Chapter 5

South African Flood Risk Research Context

"It is estimated that at least 50 000 people, and possibly more than 100 000 people are living along rivers and streams in South Africa below levels reached by previous floods. Most of these live in unplanned settlements within the jurisdiction of local or regional authorities" (Alexander, 2000b: 4).

5.1 Introduction

This chapter outlines what a flood risk assessment should entail followed by a discussion of flood risk research in South Africa. Current flood risk reduction best practices in the developing world are then examined, with the chapter concluding with a discussion of the prevailing legal framework and strategies for flood risk management in South Africa.

5.2 Flood Risk Assessment Approach

Risk assessments form the basis for developing and implementing flood risk reduction strategies, plans and actions (ADPC, 2005). A flood risk assessment has three components: hazard assessment, vulnerability and capacities assessment (VCA) and damage assessment (ibid). Flood risk assessments should also consider the occurrence of resultant secondary hazards (ibid). Risk assessments should be participatory and can be a starting point for flood risk awareness raising in the community (ibid).

5.2.1 Hazard Assessment

ADPC (2005: 50) explained that the **hazard assessment** "[d]etermines the nature of flooding based on meteorological and hydrological parameters and river basin conditions. The information can be used to determine relationships between meteorological and hydrological parameters and create flood models. Studies also outline the frequency and general magnitude of floods." Here methods such as those discussed in 5.3 are employed. Methods can be either quantitative (e.g. number of people affected, hydrological and meteorological data and economic losses) or qualitative (types of areas, damage caused, severity of floods) (ADPC, 2005). ADPC (2005: 58) listed various sources of data collection such as government records, media reports, existing documentation for construction and other projects, information or assessment data obtained through PDRAs. Further sources include hydrological information from monitoring stations, stream flow and rainfall maps, interviewing the public and experts, site investigations, geophysical tests, vegetation analysis and photos and satellite images of past flood impacts (ibid). The most suitable techniques and methods to employ depend on the nature of the flood hazard, the availability of data, feasibility of collecting additional data and resources available for analysis (WMO, 1999 in ADPC, 2005). ADPC (2005) mentioned three main types of maps for presenting flood data. These include flood inundation maps that show the variation in flood depth over the floodplain, flood duration maps which are similar to inundation maps but also consider the duration of the flooding and flood comparison maps that show the difference between two flood maps (ibid).

5.2.2 Vulnerability and Capacities Assessment (VCA)

Vulnerability and capacities assessment (VCA) "[h]ighlights the people and infrastructure most vulnerable to flooding and the potential damages that may be incurred" (ADPC: 50). VCA is synonymous with CRA where vulnerability and capacities of the at-risk population with the at-risk population are also assessed. VCA is more commonly used by the International Federation of Red Cross and Red Crescent Societies (IFRC) and its partner agencies.

ADPC (2005) from IFRC (2004) supported the view that the SL approach can be used to determine people's ability to withstand a disaster. Thus a vulnerability and capacity assessment should assess the levels of the various capitals mentioned in the SL approach (see 3.3.5 above) as these will determine how vulnerable people are to flood impacts. Data collection may be quantitative or qualitative. There are various participatory tools available to assess vulnerability (see for example Abarquez and Murshed, 2004; DiMP, 2005b; DiMP, 2008; and the Provention Consortium website: www.proventionconsortium.org).

5.2.3 Damage Assessment

A **damage assessment** is an "[a]ssessment and analysis of potential loss due to flooding" (ADPC: 50). Loss estimation can be regarded as a form of risk assessment (ibid) especially in assisting in selecting high risk areas based on areas sustaining highest losses. Furthermore, the damage assessment may also be used as part of the hazard assessment (see 5.2.1) and vulnerability assessment. The most widely respected and applied disaster loss estimation approach, based on more than 30 years of application, is the ECLAC (Economic Commission for Latin America and the Caribbean) model for estimating the socio-economic and environmental effects of disasters (ECLAC, 2003). The ECLAC model provides methods for estimating direct damages and indirect losses to the social sectors, services and physical infrastructure sectors, economic sectors and the overall effects of damages to the environment, the impact on women, macroeconomic effects and the impact on employment and income. The ECLAC methodological approach provides guidelines to the sources of information for each of the categories and the techniques employed to gather the information.

5.3 Flood Risk Research in South Africa

The majority of the published flood research in South Africa is commissioned by the Water Research Commission (WRC). The WRC operates in terms of the Water Research Act (Act 34 of 1971) whose mandate it is to support water research and development as well as building a sustainable water capacity in South Africa (http://www.wrc.org.za). The floods of 1988 and the revision of the National Flood Management Policy in South Africa resulted in *ex ante* (risk reduction/mitigation) flood damage research in South Africa (Viljoen et al, 2001). The aim of *ex ante* research (that comprised 3 phases) was to develop flood damage management aids (loss functions, computer programmes, and questionnaires) to assist planners and authorities involved in flood damage assessment and management (ibid). Flood risk estimation models were also viewed as essential for developing such flood damage management aids, especially in determining potential flood-prone areas. Consequently the majority of flood risk-related research in South Africa has historically focused on the physical parameters of the flood hazard that drew heavily from hydrological modelling. Only a limited number of predominantly unpublished studies in South Africa focused on the vulnerability of those at risk to flood hazards or extreme weather events.

5.3.1 Flood Risk Estimation Models in South Africa

The weather systems responsible for extensive flooding over South Africa include tropical cyclones; cut-off low and ridging high pressure systems; large scale, near stationery wave patterns; intense mid-latitude cyclonic systems; and squall lines, mesoscale convective systems (Alexander, 2000b also see SAWS, 2007; Taljaard, 1995 and 1996; Tyson and Preston-Whyte, 2000 for a detailed overview of South Africa's climate). Flood risk estimation models in South Africa draw heavily from hydrological models used internationally. Standard techniques for flood estimation exist for many countries and include statistical analysis of observed peak discharges (if available) and event modelling using rainfall-runoff techniques (Smithers and Schulze, 2003). Estimating design flood events are critical for the planning and design of engineering projects (Smithers and Schulze, 2003 from Rahman et al, 1998). Flood estimation methods in South Africa (as illustrated in figure 5.1) can be classified as:

- deterministic or rainfall-runoff methods;
- statistical methods, either site specific or regional
- empirical and pseudo-statistical or empirical-probabilistic methods (Alexander, 2000b; Smithers and Schulze, 2003; van Bladeren et al, 2007).

