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A.A. Ogundeji, M.F. Viljoen, H.J. Booyesen & G. du T. De Villiers

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# IMPACT OF CLIMATE CHANGE ON PLANNING AND DEALING WITH FLOOD DISASTERS IN SOUTH AFRICA: A CASE STUDY OF SOWETO ON SEA.

A.A. Ogundeji\*, M.F. Viljoen\* , H.J. Booysen\*\* and G. du T. De Villiers\*\*\*

## ABSTRACT

Climate change is an additional challenge for the African continent, which is already facing many challenges. It increases the uncertainty regarding the probability of flood occurrence, making weather less predictable, rainfall more uncertain but heavy storms more likely. This necessitates rethinking and changing the traditional ways of planning and dealing with floods. When flooding occurs according to a predictable pattern, an optimal package of flood damage control measures can be planned in advance, but when flood events become unpredictable due to climate change, the optimal package of flood damage control measures will change, cannot be planned with sufficient certainty in advance and different management strategies are needed. In this study a benefit cost analysis was applied to compare the merits of different structural flood mitigation options for Soweto-on-Sea, with and without climate change. The option with the highest net benefit remains the clearing out of the river channel for both (with and without) scenarios. In order to protect/improve the quality of life of the urban poor flood victims, the economic dimension of flood control planning, which is implied when using benefit cost analysis to select the best flood mitigation option, is insufficient. Besides the economic dimension, the social and environmental dimensions must also be included, suggesting that a multi-criteria decision analysis procedure be used.

Keywords: climate change, flood, benefit cost analysis, multi-criteria decision analysis

JEL Classification: O21, Q54

## 1. INTRODUCTION

Climate change is no longer a likely future threat – rather we are already experiencing

\* Department of Agricultural Economics, University of the Free State.

E-mail: ogundejiaa@ufs.ac.za and Viljoenmf@ufs.ac.za

\*\* NET Group, Bloemfontein.

\*\*\* Research Fellow, Department of Geography, University of the Free State.

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the impacts of a changing climate and an increased incidence and changed patterns of extreme weather events. The evidence indicating significant changes in global climate over the past century has been presented in the Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC, 2007). The report also pointed out that variability and the risk of extreme events and unexpected changes in climate patterns may increase throughout the 21st century. It is ironic that though sub-Saharan Africa per capita contributes the least to greenhouse gas (GHG) emissions (World Resources Institute, 2005), it is likely to suffer the most, as increasing climate variability is already affecting crops, livestock, water sources, land, forests and biodiversity (Collier, Conway & Venables, 2008). Climate change is an additional challenge for the African continent, which is already facing economic crises and struggling with food insecurity, high poverty levels, and an HIV/Aids pandemic. The continent faces increasing water scarcity, a reduction in agricultural productivity, increased risks of floods and droughts and negative impacts on the health sector among others.

De Villiers, Viljoen & Booysen (2008) have mentioned that consensus from a number of hydrological-meteorological circulation models show a rise in average annual winter and summer temperature of between 1.5 and 3.0°C in the next few decades (Ragab & Prudhomme, 2002), with a strong possibility of an increase in rainfall in the eastern parts and a decrease in rainfall in the western parts of South Africa. Bigger floods and longer droughts (Chishakwe, 2010) should occur more frequently, as well as severe sea onslaught activities along the eastern and south-eastern coastal areas. The net impact of the predictions on the community is negative.<sup>1</sup>

Climate change is expected to affect flooding through a range of mechanisms, including rainfall, temperature, sea-level and river channel changes. The most common meteorological process leading to river flooding in South Africa is heavy rainfall, which can greatly increase the water levels in rivers and lakes and cause water to overflow into surrounding areas. Climate change increase the uncertainty regarding the probability of flood occurrence, making weather less predictable, rains more uncertain and heavy storm rainfalls more likely. It is expected to increase the frequency and magnitude of many types of extreme events, including floods, droughts, tropical cyclones and wildfires (IPCC, 2007). The impact on flood-prone communities will further be exacerbated due to increases in the cost of living (Phalatse & Mbara (2009). Also, communities living in poverty-stricken areas of the City will be more vulnerable to health risks such as malaria and dengue fever that will be more prevalent with the expected impact of climate change (Githeko, Lindsay, Confalonier & Patz, 2000).The ability to cope with these changes will depend on the resilience and vulnerability of the society (CCVA, 2007).

What is noticed about floods in the South African region is the higher incidence

of flood events the last couple of years and also the changing nature of floods as is indicated by the following examples.

- Storm surge floods occurring during 2007 at various coastal areas along the eastern and south eastern coast of South Africa (WeatherSA, 2007).
- Three major floods occurred along the south coast of South Africa in the service area of Eden District Municipality in 2003, 2006 and 2007 (Otto, 2008).
- Floods occurring at different periods of the year than normal, such as the June 2011 winter floods ([mg.co.za/article/2011-06-08-winter-storm-causes-chaos-on-joburg-roads](http://mg.co.za/article/2011-06-08-winter-storm-causes-chaos-on-joburg-roads)).

