COJ FLOOD-PRONE AREAS STUDY:

DEVELOPMENT OF A FLOOD-PRONE AREAS DATABASE AND IDENTIFICATION OF POSSIBLE STRATEGIES TO PREVENT FLOODING IN THE COJ

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EXECUTIVE SUMMARY

Gondwana Environmental Solutions (GES) was appointed by the City of Johannesburg (COJ) to develop a database of flood-prone areas and to assess possible strategies to prevent flooding in the City. The main objective of the was to use existing data for the greater COJ catchment area to indicate flood-prone areas and to identify strategies that may be used to reduce risk in susceptible areas and to provide recommendations as to methods that may be used to protect the city against flooding.

The effects of climate change on rainfall are difficult to determine with some studies showing marginal increases in rainfall (5 – 10%) while others indicate that South Africa can expect decreased annual rainfall. In spite of the inconsistency between modelling studies, a marginal change in annual rainfall, whether an increase or decrease, is unlikely to have a significant impact on the ability of COJ stormwater reticulation systems to conduct flood waters away from the city in a safe and predictable manner.

The possibility of increased intensity of extreme weather events (Mason et al., 2004; Vogel et al., 2009), however, has the potential to reduce the capacity of stormwater reticulation systems to cope with the volume of surface runoff generated directly after a severe downpour. The catchments identified as been at risk of flooding require urgent attention, particularly in areas where informal settlements are at risk, where mitigation measures may include stormwater reticulation repairs and upgrades or resettlement of affected communities.

The stormwater bylaws provide excellent protection against future flood risks by regulating construction and development projects and by stipulating strict requirements for developments that would have a significant impact on runoff water volumes and the ability of adjacent stormwater reticulation systems to cope with those volumes. Shortcomings of the bylaws are that no provision is made for dealing with areas that are currently at risk of flooding, or to prevent the expansion of vulnerable communities. The bylaws provide flood-proof development regulations for the City of Johannesburg, if the shortcomings are addressed and the bylaws are enforced effectively.

According to the information gathered during this study and the results of catchment discharge volumes, the following actions are recommended to allow for maintaining the function of existing stormwater reticulation systems and reducing the effects of increased pressure on those systems. The recommendations have been divided into different areas of focus for improved clarity:

Stormwater reticulation systems:

- All areas that fall below the 100 year flood boundaries should be clear of human settlements, particularly informal settlements, in order to reduce the possibility of loss of property and livelihoods.

- Ensure that the regulations as stipulated by the stormwater by-laws act adhered to by all new developments.

- Improvement of existing stormwater reticulation in areas of known concern through the construction of retention dams and repair of damaged infrastructure.

- Ensuring that existing stormwater reticulation systems are clear and free of debris, silt and vegetation. Areas requiring attention may be determined from the outcomes of assessments of the stormwater drainage systems conducted by external consultants.

- Recalibration of existing river gauges, in conjunction with DWAE, to allow for river level and flood peak monitoring. Installation of equipment to allow for the remote capture of river level, flow characteristics and flood peak data.

- The Stormvoël stormwater by-laws provide excellent protection against property damage and loss, especially in terms of formal residential, commercial and industrial developments. No guidance is provided in terms of informal settlements presently at risk from flooding and no process is in place to reduce this risk or to relocate the affected population of these informal settlements.

Future contracted studies:

- Standardization of methods for the determination of floodlines and discharge data. These methods should be determined by the JRA and communicated to consultants involved in flood line determination and related work done for the City of Johannesburg.

- Development of a centralised disaster management and reporting database for the recording of flood events, disasters and emergency situations. This should be done in conjunction with the NDMC, SAPS, SAWS, local fire departments and private paramedic services.

- Improvement of the reliability of meteorological stations under the control of the City of Johannesburg for accurate and reliable data recording in order to improve data on rainfall and extreme weather events.

- Development and maintenance of a central database of accurate digital elevation models, river and stormwater reticulation system data, cadastral information, aerial photographs and associated GIS data that may be accessed by all departments in the City of Johannesburg. The existence of such a database and the contents thereof needs to be communicated to all departments within the City of Johannesburg.

- GIS data currently available requires a visual verification process using high resolution aerial photography. This will allow for the identification of errors in recording various data types. Much of the GIS data may be corrected using this method which will negate the need for costly field investigations.

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LIST OF ABBREVIATIONS

ALS	-	Airborne Laser Solutions (now Southern Mapping)
CDSM	-	Chief Directorate of Surveys and Mapping
CGIS	-	Corporate Geographical Information Systems (COJ)
CCSP	-	Climate Change Scientific Program (United States)
COJ	-	COJ
CSS	-	Climate Change Strategy
DEAT	-	Department of Environmental Affairs and Tourism
DEM	-	Digital Elevation Model
DMA	-	Disaster Management Act (Act No. 57 of 2002)
DME	-	Department of Minerals and Energy
DRM	-	Disaster Risk Management
DWAE	-	Department of Water Affairs, Agriculture and Environment
EIA	-	Environmental Impact Assessment
ESRI	-	Environmental Systems Research Institute
FFGV	-	Flash Flood Guidance Value
GCM	-	General Circulation Model
GIS	-	Geographical Information System
ICDM	-	Intergovernmental Committee on Disaster Management
IPCC	-	International Panel on Climate Change
JMOSS	-	COJ Municipal Open Space System
LDCs	-	Local District Municipalities
MDCs	-	Municipal District Councils
NCCRS	-	National Climate Change Response Strategy
NDMC	-	National Disaster Management Centre
NDRMF	-	National Disaster Risk Management Framework (2005)
NEMA	-	National environmental Management Act (Act No. 107 of 1998)
ReVAMP	-	Vulnerability, Assessment, Mitigation and Planning
RMF	-	Regional Maximum Flood
SAFFG	-	South African Flash Flood Guidance System
SAWS	-	South African Weather Service
SoER	-	State of the Environment Report (COJ)
SRES	-	Special Report on Emission Scenarios
UNFCCC	-	United Nations Framework Convention on Climate Change
WMO	-	World Meteorological Organisation

1. INTRODUCTION

Gondwana Environmental Solutions (GES) was appointed by the COJ to develop a database of flood-prone areas and to assess possible strategies to prevent flooding in the City. The main objective of the project was to use existing data for the greater COJ catchment area to determine flood-prone areas. A secondary objective was to identify strategies that may be used to reduce risk in susceptible to protect the city against flooding.

1.1. OBJECTIVES OF THE STUDY

The main objective of the study was to consolidate existing Geographic Information System (GIS) data required for the development of a clearly structured and comprehensive database that may be used for the determination of flood-prone areas for the greater COJ catchment area. The study included identification of strategies that may be implemented to reduce risk in flood-prone areas and recommendations that may be used to protect the city against flooding.

The final objective of the study was to delineate floodlines for the highest priority catchments (five catchments as identified by the Catchment Prioritization Study by SRK (2008)). The modelling approach will use a combination of ESRI ArcGIS software and calculation of flood peaks from catchment basins of which the surface area and general topography is known. The resultant flood peak values will then be fitted to the 3-dimensional topographical model constructed in ArcGIS.

1.2. TERMS OF REFERENCE

The scope of work included in this study is summarised below:

These terms of reference are based on the proposal submitted by Gondwana Environmental Solutions to the COJ for the flood-prone areas database development project:

I. Baseline Information:

- Literature review of historical data and records of previous extreme weather conditions and catastrophic flood events within the boundaries of the COJ.
- Simplified description of collected data for flood-prone areas database.

- Identification of flood-prone areas based on literature, previous studies, base maps and data provided by the COJ.
- Review of applicable legislation and buffer zones as stipulated by legislation.

II. GIS Information Analysis and Modelling:

- Modelling of existing river and topographical data to determine flood-prone areas for the COJ.
- Review of previous flood-prone area studies for comparison with current data and estimation of the influence of climate change.
- Identification of strategies to reduce risks and recommendations for methods to protect against flooding.
- Recommendations for additional areas of study and for the improvement of existing data.

III. The compilation of a final report including all of the above facets.

1.3. DELIVERABLES

The project deliverables include the following items that form part of the final report:

- Two copies of the data used in the topographical analysis including all maps, layers, and derived feature classes and shape files will be provided: one for the COJ Environmental Department and one for the COJ Corporate GIS Department, for future reference.
- One CD for the COJ Environmental Department, which will include electronic copies (if available) of the reference articles used during the compilation of this report, for future reference.
- One printed, ring-bound copy of the report which will include a literature review, description of the methodology employed and assumptions and limitations pertaining thereto, results of the modelling exercise and a list of recommendations for future studies and projects.

2. BACKGROUND

2.1. The COJ Region

The COJ is situated on the Highveld in the Gauteng Province (Figure 1), forming the largest single metropolitan centre in South Africa. The city hosts a population of 3.2 million according to the 2001 national census and has the highest concentration of industries, the highest rate of urbanization (97%) and the greatest need for appropriately designed and managed environmental, stormwater and infrastructure management plans.