Deterministic methods transform rainfall data into run-off, normally on a rainfall event basis, using different models by taking into consideration catchment characteristics: area, length and slope of the main watercourse, catchment slope, land-use, soils etc. Examples of these include the *rational method* (the oldest); *SCS* (Soil Conservation Services); *unit hydrograph*, *synthetic unit graph*; and the *Gradex method* (not applied in South Africa) (van Bladeren et al, 2007).

Deterministic flood hydrology was initiated in South Africa by the Hydrological Research Unit (HRU) as a response to the devastating floods of May 1959 and March/April 1961. Van Bladeren et al (2007) criticised these methods for assuming that the "run-off and rainfall input have the same probability of exceedance" (ibid: 5). Secondly, they argued, the methods are very data intensive and so generalised regional coefficients based on simplifications are provided. The use of these methods can be applied to sites with "no flow data, for a range of storm durations, changing catchment conditions and provide an indication of the expected hydrograph shape for a storm event" (ibid: 5).

Statistical methods "are based on the fitting of theoretical probability distributions to data for a site …. [T]he distributions selected do not relate to any characteristics of the flood producing rainfall or the catchment" (Van Bladeren et al, 2007: 5). Data extracted for flood frequency analyses are either annual maximum flood peaks (AMF) or partial duration (PD) series data also known as peaks over threshold (POT). AMF data are received from abstracting the maximum flood peak for every hydrological year. POT data is received by selecting all flood peaks above a certain threshold and may include more that one peak in a specific hydrological year. Distributions generally used for flood estimation include: log-normal (LN), Pearson Type 3 (P3), log-Pearson Type 3 (LP3), extreme value distributions such as the extreme value Type 1 and 11 (EV I and EV II) and the general extreme value distribution (GEV). In South Africa LP 3 and GEV are most commonly used and most applicable. There is also an increasing importance of parameter estimation techniques (ibid).

Empirical methods and pseudo-statistical methods "typically use observed or analysed flood information and relate these to certain catchment and rainfall characteristics and rainfall to provide estimates of the requested flood event discharges" (Van Bladeren et al, 2007:

7). These methods are then applied using regions that are determined to be hydrologically homogenous (ibid; ICOLD, 1992). The main advantages of empirical methods are their simplicity (ICOLD, 1992). However, because they are "derived for particular catchments with given topographic, geomorphological, geological and meteorological characteristics, they can have significant errors when applied to other catchments or regions with different hydrological characteristics, and so the values obtained should be used with caution" (ibid: 97).

From figure 5.1, methods for estimating design floods in South Africa can be categorised into two groups based on the sources of data collection that include: i) *analysis of streamflow data* and ii) *rainfall based methods*.

i) The *analysis of streamflow data* draws on:

a) empirical methods; and

b) statistical methods (that include flood frequency analysis and flood envelopes).

A **flood frequency analysis** of observed data is used if long records of streamflow are available at a site (Smithers and Schulze, 2003). If there are insufficient site data, then regional data are analysed. To undertake direct at-site frequency analysis of observed peak discharge requires the appropriate selection and fixing of theoretical probability distribution to the data (ibid). "There are many different theoretical probability distributions or laws in hydrology …. These probability distribution functions have either two or three parameters which can be estimated by different methods (least squares, moments, maximum likelihood, maximum entropy etc.)" (ICOLD, 1992: 101-103). There are a number of limitations associated with direct statistical analysis (see Smithers and Schulze, 2003: 117-118). Insufficient data for a given site necessitates the use of data from similar and nearby sites, known as regional frequency analysis. This approach is usually more appropriate than at-site analysis (ibid).

Flood envelopes (maximum envelopes/ envelope curves) refer to plotting the largest observed discharge against catchment area on logarithmic axes

(Smithers and Schulze, 2003). An envelope curve is drawn to include all the data points (ibid; ICOLD, 1992). This curve reflects the upper limit of expected flood peaks for the region under study (ICOLD, 1992). “The envelope tends to increase as the record length increases and larger floods are observed” (Smithers and Schulze, 2003: 120).

ii)*Rainfall based methods*

These are used when no or inadequate streamflow data are available at the site of interest (Smithers and Schulze, 2003). The choice of this approach falls into two broad methods:

a) **continuous rainfall based methods**; and

b) **design rainfall**.

a) **Continuous simulation modelling** attempts to “represent the major processes which convert rainfall into runoff. Historical data or stochastic rainfall series are used to generate outflow hydrographs over long time periods and the simulated flow can be subjected to standard frequency analysis techniques” (ibid: 125). The advantages of these models include “the simulation of the complete hydrograph and continuous simulation of antecedent moisture conditions” (ibid: 127). Van Bladeren et al (2007) for example integrated systematic, historic and palaeoflood data to provide estimates of flood growth curves that were scaled using an index flood to provide estimates of flood peaks and their associated probabilities for all the regions of South Africa.