These changing flood phenomena create various problems to people involved in planning flood damage control measures and strategies to effectively manage the negative consequences of floods. In order to address the problem of planning flood damage control measures, Viljoen *et al.* (2001) developed two computer-based models, namely FLODSIM and TEWA. The models are designed for flood control planning and management in different flood plains in South Africa and have been tested for practical applications. Using cost benefit analysis, it was demonstrated *inter alia* how TEWA can be used to optimise certain structural flood mitigation measures. Three flood mitigation options, namely channel clearance, bunding and channelisation were investigated along the Chatty River, for instance. This was done without taking climate change into consideration.

## 2. PURPOSE OF STUDY

As climate change should have an increasingly profound impact on the occurrence of floods in South Africa, the aim of this study is to show the impact that climate change might have on the flood mitigation options, using Soweto-on-Sea along the Chatty River as a case study.

## 3. DESCRIPTION OF THE STUDY AREA

Soweto-on-Sea (SOS) is an informal settlement situated approximately 15km from the central business District of Port Elizabeth in the Nelson Mandela Metropolitan Municipality. By virtue of its coastal location, it was named after South Africa's most well-known African township, Soweto, south-west of Johannesburg. The people of this area live in the dirt of an unplanned settlement on the Chatty River floodplain. The Chatty is a small seasonal river from the Greenbushes area of Port Elizabeth. It flows into the estuarine reaches of the Zwartkops River, a popular recreational area for bathing, sailing, rowing and angling, and an important asset

for the regional tourism industry. Urban settlements in the catchment area are Booyens Park, Bathelsdorp, Kleinskool, KwaDwesi, KwaMagxaki, Zwide and Soweto-on-Sea.

The land use in the Chatty River catchment consists of a combination of agricultural, residential, commercial and informal settlements. The topography of the catchment consists of several steeply sloped areas in the upper catchments. The Chatty River forms a wide, open flood plain with the Soweto-on-Sea area due to a less steep topography before the Zwartkops River confluence.

According to Mackay, Van Eeden, Van der Merwe, Hops, McCarthy and Banzana (1994), about 80 000 people lived in about 15 000 squatters' shacks in SOS. However, it is not the large number of inhabitants that sets Soweto-on-Sea apart from other informal settlements in Port Elizabeth, but rather two other factors. The first, as mentioned earlier, is that the settlement was developed on the flood plain of the Chatty River; the second is the extreme levels of poverty that the inhabitants of this area suffer on a daily basis. Soweto-on-Sea was initially developed with minimal control; approximately 3 000 shacks have been erected below the 1:50 year floodline of the Chatty River. This represents considerable danger to the 16 000 people housed in these shacks, since the Chatty River is prone to infrequent but large floods. Figure 1 is an aerial view showing the location of the Soweto-on-Sea area relative to some important tarred roads (the road at the bottom connects Port Elizabeth (to the right) with Uitenhage), the Chatty River and the area that would be inundated by a 1:50 year flood.<sup>2</sup>

The development of Soweto-on-Sea on the Chatty River floodplain and the obvious risks involved highlighted the social and environmental vulnerability of the urban poor (Solomon & Viljoen, 2003). Obvious concerns over social and environmental justice in this case are driven to a climax by the anticipated consequences of climate change in the region and the likelihood of more frequent adverse weather events. More frequent floods, of a more severe magnitude, presented an additional and life-threatening problem to the people of Soweto-on-Sea (Lead, 2010).

The link between climate change and flooding on the Chatty River floodplain is, however, not the only concern. Recent urban development in the upper catchment area of this river has heavily interfered with its natural fluvial processes. In consequence, storm-water discharge has increased; and this has widened the flood lines downstream and ultimately increased the number of people and informal dwellings at risk in Soweto-on-Sea.



Figure 1: Aerial view of Soweto-on-Sea relative to the Chatty River, some tarrred roads and the 1:50 year floodline

Source: Mackay *et al.* (1994)

## 4. METHODOLOGY

### 4.1. A scientific approach to flood damage control planning and management

Figure 2 presents a framework of relationships, variables and parameters that are causal to flood damage in a specific flood plain (Smith, Viljoen & Spies, 1981). This framework provides the paradigm for a research programme that was undertaken in South Africa during the latter quarter of the previous century. An aim of the programme was to develop so-called scientifically based integrated computer models to assist planners in the planning of optimal packages of flood damage control measures for specific floodplains in urban and irrigation areas. Two computer models developed from this research, TEWA (for urban areas) and FLODSIM for irrigation areas, were both based on this theoretical framework. (Booyesen, 2001; Du Plessis, 1998)

