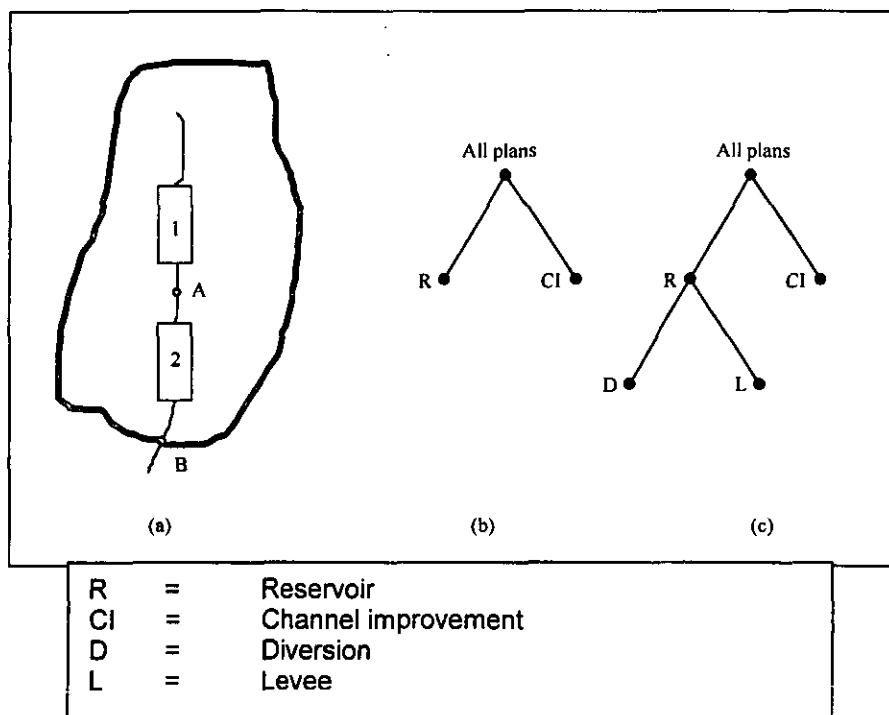


Figure 5.5 Branch-and-bound enumeration procedure for the development of an optimal flood mitigation package

5.4 THE DRAFTING OF A FLOOD PLAIN MANAGEMENT PLAN FOR THE STUDY AREA

From the discussion so far and the literature study, it is evident that the process of drafting a flood plain management plan, can be presented as in Figure 5.6.

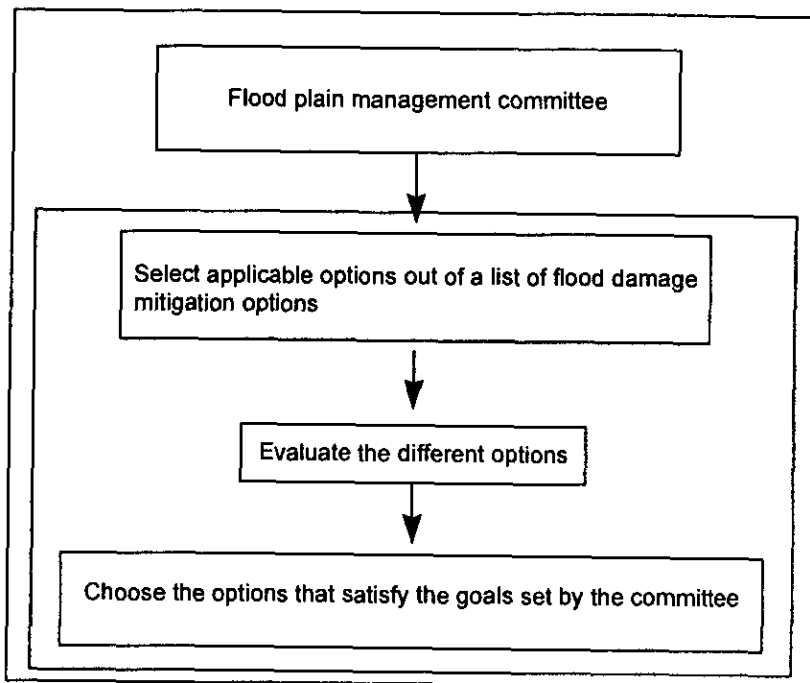


Figure 5.6 Diagrammatic presentation of the formulation of a flood plain management plan

The flood plain management committee, that can include the city engineer, city- and regional-planner, emergency- and disaster-manager and experts from the private sector, compile a list of possible flood damage mitigation options (as depicted in Table 5.1). From this list, suitable measures for the study area are selected for evaluation.

In the next sections a **hypothetical** example is used to show how a flood plain management plan can be acquired and to develop an optimal package of flood mitigation options by using TEWA.

5.4.1 THE DEVELOPMENT OF A FLOOD PLAIN MANAGEMENT PLAN FOR UITENHAGE AND DESPATCH

5.4.1.1 Activities of the flood plain management committee

The Uitenhage and Despatch City Councils decided on a joint flood plain management committee. This decision was made to ensure a holistic management of the Swartkops River flood plain.

After the flood plain management committee of the area had studied Chapter 4, and especially after observing Table 4.10 in detail, it was decided that the industrial area of the Uitenhage flood plain presents the largest problems in terms of flood damage. With the hydrology and topography of the area investigated, it is only industries that are seriously threatened by the 1:100 flood.

During their first meeting, the flood plain management committee of Uitenhage decided that their flood plan would have a dual goal: firstly to prevent loss of lives during a flood and secondly to limit damage to the minimum. The city- and regional-planner did not agree with the second goal. According to this planner, prevention of loss of lives may require measures that are not economically attainable. The planner made a proposal that the second goal should be changed to: "the effective management of Uitenhages' flood plain". This goal implies that measures must be economically achievable and to the benefit of the whole community, and that external of the measures must also be taken into account. The impact on the wild life and the fact that the measures could encourage development (by creating a false sense of safety) must for instance also be considered.

Step 1

Land use and hydrological characteristics were used to divide Uitenhage in zones. The GIS was used to overlay areas that will be flooded with 1:100 year flood with sites of industries. The properties in the middle of the flood plain are protected by the proposed levee.

Step 2

With the set goals in mind, the flood plain management committee compiled a list of possible measures that would protect the two areas. A distinction is made between measures for existing development and for new developments.

A dam upstream

The building of a dam upstream was the first measure to be considered. The city engineer's criticism against this idea was that it would be too expensive and that there is already a dam in the river. After some discussions, a mark of 2 out of 10 was allocated to this option. The committee however proposed that the Groendal Dam should be managed in a better way.

The building of levees

A disadvantage of an emergency levee would be a loss of aesthetic value to the town. That could have an impact on tourism. The committee was however of the opinion that the erection of a levee to protect the area should be investigated. After discussions this option received 6 out of 10.

The elevation of properties

It was decided that this option was not feasible because of the building material that is being used in Uitenhage. It thus scored 0/10.

Change of the river canal

The city- and regional-planner mentioned that the City Council was already busy removing blue-gum trees that grow upstream in the river. The deforestation would have ecological as well as flood damage reducing benefits. The problem was a lack of funds. After some discussions the committee allocated 7 marks to this option. It was decided to collect money for the removal of foreign trees from inhabitants in the Swartkops River area.

Flood proofing

The city engineer mentioned that this was a good idea, but that the City Council could not guarantee flood proofing of each industry and each household in Uitenhage. He made the proposal that the necessary information concerning the benefits and possibilities of flood proofing should be made available to the inhabitants. It is up to the inhabitants to make use of this measure. An 8/10 was allocated to this option.

Flood insurance

A proposal was made that insurance should be linked to another option. Although insurance should be compulsory for inhabitants that would like to develop in the flood plain. It was considered as a measure be difficult to apply. A mark of 4 out of 10 was allocated.

Zoning

According to the city- and regional-planner, zoning would take a long time to show results. It is however a good option that can be applied cost effective and received a mark of 7 points.

Removal of properties

In the current political climate, this option is not seen as feasible.

Education

Education of the community on the flood problem and how to manage it was considered by the entire committee as necessary and important and received 10 marks.

5.4.1.2 Development of a flood mitigation package

The development of an effective flood damage management strategy requires inter alia the following:

1. a comprehensive package which includes measures before, during and after floods,
2. it should be implemented continuously,
3. it should incorporate structural as well as non-structural measures and
4. it should take interaction between measures into account.

To link up with no 1 and 2, a new model for disaster management was presented in the Green Paper for Disaster Management, which was compiled by the South Africa Ministry for Provincial Affairs and Constitutional development (1998). In the "expand-contract model", disaster management is seen as a continuous process. Disasters, under which floods are categorised, are seen as a parallel series of activities in stead of a succession of actions. Prevention and restoration, for example, go hand in hand. Before a disaster, the preventative measures are more important, but after a flood restoration is the main option.

Number 3 have already been discussed, and therefore it is not necessary to discuss it in detail again. A new approach is to look wider than just structural and non-structural measures for the management of a flood plain. A new term that is used is sustainable catchment area management.

When flood damage control is practised, the interactions between the measures are not always taken into account. The effect of two measures that are applied simultaneously can for example be larger than when they are applied separately. On the other hand to obtain the same results, the size of the measures can be smaller. In this way the same effects are achieved, but less money is spent on the project.

In the following section, measures that were discussed are put together to form a package of measures. This package consists mainly of structural and non-structural measures. The interactions of the measures are not researched. An investigation of the interactions will take place during the next phase of the project.

Table 5.2 Possible flood damage reduction measures for Uitenhage and Despatch

Option	Mark	Except
Dam	2/10	No
Levee	6/10	Yes
Raising properties	0/10	No
Channel improvements	7/10	Yes
Flood proofing	8/10	Yes
Flood insurance	4/10	No
Zoning	7/10	Yes
Removal of properties	0/10	No
Education	10/10	Yes

The Flood Plain Management Committee choose the erection of a flood levee and flood proofing as options for the two areas. The method that was used is the divarication method that was discussed in Section 5.3.3.

Area 1 was first investigated. In this investigation, the benefits of the two options were estimated. First the benefits of a levee were calculated and then the benefits of flood proofing.

Levee at Area 1

To calculate the benefits of such a levee, the same approach was used that was applied by Smith (1993). With this approach, the damage curve of the area (Figure 5.7) is used to do the calculation. In this exercise, an attempt was made to protect the area against a 1:100 year flood. To determine the benefits of such an action, the curve is cut off at the 1:100 year flood and the mean annual damage is calculated. In this case, the shaded area in Figure 5.7 shows the "cutting off".