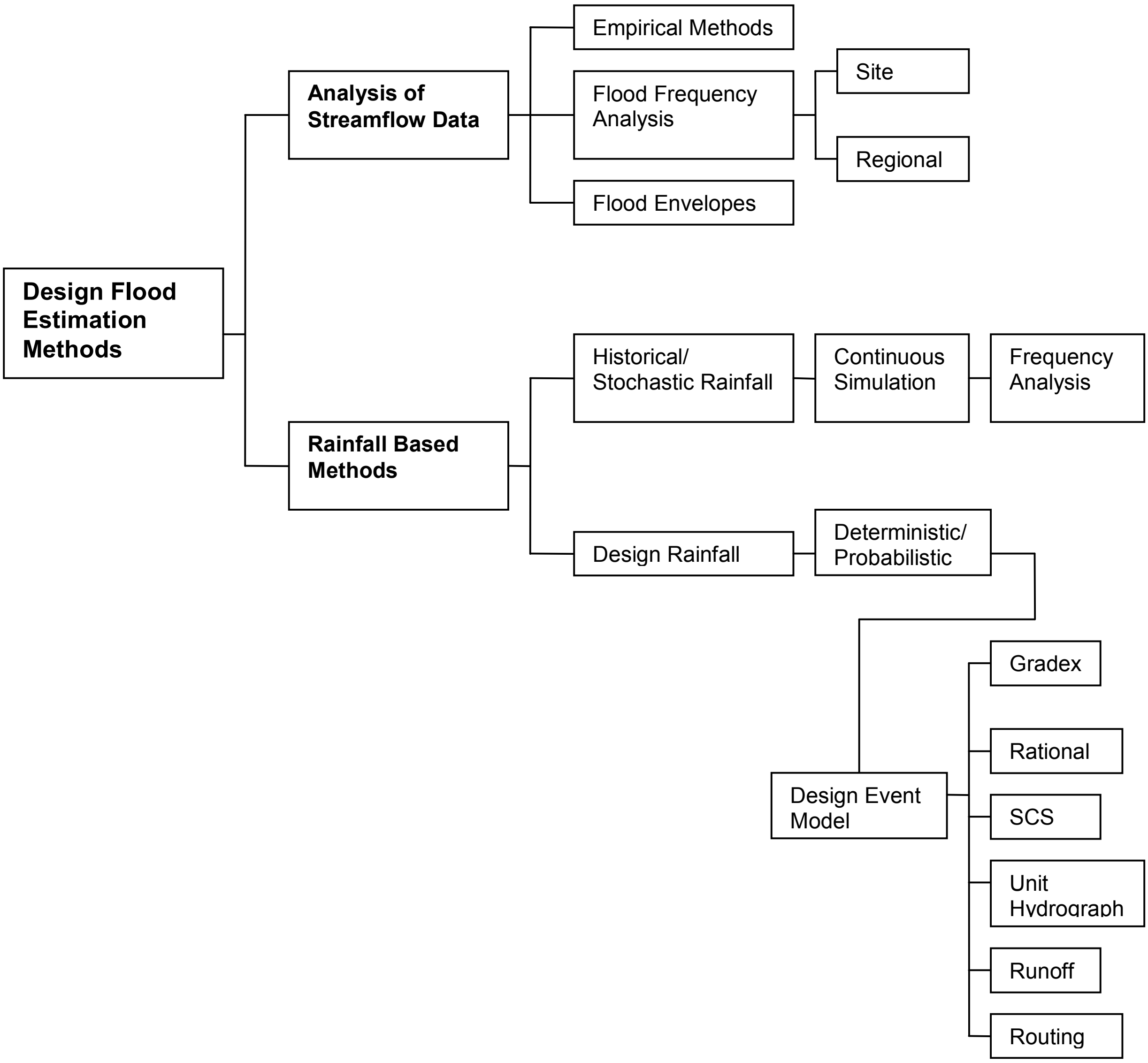
b) **Design rainfall** uses both deterministic and probabilistic models. The term design rainfall therefore refers to the “rainfall depth and duration, or intensity, associated with a given probability of exceedance, which in turn is inversely related to the commonly used term, return period” (ibid: 1). Many regional and national scale studies in South Africa have focused on estimating design rainfalls for durations of 24 hours and less (ibid). Smithers and Schulze (2003) in their research developed reliable and consistent estimates of design rainfall for durations ranging from 5 minutes to 7 days at any location in South Africa. This was done using a regionalised approach and scale invariance properties of rainfall (RLMA and SI procedure). This design rainfall is now widely used throughout South Africa. Design rainfall data are then used to model floods, known as design event models. *Design event models* assume that "the frequency of the estimated flood is equal to the frequency of the input rainfall" (ibid: 121). This model has shortcomings with respect to the accuracy of estimates as it only considers the nature of rainfall and ignores other parameters (e.g. soil, topography, vegetation etc.) (ibid). The methods used include those listed in the discussion of deterministic methods above.

The rational method is widely used internationally for both rural and urban catchments (Pilgrim and Cordery, 1993 in Smithers and Schulze, 2003). "The method is an approximate deterministic method and a major weakness is the judgement required to determine the appropriate run-off coefficient and the variability of the coefficients between different hydrological regimes. … [The method only calculates flood peaks] and is sensitive to the input design rainfall intensity, the selection of the runoff coefficient, the experience of the user and should not be used for catchments [greater than] 15 km^2" (from Pilgrim and Cordery, 1993 in Smithers and Schulze, 2003: 122).

In the U.S.A, the SCS method has replaced the rational method because of the wider database and the way in which the physical catchment characteristics are incorporated (Pilgrim and Cordery, 1993 in Smithers and Schulze, 2003). The SCS method was adapted for South Africa and it was found that the models performed satisfactorily to be recommended for design on a variety of land use and catchment size categories (Smithers and Schulze, 2003).

The unit hydrograph method "assumes a characteristic linear response from a catchment and hence may not be accurate for calculating large floods" (ibid: 124). A limitation to the approach is that it assumes spatial uniformity of rainfall. Its advantage lies in the estimation of the entire hydrograph, "which is important where storage in a catchment is found" (ibid: 124).

Figure 5.1 Methods for Estimating Design Floods



Source: Smithers and Schulze (2003: 116)

5.3.2 Urban Flood Risk Estimation in South Africa

The main concern in urban areas is the disposal of stormwater since the lack of efficient stormwater disposal systems may result in the flooding of houses, properties and roads (Alexander, 2000b). In this context drainage systems are viewed as essential in urban areas where the flooding of properties and roads needs to be avoided (ibid). As such, analytical methods are required to determine optimum pipe, culvert and channel sizes, as well as the "required sizes of detention works where these are needed to reduce flood peaks; provide temporary storage of stormwater where this exceeds the capacity of the drainage system; or to control water quality" (ibid: 103-104).

Alexander (2000b) observed that a number of computer models are used in South Africa for the design of urban drainage systems that draw from international models and have been adapted for South African conditions as well as models designed in South Africa. These models fall under the broad category of rainfall based methods, and more specifically, are derived from continuous simulation models (ibid). They may also be classified as distributed models "as the catchment is broken down into a number of sub-catchments and the flood hydrograph is calculated for each sub-catchment separately and then the combined discharges are routed through the drainage system" (ibid: 104). The hydrological components of these models are usually highly deterministic since they closely model the actual hydrological processes (ibid). Being deterministic they may be calibrated by "comparing the predicted discharge from the system with the measured discharge for a given storm" (ibid: 104). A good deterministic model that closely resembles the catchment processes for a given storm produces better results than a good empirical or statistical model whereas a good statistically based model provides better estimates of flood probability than a good deterministic model (ibid). Stephenson (2002) for example used statistical modelling to determine flood frequencies and modelling of the Vaal river in the Witwatersrand region of the Gauteng province. Alexander (2000b) stated that the Rational Method is most widely used internationally for flood estimation particularly in urban areas, however, from Smithers and Schulze (2003) we learnt that this method is now replaced by the SCS method.