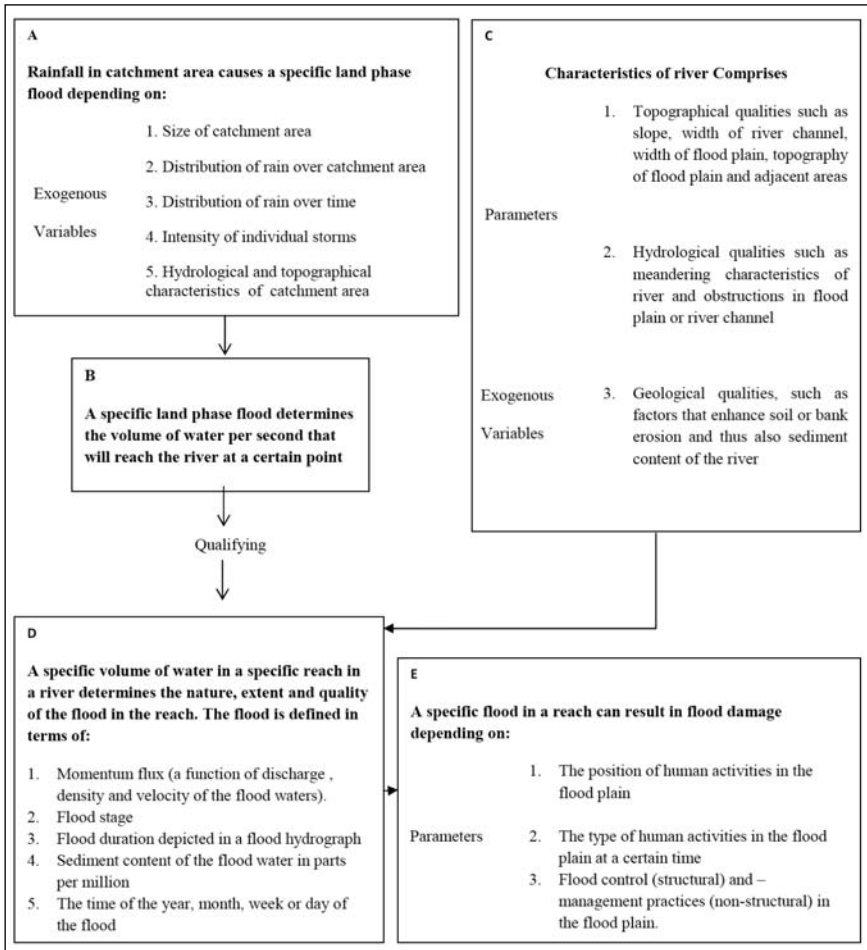


Figure 2: Relationship, variables and parameters that are causal to flood damage in a specific reach.

Source: Smith *et al.*, 1981

Figure 3 gives an outline of the simulation process and information needed when applying FLODSIM and TEWA in the design of effective flood damage control policy options (Du Plessis, 2001).

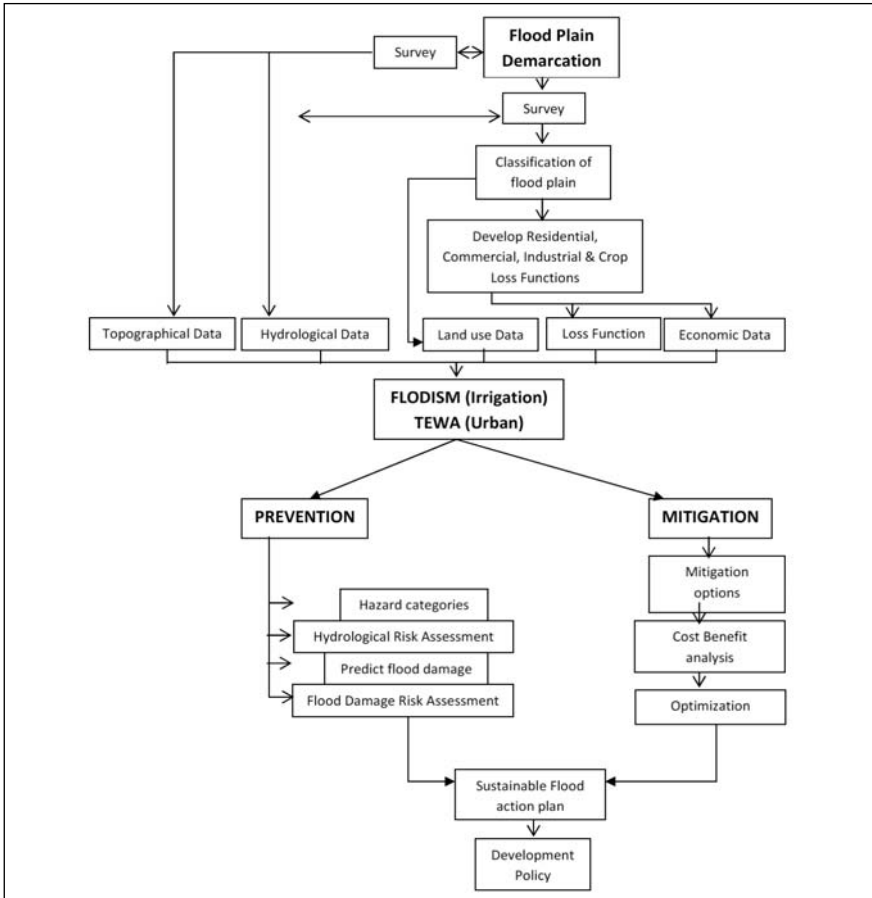


Figure 3: Simulation with FLODSIM and TEWA

Source: Du Plessis (2001).