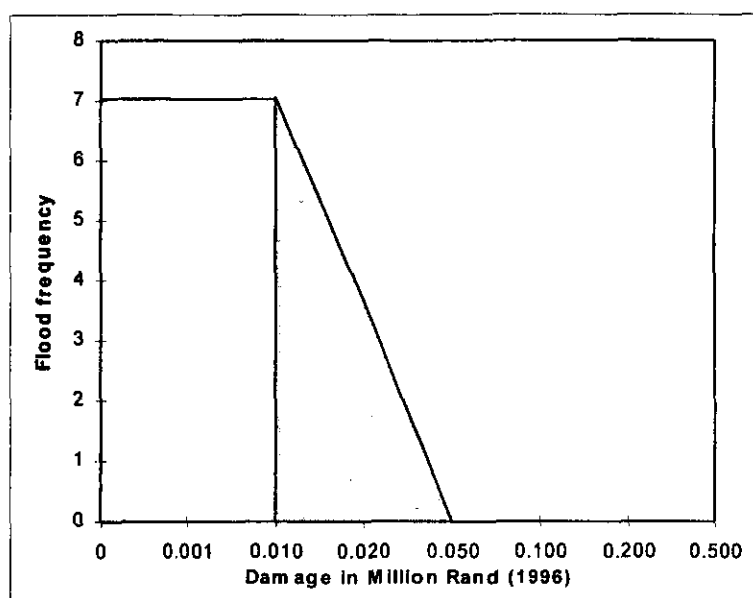


Figure 5.7 Potential flood damage in million Rand for Zone 1 in the Uitenhage flood plain, 1996

The annual average damage for an industry in Zone 1 decreased with R85 200 from R123 920 to R38 720. The construction of a levee to safeguard the area against a 1:100 year flood, can thus have an annual benefit of R85 200. While there are four industries in this zone, the value is multiplied with four and a value of R340 800 is obtained. Figure 5.8 shows the four industries that are effected by this calculations.

Uitenhage

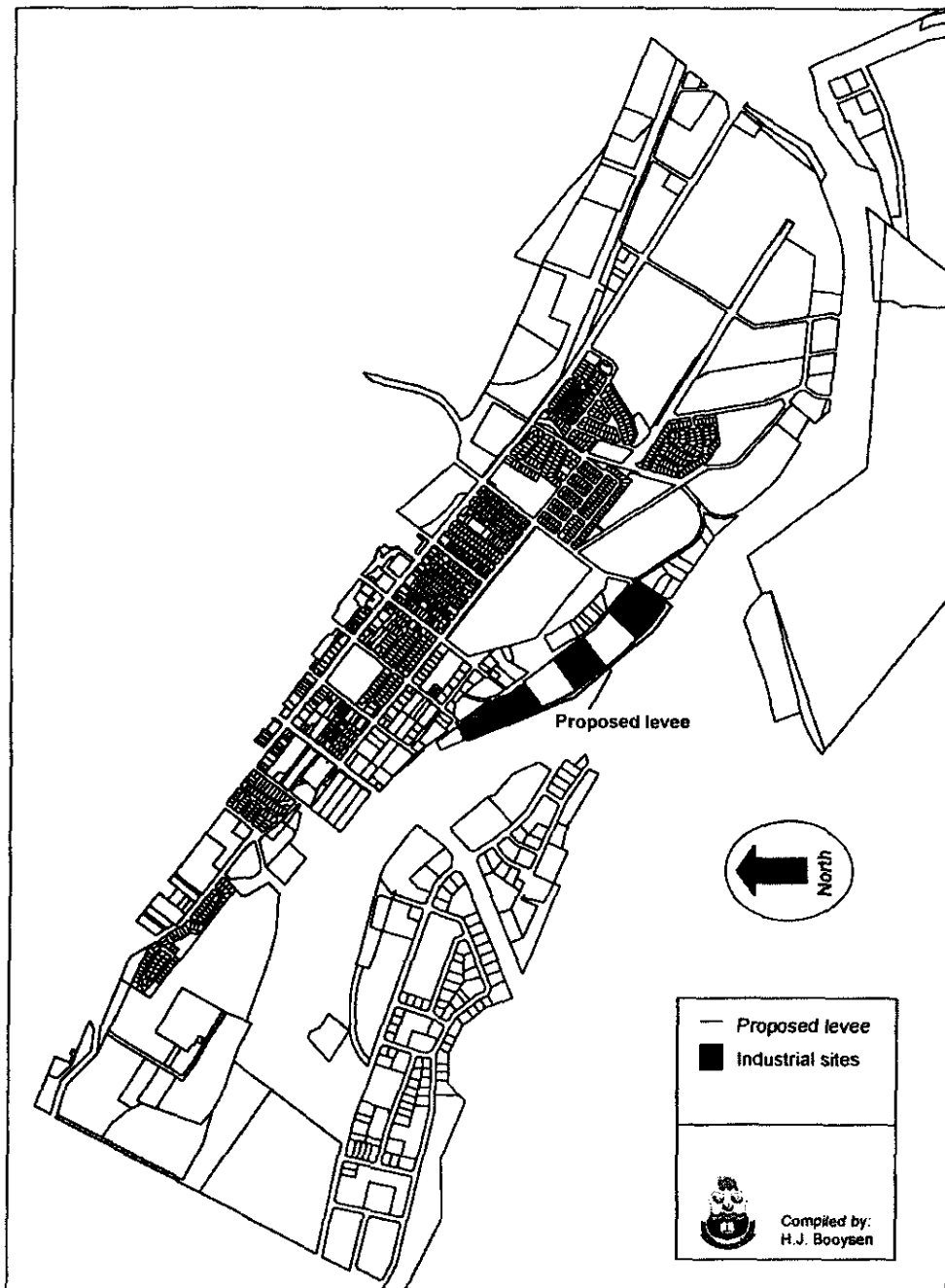


Figure 5.8 Four industrial sites that can be protected by a proposed flood levee

In co-operation with De Villiers (1998), it was determined that a levee of 2,14m should be constructed to protect Area 1 against a 1:100 year flood. Van Bladeren (1998) determined for the hypothetical exercise that, to safeguard the area, a levee of 3 m should be constructed. A levee of 1 km will use approximately 8000m³ soil be built. At R40 per cubic metre, it will cost R320 000 to build such an levee. When the levee has been erected, it must be stacked with "gabions" to stabilise it. Three thousand square metres "gabions" will be necessary to stack the levee. At R80 a square metre, the cost for this (including the stones and labour) will be R240 000. The levee plus the "gabions" will cost R560 000. This figure should be multiplied with 1,6 to incorporate professional fees and other costs. The final cost will then approximately be R896 000.

This value is the total costs, and when it is compared to the mean annual benefit of such an levee, the R896 000 should be "spread" over the lifetime of the levee. After discussions with Van Bladeren, it was decided to take 50 years as a lifetime for the levee, with maintenance expenses of R15 000 per year. In year 50 it is accepted that a 1:50 year flood will occur and repair cost is taken as 10 percent of the construction costs. All these expenses that have been incurred during the 50 year period, is discounted (at a discount rate of 5 percent) to the present value, and an amount of R1 119 427 is obtained as the present value. To compare the expenses with the mean annual damage, the yearly benefits of R340 800 should be repeated over the lifetime of the levee. The present value is calculated as R6 221 619. Should the costs of the levee be subtracted from the benefit, a net benefit of R5 102 192 is obtained. The benefit-expense ratio for this scenario is thus 5,56.

The development of flood proofing

The next option that was tested for Area 1, was the development of flood proofing. After some runs with TEWA, it was determined that an entrenchment of 0,5m is high enough to prevent flood damage. This benefit is shown in Table 5.3.

Table 5.3 Residual damage and benefit that is caused by a 0,5 metres flood proofing for Area 1 (1996)

Flood frequency (years)	Damage in Rand	Residual damage in Rand	Benefit in Rand
1:5	0	0	0
1:10	0	0	0
1:20	0	0	0
1:50	3 664 000	0	3 664 000
1:100	7 040 000	0	7 040 000
RMF	7 040 000	7 040 000	0

The mean annual damage for Area 1 without flood proofing is R123 920 and with the 0,5m flood proofing it is R38 720 with a benefit of R85 200 a year. To take the four industries into account, the value is multiplied with four. The result is R340 800.

The industry, for which this damage was calculated, has already developed flood proofing. The feasibility and cost study found in 1984 that it would cost R16 000 to develop proofing structures. By using the consumer price index (Papers of the Reserve Bank, June 1996 and November 1992), the costs were adapted to 1996. In 1996 it would cost the industry R70 000 to erect the same structures. Taking maintenance costs over a period of 50 years into account (to compare it with the levee), as well as repair costs of 10 percent for a 1:50 year flood, the present value of the costs is R176 466. Should the R70 000 be multiplied with four to incorporate the other three industries, and the maintenance costs added, the current value will be R680 225.

A total benefit of R6 191 900 is attained if the average annual benefit of R340 800 is achieved over the period of 50 years. The net benefit of flood proofing for Area 1 is thus R5 511 675 with a benefit-cost ratio of 9,1.

For Step 1, it is assumed that the option for Area 2 will be optimal, the benefit-cost ratio and net benefit of the measures of Area 1 should be compared with one another. Flood proofing for the four industries are identified as the most beneficial.

As in the example of the branch-and-bound enumeration procedure that was discussed earlier, this plan is further divided and it was decided on a levee for Area 2.

Levee for Area 2

For the protection of Area 2 (Despatch), it was calculated that a levee of 175m long and 4m high will safeguard the area against a 1:100 flood. A levee of 4,86 high is constructed to support the bank under the surface of the water. The same calculations as for Uitenhage were done, and it was found that the levee would cost R220 000 to construct. For the calculation of the present value, the same approach as in the case of Uitenhage was used. Annual maintenance costs for the levee was taken as R3 667. For year 50, repair costs of 10 percent were taken into account when it was assumed that a 1:50 year flood would occur. With these variables taken into consideration, the present value was calculated as R274 763.

The effect of this levee on mean annual damage can be described in the following way. Before the construction of the levee, the mean annual damage was R872 245. After completion of the levee the damage was R528 751 which gives a difference of R343 494. Should this value be spread over 50 years, a present value of R6 270 800 with a net benefit of R5 996 037 (benefit-cost relation 22,8) is obtained. Figure 5.9 shows the properties that will be inundated by a 1:50 year flood if there is no flood damage mitigation option in place.