Alexander (2000b) argued that accurate hydraulic calculations are more important in urban drainage problems than accurate hydrological analysis. "This is because under-design will result in the inconvenience of functional failure and not the costly consequences of structural failure or possible loss of life" (ibid). However for urban development and emergency response planning hydrological modelling is more applicable for determining flood-prone areas.

5.3.3 Integrated Hazard and Vulnerability Approach to Flood Risk Research in South Africa

There remain a limited number of "near-flood risk" studies in South Africa that integrate both a hazard and vulnerability approach. The term "near-flood risk" is used here because not all of the research adopting a hazard and vulnerability approach solely focused on flood risk but included extreme weather events such as convective storms, cut-off low pressure systems and even drought (i.e. hydro-meteorological risks).

Pyle's (2006) research suggested that Myburgh's (1991) PhD research should be seen as pioneering work to integrated hazards research in South Africa. Myburgh used an integrated hazards framework to explore the physical, behavioural and social aspects of flood and drought hazard in order to gain a more comprehensive understanding of the complex interrelationships at play in defining the hazardousness of the arid and semi-arid regions of the previously-called Cape Province of South Africa. The focus of Myburgh's research was to identify the range of human adjustments and adaptations to the hazard (Pyle, 2006). Myburgh's research adopted a human ecology approach because of his focus on the physical hazard and human adjustments and adaptations to the hazard.

Mgquba's (2002) Masters research investigated the physical and human dimensions of flood risk in Alexandra township of Johannesburg. This study applied Blaikie et al's (1994) PAR model to unpack the root causes, dynamic pressures and unsafe conditions of severe flooding of the Jukskei River in the township that increased vulnerability and associated risk of the urban poor living in the floodplain. Mgquba's research adopted a political ecology approach to flood risk because of the PAR model utilised.

Research by DiMP (2003; 2004; 2005a; 2007) of severe weather events in the southern-Cape region of the Western Cape Province of South Africa adopted a disaster risk conceptual framework to allow for a focus on the interplay between natural or other threats and conditions of socio-economic, environmental or infrastructural vulnerability to be illustrated. These studies required a multidisciplinary conceptualisation and associated methodology. The shortcoming though of these studies is that they do not adequately investigate the root causes of vulnerability as they studied the post-event socio-economic and environmental impacts of the extreme weather events. In essence, these studies can be classified as human ecology because of their emphasis on how development patterns have contributed to risk (especially DiMP, 2003 and 2007). Furthermore these studies also propose human and institutional adjustments. Along with a human ecology approach, it can also be said that the research (especially DiMP, 2007) employed a PDRA approach where participatory methods were employed in the field research.

Simarly, Pyle (2006) in his PhD employed a conceptual framework that emphasized the combined role played by hazard and vulnerability conditions in defining risk. This enabled him to investigate the temporal, spatial and impact characteristics of severe convective storm hazard and associated risk in the Eastern Cape Province of South Africa. Through this he was able to assert that severe convective storms can occur throughout the province, but with clearly demarcated areas of higher frequency and concentration and that the impact of storms are more severe on poor and vulnerable rural populations in the eastern parts of the province. The vulnerability analysis of his study depended heavily on census data because of the analysis being at a municipal scale. While Pyle did ground-truth the census data through field research, this was not quantified through household sampling surveys but depended on individual interviews. As this constrained the study's explanation of the root causes of vulnerability, Pyle's research adopted a human ecology approach.

Durham's (2007) Masters research adopted a disaster risk reduction framework to assess the effectiveness of existing flood risk reduction efforts along the Baths River of the Western Cape Province. In so doing she conducted a risk assessment that considered the physical hazard as well as the human, financial, technical and institutional capacity to manage the flood risk along the respective river. Durham undertook a flood risk assessment using participatory approaches of interviews, focus groups and consultations with the community and key stakeholders thereby making her approach that of PDRA. The participatory component however provided limited input to the hazard analysis. Other participatory approaches to flood risk research include that by Benjamin (2005) in an honours thesis that built on research from Scott and Benjamin (2005) in an honours project. DiMP (2008) in a participatory facilitator's guide documents approaches to community risk assessments based on eleven CRAs conducted in informal settlements of the Western Cape during the period of November 2005 to June 2007 where flood risk appeared in all eleven settlements. Recurrent aspects of flood risk in informal settlements are also discussed in this publication.

Within South Africa, it is evident then that there is an emerging body of flood risk research that combines both a hazard and vulnerability paradigm. These studies reflect human ecology, political ecology and PDRA approaches (table 5.1). However a hazardscape approach to flood risk research is yet to be applied. This study contributes to an emerging thrust in flood risk research in South Africa that places a particular focus on urban flood risk. The study combines elements of the human ecology and political ecology approaches in the form of the hazardscape approach as well as elements of the PDRA approach. This research therefore employs a *participatory-hazardscape* approach to urban flood risk.

Table 5.1 Approaches of Flood Research in South Africa that focus on Integrated Hazard and Vulnerability Analysis

	Political Ecology	Human Ecology	PDRA (Participatory)	Hazardscape
Characteristics	Addresses root causes and dynamic pressures of vulnerability; limited emphasis on physical hazard	Strong analysis of physical hazard; vulnerability analysis fails to address root causes and dynamic pressures but concentrates on human adjustments	Employs participatory approaches to analyse the hazard (usually limited as scientific analysis is more robust) and vulnerability of at-risk population	Flood hazard viewed as a 'hybrid' hazard; addresses social vulnerability and dominant understanding of flood hazard; allows for structural and non-structural risk reduction measures
Examples	Mgquba (2002)	DiMP (2003; 2004; 2005a; 2007); Myburgh (1991); Pyle (2006)	Benjamin (2005); DiMP (2007; 2008[forthcoming]); Durham (2007); Scott & Benjamin (2005)	None