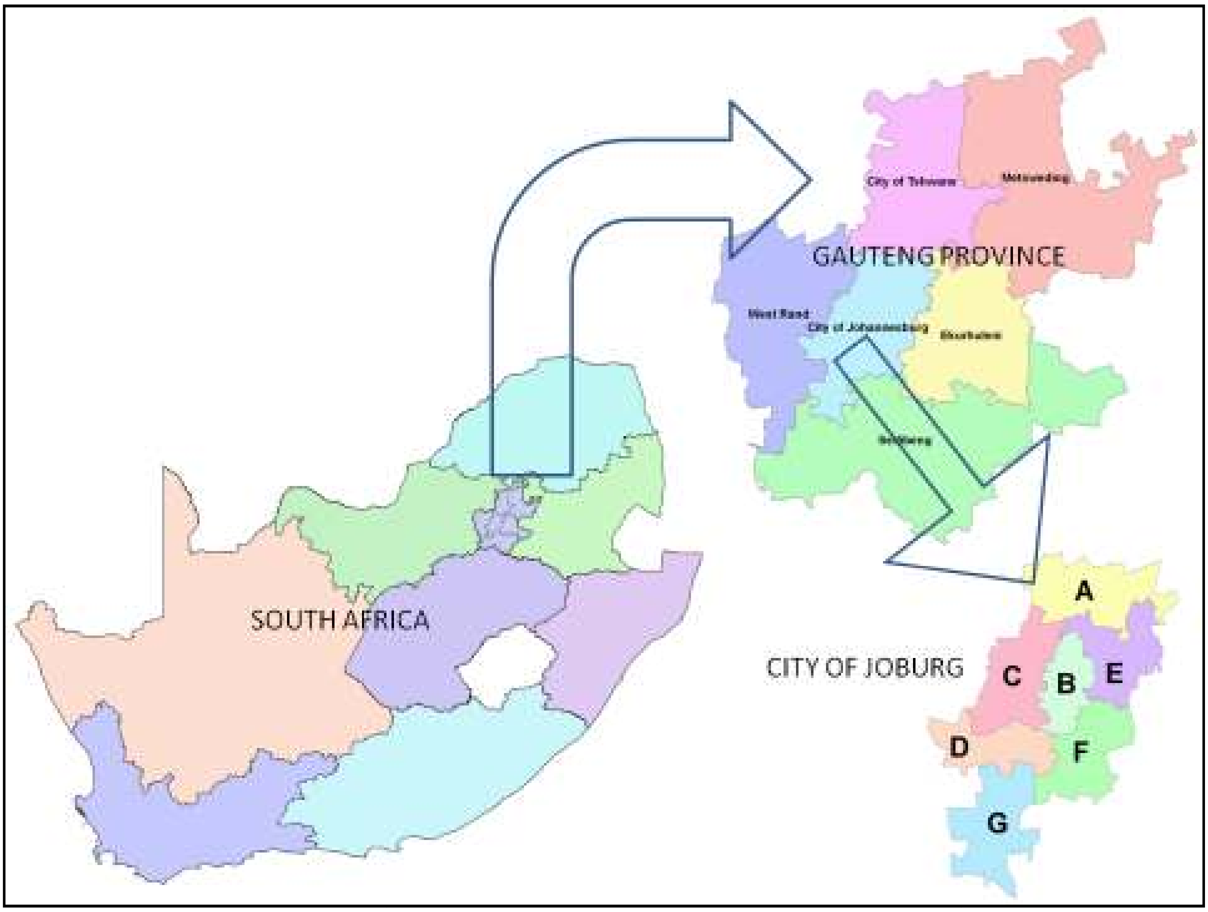

Figure 1: Location of the COJ within the Gauteng Province in South Africa.

The elevation of COJ ranges from 1,500 m to 1,800 m above sea level (Figure 2). COJ climate is dry and sunny all year round. Average day-time minimum and maximum temperatures are 22˚C and 10˚C with highs of 35˚C being reached in summer. Temperatures seldom drop below 0˚C in winter although frost occurs in winter, as is characteristic of Highveld winter nights

The COJ region experiences summer rainfall and receives about 700 mm per annum. Heavy afternoon thundershowers are characteristic of the Highveld summer rainfall region with the majority of rain falling between the months of October and April (Wordtravels, 2007a).

The COJ and surrounding metro municipalities may experience negative impacts of climate change on various socio-economic sectors such as reduced fresh water supplies, damage to urban drainage and transport infrastructure and human settlements from extreme flooding events. The influence of the urban heat island phenomenon may enhance the effects of climate change on the city, due to the influence air circulation characteristics and pollution concentrations. Thus estimating the extent and magnitude of flood risk is necessary to determine the effect of climate change at City level. (COJ CCS)

2.1.1. Topography and Drainage Characteristics

The COJ contributes to two major drainage basins (Northern catchments and Southern catchments), the Witwatersrand serving as the watershed between catchments draining into the Indian and Atlantic oceans. All rivers north of the Witwatersrand flow into the Limpopo River to the North and the Olifants River to the east. All the rivers found to the south of the Witwatersrand drain into the greater Vaal River and Orange River catchments. These larger, quaternary catchments are divided into 38 regional catchments for each of the larger rivers within the COJ municipal boundaries as shown in Figure 4.

2.1.2. Projected Climate Scenario for COJ

In order to estimate the effects of climate change on temperature and precipitation at city scale, various regional predictive models have been developed (Engelbrecht, 2005; Hewitson et al, 2006).

Temperature

According to the IPCC A2 (with continued green house gas emissions at current levels) climate scenario, South Africa will experience increases of 3 to 4°C on average throughout the year (IPCC, 2007). Winter rainfall regions and the western parts of the country are expected to experience decreased rainfall. Increases in early summer rainfall are expected in the eastern parts of the country with a reduction in rainfall during late summer (Engelbrecht, 2005; Hewitson et al., 2006).

The number of frost days is expected to decrease, particularly between the months of April to August (COJ, 2008). Daily maximum temperatures are expected to increase by 2.3 to 2.5°C from December to April, thereafter increasing by 1.8 to 3.2°C over the remaining months (COJ 2008).

Rainfall

The results from precipitation model applications are conflicting. Some modelled results project decreases in rainfall while others project increases. This is due to the multi-factorial nature of rainfall estimation, being reliant on accurate understanding of atmospheric processes (chemistry and circulation), interactions between natural processes and anthropogenic influences. In addition, individual climate models simulate rainfall differently (COJ, 2008).

Indications are that rainfall patterns over South Africa are expected to change in the following ways:

- The yearly rainfall totals show little change in the future climate, with changes generally projected to be less than 10%. An important exception is the south-western Cape of South Africa, where a considerable decrease in rainfall is projected. Eastern South Africa is projected to become drier despite the projected increase in summer rainfall. This is in contrast to the general perception that South Africa will become wetter in the east and drier in the west as a result of greenhouse gas forcing (Engelbrecht et al., 2008).
- Seasonal rainfall patterns will change. These changes will include the earlier onset of rainfall in the summer rainfall regions and a dryer winter (Hewitson and Crane, 2006). This is particularly significant in the winter rainfall region of the Western Cape, where decreases in seasonal rainfall of up to 40% are indicated (Engelbrecht et al., 2008).
- The Hadley Centre in the UK predicts a decrease of rainfall in South Africa by 2050 of 15% in the summer rainfall areas, and 25% in the winter rainfall areas
- Schulze and Perks in 2000, showed that mean annual runoff for South Africa is expected to decrease incrementally over the period of 2015 to 2060 (Figure 4).

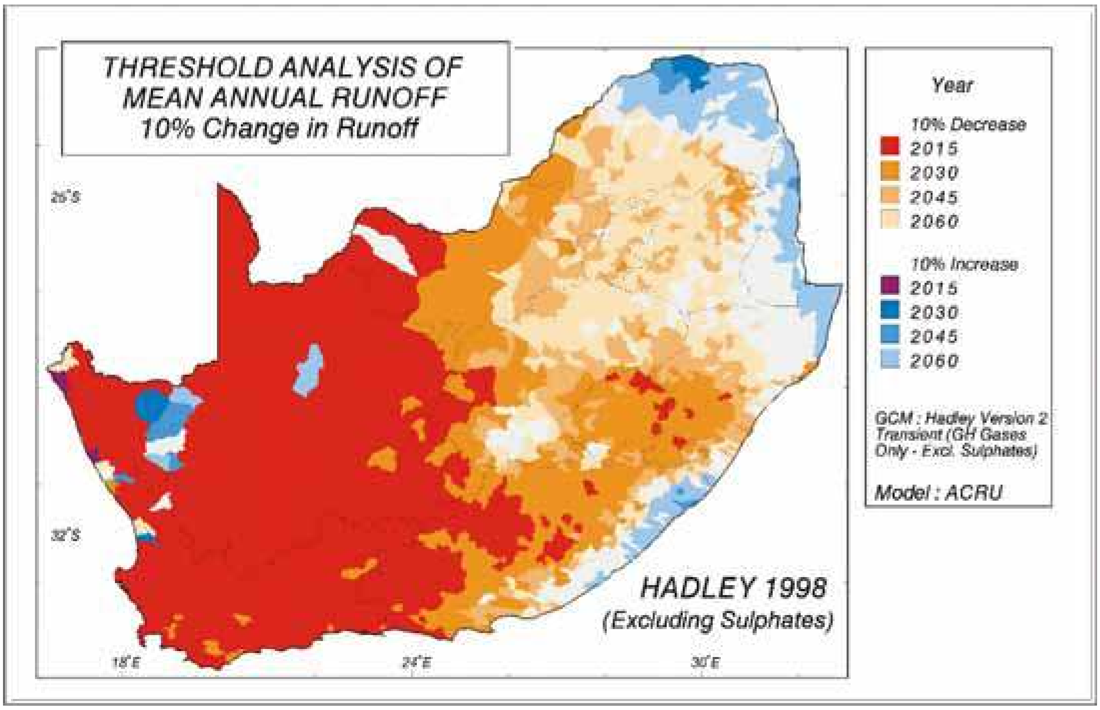

Figure 2: Threshold analysis indicating when a 10% change in mean annual runoff could occur in southern Africa, using scenarios generated with the HadCM2 General Circulation Model (Schulze & Perks 2000)

3. LITERATURE REVIEW

A review of case-studies was conducted in order to determine the state-of-the-art of floodplain determination, climate change studies, understanding and interpretation of historical data and the emergence of new management approaches associated with flood-prone areas and their management. The review is intended to provide guidance for future studies related to flood-prone areas, floodline determination and the effect of climate change on stormwater management infrastructure for the City of Johannesburg.

3.1. Overview of Applicable Legislation and By-laws

The Stormwater By-laws for COJ have been designed in order to maintain the drainage capacities of original stormwater reticulation systems and to prevent negative impacts of new developments and land-use changes on drainage characteristics and expected flood-peak levels. These by-laws include a requirement by all new developments to indicate the expected discharge levels and total volumes. Any stormwater discharge levels found to have a significant impact on the drainage characteristics of a specific basin adjacent to the municipal stormwater reticulation system require the construction of stormwater retention facilities on the development property. Such retention systems need to be designed to allow stormwater leaving the property to do so at rate that does not exceed the capacity of the adjacent municipal reticulation system. As such, the stormwater by-laws are virtually flood-proof in that design capacities are strictly adhered to and all new formal developments are required to comply. Difficulties with the stormwater by-laws only arise in when informal settlements are concerned or in cases where incorrect or inaccurate floodline information is submitted by new developments seeking approval.