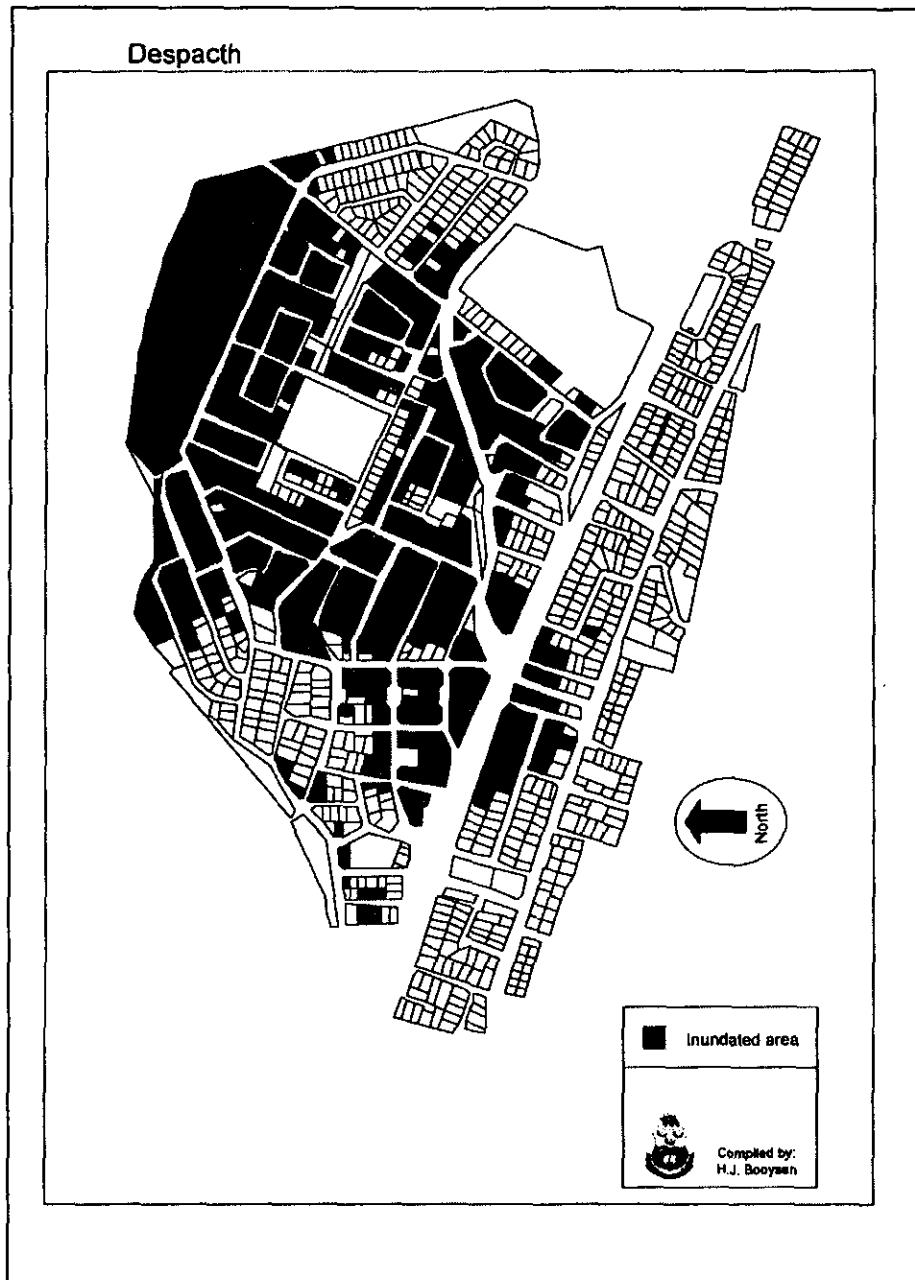


Figure 5.9 Inundated properties (1:50 year flood) in Despatch with no flood damage mitigation options in place

Figure 5.10 shows the impact if a flood levee is built to protect Despatch. A considerable amount of properties are safeguarded from a 1:50 year flood.

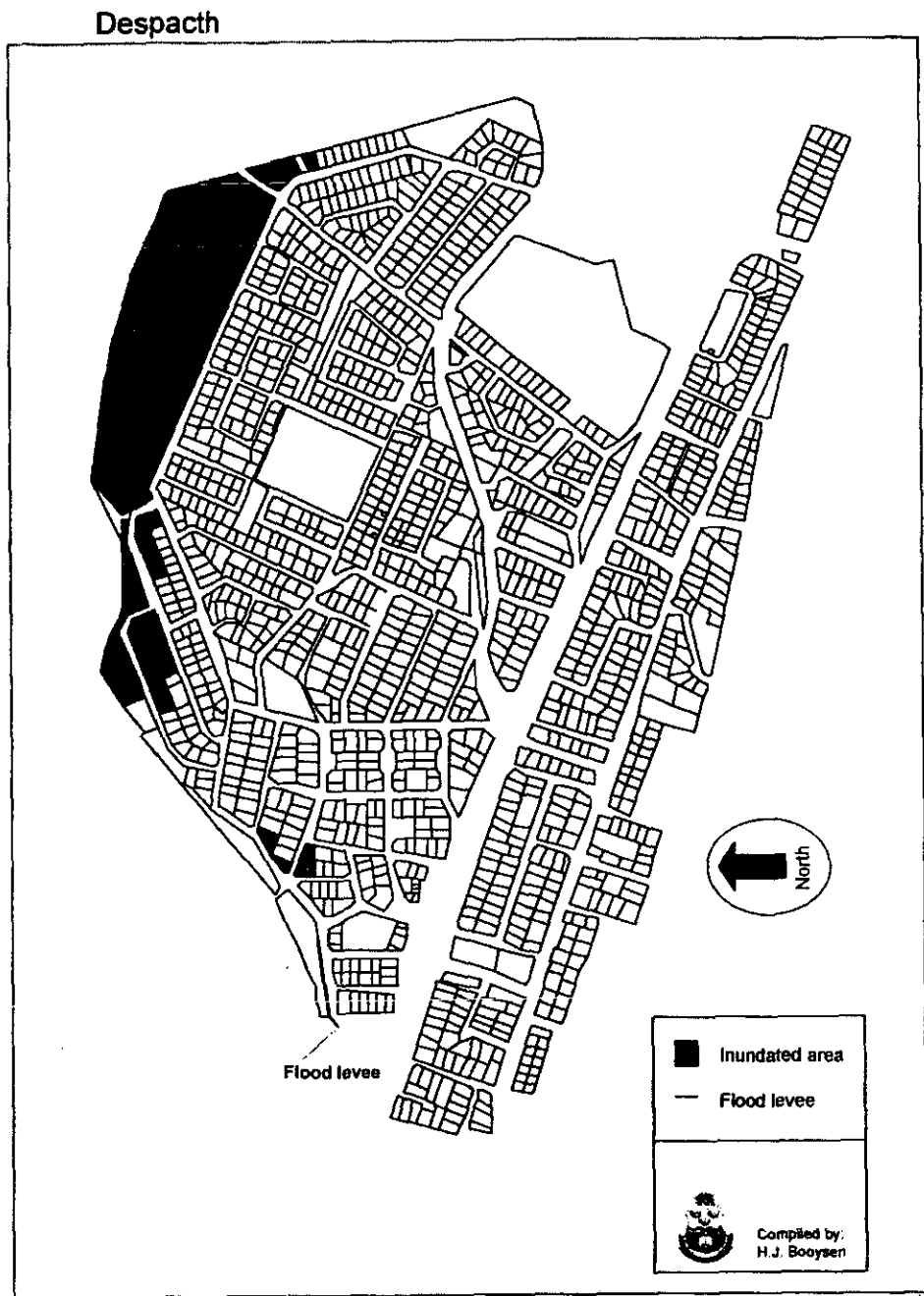


Figure 5.10 Inundated properties (1:50 year flood) in Despach with flood damage mitigation options on place

The development of flood proofing

The flood plain management committee decided not to consider flood proofing as an option, because the inhabitants would not be prepared to pay for the construction, and the city council did not have the necessary funds to subsidise it. In this case, the construction of the levee was chosen as a flood damage mitigation option.

5.4.1.3 The formulation of the flood plain plan

To attain the goals set by the flood plain management committee, the following plan can be formulated:

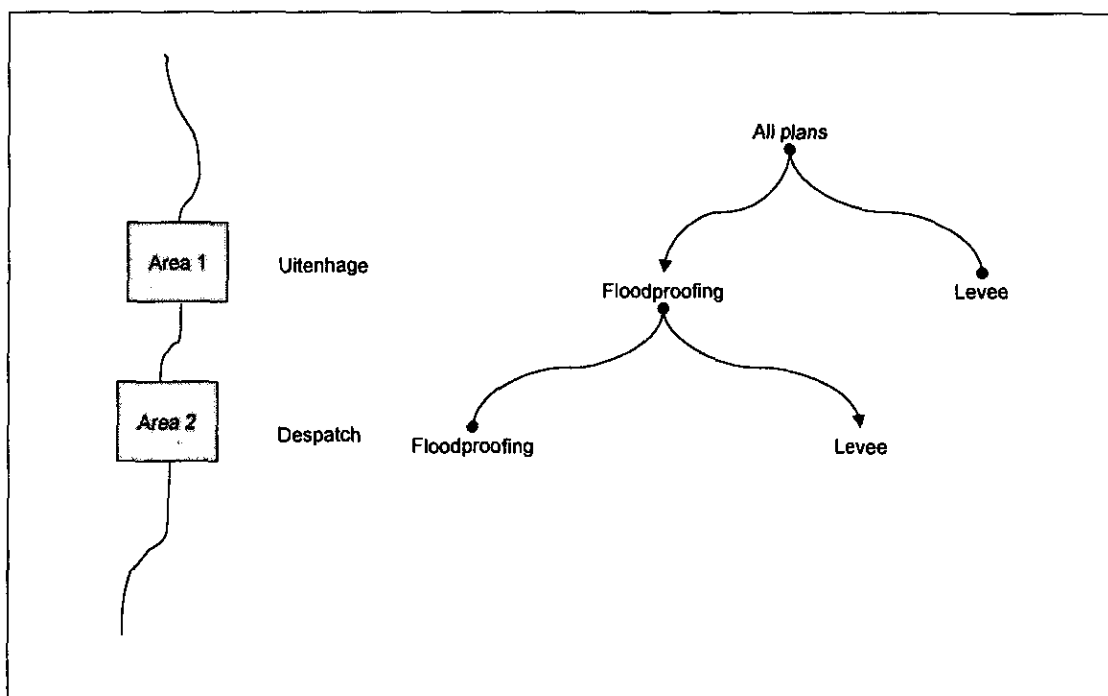


Figure 5.11 Possible flood damage reduction plan for Uitenhage and Despatch

In Figure 5.11 the combination of flood damage mitigation options that were determined by the “branch-and-bound enumeration procedure” are shown. Other options that were considered, were the removal of blue gum trees from the river near Uitenhage, as well as an educational program in which the community can be

informed on how to reduce the risks of flood damage Further study is necessary to determine the costs of these two measures. It is, however, important that the escalating effect that has been discussed in Section 5.2 should be taken into consideration. To counteract this effect, it was decided to allow no further development in the flood plain.

5.4.2 OTHER OPTIONS

Two options (constructions of levees and flood proofing) were tested in the example above. There are many other options that could be exercised but they were not so applicable in the study area. For TEWA to be used in other areas it is necessary for the model to be able to evaluate other flood damage mitigation options as well. The model is able to do that by changing some of the flood damage characteristics. In Figure 5.12 the main characteristics are shown and the linkages between them described.

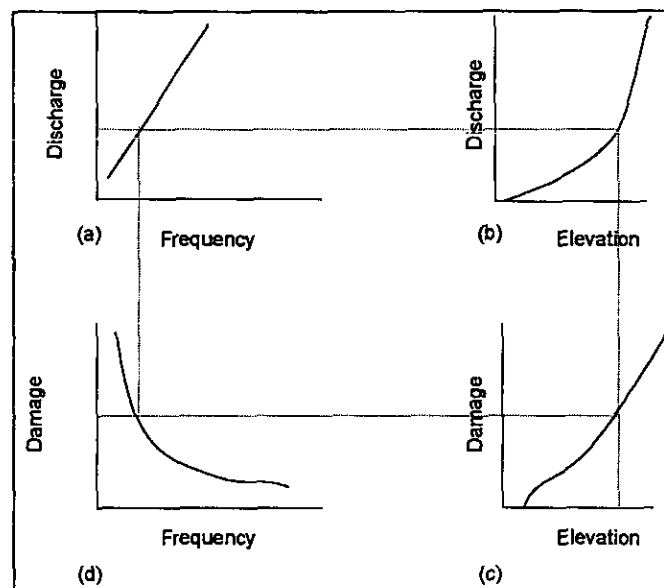


Figure 5.12 Interrelation between (a) probability/discharge, (b) elevation/discharge, (c) probability/damage and elevation/damage relationships

To calculate the effects of flood damage mitigation options it is necessary to change the values of these relationships. For example if discharge is changed, elevation is changed with an effect on flood damage.