5.4 Current Flood Risk Reduction Strategies

Flood risk reduction strategies can be classified as structural and non-structural measures. Structural measures are those measures supported by scientific, technical and engineering solutions (tech-fix) that were promulgated during the dominant (behavioural) paradigm of hazards research discussed in 3.3.3 above. Structural measures rely on the building of physical structures to avoid flooding of the floodplain in the case of rivers (Miller, 1997) or urban areas in the case of stormwater systems. Non-structural measures include those measures that involve proper development planning, awareness/preparedness and social protection that gained increasing importance during the radical (structuralist) paradigm era of hazards research where the 'tech-fix' (structural) solutions were criticised for being inadequate and even in some cases responsible for exacerbating the flood risk. Increasingly during the 1990s of the radical paradigm emphasis was placed on community participation in selecting the most appropriate structural and non-structural measures. This is reflected in the efforts of the second half of the United Nations' (UN) *International Decade for Natural Disaster Reduction (IDNDR)*, where dissatisfaction to top-down, technocratic approaches to disasters during the first half of the UN's decade's activities were voiced (Wisner et al, 2004). Currently community participation in the form of Community Based Disaster Risk Management (CBDRM) is gaining popular currency. A key component of CBDRM is also to use local technology and expertise. The ADPC's (2005) flood primer reflected on how even structural measures may be conducted by locals (as opposed to engineering firms) where construction costs are less expensive.

Structural measures include the following:

- Embankments, dykes, levees, floodwalls or stopbanks;
- Channel improvements;
- Bypass channels and floodways;
- Discharging drainage water by pumping; and
- Infrastructure for community flood protection

Embankments, *dykes*, *levees*, *floodwalls* or *stopbanks* –these are earth banks built along both sides of the river that offers protection up to the height or design limits of the particular floods (ADPC, 2005; Miller, 1997; Smith, 2004). There are several limitations to these measures. Firstly, the structures can only provide protection up to the height of the structure (ADPC, 2005). Secondly, embankments occupy a lot of space as the width depends on the height of the structure (ibid). This becomes a major challenge in urban areas where land is limited and highly sort after for development as well as 'green-belt' purposes (see for example Stephenson, 2002). Thirdly, they provide a false sense of security (ADPC, 2005). Fourthly, if the structures are built from earth they become highly susceptible to erosion (ibid). Finally, informal dwellers often occupy embankments where spacious often free land is available, building large slum settlements such as in Bangladesh (ibid).

Channel improvements –to increase or improve the carrying capacity of the river or stream that was obstructed especially by development and urbanisation so that flood flows are contained within the banks (ADPC, 2005; Smith, 2004). There are different forms of channel improvements that include: widening and deepening the channel; removing of debris and vegetation restricting the flow; straightening the channel; removing or altering obstructions; deepening (dredging) the channel; lining the channel; widening the channel mouths; and raising and/ or widening of bridges, culverts and barriers that prevent free flow (ADPC, 2005). Some limitations to channel improvements include the following. Firstly, through straightening the channel and cutting off the meander, the slope is increased thereby increasing the water flow velocity and reducing the flood stages (i.e. the onset of flooding increases). Furthermore increased velocity may result in uncontrollable erosion that eventually may produce new meanders and damaging adjacent land and property (ibid). Secondly, straightening of a meandering alluvial river may only be successful if the channel is lined or the banks reinforced (ibid). Thirdly, dredging the channel will only decrease the flood height according to how far the channel is deepened (ibid).

Bypass channels and floodways –involve using tunnels or open channels to divert water elsewhere (ADPC, 2005). These diversion systems serve two purposes in flood mitigation: (i) they provide storage through reservoirs which decreases the flow in the main channel below the diversion (these reservoirs are known as *flood control dams/ reservoirs* (Miller, 1997; Smith, 2004); and (ii) they provide an extra outlet for water discharge from upstream (ADPC, 2005). Methods of diversion include: (a) <u>spillway</u> that enables water to flow naturally over into a channel when it reaches the height of a spillway; (b) <u>sluice gates</u> in control structures; and (c) intentionally <u>breaching a dyke</u> to divert water during an emergency (ibid). The following limitations exist with these measures. Firstly, floodways are limited by topography (ibid). Secondly, in rural areas to optimise agricultural land, diversion channels are only used during major flood times. However, in urban areas where land is limited, this option is not viable because the land cannot be developed (ibid). Thirdly, informal dwellers may occupy the land exposing them to increased risk when the diversion channels are in use (ibid). Fourthly, people living behind the floodwall become vulnerable since these structures only protect up to a certain flood level (ibid).

Discharging drainage water by pumping –this is however not a very effective approach on its own (ADPC, 2005). Limitations to this approach include that pumps are dependent on electricity or generators which may fail during floods. Secondly, the working components of the pump are susceptible to failure and clogging (ibid).

Infrastructure for community flood protection –structural interventions can be implemented at community level where people have been doing this throughout history applying indigenous knowledge (ADPC, 2005). Such methods vary according to cultural practices and the flooding environment (ibid). A limitation to these methods is that they become extremely vulnerable to larger than normal floods (ibid).

ADPC (2005: 134) highlighted a number of environmental and social concerns that arise with large-scale structural solutions such as dams and embankments. These include:

- i) resettlement issues;
- ii) creation of a false sense of security;
- iii) loss of natural and environmental value;
- iv) lack of community participation;
- v) transboundary concerns, particularly where rivers cross political boundaries; and
- vi) dependency that discourages human resilience.

Non-structural measures aim to keep people and their property away from floods and are often portrayed as "working with nature" compared to the structural measures (Miller, 1997) mentioned above. The following are non-structural measures:

- Integrated watershed management;
- Flood proofing; and
- Preparedness planning

Integrated watershed management (IWM) is the most important non-structural measure for flood risk management (ADPC, 2005). This involves the management of activities within the watershed to ensure they do not increase the risk of flooding through effective land-use planning and zoning that requires good governance to enforce (ADPC, 2005). A watershed refers to the "land area that drains water to a particular stream, river, or lake. It is a land feature that can be identified by tracing a line along the highest elevations between two areas on a map, often a ridge. Large watersheds can contain thousands of smaller watersheds" (USGS Glossary, 2004 in ADPC, 2005: 85). The approach is effective in managing the contributing factors and impacts of flooding and involves a multi-sectoral and often transboundary (across either district, provincial or national boundaries) approach (ADPC, 2005). The goals of IWM in terms of flood mitigation are related to the hazard and environmental protection (ibid). There are four main strategies in implementing IWM each with specific tools. These include *floodplain* management (ADPC, 2005; Miller, 1997); *land use* planning (ADPC, 2005; Miller, 1997; Smith, 2004); *urban development planning* (ADPC, 2005); and *rural development planning* (ibid). Table 5.2 summarises the different strategies and tools employed in IWM, excluding that of rural development planning. There are several limitations associated with an IWM approach. Firstly, the problems that are worsening flooding downstream may be occurring upstream which may be in another district, province or country which makes the management of the water resource a politically sensitive issue (ibid). Secondly, it can become difficult to meet all the needs of the various stakeholders necessary in an IWM approach thus producing the possibility of conflict arising between stakeholders (ibid). Thirdly, a lack of political will at national level to address floods through an IWM approach means that policy and legislative tools may be limited to encourage this approach (ibid). Finally, policies, legislation, agreements and cooperation can only be effective through good governance (ibid).