Two crucial bits of information needed in the application of these models are flood hydrographs and loss functions, which respectively summarise the hydrological data and link the hydrological data to flood damages for different land-use types. Figures 4 and 5 are examples of flood hydrographs and loss functions ([www.filter.ac.uk/.../getinsight.php?](http://www.filter.ac.uk/.../getinsight.php?); Berning, Du Plessis & Viljoen, 2001).

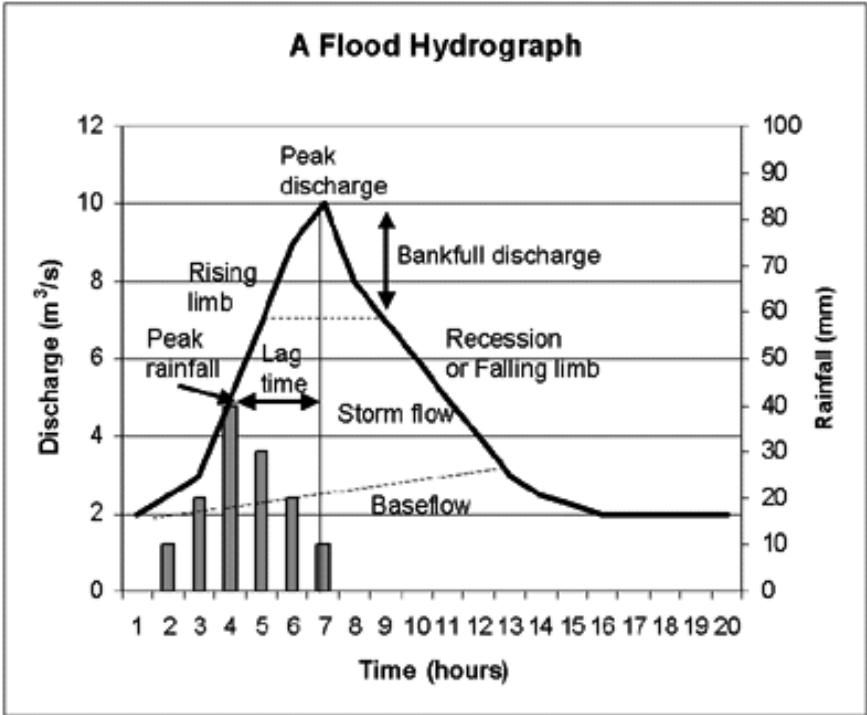


Figure 4: Example of a flood hydrograph

Source: [www.filter.ac.uk/.../getsight.php?](http://www.filter.ac.uk/.../getsight.php?)

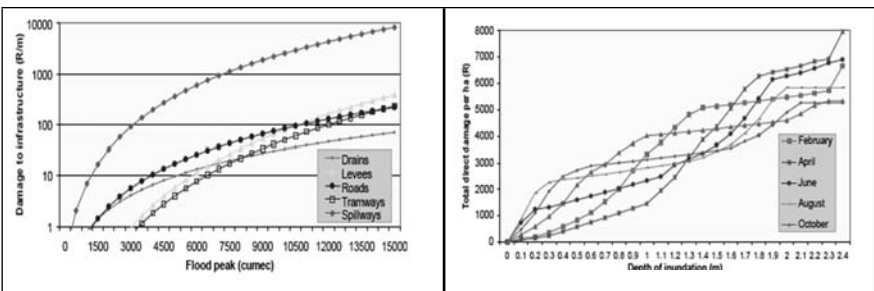


Figure 5: Loss functions for infrastructure and sugar-cane in the Mfholzi floodplain (1994)

Source: Bering *et al.*, 2001

Important to note is that although the loss function only reflects the relationship between flood peak (depth of inundation) and flood damage to a specific land-use type, duration of inundation (through its relation with depth of inundation

as indicated in the flood hydrograph) is also taken into account. When the form of the flood hydrograph changes (for instance becoming steeper and narrower, as expected from higher-intensity-shorter-duration rainfall events) the damage caused by different depths of inundation (thus the slope of the loss function) may also change. This is to show that the practical use value of models like these is *inter alia* determined by the validity of the underlying assumptions.

For the discussion here, the impact of climate change on the following will be covered: the hydrological characteristics of the floods; the nature, extent and composition of the damages; the increasing vulnerability of flood victims; and the relative effectiveness of different flood mitigation measures and coping strategies.

## 4.2. The effect of climate change on the hydrological characteristics of floods

The nature and extent of the impacts of floods are to a large extent determined by weather and flood characteristics, indicated in blocks A and D in Figure 2. Indications are that climate change affects the distribution of rain over catchment areas, as well as the distribution of rain over time (the duration of rainfall events may be shortened) and the intensity of individual storms (which tends to increase). These changes affect the flood stage and flood duration (reflected in the flood hydrograph); the momentum flux (a function of discharge, density and velocity of flood waters) and the sediment content of the flood waters (in parts per million).