The City of Johannesburg has the highest rate of urbanisation in South Africa and as a result lacks sufficient open space for the construction of new settlements. A general lack of space and a rapidly growing population often forces people from rural communities who come to the city in search of employment to take up residence in informal settlements. This results in overcrowding in most settlements and the people start constructing rudimentary shanties on the edges of rivers and streams in the area (

These problems may be avoided if management structures are put in place needed to allow for the effective enforcement of the stormwater by-laws act, which including, but are not limited to, the following:

- Standardization of methods accepted by the JRA for the determination of floodlines and discharge data.
- Strict procedures to address formal and informal settlements found within the 100 year flood boundaries.
- Strategies for the relocation of informal settlements to areas above the 100 year flood boundaries.

The management of flood risks and planning of mitigation measures involves the legislation and by-laws as listed in Table 1 below.

Table 1: Bodies of legislation applicable to urban drainage and flood plain management

Legislation or By-laws	Requirements
NEMA (Act No.107 of 1998)	• Provide environmental information; • Promote cooperative environmental governance • Assess impacts of policies, programmes, plans and projects on the environment; • To clean up after an emergency activity that threatens the environment
Municipal Systems Act (Act No. 32 of 2000)	• Strategic Development Frameworks and integrated development plans to guide the development direction of cities.
Stormwater By-laws for the COJ	• Manage, control and regulate the quantity, quality, flow and velocity of stormwater runoff from any property which it is proposed to develop or is in the process of being developed or is fully developed, in order to prevent or mitigate –
Disaster Management Act (Act No. 57 of 2002)	• Prevent and reduce the risks associated with disasters, mitigating their severity. • Emergency response strategies for municipal districts. • Recovery and rehabilitation strategy after disaster event.
The Constitution of the Republic of South	• Firstly the right in section 24(a) – Everyone has the right to an environment that is not harmful to their health or well-being

Africa, 1996 (Act no. 108 of 1996)	• Secondly the right in section 24(b) – Everyone has the right to have the environment protected, for the benefit of present and future generations, through reasonable legislative and other measures.
SAWS Act (Act No. 8 of 2001)	• SAWS mandate to provide weather outlooks, forecasts and warnings to the general population and aviation authorities. • To collect and maintain a consistent, accurate and coherent database.
Health Act (Act No. 63 of 1973)	• Local government to prevent nuisance and pollution

3.2. Review of Case Studies

3.2.1. Flood Plain Modelling

3.2.1.1. Nylsvley study

The Nyl river is situated in the Limpopo province of South Africa and represents the southern most tributary of the Mogalakwena River (Birkhead, 2006). The river passes through the Nyl River floodplain, which forms the Nylsvley Nature Reserve, near the town of Naboomspruit in Limpopo, and includes part of the largest floodplain vlei in the South Africa. The reserve is renowned for its exceptional birdlife diversity, with 370 species recorded, of which 102 are waterfowl. During good rainy seasons the floodplain becomes a hive of activity, with the best estimate for water bird numbers being approximately 80 000. The system also plays an important role for frogs and fish, which gather in large numbers to breed during seasonal floodplain inundation (Web 3, 2009).

Recent upstream catchment land-use and water resource developments, affecting the timing and volume of water delivered, may threaten the ecological integrity of the Nyl River floodplain (Birkhead, 2006). The Nylsvlei study was thus commissioned to determine the impact of the developments on the Nyl river catchment in terms of the water supply regime to the floodplain by means of hydrological modelling. An indicator species was chosen (*Oryza longistaminata* – Wild Rice) due to known sensitivity to extent, depth, duration and timing of flood inundations.

The types of information required for the Nylsvlei modelling study are shown in Table 2 below.

Table 2: Data requirements for the Nylsvlei study procedure

Nylsvlei Floodplain Data Requirements	
Type	**Source**
Topographical and photographic surveys	Airborne laser mapping and colour photographic survey
Inundation and flow data	River gauging and water mass balance
Local rainfall	Nylsvlei Meteorological Station
Evapo-transpiration, infiltration and ponding	Previous studies and site specific survey

A suite of models listed in Table 3 was used to apply one-dimensional modeling for the prediction of the flood characteristics. Separate but linked models were developed for each of the continuous portions of the large floodplain. Application of these models allowed for surface mapping, unsteady one-dimensional flow analysis, and graphical representation of output, including plan plots of inundation areas and depths, rating curves, hydrographs and plots of other relevant hydraulic information.

Table 3: List of models and justification

Models Employed	
Model	**Justification**
HEC-DSSVue	Database system as utilized by HEC-River Analysis System (HEC-RAS) which allows for storage and access of sequential river analysis data.
HEC-RAS	One-dimensional river drainage analysis software for determining flood levels, volumes and influence of stream channel obstructions.
RiverCAD	Provides the tools for positioning and extracting cross-sections, measuring longitudinal distances between adjacent cross-sections and mapping floodplain inundation.
Quicksurf	Allows for conversion of surface mapping data such as point data (as obtained from the LIDAR survey) into contours, grids and triangulated irregular networks for terrain analysis.

Hydraulic modelling has been used to transform inflow discharge hydrographs provided by hydrological models (Havenga et al., 2007) into ecologically relevant flood characteristics. Separate hydraulic models have been developed, calibrated and verified for three continuous sections. These three sections included the Nylsvlei Nature Reserve and the areas upstream and downstream of the reserve. Each model accounts for inflows, local rainfall, evapo-transpiration, infiltration and ponding losses. The modelling scale and resolution were defined by previously observed spatial distributions and temporal responses of the Wild Rice. Although the characteristics of the Nyl River floodplain suggested two-dimensional hydraulic modelling, the system was ultimately analysed using one-dimensional hydraulics which was sufficient in providing adequate information for ecological interpretations.

Result

The models were successfully calibrated through adjustment of the Manning's *n* value for the main channel and floodplain, and were able to predict flooding characteristics at a resolution appropriate for ecological interpretation.

The hydraulic analysis involved an investigation of hydraulic models and methods for hydraulic analysis. From these investigations, the hydraulic behaviour of the floodplain was shown to be well replicated by the models, with predicted peak flood stage levels generally agreeing to within 200 mm of observations. Furthermore, the calibrated models and experience gained with this study will be of benefit in analyses of other wetland and floodplain systems in South Africa.

3.2.1.2. *COJ catchment prioritization study*

In 2008 a study was conducted by SRK to prioritize catchments according to the need for the determination of floodlines in sensitive areas. A flood prioritization model was compiled using a one hectare grid size to identify potential flood problem areas. The model considered the following data inputs:

- Existing flooding problems
- Existing useful floodlines
- Existing land use
- Future potential development potential
- Average income
- Population density

As part of the project, areas in need of floodlines were then determined using a buffer of 100m to select all cells in close proximity to watercourses throughout the city. A map of areas previously affected by floods or having received complaints related to flooding is shown in Figure 3. The resultant catchment prioritization map is shown in Figure 5, showing 38 catchments prioritized for floodline delineation.

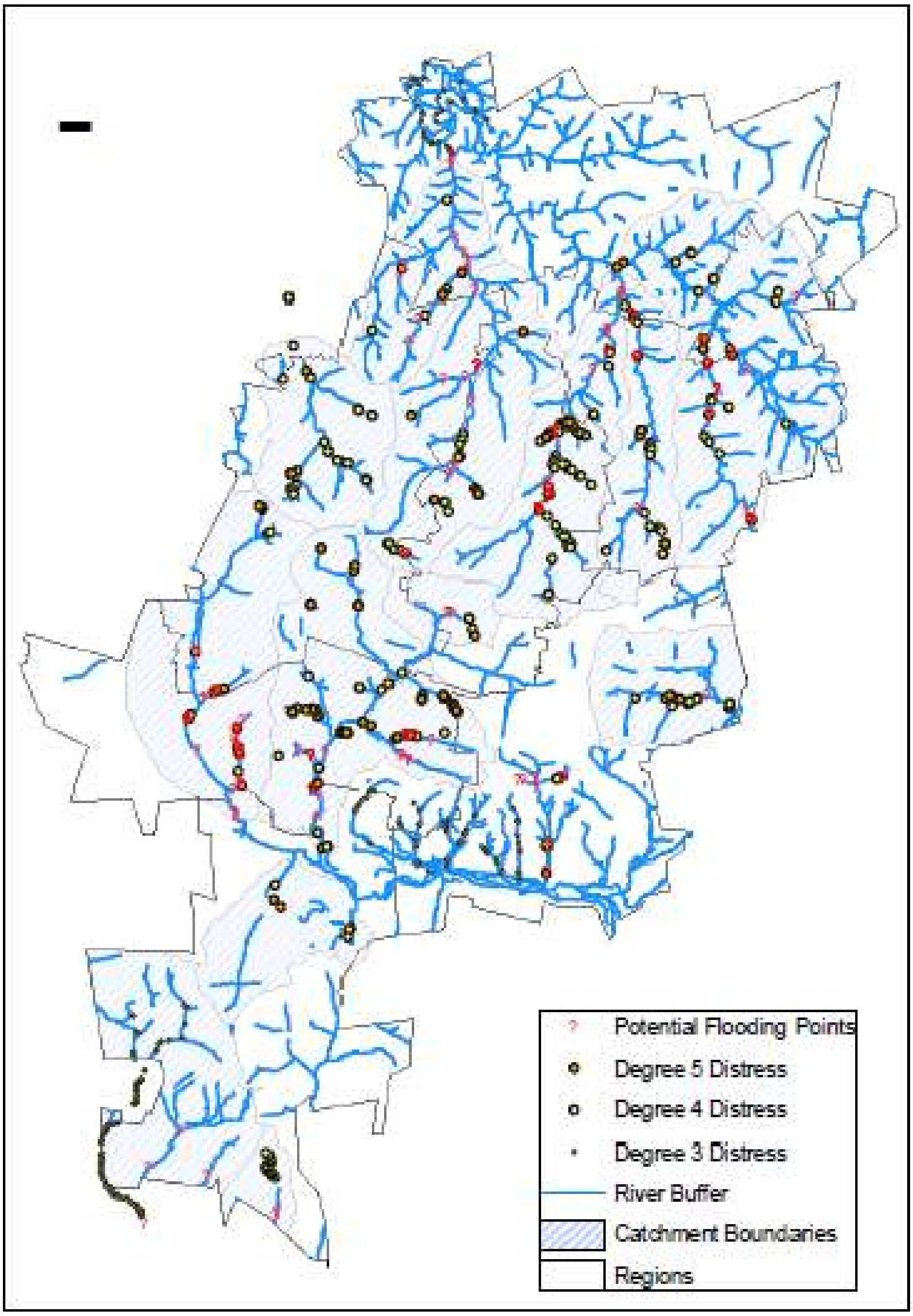

Figure 3: Map indicating stormwater hotspots for the COJ (SRK, 2008)