The following sections discuss how the model calculated the effect of the two options that were tested and described how TEWA can evaluate other flood damage mitigation options. Information about the impact of the measures were obtained from the US Army Corps of Engineers, 1989.

5.4.2.1 Effect of flood control reservoir

The purpose of a flood control reservoir is to store flood water during storm periods and release it during periods of lower flow. Because the streamflow is altered by the reservoir, the flood frequency at all locations downstream are altered, generally by lowering the flow for a given frequency of event (Figure 5.13).

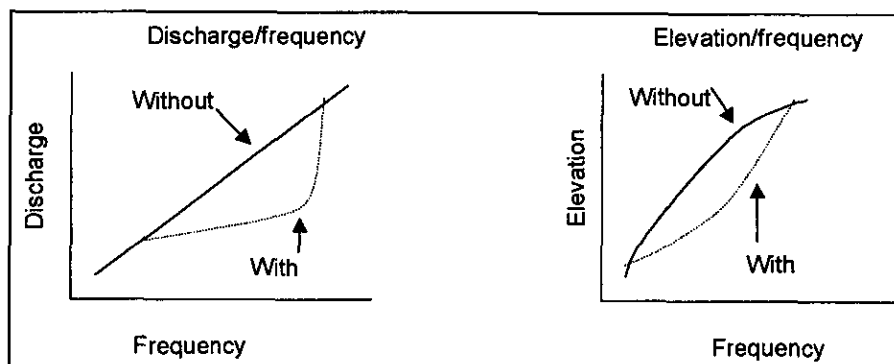


Figure 5.13 Discharge/frequency relationship depicting the effect of flood control reservoirs

Variables that must be changed in TEWA to calculate new damage values is the frequency and elevation data sets.

5.4.2.2 Effect of levee and floodwall

Levees and floodwalls are designed to prevent flooding to adjacent protected areas. The direct planned for effect is a reduction in the elevation/damage relationship below the proposed flood mitigation option (Figure 5.14). Damage will be prevented until the levee is overtopped and then the damage will be the same as without the measure. The river elevation can be raised for a given discharge. Higher flow rates can be induced downstream if a quantity of flood plain storage is eliminated.

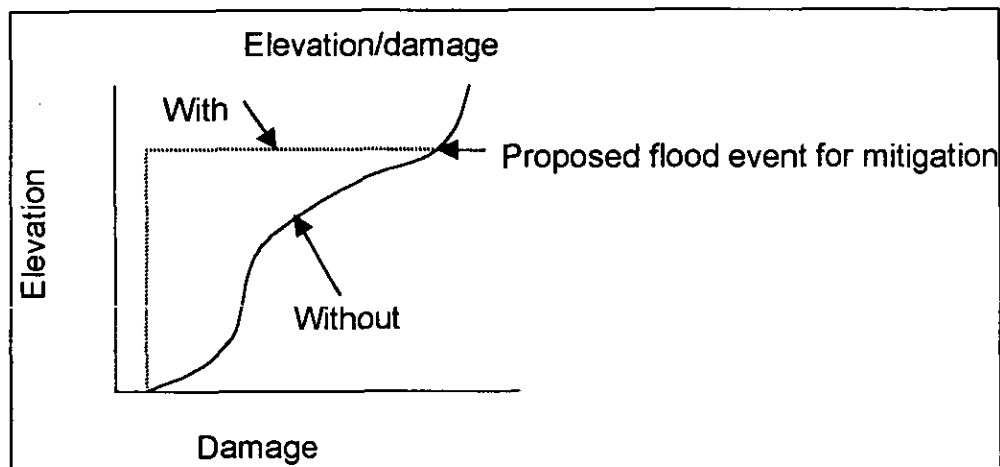


Figure 5.14 Elevation/damage relationship depicting the effect of levees and floodwalls

TEWA calculates the effect by elevating the ground height of the properties (with consideration if the levees or floodwall over tops) or discarded the flood damages which are contributed by the proposed flood measure for mitigation.

5.4.2.3 Effect of channel modification

Channel modifications are designed to increase the stream conveyance capacity by enlarging the channel flow. These actions generally lower the elevation and increase velocity for a specific flood event. The direct planned for affect is therefore a lowering of the elevation/discharge relationships (Figure 5.15).

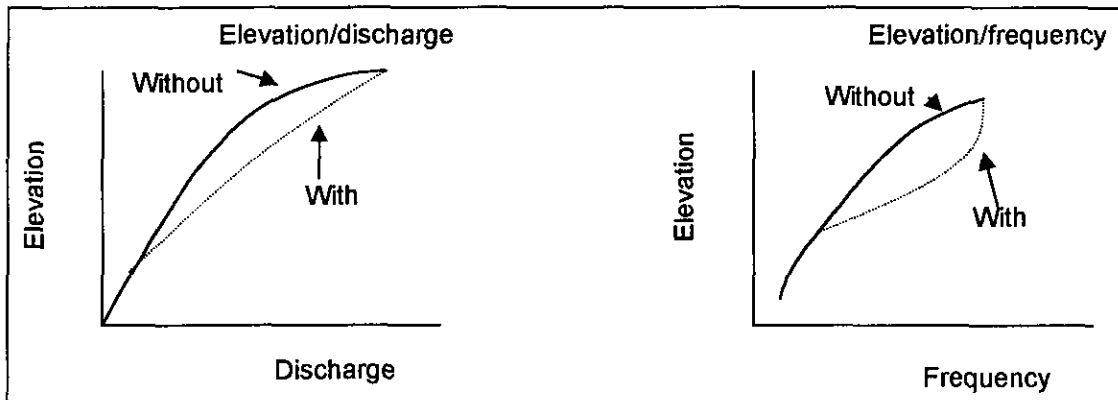


Figure 5.15 Elevation/discharge and elevation/frequency relationship depicting the effect of channel modification

The flood elevation values must be changed in TEWA to calculate the new damage values.

5.4.2.4 The effect of diversion

A diversion removes flow from the river during high stages and passes it safely away from damage areas. The direct planned for effect is the lowering of the discharge/frequency relationship (Figure 5.16).

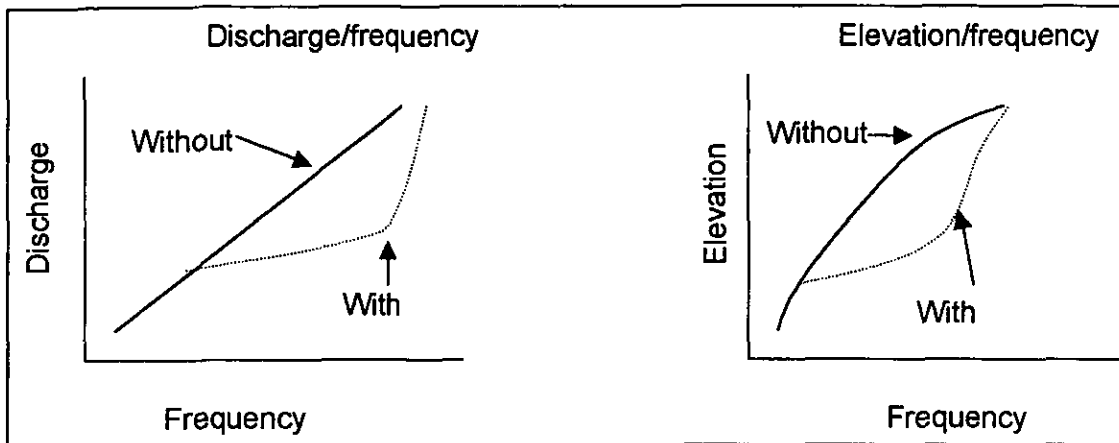


Figure 5.16 Discharge/frequency and elevation/frequency relationship depicting the effect of diversion

The flood elevation values must be changed in TEWA to calculate the new damage values.

5.4.2.5 Effect of flood warning

Advance warning can allow temporary measures to be implemented to protect or remove damageable property.

TEWA can use two methods to calculate the effect of flood forecast. Both use the actual/potential damage ratio. The first is the much quoted diagram that illustrates the relationship between actual and potential tangible damages developed by Smith *et al.* (1986) and the second one is the method used by Lustig *et al.* (1986).

5.4.2.6 Effect of flood proofing of individual structures

When protection is provided and a single structure or group of structures is “flood proofed” the relationship between elevation and damage is modified (Figure 5.17). The figure shows the impact of flood proofing all structures in a flood plain by a uniform amount. The effect of property elevation is higher than with water protection.

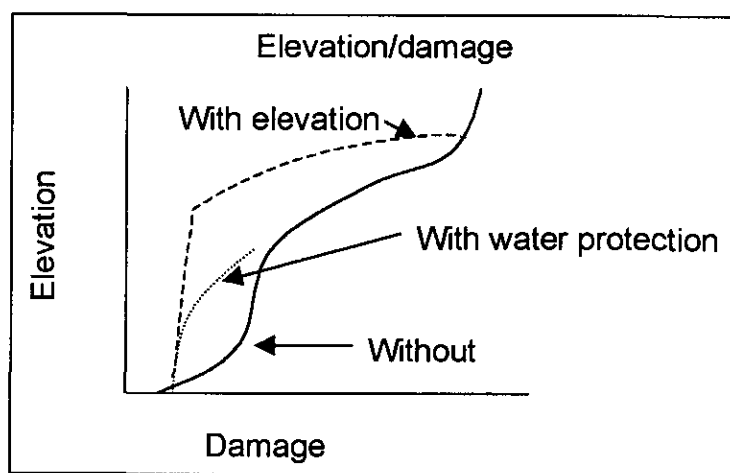


Figure 5.17 Elevation/damage relationship depicting the effect of flood proofing individual structures

TEWA calculates the effect by elevating the ground height of the properties (with consideration if the levees or floodwall over tops).

5.4.2.7 Effect of structure relocation

Land use of the study area is changed to evaluate the change that relocation brings.

5.4.2.8 Effect of future land use control

Land use controls always alter future development. These controls are design to influence future decisions so that the long term effects is to cause the stage damage curves that will exist in the future to be lowered (Figure 5.18). The figure shows that without land use control the potential of flood damage can increase. With land use control is larger floods necessary to cause flood damage.

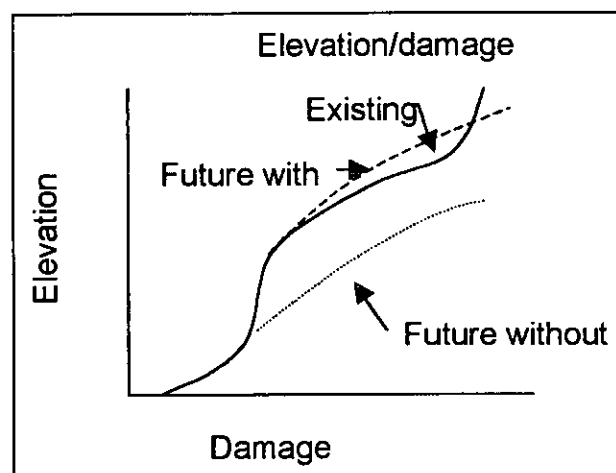


Figure 5.18 Elevation/damage relationship depicting the effect of future land use control

Again the land use data file in TEWA will be changed with proposed land use controls and the new damage values calculated.