For the models to be of value it is assumed, for instance, that the form of the flood hydrograph for floods of different magnitudes to occur (probabilities, e.g., a one in a hundred year flood) is predictable with regard to flood duration and height. With climate change, this is no more the case, as duration of rainfall events tend to be shortened, while the intensity of individual storms increase, thus the height of the flood peak will increase (see Figure 6). ([www.ene.gov.on.ca/envision/gp/4329e\\_1.htm](http://www.ene.gov.on.ca/envision/gp/4329e_1.htm)) The pre-climate change situation is reflected by the old flood hydrograph and the climate change situation by the new flood hydrograph

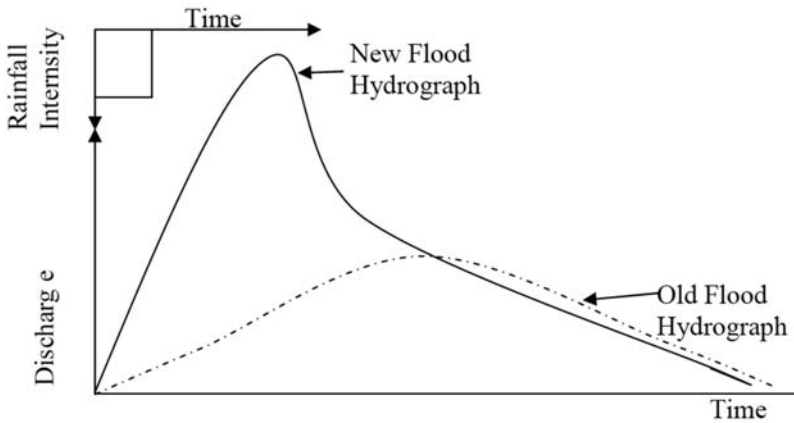


Figure 6: Schematic presentation of how a flood hydrograph might change  
Source: [www.ene.gov.on.ca/envision/gp/4329e\\_1.htm](http://www.ene.gov.on.ca/envision/gp/4329e_1.htm)

For a flood with the same probability of occurrence, the peak flood water discharge will be more (the height of flood waters higher) but for a shorter duration.

When the period of the year when floods normally occur also changes due to climate change, the damage will also change, as can be deduced from the loss functions of sugar cane shown in Figure 5.

### 4.3. The effect of climate change on the nature, extent and composition of damages

It is shown in Block E of Figure 2 that flood damages in a specific river reach are dependent on the location of human activities/land uses in the floodplain, the type of human activities/land uses in the floodplain at a certain point in time and the flood control and management practices applied. Under the assumption that, due to climate change, floods of different magnitudes will occur more often, caused by higher intensity rainfall events of shorter duration, the impact on damages will in general be to increase but with the relative impact differing between damage categories or types.

- With slower developing floods and sufficient flood warning evacuation of removable items from the floodplain can help to reduce flood damages. The effectiveness of evacuation should be reduced with quicker onset floods due to climate change and the relative increase in damage to the removable items category.

- Storm water drainage works planned with pre-climate change hydrological data, for instance, will become inadequate to drain flood water. This can lead to inundation of areas in and outside floodplains that will not have been flooded under pre-climate change hydrological conditions.
- If roads and low water bridges are inundated due to failure of storm water drainage, indirect damages due to the need for detour roads will increase.
- Structural damage to houses and other physical infrastructure such as roads and bridges can also increase due to increase of the momentum flux of the flood water.
- Higher momentum flux on steep barren slopes will increase soil erosion and the sediment content of the flood water. When buildings and other areas are flooded with water carrying more sediment, deposition of the sediment will require higher cleaning up costs. The occurrence of landslides due to heavy rainfall has become a reality.
- The greater insecurity brought about by the more frequent and unpredictable floods can also contribute to increasing the intangible damages that are linked with this aspect. The need for rescue operations and trauma counselling becomes very important
- With increasing population and inadequate living space, more people are moving to live in areas with a high potential for flooding. This is true for various flood plains in South Africa. The poor people of the community are most vulnerable and the detrimental effects of the changing post-climate change flood scenario are especially bad for their livelihoods.
- But it is not only the vulnerability of the poor that is affected by the more frequent high intensity floods caused by climate change. The wealthier stratum of the community is also affected. The inconvenience and tangible damage to some people and properties can be quite severe.

#### 4.4. Flood mitigation measures and coping strategies

A spectrum of flood mitigation measures and coping strategies are theoretically available to address the negative impacts of floods. The effectiveness of different measures and strategies will be determined by the nature and extent of the flooding impacts to be addressed; flood characteristics; the policies, measures, strategies and infrastructure in place; and the phase of the flood (pre, during or post flood), *inter alia*.