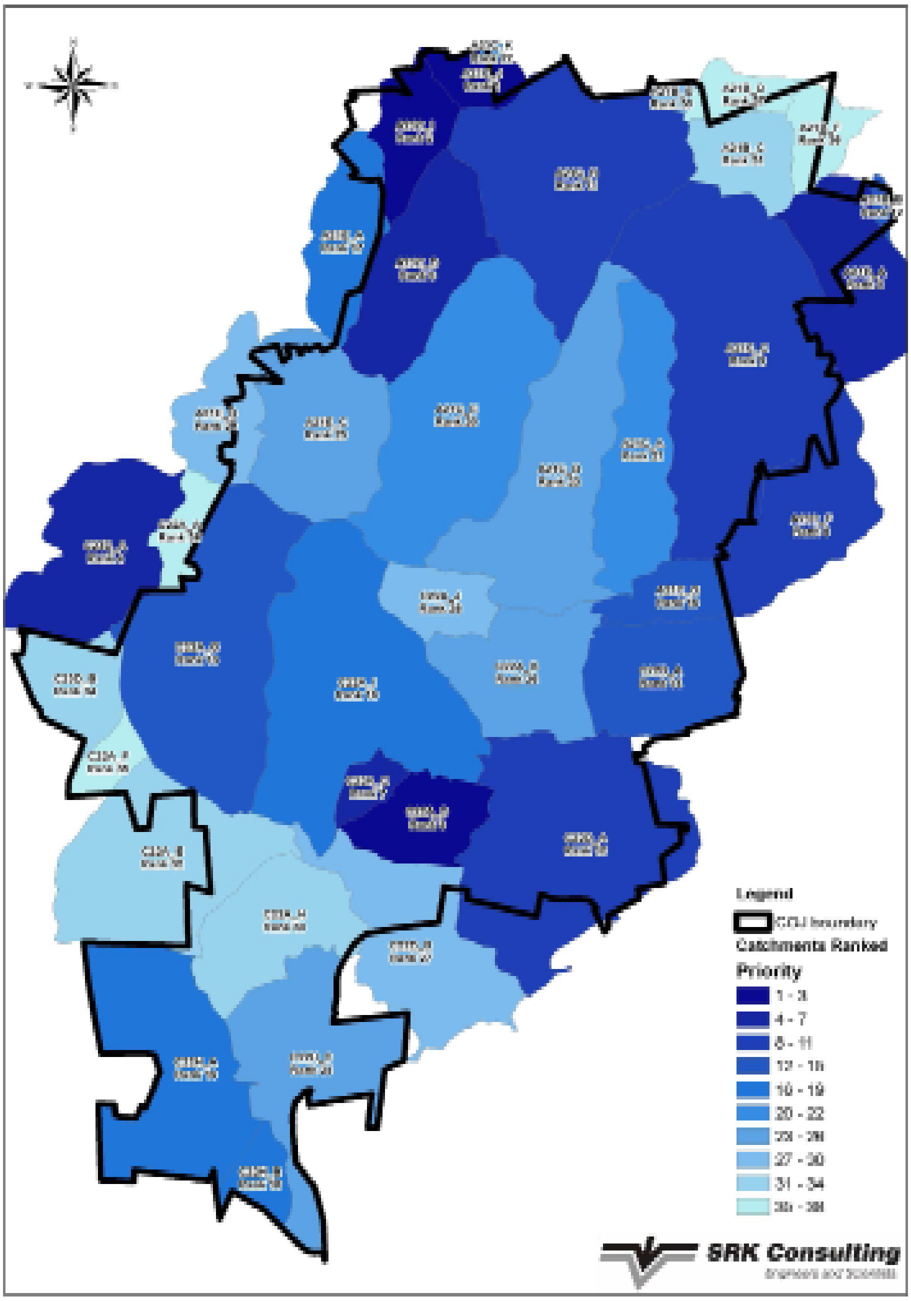

Figure 4: Map indicating prioritized catchments requiring floodline determination in the COJ. (SRK, 2008)

3.2.2. Predictive Modelling

3.2.2.1. SAWS NDMC case study

According to the CRED Disaster Database about 90% of natural disasters in Southern Africa are weather-related. Of these, floods are causing the most damage and result in more human fatalities in comparison to any other natural disaster in South Africa. Information currently supplied by the South African Weather Service (SAWS) early warning system does not provide an indication of specific basins at risk, thereby reducing the capacity of emergency response teams to target their efforts on specific areas.

A South African Flash Flood Guidance System (SAFFG) is in the process of being developed in a combined effort between SAWS and the National Disaster Management Centre (NDMC). Additional information and support for the SAFFG will be provided by DWAE in the form of hydrological data for each of the catchments that fall under the continuous modelling project areas. This project is expected to be completed by mid 2010. The system will be implemented under the radar canopies, (within 150 km) of weather radars in Gauteng, Durban, Cape Town, Port Elisabeth and the Cape South Coast (Figure 5). The images in Figure 6 provide an example of the output from a similar system currently in operation in Costa Rica, with a radar image of rain-bearing clouds on the left and the associated flood-prone catchments indicated on the right.

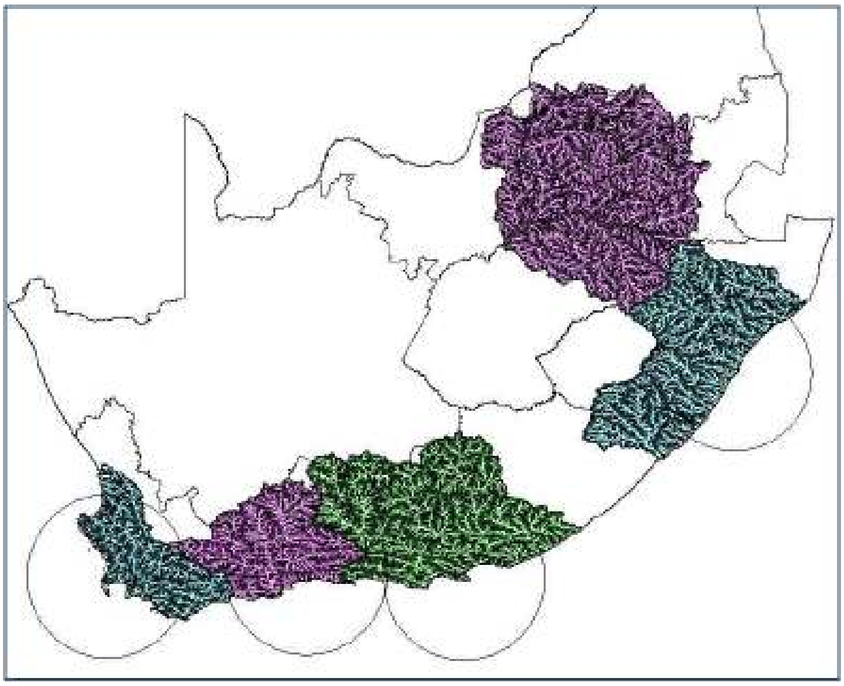

Figure 5: The SAFFG will be implemented under the radar canopies of SAWS radars as shown by the range-rings of the relevant radars (Poolman, 2009)

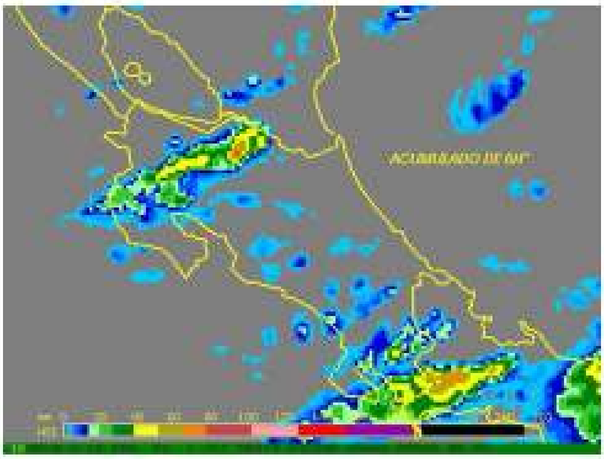	
Precipitation field measured by satellite and radar.	River basins for which warnings of flooding are issued.

Figure 6: Information provided by the system in Costa Rica

The SAFFG system will:

- Calculate the amount of rain needed to overflow the river basin (flash flood guidance value or FFGV) at its outlet by continuous modelling of soil moisture, surface run-off, 24 hour precipitation values (in mm of rainfall) and basin hydrology characteristics for catchments less than 50 km^2 in size;
- Compare (in real-time) the current rainfall (from weather radar, satellite and real-time rain gauges) with the flash flood guidance values (FFGV) for each catchment and indicate which catchment is at risk of flooding.
- Issue a warning (upon authentication by an experienced forecaster), to disaster management teams in affected catchments and areas expected to experience flooding in one to six hours.

Studies applying continuous hydrological modelling for the purpose of predictive flood forecasting in catchments have demonstrated the need for the reduction of uncertainty in the observed results. This may possibly be achieved through the inclusion of the parameters considered in the SAFFG system. Support for this system would be required from DWAE, affected municipalities and their environmental departments and the NDMC.