5.5 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

In this chapter it was endeavoured to show that the computer model (TEWA) is suitable for flood plain management. At the beginning of this section, policies and views of different countries with regard to flood damage reduction measures were discussed. That was followed with a discussion of procedures for the management of a flood plain. The management system of New South Wales was discussed and

the rest of the chapter was planned with this system in mind.

The procedure for flood plain management starts with the establishment of a flood plain management committee. This committee should have wide representation. All role-players involved with floods should be represented on the committee, e.g. representatives of industries, and the commercial and residential sectors of the area. The reason for this is that the decisions of this committee will have an effect on the circumstances of all the people in the flood plain.

The task of the committee is to research the flood situation and to construct plans to reduce the risk for damage and disruptions caused by floods. For the drawing up of plans, some procedures have to be followed. Firstly, a flood standard must be determined, and secondly, hazard areas in the flood plain must be identified. After that, goals and aims that should be attained by the committee must be compiled. One such goal can be to safeguard the area against a standard flood. In the mentioned example, the 1:100 year flood was taken as a standard flood. Another goal can be that the control measures should be economically beneficial and that it should protect peoples' lives.

For the following step, measures to attain the goals should be identified. Measures must be evaluated in order to choose the best ones. This is where TEWA is used. TEWA determines what the economic benefit of each measure will be. These values are used to determine which option will be the most appropriate to achieve the goals. After the measures have been evaluated, they are combined into a plan.

In this chapter, the residential as well as industrial areas were investigated. The poor co-operation of industrialists caused that the measures could not be tested more accurately. This had as a result that assumptions had to be made to test the rest of the model. For the next phase of the project, an attempt should be made to receive information from all industrialists in the area. This will make it possible for

flood damage reduction measures to be tested more accurately.

A discussion of alternative measures that can be evaluated by TEWA conclude the chapter. The methods TEWA uses to do the calculations are also mentioned.

From this research it is evident that, for the effective management of a flood plain, the co-operation of all inhabitants of a flood plain is necessary. This starts with the compilation of data for the evaluation of flood damage reduction measures, representation on the flood plain management committee to direct involvement in flood plain management activities. Should there be a deficiency in the co-operation, the management cannot be optimally done.

CHAPTER 6

SUMMARY, CONCLUSION AND RECOMMENDATIONS

6.1 INTRODUCTION

The main aim of this report is the development and adaptation of flood damage functions, models and computer programs for urban areas in the RSA. It is an extension of previous research done in South Africa also dealing with the development of flood damage functions, models, and computer programs. During the present phase, flood damage functions were developed for new land uses such as informal settlements, and standard flood damage functions were constructed for the residential and commercial sectors.

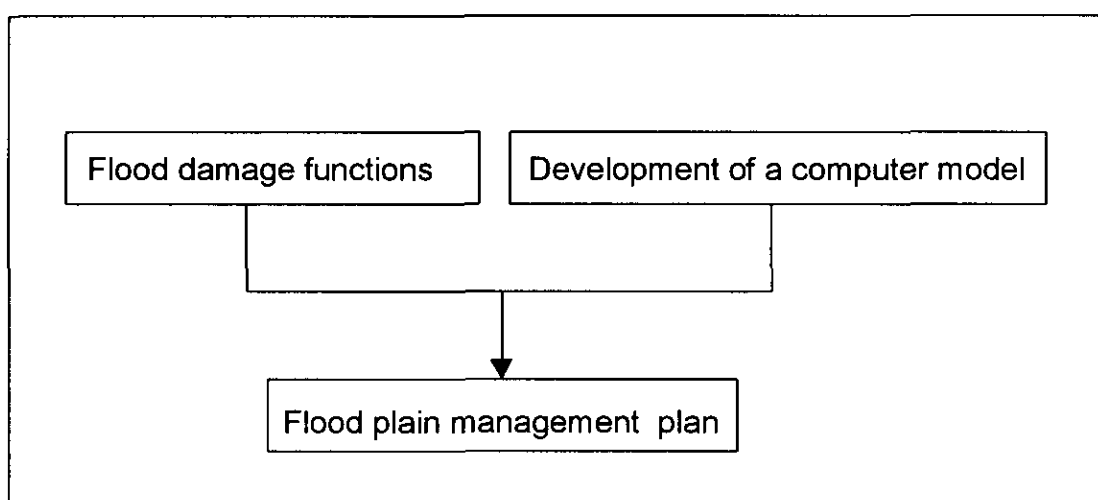


Figure 6.1 The main divisions of the research

The report is divided into three parts, namely flood damage functions, computer models and the development of a flood plain management plan. Figure 6.1 shows the relationship between the three components. Flood damage functions are an

important part of the computer model in the evaluation of flood damage mitigation options that are part of a flood plain management plan.

The rest of this chapter is divided into three parts. In the first part the accomplishment of the objectives are discussed. Secondly the conclusions of the research are given and lastly some recommendations are listed.

6.2 OBJECTIVES

6.2.1 OBJECTIVE 1

The development of flood damage functions for a few land uses within flood plains in urban areas.

In **Chapter 3** the development of flood damage functions for Despatch, Uitenhage and Soweto-on-Sea are discussed. The depth/percentage as well as the depth/damage ratios are discussed in this report. A question that arises, especially with regard to the residential sector is: Should the market value of houses be used or should their municipal value be used?

According to people who have knowledge of the house market, there is a large variation in the prices of houses throughout the country. To solve this problem, Smith (1993) used the depth/damage approach. He identified categories by using the front views of houses. Booysen (1996) also used this method in South Africa. Depth/damage functions were drawn up for each category. In successive research (Despatch and Uitenhage) it was confirmed that this approach can be applied successfully, and it was decided to use the depth/damage approach in future research.

6.2.1.1 The development of residential flood damage functions

For the formulation of residential flood damage functions, the damage functions were divided in two parts. Firstly damage functions for the structure and contents of houses were determined (Booyesen, 1996) and secondly a combined damage function was calculated by combining the contents and structure damage functions.

The development of flood damage functions for formal housing

Booyesen (1996) discussed the development of residential damage functions in detail. In short it boils down to the development of separate functions for contents and structures. Properties were categorised and for each category a contents and structure damage function was developed. These functions were then combined for each category.

The development of flood damage functions for informal housing

Flood damage functions for informal settlements were not determined during former research in South Africa. Such settlements are however a reality on South African flood plains, as is the case in the study area. This area was used to develop flood damage functions for informal houses. During pre-investigation houses in this flood plain were categorised into two classes, Class 1 were houses with only one room and Class 2 were houses with two or more rooms.

The development of residential flood damage functions which can be applied generally

In the first approach damage functions were determined by expressing damage as a percentage of the overall value of the contents of a house. Subsequently the flood damage functions, which were developed for Upington, Vereeniging (Booyesen, 1996), Despatch and Uitenhage, were combined to determine standard flood damage functions.

Damage as percentage of total value

Contents of houses were categorised according to the rooms in a house (see the table in Appendix 2 of Booysens' dissertation, 1994). Items were categorised into the following categories: Lounge, Dining room/Kitchen and Bedroom. Other categories are: Wall hangings, Ornaments and Other. Items like vacuum cleaners, washing machines and bedding were categorised as Other, and paintings as Wall-hangings. The total value of the items in each room were recorded at the present value of the items. Present value was determined as the current market value of the items and not the replacement value thereof. Age and value reductions were thus taken into account. All data in similar categories were grouped, and a regression-analysis performed.

Standard flood damage functions

Standard flood damage functions were developed by examining a variety of housing units in different parts of the country. Categories that were identified for the different areas were combined to develop standard categories. Four urban areas in South Africa that had already been researched were Upington, Vereeniging, Despatch and Uitenhage. The Upington residential area was divided into eight categories, Vereeniging into 15, Despatch and Uitenhage into three each. After the residential flood damage functions of the four study-areas were compared, different categories were combined to form new categories. This combining was done according to the house content flood damage functions of the various categories.

Eight new categories were identified, of which five represented single-storey and three double-storey buildings. After grouping the content flood damage functions of the individual houses in the new categories regression-analyses was done and new functions determined.

Finally the structural damage functions were added. These damage functions that were developed in 1993 (Booyesen, 1996), were adapted for inflation after 1993.

6.2.1.2 The development of flood damage functions for commercial areas

In this section the development of flood damage functions for Despatch and Uitenhage is summarised. The method that was used for the development of flood damage functions, is the same as the one applied by Booyesen (1996).

The development of commercial flood damage functions for the Despatch and Uitenhage area

The first step was to identify businesses situated in the flood plain. Information from these businesses was obtained through the completion of questionnaires by the owners of the businesses. From the collected data, a damage function for each business was calculated. For each business a damage function was compiled for stock, equipment, structure and the loss of income. To obtain an overall flood damage function for the business, the damage to the different components were added together.

The development of standard commercial flood damage functions

Practically, while conducting this research, and from the literature it was confirmed that developing standard flood damage functions for the commercial is more difficult than for the residential sector. By using Smith's (1993) approach, it was possible to develop such functions. From the areas that have been researched (Vereeniging, Despatch and Uitenhage) data was compiled and an attempt was made to draw up a standard function for the commercial sector. These flood damage functions are the total flood damage functions, which include structure damage. Since the same approach (as discussed above) was used for the development of flood damage functions in the three areas, it was decided that the data could be combined to develop a standard flood damage function. Seeing that Vereeniging's survey was

done in 1993, the values were adjusted to reflect 1996 prices. The original data sets for the development of standard flood damage functions were used for Vereeniging, Despatch and Uitenhage and all the individual flood damage functions were sorted according to the value of stock and the floor area of the property.

6.2.1.3 The development of industrial flood damage functions

From the literature Booyesen (1996) found that industrial flood damage functions couldn't be categorised like residential and commercial flood damage functions. The reason for this is that the plants differ too much. Some of the differences lie in the methods of production, management differences and variations in size of the plants. For the calculation of industrial flood damages, the procedure is thus to have questionnaires completed at each plant in the study area and to construct a function for each one. During the research in Uitenhage the co-operation of the industrialists differed to a large extent. Some of the industrialists were immediately supportive and completed the questionnaires while others consented to an interview, but questionnaires were never received back from these people as was promised. Only six questionnaires were processed.

6.2.2 OBJECTIVE 2 AND 3

The further development of flood damage models and computer programs to be generally more applicable in urban areas. Beside the utilisation of new technology like remote sensing, the models will be adapted for three levels of decision-making (local, regional and national) and they will fall into line with the revised national flood-management policy. The drawing up and adjustment of guidelines (if necessary) to make the policy feasible on all three levels, will also receive attention.

.And

The testing, validation and verifying of models and computer programs for selected areas.

6.2.2.1 Chapter 4

The aim of this chapter was to report on the development of computer models for the management and planning of a floodplain. Firstly the adjustment of an Australian developed computer model (Anuflood) for South African situations and secondly the development of a GIS based model (TEWA) were discussed. Knowledge that was obtained by adjusting ANUFLOOD for South African situations and by studying the FDA package (from the USA) was used to develop a new flood plain management tool TEWA. TEWA is the acronym for "a computer model for Tangible Economical flood Water damage Assessment", and thus is a computer model that calculates tangible flood damages. Furthermore the model can also evaluate different flood damage mitigation options. With this facility the model is also able to determine the optimal location for new development in a floodplain. There are mainly two reasons that resulted in the development of TEWA. The first reason is the benefits of Geographical Information Systems (GIS) which are better map production (the study area is represented visually on the computer screen) and additional query possibilities (for example to determine which area satisfy certain criteria) that can be handled. The other reason is because ANUFLOOD was developed in Australia there is no backup support in South Africa.