When flooding occurs in a predictable pattern, an optimal package of flood damage control measures can be planned in advance, but when flood events become unpredictable due to climate change, the optimal package of flood damage control measures will change, cannot be planned in advance and different management

strategies are needed. For instance, where pre-flood damage control measures like flood control dams, levies, (in the case of this paper channel clearance, bunding and channelisation) and land-use zoning would be more effective to mitigate the impacts of predictable pattern floods, relatively more resources should be needed during and after the flood to be effective for climate change-induced floods. Also important to note is that the relative effectiveness of different measures should differ according to the nature and needs of different people in the community, see Table 1 (Viljoen & Booysen, 2005).

Table 1: Flood related characteristics of different income groups

Low income group (informal settlement)	High income group (formal)
Often many houses inside 100-year floodline	Most houses outside 100-year floodline
Intangible damages often very high	Tangible damages can be high
Vulnerability high	Vulnerability low
Post-disaster relief and recovery emphasised	Pre-disaster risk reduction
Short-term survival outlook dominates	Long-term outlook dominates

Source: Viljoen & Booysen (2005)

## 5. ANALYSIS

### 5.1. Evaluating structural flood mitigation options with TEWA

TEWA, already referred to in Figure 3, is the acronym for a computer model for Tangible Economic Flood Water Damage Assessment used for calculating tangible flood damage and evaluating different flood damage mitigation options. Figure 7 (Booyesen and Viljoen, 1999) shows the layout of the TEWA model. The process starts with the inputs TEWA requires to calculate flood damage, which are flood damage/loss functions, geographical data, land-use data and hydrological data. The output of TEWA includes flood damage potentials, area under risk and the impact of different flood damage mitigation options for a specific urban floodplain.

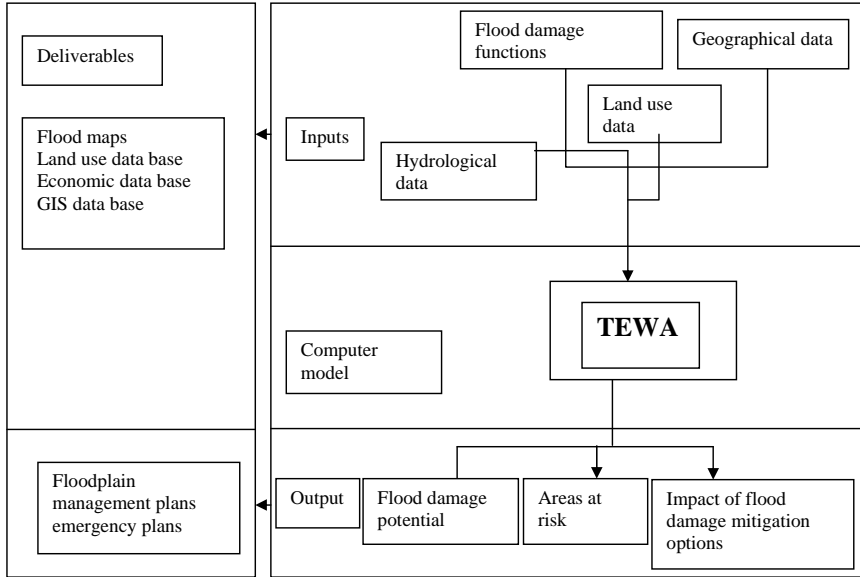


Figure 7: Inputs, outputs and deliverables of TEWA  
 Source: Booysen & Viljoen (1999)

TEWA works on the principle that flood damage to an individual structure or property, to groups of properties or to a floodplain zone is indicated by the monetary value of flood damage for different magnitudes of flooding. Damage caused to a property or a number of properties by a single flood event is calculated directly from flood damage/loss functions. Table 2 is an example of a content loss function developed for two categories of informal houses in Soweto-on-Sea and adapted to 2010 with an appropriate price index.<sup>3</sup>

Table 2: Loss functions in Rand (2010) for the content of informal houses in the Soweto-on-Sea flood plain.

Category	Depth of inundation in meters									
	0	0.2	0.3	0.6	0.9	1.2	1.5	1.8	2.1	2.4
Category 1*	39	702	1001	1794	2418	2886	3185	3328	3328	3328
Category 1**	104	2444	3510	6266	8372	9828	10634	10803	10803	10803
Category 2*	468	2600	3562	6110	8073	9451	10270	10517	10517	10517
Category 2**	234	4979	7124	12701	16926	19812	21359	21580	21580	21580

\*Valuation by respondents

\*\*Replacement value

Source: Own computation

For the calculation of flood damage to individual properties in a zone, TEWA links the hydrological data of the zone to the depth of inundation of all the properties in the zone. Geographical data are used to locate the properties and link topographic data such as height above sea level to the properties. The mean annual damage (MAD) for all possible flood events that can occur in a specified floodplain is then calculated with TEWA for each flood mitigation option considered and used as an input in a benefit cost analysis (BCA) to determine the economic viability of each mitigation option.

## 5.2. Data used and scenario development

The same land-use data file that was used by Booysen, Viljoen and De Villiers (1996) was used in 2010 as input to calculate flood damage for different scenarios. Land-use data included the geographical location, the physical address and the classification of the property. Hydrological information provided by SRK Consultants in the previous study by Booysen *et al.* (1996) was linked to river cross-sections and used to determine depth of inundation of various houses.