3.3. Historical Data

3.3.1. Extreme rainfall events in COJ: physical and social dimensions

A study is currently being conducted to determine whether extreme weather and rainfall events are within the range of natural rainfall variability (Tyson et al., 1975) or if these occurrences are as a directly result of climate change. One storm in particular wreaked havoc in Soweto. Houses and roads were flooded, bridges and cars washed away, three people died in the flooding and the district suffered approximately R 350 million worth of damage (Mail & Guardian, 17 Feb 2009; COJ, 2009). Moreover the links between climate variability and climate change remain an area of keen debate (e.g. IPCC, 2007). Climate change projections for Africa are still unreliable as current multi-model data sets contain errors and inconsistencies which create severe prediction limitations (IPCC, 2007). This uncertainty frustrates efforts to better enable coping and effective risk reduction measures to possible future extreme rainfall events. This is particularly relevant in Johannesburg where a large percent of the city's population is vulnerable to thunderstorms and flooding. In order for the local government to provide appropriate policies and coping mechanisms, a full understanding of the climatic situation is vital.

The objectives of the study are as follows:

- Improve knowledge of the past and present climate and environment, including the natural variability with regard to severe thunderstorms, and improve the understanding of the causes of observed variability and change;
- Improve understanding and classification of the forces causing changes in the COJ climate and related systems;
- Reduce uncertainty in projections of how extreme rainfall events and environmental systems may change in the future;
- Understand the sensitivity and adaptability of the COJ natural and managed ecosystems and human systems to climate change; and
- Understand the extent and limits to which knowledge may be used to manage risks and opportunities related to climate variability and change (CCSP, 2008a).

3.3.2. South African Weather Services Caelum

The Caelum is a historical summary of significant weather events in South Africa with reports from the year 1500AD to present. The summary was compiled by the SAWS library and consists of the following:

- Newspaper reports and articles on weather-related events.
- Internal SAWS publications (monthly and annual reports, internal newsletters) were included for verification and additional unreported events.
- Actual weather observations from SAWS included for verification where available.

However it is imperative for one to remember that the Caelum historical record has the following limitations:

- Reports on weather-related events are not consistently recorded or produced by the media and are only available when popular interest has been stimulated.
- Emphasis of reporting on weather-related events differs from one region to another and is dependant on the requirements of the local population.

- The spatial distribution of such reports is not able to be verified in most cases due to the transient nature of extreme weather events and due to a possible lack of monitoring stations at or near to the affected area.

Due to the inconsistent nature of weather-related topics reported in the Caelum, and the lack of verifiable spatial information, no assumptions can be made regarding the frequency of extreme weather-events for COJ from the Caelum historical record. The only information of use is that the number of reports per year has increased significantly from 1994 to present. This possibly indicates to the effects climate change may be having on the weather over Southern Africa i.e. increasing the frequency of extreme weather events.

3.3.3. Changes in extreme weather conditions in South Africa

There is significant evidence of increases in the intensity of high rainfall events between 1931–1960 and 1961–1990 over much of South Africa. The highest percentages of increase in intensity were found to be associated with the most extreme rainfall events. The intensity of 10-year high rainfall events has increased by over 50% along the east coast owing partly to the impact of cyclone Demoina in January 1984. Other high rainfall events, in the form of cut-off lows, also occurred during the period 1961 to 1990, contributing to the large increase observed along the east coast (Mason et al., 2004) (Figure 7).

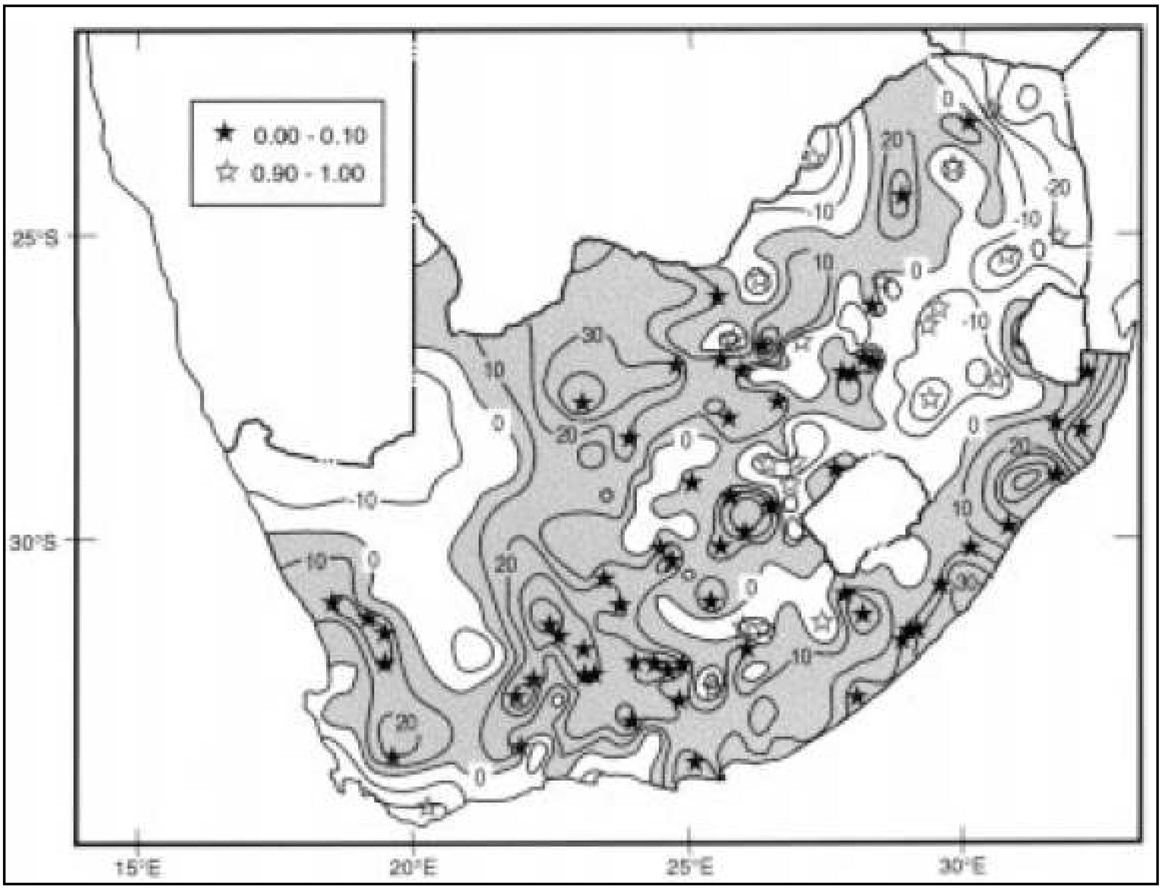

Figure 7: Percentage changes (a) in the intensity of 10-year high rainfall events over South Africa between 1931–1960 and 1961–1990 (Mason et al., 2004).

Note [a]: Areas in which the intensity of 10-year rainfall events increased are shaded. Solid and hollow stars indicate stations where increases and decreases, respectively, in intensity are significant at the 90% level.

Over South Africa, there is little evidence of significant long-term trends in annual rainfall totals, except for a possible decrease in rainfall in the far eastern part of the country (Mason, 1996; Jury and Majodina, 1997; Mason and Jury, 1997). Similarly the intensity of extreme rainfall events has also decreased in these regions.

The results of this study illustrate the importance of differentiating between general precipitation (long-term average data) and extreme rainfall events (instantaneous, short term data). Furthermore, there are inconsistencies in extreme rainfall event predictions with some studies (Engelbrecht, 2005 and Schulze, 2005) indicating a general increase in rainfall over the north-eastern parts of the country whereas the study by Mason et. al., 2004 indicates a decrease in 10-year high rainfall events over COJ. This may be due a combination of data inconsistencies from sample stations or difficulties in spatial down-scaling of sampled data and analysis procedures.

The incorporation of the probability of extreme rainfall; the frequency of which is expected to increase as a result of climate change and associated flooding events into the design of stormwater reticulation systems will negate the need for reactive response to catastrophic flood events and provide systems with improved flexibility while allowing for long-term cost and risk minimization. (Klein and Tol, 1997)

3.4. Disaster Risk Management

The National Disaster Risk Management Framework of 2005 (NDRMF) as described by the Disaster Management Act (Act No. 57 of 2002) requires that integrated institutional capacity be developed to enable effective implementation of disaster risk management policy and legislation.

The framework informs members of the Intergovernmental Committee on Disaster Management (ICDM) on risk-avoidance mechanisms that are critical to the development of effective disaster risk reduction strategies. These mechanisms are employed to discourage risk-inclined behaviour and to minimize the potential for loss. Municipalities are bound to introduce measures to ensure compliance with the Act, including:

- Amendment of urban planning standards.
- Amendment of land-use regulations and zoning.
- Development of disaster management plans for their regions.
- Establishment and enforcement of minimum standards for disaster management planning as part of the environmental impact assessment process.
- Introduction of standards to ensure functionality of lifeline services and critical facilities in the event of a disaster.
- Introduction of by-laws to implement extraordinary measure to prevent disaster escalation or to minimize its effects.

3.4.1. Floods

Flooding is the most common environmental hazard worldwide with approximately 20 million people negatively affected by flooding per annum and claiming around 20 000 lives. Although flood-related deaths and homelessness are most prevalent in developing countries, large economic losses are suffered in developed countries in spite of heavy investment in flood defense and emergency measures.

Flood hazards are dependent on various factors, including:

- Depth
- Velocity
- Duration
- Flood load (material such as sediment, salts, sewage and chemicals carried by the water).

Figure 8 below shows an increasing trend in the number of floods, destructive force and area of impact. There is consensus that increased losses may be due to more detailed monitoring, population growth and increasing numbers of people placed at risk through continuous floodplain encroachment.