Table 5.2 Different strategies employed in Integrated Water Management (adapted from ADPC, 2005)

Strategy	Aims	Tools	Supporting Mechanisms
Floodplain management	To reduce vulnerability of flooding & the losses that occur through effective use of the flood plain to minimise risk	Land use planning; zoning; building codes; urban and rural planning	Pilot programmes; institutional arrangements & capacity to enforce legislation; developing capacity of local staff to enforce the law; training staff to use appropriate tools (e.g. GIS); monitoring & evaluation
Land use planning	To guide settlement expansion & redevelopment away from flood-prone areas	Zoning; encroachment lines; urban development planning; building codes; relocation & resettlement; and conservation	As above; NGOs; CBOs
Urban development planning	To plan settlements away from high risk areas	Urban stormwater drainage planning; infrastructure design & development	Finance; technical expertise; good governance; legislation

Flood proofing involves adjusting or modifying the design of individual structures to reduce flood damages and includes long-term, non-structural or minor structural measures to mitigate the effects of flood (ADPC, 2005; Miller, 1997; Smith, 2004). It includes permanent, contingent and emergency measures (ADPC, 2005). The SEI/ASCE (2000) in their design standard provides minimum requirements for flood-resistant design and construction of structures located in flood hazard areas. The following are key approaches to flood proofing:

- Relocation –temporary moving away from the flood-prone area (ADPC, 2005; Miller, 1997; Smith, 2004)
- Elevation –raising the building above the flood level by piles, bamboo or timber stilts, land-fill, or making basements water tight (ADPC, 2005; Miller, 1997; Smith, 2004)
- Flood walls –concrete or steel walls to keep the flood out (Miller, 1997; Smith, 2004)
- Dry flood proofing –sealing the property to prevent flood water from entering using waterproof sheeting, shields, sandbags, and other material that prevent water from entering doors and windows (ADPC,

2005; Miller, 1997; Smith, 2004). This is only suitable in shallow water with a low velocity and should only be applied to buildings constructed of brick, concrete blocks or brick veneer on a wood frame (ADPC, 2005).

- Wet flood proofing –allowing the basement and ground floor to flood while keeping the habitable portion of the building above flood level (ADPC, 2005; Miller, 1997; Smith, 2004).
- Demolition –demolishing a damaged property and rebuilding it more securely on the same site or a safer location (Smith, 2004).

There are several limitations and disadvantages associated with flood proofing. Firstly, flood proofing is not suitable in areas subjected to fast moving water or violent wave action during flooding (ADCP, 2005). Secondly, the additional costs involved in land filling or reclamation, or applying other flood proof techniques is one of the disadvantages of flood-proofing (ibid). Some disadvantages are that there may be a short supply of earth for fill material, the poor aesthetics associated with flood proofing of houses, and the restricted usage of areas where people tend to migrate during floods (ibid). Fourthly, flood proofing may cause further flooding problems, for example earth mounds and dykes may reduce the infiltration and retention capacity of the given area, or may divert flood waters causing flooding elsewhere (ibid). Fifthly, flood proofing is only safe up to a certain flood level (ibid).

Preparedness planning comprises of a variety of activities that includes emergency planning, early warning, and specific actions to reduce risk (ibid). Flood disaster preparedness considers the following: (i) flood response and emergency planning; (ii) flood forecasting and early warning systems with effective dissemination of information especially to the at risk community; (iii) review and revision of systems and plans, providing specific training in areas needing capacity building to ensure timely and effective response (ADPC, 2005 from UNDMTP, 1994). Public awareness of flood risks is also an important component of preparedness (ADPC, 2005) as people's understanding of flood risks will influence effective community responses. ADPC (2005) highlighted four limitations to preparedness planning that included:

i) complications in preparing plans;
ii) uncertainty around effective risk communication;
iii) ineffectiveness in early warning communication; and
iv) problems in obtaining cross-border Flood Early Warning Systems (FEWS).

It can be seen that there are various structural and non-structural measures for managing flood risks. However there are various limitations associated with the different types of structural and non-structural measures. An effective flood risk management strategy would therefore be to adopt both appropriately selected structural and non-structural measures (cf. Miller, 1997). Appropriate structural measures should be based on design flood estimates, available resources and social acceptance. Non-structural measures should be based on cultural practices, the natural environment and available resources. Miller (1997) presents a strategy framework (box 5.1) that would be useful to consider in designing a flood risk management strategy.

5.5 South African Flood Risk Management Policy, Institutional Arrangements and Strategies

5.5.1 Flood Risk Management Policy in South Africa

a) <u>National Disaster Management Act (Act 57 of 2002) and Framework (2005)</u>

Pyle (2006) documented the historical development of South Africa's National Disaster Management Act (NDMA) and National Disaster Management Framework (NDMF) from the Green Paper in 1998 to the White Paper in 1999 and the resultant act in 2002 and framework in 2005. The Act and framework are "coordinating" and "enabling" legal instruments which are intended to facilitate transversal engagement in disaster risk reduction by different stakeholders (Durham, 2007). The Act has ensured a paradigm shift to disaster management

Box 5.1 Strategies and tools for floodplain management (modified from Miller, 1997: 26)

STRATEGY I: REDUCE FLOODING

Dams and reservoirs
Dykes, levees, flood banks
Channel improvements
High flow diversions
Land treatment measures
On-site detention

STRATEGY II: REDUCE SUSCEPTIBILITY TO DAMAGE

Integrated Watershed Management

Floodplain regulations

Zoning
Subdivision regulations
Building Codes
Housing codes
Sanitary codes
Other regulations