Three different mitigation options, namely, channel clearout, channelisation and bunding were considered in this study. For each of the options the “as is” scenario was first considered. The “as is” scenario refers to the situation as it was in 1996 (thus without climate change). The second scenario considered was “probability-doubling”; this was to look at the impact of increase in the frequency of flood occurrence (assuming that climate changes will double the frequency/probability of flood events). Should maintenance costs also double, together

with the doubling of probability of flood occurrence, this was tested as the third scenario, that is, double flood probability and double maintenance costs.

The remaining damage (damage that will not be prevented by flood mitigation measures) calculated in 2010 prices for floods with different frequencies (years)/probabilities of occurrence for the “as is” scenario and different mitigation options are presented in Table 3.

Table 3: Remaining damage (Rand million) for the “as is” scenario for different sized flood and mitigation options, Soweto-on-Sea, 2010.

Flood frequency (years)	Flood probability	Without mitigation	With channel clearout	With channelisation	With bunding
	0.000	27.51	27.51	21.22	27.51
10000	0.0001	27.51	27.51	21.22	27.51
1000	0.0010	24.80	24.80	18.28	24.67
500	0.0020	24.65	24.65	18.25	24.65
100	0.0100	23.17			
50	0.0200	22.07			
20	0.0500	21.29			
10	0.1000	20.41			
2	0.5000	18.07			

Source: Own computation

With the information in Table 3 it was possible to calculate the mean annual damage (MAD) for the different mitigation options for the “as is” scenario.<sup>4</sup> The MAD amounted to R9.86 million without mitigation, R149 609 when the Chatty River channel is cleared out, R111 166 when the river is channelised and R149 486 with bunding. The cost involved in the clearing of the channel was estimated at R6.66 million and R43.91 million to channelise the river course. Bunding of the river could cost R32.12 million. Although channelisation had the greatest impact on reducing the potential for flood damage, it was also the most expensive to implement.

With similar tables as Table 3 compiled for the other two scenarios, it was possible to calculate the MAD, construction and maintenance costs for the other two scenarios (doubling of flood probabilities and doubling of flood probabilities and maintenance cost). By considering the savings in mean annual damage of the different mitigation options as benefits, and accounting them (over a period of 50 years) against the annual construction and maintenance costs of the different mitigation options within a benefit-cost analysis (BCA), the present values of net

benefits of the mitigation options were calculated at different discount rates for each of the scenarios earlier mentioned, as illustrated in Table 4.<sup>5</sup>

From the analysis it is clear that the option with the highest net benefit remains the clearing out of the channel for all situations considered. What is more interesting is that with the assumption that climate change will increase (double the probability of) the occurrence of flooding, the net benefit *more* than doubles, even with the doubling of the maintenance cost of flood mitigation measures included. The inference from the analysis is that the impact that climate change could have on structural flood mitigation measures is to make them relatively economically more viable.

Table 4: The present values (R million) for the net benefit for the Chatty River for implementing flood mitigation measures, 2010.<sup>6</sup>

Discount rate (%)	"As is" scenario				Double flood probabilities				Double flood probabilities & annual maintenance cost			
	Net present value				Net present value				Net present value			
	Clearout	Channel-isation	Bunding		Clearout	Channel-isation	Bunding		Clearout	Channel-isation	Bunding	
5	R156.70	R89.34	R110.18		R325.45	R258.91	R278.95		R319.66	R220.73	R250.97	
8	R100.05	R44.79	R61.95		R210.00	R155.27	R171.90		R206.22	R130.39	R153.68	
12	R63.59	R16.73	R31.32		R135.55	R89.04	R103.29		R133.08	R72.76	R91.36	
18	R38.50	(R1.71)	R10.85		R84.18	R44.20	R56.54		R82.61	R33.86	R48.96	

Source: Own computation

## 6. DISCUSSION

The analysis above shows the implications of climate change for the recommendations with regards to structural flood mitigation measures when the original model/analysis is adapted with new prices and cost (due to inflation) and the probability for any flood event to occur is doubled (due to climate change). However, this “partial” adaptation of the original analytical model and its application to a land-use pattern that is assumed to remain the same as previously in the floodplain can lead to unfounded results. The following *inter alia* also need to be addressed and the implications for optimal/effective flood mitigation evaluated:

- Changes in the land-use pattern in Soweto-on-Sea.

The land use pattern has changed considerably due to the fact that many people have been removed from the floodplain and resettled in a safe area outside the flood plain. The land-use information in the model thus needs to be adapted.

- Changes in the flood hydrograph and loss functions.

The flood hydrograph on which the loss functions in the model and cost for engineering work are based have changed. It is expected that the flood hydrograph will become steeper and narrower due to higher-intensity-shorter-duration rainfall events. The momentum flux (destructive power) and sediment content of floodwaters may thus increase. In the case of Soweto-on-Sea, damage to houses and content of houses can thus increase for a similar (as before) probability flood.

- Changes in vulnerability of flood plain residents and implications on flood mitigation measures.