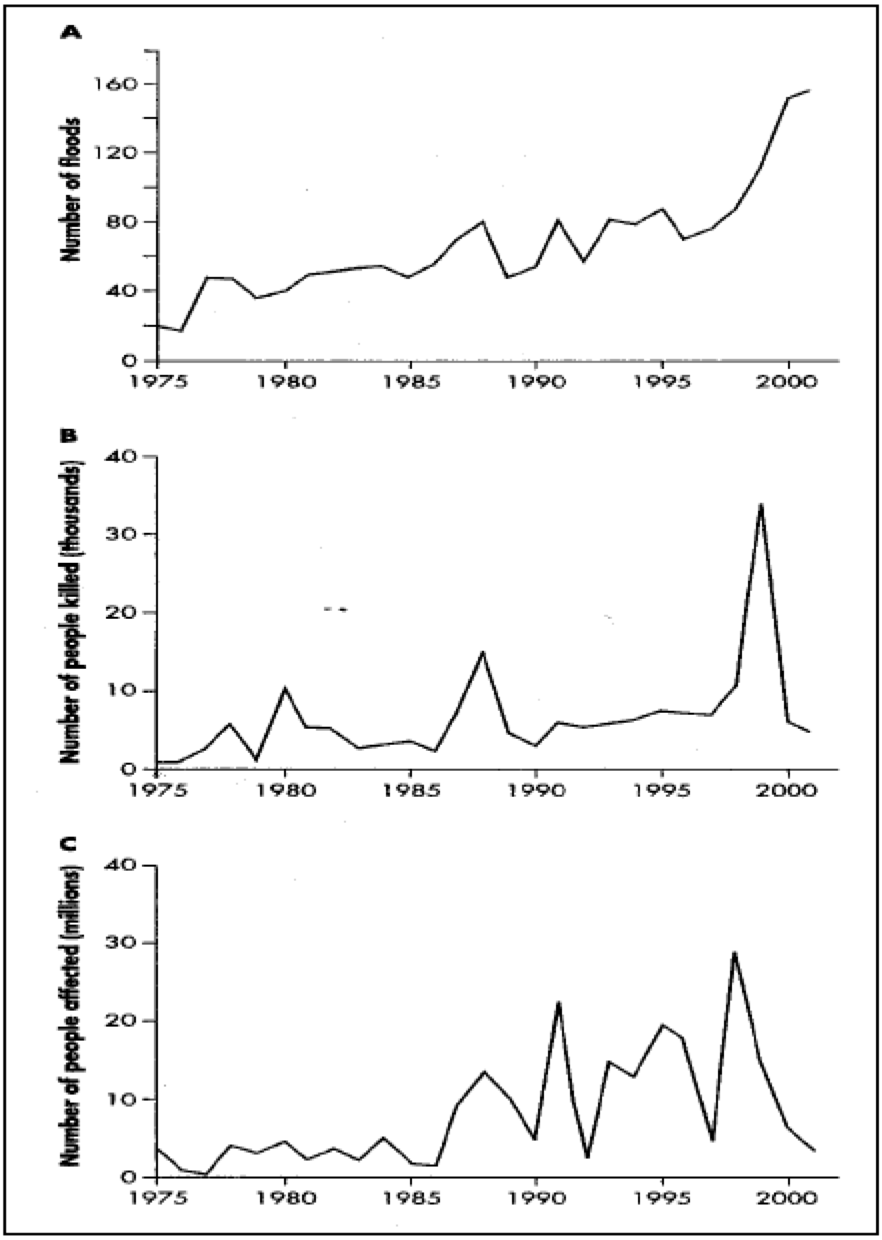

Figure 8: The annual pattern of global flood and flood losses 1975 – 2002. (A) number of flood disasters; (B) number of people killed; (C) number of people affected. (Van Zyl, 2006)

3.4.1.1 Types of Flooding Experienced by COJ:

River floods

A river flood is a high level of water that overtops the river banks, irrespective of the river bank being natural or artificial. However, such an event is not a hazard unless it threatens human life and/or property. For a hydrologist, flood magnitude is best expressed in terms of instantaneous peak river flow (discharge), whilst the hazard potential will relate more to the maximum height (stage), that the water reaches. Smith and Ward (1998), distinguished between the primary causes of floods mainly resulting from widespread climatologic forces, and secondary flood-intensifying conditions that are more drainage basin-specific. It is also possible to relate the physical causes of floods to other environmental hazards.

Urban flood

Urban development and land-use change increases run-off between two to six times over what would occur on natural terrain. The impacts of this increases run-off are exacerbated by the lack of basic maintenance, such as clearing urban stormwater reticulation systems. The flooding events, therefore often result in significant damage to the reticulation system and surrounding property.

Flash floods

Flash floods occur when an excessive amount of rain falls within a short period of time (i.e. cloud bursts) or when a massive amount of water is suddenly released by a dam or the release of blockages in a river. Flash floods often exacerbate urban flooding as the urban storm water management structures are overwhelmed by the impact of flash flood waters.

These short duration events cause rivers to swell and gain velocity with a high level of destructive force within a matter of minutes. Many areas in South Africa, such as Alexandria in COJ and the Cape Flats in Cape Town, experience annual flash floods.

4.3.2 Causes of floods

4.3.2.1 Physical causes

Atmospheric extremes, especially excessive rainfalls, are the most common cause of floods. They vary from the semi-predictable seasonal rains over wide geographic areas, which give rise to the annual wet-season floods in tropical areas, to almost random convectional storms over small basins. Prolonged rainfall over large drainage basins is also associated with tropical cyclones and other intense depressions.

Hazardous flooding of coasts and estuaries tends to occur when the sea surface is raised above the normal fluctuations created by waves, tidal action and strong offshore depressions. Such increases in height result either from short-term factors or from very much longer-term processes.

4.3.2.2 Social causes

The earliest settlers were usually aware of the dangers of flood-prone land. Settlements were established in close proximity to the floodplains in order to take advantage of highly fertile soils for the purposes of crop production (e.g. The Nile River floodplain in Egypt). In many countries, major floodplain encroachment did not occur until the late nineteenth century but then expanded rapidly. An example of the effect of a general lack of space in the COJ, due to a high rate of urbanization, is the floodplain settlement evident in Alexandra along the banks of the Juksei River. This situation is sometimes exacerbated by deliberate settlement on the floodplain in order to take advantage of government housing initiatives. An example from the United States shows that by 1975 more than half of the floodplain land in the USA was developed and urban areas were spreading onto floodplains at the rate of 2% per year. Rapid City, South Dakota, is a typical case.

4.3.3 Mitigation

Calls for disaster aid in the form of government relief following flood disasters are common, but there is recognition in the municipal district councils (MDCs) that the taxpayer cannot be expected to fund all the losses. This attitude is sometimes enforced by legislation limiting any disaster relief to uninsurable losses like floods and tornados. For many of the local district councils (LDCs), international aid is an important factor in flood mitigation. Large flood disasters in the LDCs overwhelm local resources, but there can be a tendency to exaggerate aspects of the contribution by international agencies. For instance, the Mozambique floods of 2000 attracted thousands of emergency aid workers attached to 250 different organisations.

4.3.4 Protection

Regulating the flow of surface run-off water through the application of abatement or control measure is a reliable method used to provide flood protection in flood-prone areas.

Flood abatement or flood reduction, involves decreasing the amount of runoff contributing to a flood peak within a drainage basin. Watershed treatment through land use management is the method used. To be effective, treatment practices have to be adopted over a majority area of the drainage basin.

Typical strategies include reforestation or reseeding of sparsely vegetated areas, increased evaporative losses, mechanical land treatment of slopes, such as contour ploughing or terracing to reduce the runoff coefficient, comprehensive protection of vegetation from wildfires, over-grazing, clear-cutting of forest land or any other practices likely to increase flood discharges and sediment loads. In addition, peak flows downstream can be reduced by the clearance of sediment and other debris from headwater streams, construction of small water and sediment holding areas (e.g. farm ponds), and the preservation of natural water retention zones such as marshes and other wetland environments. Within urban areas some water storage can be achieved by the grading of building plots, retention ponds and the creation of green zones such as parklands and conservancies.

4.3.5 Adaptation

4.3.5.1 Preparedness

Some countries rely on the routine civil emergency arrangements, including voluntary organisations and the military, to combat flooding and flood losses. However, specialised flood preparedness programmes have increased with the spread of forecasting and warning systems. The greatest need for advice exists in flash flood events with short warning times.

4.3.5.2 Prediction, forecasts and warnings

Flash floods present different problems because forecasts and warnings are not always accurate, timely or heeded in small river basins (Montz and Gruntfest, 2002).

4.3.5.3 Land use planning and management

During recent decades, urban communities have adopted more regulatory approaches whereby land use management is employed to restrict further floodplain development. In the future, land use planning is likely to include a much greater element of what has been called the 'living with floods' approach.

4. METHODOLOGY

4.1. Modelling Approach

4.1.1. Type of model

The regional maximum flood (RMF) method as developed and reported by Kovacs (1988) which is based on the maximum flood peaks recorded since 1856 at more than 500 sites in Southern Africa. The relative flood peak magnitude is expressed by the Francou-Rodier regional coefficient K. Eight maximum flood peak regions were delimited by a joint consideration of K, maximum observed three day rainfall and catchment characteristics. The respective K envelope line (K_e) was established by taking into account the number and quality of data. The RMF method was chosen due to the minimal data requirements, needing only geographical position of the site and the effective catchment area, for calculations to be performed. The RMF method yields consistent results, compares well with results obtained by other methods and allows for the calculation of flood peaks in the 50 to 200 year recurrence interval (Brooker, 2009; Kovacs, 1988).

4.1.2. Data preparation steps and work flow

The information gathered during the database development included topographical and aerial photography from the 2006 LIDAR survey for the COJ (ALS, 2006) and related Geographical Information System (GIS) shape-files for hydrological characteristics, boundary data, town and census data and information from selected previous studies.

The GIS data was divided into each of the 38 major river catchments in the City of Johannesburg. The data was manipulated and stored using ESRI ArcMap with 3D and Spatial analyst extension and catchment boundaries were determined using the Arc Hydro Toolset for the ArcMap program.