Development and redevelopment policies

Design and location of facilities
Land rights, acquisition and open space
Redevelopment
Permanent evacuation

Flood proofing

Flood forecasting and early warning systems

STRATEGY III: REDUCE THE IMPACT OF FLOODING

Information and education
Disaster preparedness
Disaster assistance
Tax adjustment
Flood emergency response
Post-flood recovery

STRATEGY IV: RESTORE AND PRESERVE THE NATURAL AND CULTURAL RESOURCES OF THE FLOODPLAIN

Floodplain and wetland regulations

Zoning
Subdivision regulations
Building codes
Housing codes
Sanitary codes
Other regulations

Development and redevelopment policies

Design and location of facilities
Land rights, acquisition and open space
Redevelopment
Permanent evacuation

Information and Education
Tax adjustments
Other administrative measures

in South Africa from “reactive” to “proactive” activities. The Act gives explicit emphasis to risk and vulnerability reduction particularly of the most vulnerable in society. An important aspect of the Act is its emphasis on cooperative governance as a priority in meeting disaster management objectives. Here a critical aspect is the formulation of disaster management plans at the provincial and municipal level that needs to be integrated into provincial development planning and local municipal Integrated Development Plans (IDPs).

The NDMF is the legal instrument specified by the Act to address the need for consistency across multiple interest groups and gives priority to developmental measures, disaster prevention and mitigation (Pyle, 2006). The four key performance areas focus on institutional arrangements; disaster risk assessment and monitoring; disaster risk reduction and disaster response; and recovery and rehabilitation. The following three enablers are set out to attain the objectives: information management and communication; education, training, public awareness and research; and funding arrangements.

The Western Cape Province has its own framework in addition to the NDMF –the Western Cape Provincial Disaster Management Framework (WCPDMF) that was drafted even before the NDMF was gazetted. The WCPDMF requires that within the Western Cape every organ of state has a representative on the Western Cape Disaster Management Advisory Forum (Durham, 2007).

b) National Water Act (Act 36 of 1998)

The purpose of this act is to ensure that the country's water resources are protected, used, developed, conserved, managed and controlled in ways which take into consideration amongst other factors (as listed in section 2 of the act) the managing of floods and droughts.

With respect to flood management there are several important chapters within this act for example chapter 2, part 2 that outlines the legal requirements of catchment management strategies. This should be read in relation to chapter 7 of the act that is concerned with catchment management agencies. Section 80, in particular, outlines the functions of the catchment management agencies. Finally chapter 14, part 3 is also specifically relevant to flood management. Here section 144 stresses the importance of floodlines on township plans. Furthermore section 145 stresses the importance of making flood related information available to the public.

c) <u>South African Weather Services Act (Act 8 of 2001)</u>

This act concerns the objectives, functions and method of work of the South African Weather Service (SAWS). Section 4, subsection 3 of this act stipulates that only the South African Weather Service may issue severe weather-related warnings over South Africa.

d) <u>Municipal Systems Act (Act 32 of 2000)</u>

A key feature of this act is the requirement of Integrated Development Planning by all municipalities where 5 year strategic development plans are to be drawn up and annually reviewed in consultation with local communities and stakeholders. The resultant Integrated Development Plans (IDP) is to guide and inform all planning, budgeting, management and decision making within a municipality. The IDP identifies resources and allocates these to priority areas so that institutional capacity to implement basic responsibilities is not compromised. This act is important for flood risk management since disaster management plans need to form part of the IDP of a municipality and therefore any efforts to reduce flood risk should be incorporated into the integrated development plans.

e) <u>National Building Regulations and Building Standards Act (Act 103 of 1977)</u>

With regards to flood management this act concerns development within the 1:50 year floodline area where requirements are based only on safety considerations without proper consideration and understanding of the underlying natural streamflow process (CSIR, 2003).

f) <u>Town Planning and Townships Ordinance (Ordinance 15 of 1986)</u>

This ordinance makes provision in Regulation 44 (3) for the extension of floodline areas up to 32 metres from the centre of a stream in cases where the 1:50 year floodline is less than 62 metres wide in total (CSIR, 2003).

5.5.2 Institutional Arrangements to Flood Risk Management in South Africa

From a meeting in Bethlehem in May 2005, the South African Weather Service (SAWS) accepted responsibility for Flash Flood Forecasting in the country. This meeting saw the following institutional arrangements for flood forecasting in South Africa take effect:

- SAWS weather forecasters became the channels of warning to local metropolitan and district Disaster Managers for both severe weather and flash floods;
- SAWS began to deploy soil moisture probes at selected sites to telemeter rainfall information on a daily basis to their data-base that will allow for ground-truthing of satellite remote sensing of soil moisture indicators;
- DWAF (Department of Water Affairs and Forestry) continued to work with large rivers and dam releases to issue flood warnings and monitor their progress;
- The "division of labour" between SWAS and DWAF was determined by the response time of the catchments of interest. In South Africa, on average, flash floods occur in catchments with response times less than 6 hours. Predicting these floods is the responsibility of SAWS. Predicting floods in catchments with response times exceeding 6 hours became the responsibility of DWAF who agreed to work through the National Disaster Management Centre (NDMC), (Pegram et al, 2007).

The response to floods and emergency evacuation of citizens are the responsibilities of local disaster management (ibid). In this context, municipalities need to undertake flood inundation analyses if their disaster management plan suggests this is a significant risk (ibid). It is not clear which department is responsible for handling floods which have a longer lead-time but the Disaster Management Act mandates local authorities to provide proactive disaster mitigation strategies including early warning systems (ibid). While prevailing policy views this responsibility lying with local authorities, it is also recognised that this is unlikely due to capacity and budgetary constraints at the local/Metro level (ibid). Pegram et al (2007) suggested that while DWAF should develop the necessary skills and capacity to do hydrological modelling of the larger catchments which pose a threat, they acknowledge that DWAF lacks a mandate to act (and spend) to achieve this. In this regard, the NDMC is mandated only to play a coordinating role and not to provide skills and services to local disaster managers (ibid).