The development of TEWA

The GIS-program used to develop TEWA was AllyMap, a GIS program distributed by Allyson Lawless in Johannesburg. The data base program used for the calculations and data management was dBase III Plus. Firstly the input data were discussed, the different types of data that were used in the simulations, as well as the methods used to manipulate the data for computer analyses.

The input for the GIS model includes geographical and attribute data. The geographical data (maps) were obtained by using two approaches. Firstly maps in

digital form were obtained from the municipality of Uitenhage. The municipality obtained their maps either from digitising themselves or from the Surveyor-General. These maps were in dxf-format and were imported into the AllyMap data structure. In the second approach a map of Despatch was digitised. On all the maps plot-numbers were used as identifiers and were put manually on the maps. It was done by viewing the maps on computer screen and using the mouse to put the plot-numbers onto the map. With an operation in AllyMap these plot-numbers were incorporated into the map's database.

Characteristics of the properties prevailing in the floodplain were necessary to do the analyses. From these characteristics it was possible to link the properties to other information sources such as flood damage functions and hydrological data. Information such as the type of properties, height above sea level and the location of the property were used to determine the flood damage. Additional information such as addresses of properties that can be used in emergency planning were also included in the attribute data.

Information collected

Two approaches were followed for Uitenhage. (1) the residential houses were classified using aerial photography and ortho-maps. After the houses on the photos were compared, they were categorised into three classes: small, medium and large. (2) the land uses were classified by driving through the study area and noting the different characteristics in matrix form. During these surveys information on the properties was collected. For residential land uses the information that was gathered was the general location of the property, street address and -numbers, height raised, number of storeys, building materials used and socio-economic classification. Other information retrieved from maps was the heights above sea level of the houses. Although the information can be obtained from a DTM, the GIS program that was used in this research does not support this function and therefore the elevation information that was gathered from ortho-maps was inputted into the computer

database manually. The same type of data as for the residential properties: general location, street address, height raised, building materials used and commercial classification was gathered for commercial land uses. Information from industrial sites was more specific. Only the second approach was used for Despatch.

Program description

The main aim of the program is to calculate tangible flood damage. Using this information the program evaluates flood damage mitigation options. (1) the program looks at the location, (2) the location determines the hydrological data that must be used, (3) flood depth is replaced by flood elevation minus ground height, (4) class and flood depth determine the potential damage to the property, (5) damage in the main file is replaced by the flood damage function's damage calculation and all the damages are added together to get the total damage for a particular scenario.

The use of TEWA in the study area

A problem that has been identified is that the lower areas in the flood plain of the study area form "islands". At Despatch, for example, there is an area in the middle of the town that is lower than the surrounding areas. Because these areas are lower than the flood elevation, it implies that they too might become flooded. However higher surrounding areas will prevent these areas from being flooded during specific floods. AllyMap could not handle this problem and an alternative solution had to be found.

Soweto-on-Sea

Two methods were used to project the potential magnitude of financial losses in the Soweto-on-Sea informal settlement area. (1) each house was dealt with separately. (2) the area was grouped into 94 zones, and an estimate was made of damages in each separate zone.

The data inputs, which were necessary to do the estimation, were the same as those that were used for the formal settlements. As was discussed in Chapter 3, two flood damage functions were drafted for informal housing: one for a one-roomed house and a second one for a house with more than one room. For calculating damages, two methods were used. Firstly, the location of the house was determined. That determined the cross section and thus also the hydrological information used. The region was divided into 23 areas and each area had its own cross section. After the depth of the flood was calculated, the damage for each flood was determined. The site of each house was drawn from maps (1994) provided by private consultants.

In the second method the previous two flood damage functions had been reduced to one. The reason for this was because identification and classifications had been made from aerial photographs.

Calculation of damage for different zones

TEWA was used to determine potential damage to different sectors in the study area. Firstly the residential damage of the three areas, Despatch, Uitenhage and Soweto-on-Sea, was determined. Subsequently, damage for the commercial and industrial sectors was calculated. Potential damage was determined by flood occurrence and presented in tables.

Residential area

Despatch

The total damage if the regional maximum flood occurs was calculated as R56 000 000 at 1996 price levels.

Uitenhage

Only the Regional Maximum Flood will cause damage in the residential areas. The damage value of Method 2, which is the more accurate calculation, was 17,21 percent lower than the calculations from Method 1.

Soweto-on-Sea

Damage for Soweto-on-Sea varied from R2,7 million (1:2 year flood) to R6 million (RMF) according to Method 1. The relatively high damage figures show that, although Soweto-on-Sea is an informal settlement, the potential for damage to informal settlements cannot be underestimated. Although Method 1 is more accurate than Method 2, the two values do not differ very much. This means that Method 2 can also be used for the calculation of flood-damage.

COMMERCIAL SECTOR**Despatch**

According to the analysis, the potential for damage in the Despatch commercial sector is not high, especially when it is compared to that of the residential areas.

Uitenhage

Damage only occurs from a 1:50 year flood and above. It is only the Regional Maximum Flood which will cause significant damage in Uitenhage's commercial and industrial sectors.

During a 1:50 year flood, damage of only R28 000 can be expected, while the Regional Maximum Flood can cause damage of R2,7 million for the commercial properties at 1996 price levels.

INDUSTRIAL SECTOR**Uitenhage**

In the case of Uitenhage it was not possible to do a meaningful analysis because problems were experienced with the co-operation of manufacturers. Damage to the five industries researched varied from R3 664 000 for the 1:50 year flood to R26 247 500 for the Regional Maximum Flood. If it is taken into account that this constitutes only 28 percent of the industries in the flooded area, it can be accepted that the potential for damage in the Uitenhage area can be considerable.

TOTAL DAMAGE FOR THE WHOLE STUDY AREA

The largest damage component in Despatch is the residential sector. The commercial sectors constitute only 2,9 percent of the total potential damage. Earlier in this chapter it was noted that only five of the estimated 18 in the flood plain of Uitenhage were researched. Despite this the industrial damage is still the largest component of the total damage. Industrial damages constitute 99 percent of the total for a 1:100 year flood and 56 percent for the RMF. In Chapter 5 it is discussed how this phenomenon could make an impact on the flood damage mitigation options.

THE CALCULATION OF THE MEAN ANNUAL DAMAGE (MAD)

To determine the mean annual damage for the study area, it was accepted that floods larger as the 1:4 year would cause flood damage. The yearly damage was calculated by determining the surface under the damage function. The MAD was obtained by calculating the surfaces of the triangles and rectangles under the different line segments and then by adding them together.

6.2.2.2 Chapter 5

In this chapter it was endeavoured to show that the computer model (TEWA) can be used for floodplain management. At the beginning of this chapter, policies and views of different countries with regard to flood damage reduction measurements were discussed. That was followed by a discussion of procedures for the management of a floodplain. The management system of New South Wales was discussed and the rest of the chapter was outlined with this system in mind.

The procedure for floodplain management starts with the election of a floodplain management committee. The composition of this committee should have a wide representation. All role-players involved in floods should be represented, e.g. representatives of industries, and the commercial and residential sectors of the area. The reason for this is that the decisions of this committee will have an effect on the circumstances of all of the people in the floodplain.

The task of the committee is to do research on the flood situation and to draw up plans to reduce the risk for damage and disruptions caused by floods. For the drawing up of plans, some procedures have to be followed. Firstly a flood standard must be determined, and secondly hazard areas in the floodplain must be identified. After that, goals and aims that should be attained by the committee must be compiled. One such goal can be to safeguard the area against a standard flood. In the mentioned example, the 1:100 year flood was taken as a standard flood. Another goal can be that the measures should be economically beneficial and it should protect peoples' lives.

In the following step, measures to attain the goals must be identified. Measures must be prioritized. This is where TEWA is used. TEWA determines what the economic benefit of each measure would be. These values are used to determine which options will be the most appropriate so as to achieve the goals. After the measures have been evaluated, they are combined to form a flood plain management plan.

6.3 CONCLUSION

The main aim of this report was the development and adaptation of flood damage functions, models and computer programs for urban areas in the RSA. It was an extension of previous research, which also dealt with the development of flood damage functions, models, and computer programs. During this last phase, flood damage functions were developed for other land uses such as informal settlements together with standard flood damage functions for the residential and commercial sectors. The development of the new and standard flood damage functions have expanded the database for flood damage functions. Currently the data base consist of the relevant flood damage functions and a description of the different categories . Photos showing the properties of relevant land use types are included with the descriptions. The photo gallery for the residential properties is complete but the commercial activities still need some more photos.

6.3.1 THE TRANSITION FROM ANUFLOOD TO TEWA

The reasons for choosing to develop a new model was discussed earlier in this report but the main reasons were the origin of ANUFLOOD and the changing requirements for the applications of the model. It was necessary to evaluate a new approach to flood plain management. The new approach entails less structural measures but more management. Furthermore the use of a GIS improves the application of the model as a managing tool, the most obvious reasons being the map creation capabilities and the ability to combine different sets of data in a GIS.

The workings of the model are very basic. It uses a map of the study area and combines it with attribute data of the properties in the floodplain. The attribute data is stored in a fixed data file that makes it easier to input the data. It is also not necessary to export or import to other file formats; the data file can be used as it is. In the next phase the model will be programmed so that it can be used without the help of a model developer, after which TEWA will be tested for its suitability to simulate optimal flood plain management decisions.

The main application option of the model is the calculation of potential flood damage, furthermore it can evaluate flood damage mitigation options. Currently it can only evaluate most structural measures but is already being modified to test other options such as zoning and the best location for land uses in terms of flood damage. Another aspect that still needs attention is the capability to examine options that can be implemented during and after a flood.

The answers generated by the model to calculate flood damage were tested in Section 4.4.3.4. The conclusion was that it gave satisfactory results and that the program can be used for the calculation of flood damage and the evaluation of some mitigation options.

6.4 RECOMMENDATIONS

Looking at the aims of the research, the development of flood damage functions was one of the main aspects of the study. The construction of flood damage functions is an important phase in the process of calculating flood damage. Three methods can be used to construct flood damage functions for a study area. The first one is simply using standard flood damage functions in the calculations. Secondly a percentage flood damage function can be used. To use this method it is necessary to complete a short questionnaire in which the respondent inter alia gives the values of household items. The third option is to conduct a complete survey in the study area. During this survey respondents are asked to supply a full inventory of their property. Flood damage functions are then calculated from this.

The method used will depend on the following aspects:

- time available for the study,
- the finances available and
- the expertise of the project members.

6.4.1 RECOMMENDATIONS FOR THE USE OF THE MODEL

At the moment it is still necessary for the developer of the model to perform the operations. The recommendation is therefore that the model be developed further so that potential users can use it with little or no assistance.