Flood discharge rates were calculated by applying the RMF method, as described in detail in Kovacs, 1988, to Manning's equation for open-channel flow. The result was used to generate discharge rates for each catchment, which were then equated to vertical height above the stream or river bed. These vertical heights were used to determine the inundation plane for each catchment and river system. The results were plotted in ArcMap. The resultant maps are shown in section 8 and provide a rough indication of potentially flood-prone areas for the entire City of Johannesburg. The flood boundaries delineated using this approach are estimates only and can not be used for planning or regulatory purposes. The assumptions and limitations for these maps are detailed in section 5.

4.1.3. *RMF flood peak estimation*

The region into which COJ falls in the Regional Maximum Flood (RMF) system is summarised in Table 4 below.

Table 4: Hydrological characteristics of eight RMF regions in South Africa (Kovacs, 1988)

Region	3 Day max. observed rainfall	Mean annual rainfall (mm)	Dominant relief	Soil permeability
5	Western Cape: 200 – 500	200 – 1500	Mountainous to hilly	S&W: semi-permeable to impermeable NE: permeable to semi-permeable
	Karoo: 150 – 300			
	Other: 200 – 300			

5. ASSUMPTIONS AND LIMITATIONS

5.1. Modelling assumptions and limitations

5.1.1. River depth determination

Assumptions for river discharge volume determination

- All water in the rivers experience free, unobstructed flow.
- All river systems conform to the channel cross-section characteristics shown in Appendix C.
- Design flood estimation and runoff discharges conform to RMF region 5 estimates (Kovacs, 1988).
- All river system shapefiles are assumed to be accurate representations of the rivers as they occur in reality.

Limitations for river discharge and depth determination

As a result of the following limitations, a standard river cross-section profile was used to allow for calculation of flood discharge rates and applied to all of the rivers in each of the 38 catchments. The vertical height above stream bed and the flood boundaries shown in section 8 are therefore gross overestimates of flood plains, particularly for the upper reaches of each catchment. The accuracy of the delineated flood plains is greatest at the bottom of each catchment and decreases as one moves up each catchment. Each catchment was considered separately and the effect of discharge from one catchment on the flood volume of another was not considered.

- Lack of indexed and digitized positions of river obstructions for each river system such as culverts, bridges and engineering interventions.
- Absence of river gauging stations designed for flood peak estimation.
- No river cross-section data available for any river system in any of the 38 catchments.
- Lack of physical characteristics of flood plains along the course of each river system, including channel position, depth, slope characteristics, geology and width.

- Lack of estimates of groundwater recharge and observed water balances for each catchment.

5.1.2. DEM Creation

Assumptions for DEM creation

- Lidar ground point data is assumed to be of adequate resolution for the creation of 200 to 250 mm contour files.
- River and catchment shapefiles are assumed to be accurate complete.

Assumptions for estimated floodlines

- The flood level above the stream bed is determined from the results of the RMF estimations for individual catchments of a fixed area.

- Each catchment was considered separately and the model does not consider contributions to flood volumes from adjacent catchments.

Limitations for estimated floodlines

- The floodlines determined are estimates and do not constitute accurately determined floodlines for use by City planning. They are merely intended to be a guideline.

- Areas without discernible rivers indicated in the river shapefile provided by the JRA were not modelled.

- The model does not consider river basal flow. An absolute discharge rate was calculated per catchment and related directly to a vertical height above the stream bed.

6. DATA ANALYSIS

6.1. Outline simplified understanding of data

Table 5 gives a brief outline of the GIS information collected during the data collection phase of the study.

Table 5: Description of the collected data

Existing Information	Feature	Content	Comments
Contour, DEM Data	Line and Point	contour values and XYZ Lidar (extended for 1km buffer beyond borders)	LiDAR Survey data available.
Major Defined Catchments	Polygon	Defined Major Catchments	Total number of major Catchments = 38.
Aerial Photography	Image	Mr Sid digital images photography(2006)	
Rivers	Polyline	Rivers and stream	
Cadastre	Polygon	Cadastral information	Latest available from Corp GIS Dept

6.2. List of data sources

Table 6: List of data sources used during the data gathering process

Data Sources	
Source	**Data Type**
South African Weather Services (SAWS)	Historical extreme weather occurrence in South Africa. Information regarding current predictive modelling projects.
SRK Consulting	Previous studies relating to flood plain delineation. Technical reports for the JRA. GIS data.
COJ Roads Agency (JRA)	Stormwater By-laws and reports on previous studies.
Department of Water Affairs & Environment (DWAE)	River and catchment information. Nature and extent of river gauging data for South African Rivers.
Corporate Geographical Information Service for the COJ (CGIS)	GIS data specific to the COJ.
Chief Directorate of Surveys & Mapping (CDSM)	Topographical and associated GIS data by province.

6.3. Available floodlines

Figure 9 shows a map of available 100-year floodlines for COJ (SRK, 2008).

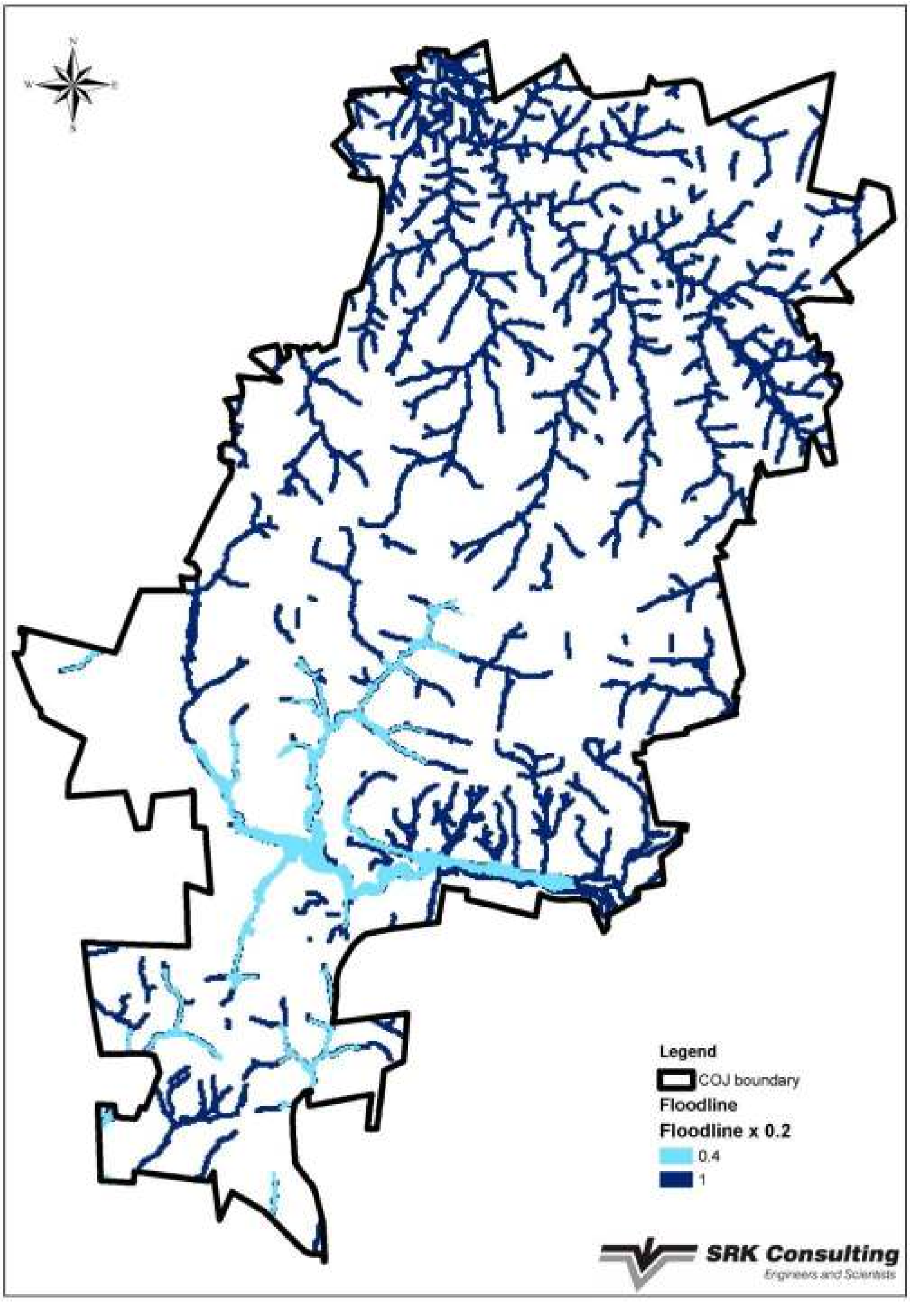

Figure 9: Location of river and existing 100 year flood lines within the COJ (SRK, 2008)

7. GAP ANALYSIS

The purpose of this study was to develop a database of flood-prone areas for COJ and to broadly define flood plains for the COJ municipal region. A full flood risk assessment requires 4 types of information to be gathered:

- Geographical information for analysis terrain analysis and determination of potential areas exposed to flood risk and the capacity to cope with the flood event. On the geographical side this refers to natural drainage, wetlands and flood plains. The institutional, social and economic implications are dealt with be vulnerability assessment. This field is represented in yellow in the diagram below.

- Definition of flood hazard scenarios based on 20, 50, 100 and 200 year return frequencies and subsequent identification of sites under threat.

- Flood risk policy is compared with the estimated flood risk figures estimated from the blue phase. This determines institutional capacity to deal with floods and to respond to and rehabilitate an area stricken by flooding. The decision to continue with ‘business as usual’ or to provide mitigation measures in the form of infrastructure construction, upgrade or maintenance; acceptable flood risk policy adjustment; introduction of conservative stormwater by-laws (see Appendix A); education and public awareness campaigns may or a combination of all of these strategies may then be made and form part of the flood risk management system, land-use planning and disaster management.

The City of Joburg has accomplished portions of the phases shown in Figure 10 below (highlighted in blue and yellow) through the completion of the flood-prone areas study. The assessment provides the gaps in GIS data required for accurate analysis of flood risk and highlights areas most likely to experience flooding under worst-case scenario flooding per catchment.