5.5.3 Flood Risk Management Strategies in South Africa

Alexander (2000b) outlined that the objectives of a flood preparedness policy are to (i) limit the loss of life and direct damage to property as well as indirect damage to the national or local economy; (ii) ensure the acceptance of risk is equally shared between national and local authorities and the public; (iii) develop and implement flood management criteria for local authorities and the public. Thus a flood management policy is to be formulated within the framework of these objectives (ibid). The selection of the appropriate method for reducing flood risks is dependent on the nature of the development (ibid).

There are three criteria used to determine the optimum method for reducing floods. The first concerns determining the *economic optimum size* of a design structure for example urban drainage systems, which can be calculated fairly easily (ibid). Secondly, the acceptable level of public inconvenience or *public acceptance optimum* which is a subjective assessment (ibid). The third criterion concerns development of risk reduction measures for unplanned residential occupation of flood prone areas where *social, political and economic criteria* become important (ibid). All of this indicates "the wide range of knowledge and analytical methods required for the development of flood risk reduction measures, and the large measure of experience-based judgement required for devising solutions" (ibid: 225). Most local authorities in South Africa have developed design standards based on judgement and experience rather than optimisation criteria (ibid).

The *ex ante* (risk reduction/mitigation) stage of flood damage research in South Africa has contributed to the knowledge base of determining flood risk reduction measures. Here, research by Viljoen et al (2001) that stretched over the three phases of *ex ante* research resulted in the development of the *Flood Damage Management Aids for Integrated Sustainable Development Planning in South Africa*. The aids were intended to be applied as part of a holistic approach to integrated hydrological catchment management. They developed a *continuous flood disaster management system* that comprised a proactive, reactive and post (event) component. The three phases are informed by computer programmes for design modelling, loss functions and questionnaires for damage assessments. Within this continuous disaster management system, the key area, particularly with regards to flood risk reduction, concerns the proactive component.

The features of note within this proactive component concern the computer models of FLODISM (Flood Damage Simulation Model for Irrigation Areas) and TEWA (Computer Model for Tangible Economic Flood Water Damage Assessment). The purpose of these models is to optimise certain structural flood mitigation measures. FLODISM concerns rural areas, thus rural flood risk whereas TEWA is dedicated to concentrate on urban flood risk. TEWA calculates tangible flood damages and enables evaluation of different flood damage mitigation options. The inputs into the model required to calculate flood damage include flood damage functions, geographical data, land use data and hydrological data. The deliverables from these inputs include flood maps, land-use data base, economic data base, and GIS data base. The outputs of TEWA enables the determination of the flood damage potential, the area under risk and the impact of different flood mitigation options for a specific urban flood plain. Thus the deliverables of the outputs includes that of flood plain management, emergency and sustainable flood action plans.

The study by Viljoen et al (2001) used an economic-engineering approach with an emphasis on hydrological modelling of rivers. This therefore places more emphasis on the hazard component and limited emphasis on vulnerability reduction that allows for participatory approaches. The research did include a sociological study that highlighted certain social aspects to be considered in the flood management model. However, the sociological study failed to mention that emphasis should also be placed on existing local non-structural measures.

Pegram et al (2007) observed that in most metropolitan areas of South Africa, flood studies are limited to static flood assessments designed for zoning and risk assessment. They also noted that considerable work has gone into defining flood-lines (see for example City of Cape Town, 2003; 2004). Pegram et al (2007) stated that it is only recently that a series of flood forecasting related projects (funded by WRC) resulted in awareness that there are data available that can assist in anticipating a flood rather than waiting for it to happen (see for example Pegram and Sinclair, 2002; Sinclair and Pegram, 2004; Mkwananzi and Pegram, 2004). Building on previous research and development Pegram et al (2007) developed a *National Flood Nowcasting System* in order to develop an integrated flood mitigation strategy for South Africa.

The flood nowcasting system is heavily dependent on hydrological (especially the TOPKAPI model) and hydraulic modelling. It draws from rainfall estimation, historical rainfall data and streamflow data along with catchment characteristics and satellite radar data to produce the flood forecasts. The model was thus far installed in the offices of *Umgeni Water* and *Durban Metro's Flood Management Centre*. The research resulted in a proposed framework for the lines of communication from forecasters to disaster managers to the at-risk communities. However there has been no research to date exploring efficient means of communication from disaster management centres to the at-risk communities which remains a problem in many metros and local municipalities across South Africa. Hall (2007) for example notes this to be an international problem with regards to early warning research where funding is channelled towards the current capabilities and developments in science and technology thereby shifting focus away from the central issue of addressing the real needs of the communities and people at risk.

CSIR (2003) published guidelines for human settlement planning and design, known as the “Red Book” based on its colour. Previously this was known as the “Blue Book” under the reference CSIR (1994). The Red Book contains many guidelines relevant for flood risk reduction. Here for example there are guidelines to the ideal geological conditions for urban development in terms of soil and slope profile. There are also guidelines around floodplain development especially the importance of identifying the 1:50 year floodline. The guide also contains in-depth guidance and design specifications for stormwater management as well as available structural technologies for flood reduction.

In terms of local strategies of flood proofing, these have been very poorly documented where some examples occur in DiMP (2007 and 2008), Scott and Benjamin (2005) and Sowman and Urquhart (1998). Thus the majority of risk reduction measures in South Africa focus on structural measures and non-structural measures are more orientated towards early warning systems that often do not assist the at-risk communities as warnings fail to reach them timeously.

5.6 Conclusion

This chapter presented what a flood risk assessment should entail and then explored the nature of flood risk related research in South Africa. It was found that the majority of flood research in South Africa has adopted a hazards approach that is concerned with hydrological modelling of floods. These typically employ deterministic or rainfall-runoff methods; statistical methods, that are either site-specific or regional; and empirical and pseudo-statistical or empirical-probabilistic methods. Very limited research has employed an integrated hazards and vulnerability paradigm to flood risk. Consequently the majority of risk reduction research and practice in the country is orientated towards structural measures or the technical, hydrological component of the non-structural early warning systems. Limited emphasis has been placed on community-based approaches to flood risk reduction practices. There are various legal instruments in South Africa that support flood risk management and the Disaster Management Act and associated framework, in particular, promote consideration of community-based approaches.

In accordance with international best practice, an effective flood risk management strategy should strike a balance between appropriately selected structural and non-structural measures that involve the at-risk community throughout the design of such a strategy –from conceptualisation to implementation. Thus a focus on both an assessment of the flood hazard and the vulnerability conditions of an at-risk population is essential in achieving such a balanced flood risk management strategy.