6.4.2 RECOMMENDATIONS FOR FURTHER RESEARCH

During this phase of the study the need for further research was identified. Although the UOFS is busy with the development of tools/aids to calculate flood damage and evaluate flood damage mitigation options, there is a need to integrate the different tools/aids into one system. This includes the questionnaires that can be used to obtain data to develop flood damage functions, land use and hydrological data and the models themselves.

A Further task is to make the information accessible to potential users. One way to do it is to use the Internet. It is envisaged that flood damage functions with photos, questionnaires and software will be placed on the Internet where it can be downloaded. When the information is downloaded it can be combined with local information such as land use data. Technology transfer by way of workshops and seminars is also needed.

A further field of research is the management of urban floodplains as part of the integrated catchment area. For the development of an optimal package of flood damage mitigation options it is important to research the interaction between mitigation options in South Africa. Options that can be used before, during and after a flood must especially be evaluated.

Another area that needs further research is the replacement of rigid flood lines for the restriction of flood plain development with development lines for potential development areas. Development areas can be determined by flood depth, water velocity and land use. Development that is suitable for one area may be unsuitable for another area both areas can be situated below the same flood line.

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APPENDIX **A**

- Figure A.1 Residential and commercial properties in the Despatch flood plain
- Figure A.2 Residential, commercial and industrial areas in the Uitenhage flood plain
- Figure A.3 Residential zones in Despatch used for the calculation of flood damage
- Figure A.4 Residential zones in Uitenhage used for the calculation of flood damage

Despach

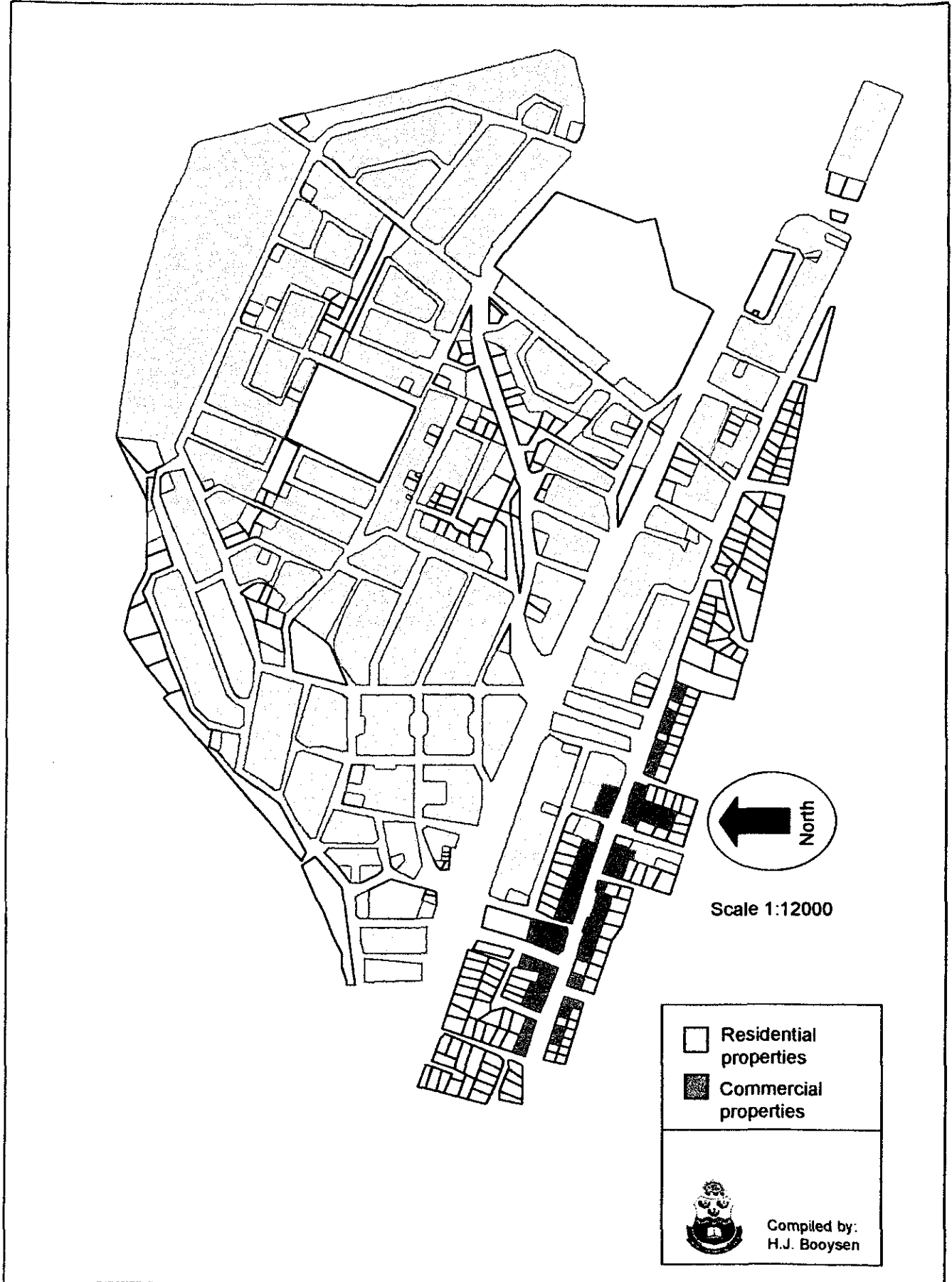


Figure A.1 Residential and commercial properties in the Despach flood plain

Uitenhage

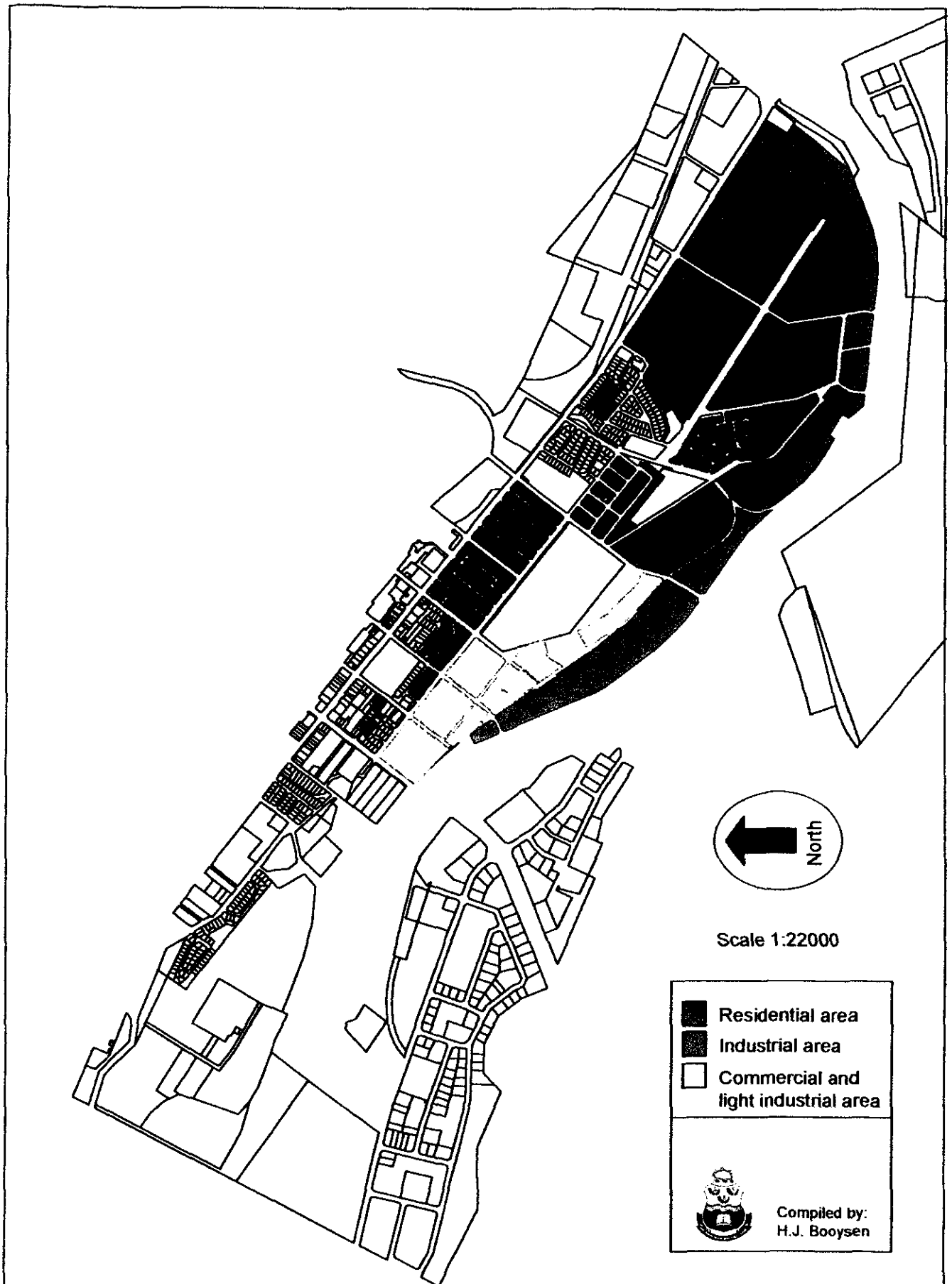


Figure A.2 Residential, commercial and industrial areas in the Uitenhage flood plain