Increase in flood events increases the vulnerability of especially poor people living in floodplains. Relocating people outside the floodplain, as is happening at Soweto-on-Sea, is probably the best measure to counter the vulnerability problem. For people still living in the flood plain it is important that the flood mitigation measures must change to be effective. Greater emphasis must be placed on effective early warning systems, quick removal of people and removable items from unsafe places during a flood, trauma counselling and resettling assistance after a flood.

- Changes in the theoretical framework.

BCA as used above is a valuable technique with which to determine, from a set of feasible decisions, the one that is economically most efficient. However, it is not a sufficient basis on which to decide which mitigation measure(s) is/are optimal or sustainable when non-economic criteria are also considered (Mirrilees, Forster & Williams, 1994). In order to improve the quality of life of the urban poor, looking at the economic dimension to flood management alone cannot provide the best solution. The challenge is how to find an acceptable flood mitigation mix for a flood community when all dimensions such as the economic, social and environment are taken into account.

In order to consider several objectives at the same time, the multiple criteria decision analysis (MCDA) techniques have been developed (Goicoechea, Krouse & Antle, 1982). It can thus be viewed as part of the transformation from single objective methods such as BCA to multi-objective analysis. MCDA focuses on finding satisfactory alternatives that are acceptable across a number of objectives as opposed to optimal solutions that dealt with single objective functions (Van Zyl, 1997). According to Mirrilees *et al.* (1994), BCA should be treated as one input into the MCDA method for a comprehensive analysis.

## 7. RECOMMENDATIONS

Due to the uncertainty that surrounds climate change, a multi-criteria analysis is advocated. This can inform an optimal package of flood mitigation measures in a multi-criteria framework. An effective early warning system should form part of a comprehensive strategy to manage flood disasters. Perez *et al.* (2007) gave an example called the community-based early warning system (CBEWS). CBEWS is a people-centred system that empowers individuals and communities threatened by hazards to act in sufficient time and in an appropriate manner so as to reduce the possibility of personal injury, loss of life, damage to property, environment and loss of livelihood. It provides community and disaster risk management workers with advance information on the risks (floods, landslides, debris flow) that can be readily translated to disaster prevention, preparedness and response actions against loss of lives and injuries.

Necessary policy changes are thus needed to cater for the effective management of flood hazards induced by climate change. For instance, in the past, people were told not to build below the 100-year floodline, but this proscription needs to be revisited because of the more frequent occurrence of floods. New policy recommendations should thus be made in respect of this as well as all aspects that

need adjustments to be relevant for effective flood hazard management in an era of more frequent flooding as a result of climate change.

## 8. CONCLUSION

Although the reality and causes of climate change remain controversial issues in South Africa, what has been noticed since the start of the new millennium is the higher incidence of major flood events with different characteristics. The impacts of this are that as the nature and extent of flood damage change, the models used to plan flood damage control measures become obsolete and that optimal strategies and packages of flood damage control and mitigation measures change. The new challenges posed to people involved in flood disaster planning and management are further complicated by the fact that the South African community consists of a wide spectrum of people with different needs and expectations. In this study, the impact of climate change on flood damage assessment and the influence that it might have on the flood mitigation options were evaluated.

Three different mitigation options, namely, channel clearout, channelisation and bunding were considered in this study. The option with the highest net benefit is the clearing out of the channel for all the situations considered. With the assumption that climate change will increase the occurrence of flooding, the net benefit more than doubles even with the doubling of the maintenance cost of flood mitigation measures. The motivation for flood mitigation measures to be economically viable, based on the net present value criteria, thus increases relatively when the impact of climate change is to increase the probability of flooding events. In order to protect or improve the quality of life of the urban poor (flood victims), using the economic dimension alone to plan flood mitigation options, is not sufficient. Besides the economic dimension, the social and environmental dimensions must also be considered in a multi-criteria analytical framework to determine an optimal package of flood mitigation measures.

## NOTES

- 1 There are, however, researchers such as Alexander (1995), who showed with their analysis, based on extensive hydrological/meteorological data sets that there is insufficient evidence to support this general view (de Villiers et al., 2008).
- 2 The situation in the Soweto-on-Sea area has changed in the meantime as a considerable number of people who settled in the floodplain of the Chatty River have been resettled elsewhere since 2006 as part of the Zanemvula social housing project (Lead, 2010). Results of a new flood line study conducted for the Soweto-on-Sea is not included in the discussion (see SRK Consulting report on Soweto-on-Sea & Veeplaas 50 & 100 year floodline study, project number 390083/2, October 2011)
- 3 Booysen et al., (1996) calculated flood damage functions during the development of the computer models to calculate flood damage. Flood damage functions were developed for

residential properties in Uitenhage, Despatch and Soweto-on-Sea; for commercial services in Uitenhage and Despatch and for certain industries in Uitenhage.

- 4 The mean annual damage (MAD) refers to the average annual damage over the long term.
- 5 Annual maintenance cost was assumed as 5% of initial construction cost.
- 6 It is only the channelisation measure that presents a negative net benefit of R1.71m, if the rate at which the present values were calculated is larger than 12 %.

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