Despach

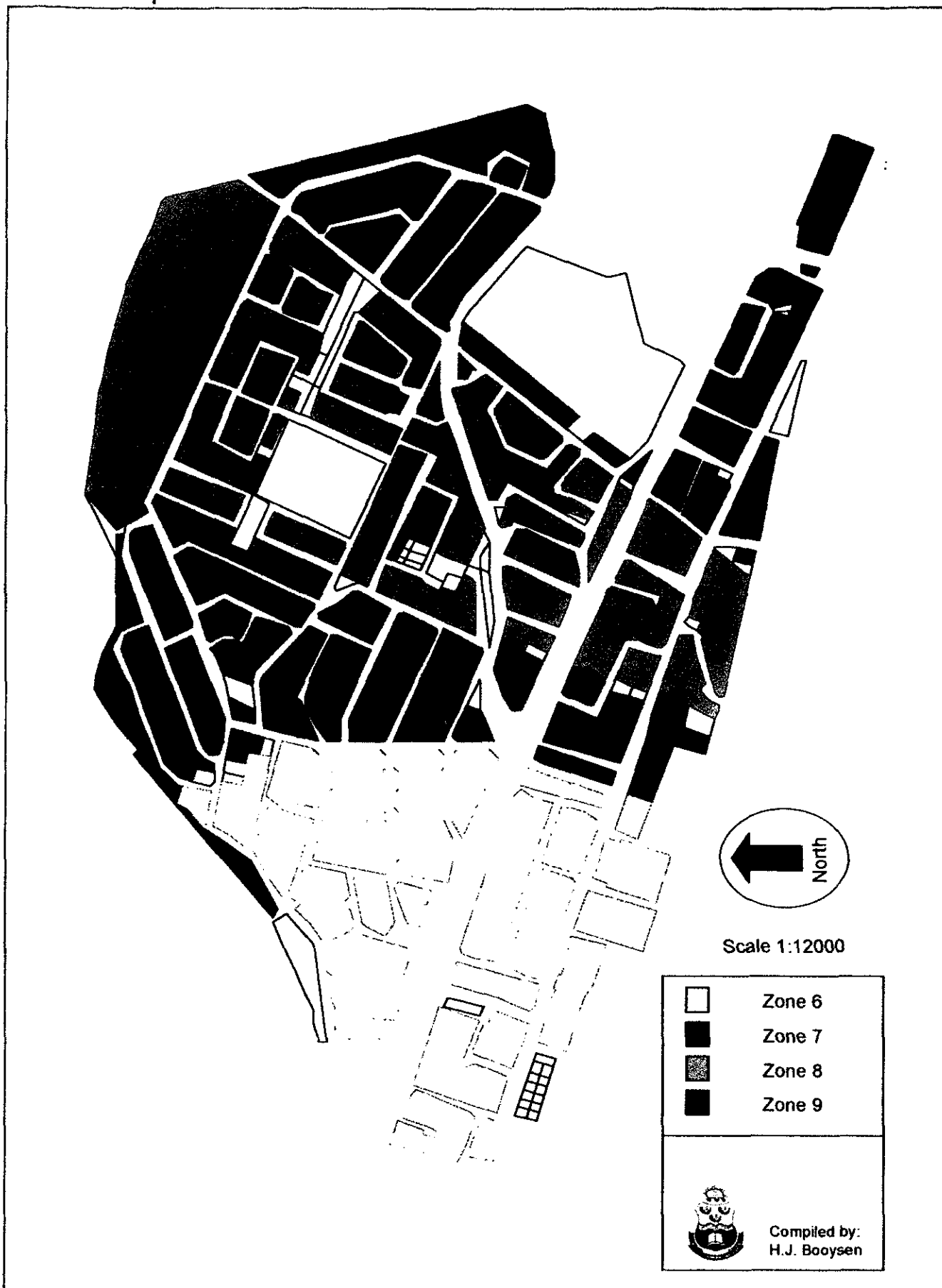


Figure A.3 Residential zones in Despach used for the calculation of flood damage

Uitenhage

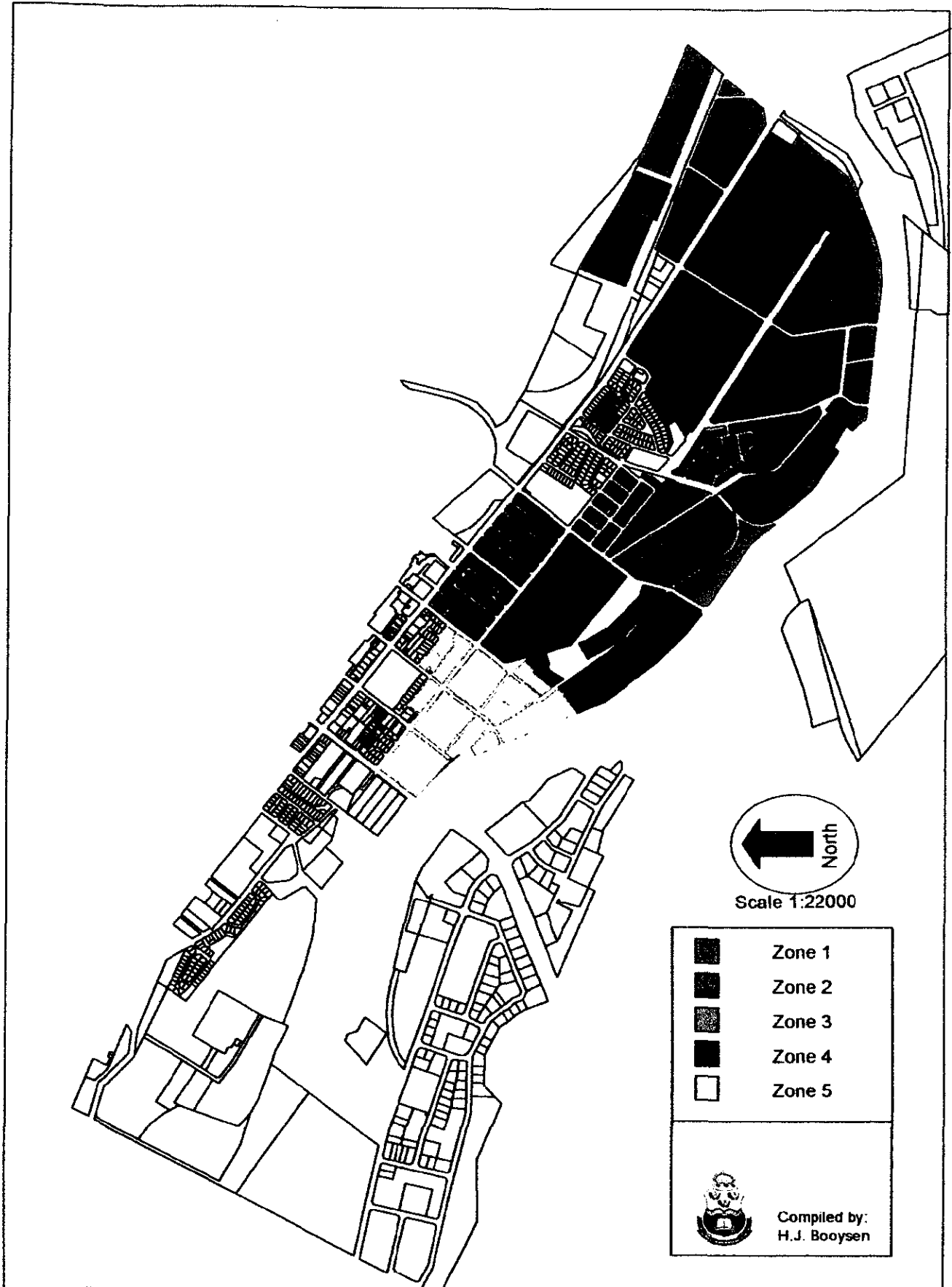


Figure A.4 Residential zones in Uitenhage used for the calculation of flood damage

APPENDIX **B**

Categories of home units according to which standard flood damage functions are grouped

Categories of home units according to which standard flood damage functions are grouped

Group 1 Big luxurious houses



Group 2 Big high economic class houses



Group 3 Medium high economic class houses



Group 4
Medium/Big medium economic class houses



Group 5
Small/Medium medium economic class houses



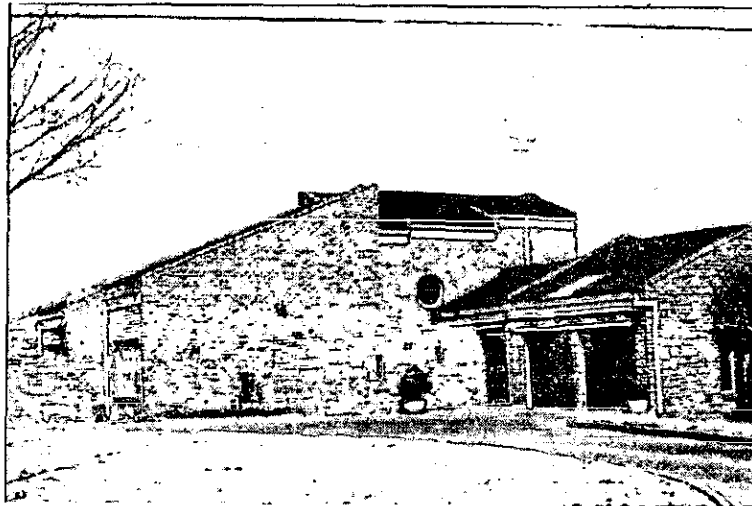
Group 6
Big luxurious high economic class houses (two storey)



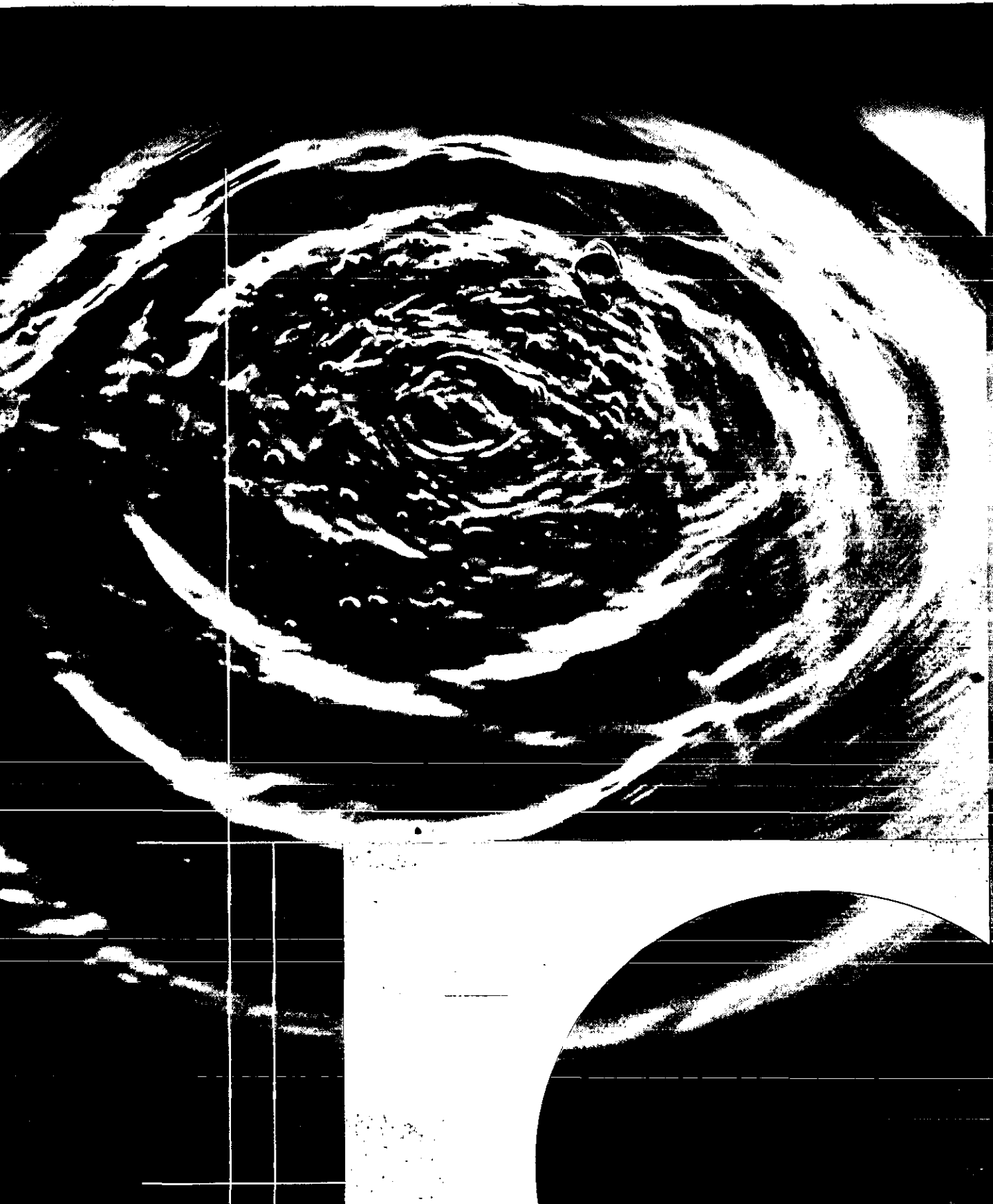
Group 7
Big high economic class houses (two storeys)



Group 8
Big/medium high economic class houses (two storey)







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