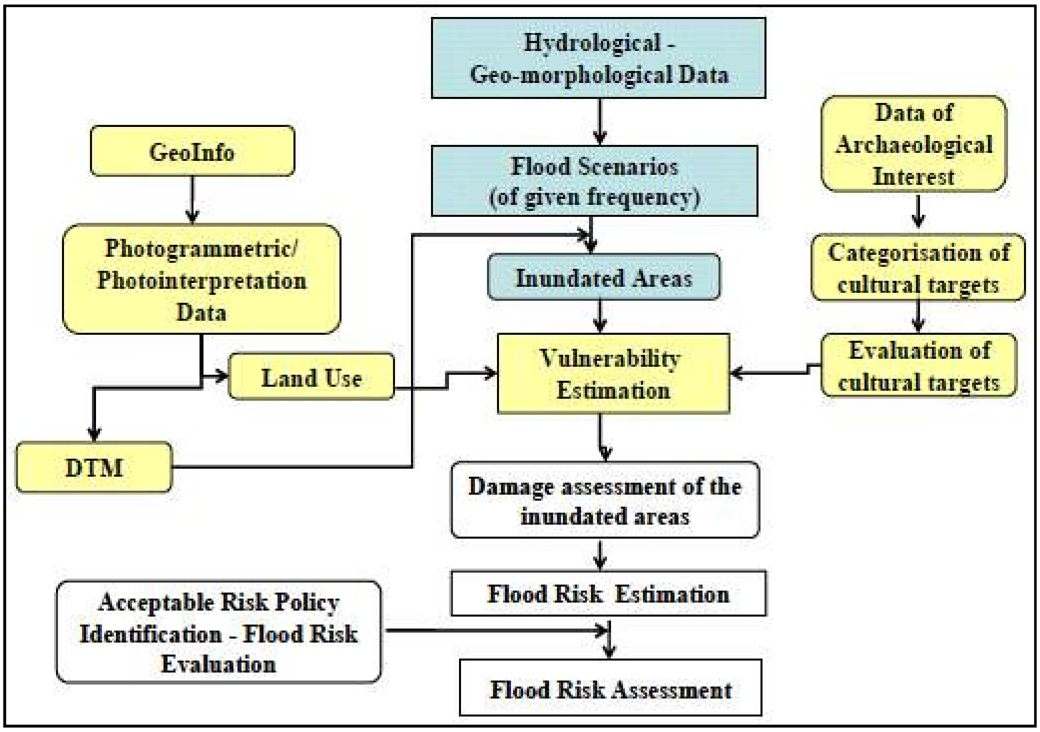

Figure 10: Methodological framework for flood risk assessment (Pistrika, 2007)

8. MODELLING RESULTS

The modelling study involved the determination of flood discharge volumes for each of the 38 major river catchments in the City of Johannesburg. This was done using the RMF method as described in section 4.1. The flood plains for each catchment were delineated using the 100 year flood event levels shown in Table 7 below.

Table 7: Summary of Flood Esitmates per Catchment

Catchment Information					
Catchment	Area (km^2)	50-Year Flood Event		100-Year Flood Event	
		Discharge (m/s^2)	Height Above Stream (m)	Discharge (m/s^2)	Height Above Stream (m)
A21B_A	62	310.0139	4.25	394.2786	4.5
A21B_B	2.82	82.2366	2.5	98.74688	3
A21B_C	26.60	215.5621	3.75	269.8726	4
A21B_D	14.13	164.2855	3.5	203.271	3.75
A21B_E	3.49	90.11922	2.75	108.642	3
A21B_F	17.70	180.9706	3.5	224.8556	3.75
A21C_A	58.87	303.1941	4.25	385.2337	4.5
A21C_B	97.85	377.1161	4.5	483.7077	5
A21C_C	160.51	497.849	5	633.7048	5.5
A21C_D	59.33	304.2091	4.25	386.5794	4.5
A21C_E	112.89	407.2852	4.5	521.8323	5
A21C_F	57.17	299.4031	4.25	380.2096	4.5
A21C_G	19.76	189.7314	3.5	236.2242	4
A21C_H	115.00	411.6108	4.5	527.1929	5
A21C_I	26.63	215.6664	3.75	270.0089	4
A21C_J	13.64	161.8145	3.5	200.0823	3.75
A21C_K	1.35	59.9368	2.5	70.99067	2.75
A21E_A	36.70	247.5117	4	311.7326	4.25
A21E_B	32.98	236.4096	4	297.1584	4.25
A21E_C	66.63	319.7511	4.25	407.2076	4.5
C22A_A	13.50	161.0993	3.5	199.1596	3.75
C22A_B	53.08	290.0104	4.25	367.7738	4.5
C22A_C	9.77	140.2132	3	172.2997	3.25
C22A_D	30.15	227.4753	3.75	285.4516	4
C22A_E	90.49	364.6637	4.5	467.0559	5
C22A_F	11.04	147.7676	3.25	181.996	3.5

C22A_G	120.04	421.8073	4.5	539.8218	4.75
C22A_H	50.96	284.9788	4	361.1192	4.5
C22A_I	134.29	449.6841	5	574.2985	5.5
C22A_J	22.02	198.7623	3.5	247.967	4
C22B_A	52.65	288.9992	4	366.4361	4.5
C22D_A	133.25	447.694	5	571.8396	5.5
C22D_B	72.45	331.4581	4.25	422.7747	4.5
C22H_A	89.03	362.1255	4.5	463.6647	5
C22H_B	13.77	162.475	3.5	200.9343	3.75
C22H_C	70.90	328.3944	4.25	418.6984	4.5
C23D_A	66.41	319.2973	4.25	406.6047	4.5
C23D_B	28.83	223.1441	4	279.7835	4.25

The catchments at risk of flooding under the 100-year flood event are shown in Table 8. The remaining catchments showed low levels apparent risk to communities living adjacent to the rivers in these catchments.

Table 8: Summary of Catchments at Risk of Flooding for the 100-Year Flood Event

Catchments At Risk of Flooding for the 100-Year Flood Event			
Catchment	**Suburb**	**Housing Type**	**Risk Level**
A21BA	Ivory Park	Informal Settlements	Very High
	Ivory Park SP		
	Rabie Ridge Ext. 5	Low-cost Housing	
A21CC	Alexandra	Informal Settlements	High
	Halfway Gardens		
A21CD	Cedar Lakes	Informal Settlements	High
	Kaya Sands		
A21CI	Randburg NU	Informal Settlements	High
C22AE	Lenasia Ext. 13	Low-cost Housing	High
C22AG	Doornkop	Low-cost Housing	Very High
	Protea Glen		
	Protea South		
	Tladi		
C22DA	Abmarie SH	Farmsteads	Very High
	Winchester Hills		
C22HA	Enerdale Ext. 8	Informal Settlements	High
	Lawley Estate		
	Lawley Estate Ext.1		
	Poortlie SP		
C22HC	Unknown	Informal Settlements	Unknown

Note: Unknown suburbs and risk levels are indicated due to a lack of an up to date river shapefile for catchment C22HC.

Figure 11: Potential Flood-prone Areas for Catchment A21B_A (1)

Figure 12: Potential Flood-prone Areas for Catchment A21B_A (2)

Figure 13: Potential Flood-prone Areas for Catchment A21B_A (3)

Figure 14: Potential Flood-prone Areas for Catchment A21C_C

Figure 15: Potential Flood-prone Areas for Catchment A21C_D

Figure 16: Potential Flood-prone Areas for Catchment A21C_I

Figure 17: Potential Flood-prone Areas for Catchment C22A_E

Figure 18: Potential Flood-prone Areas for Catchment C22A_G (1)

Figure 19: Potential Flood-prone Areas for Catchment C22A_G (2)

Figure 20: Potential Flood-prone Areas for Catchment C22D_A

Figure 21: Potential Flood-prone Areas for Catchment C22H_A

9. RECOMMENDATIONS AND CONCLUSION

The effects of climate change on rainfall are difficult to determine with some studies showing marginal increases in rainfall (5 – 10%) while others indicate that South Africa can expect decreased annual rainfall. In spite of the inconsistency between modelling studies, a marginal change in annual rainfall, whether an increase or decrease, is unlikely to have a significant impact on the ability of COJ stormwater reticulation systems to conduct flood waters away from the city in a safe and predictable manner.

The possibility of increased intensity of extreme weather events (Mason et al., 2004; Vogel et al., 2009), however, has the potential to reduce the capacity of stormwater reticulation systems to cope with the volume of surface runoff generated directly after a severe downpour. The catchments identified as been at risk of flooding require urgent attention, particularly in areas where informal settlements are at risk, where mitigation measures may include stormwater reticulation repairs and upgrades or resettlement of affected communities.

The stormwater bylaws provide excellent protection against future flood risks by regulating construction and development projects and by stipulating strict requirements for developments that would have a significant impact on runoff water volumes and the ability of adjacent stormwater reticulation systems to cope with those volumes. Shortcomings of the bylaws are that no provision is made for dealing with areas that are currently at risk of flooding, or to prevent the expansion of vulnerable communities. The bylaws provide flood-proof development regulations for the City of Johannesburg, if the shortcomings are addressed and the bylaws are enforced effectively.

9.1. Recommended actions

According to the information gathered during this study and the results of catchment discharge volumes, the following actions are recommended to allow for maintaining the function of existing stormwater reticulation systems and reducing the effects of increased pressure on those systems. The recommendations have been divided into different areas of focus for improved clarity:

Stormwater reticulation systems:

- All areas that fall below the 100 year flood boundaries should be clear of human settlements, particularly informal settlements, in order to reduce the possibility of loss of property and livelihoods.

- Ensure that the regulations as stipulated by the stormwater by-laws act adhered to by all new developments.

- Improvement of existing stormwater reticulation in areas of known concern through the construction of retention dams and repair of damaged infrastructure.

- Ensuring that existing stormwater reticulation systems are clear and free of debris, silt and vegetation. Areas requiring attention may be determined from the outcomes of assessments of the stormwater drainage systems conducted by external consultants.

- Recalibration of existing river gauges, in conjunction with DWAE, to allow for river level and flood peak monitoring. Installation of equipment to allow for the remote capture of river level, flow characteristics and flood peak data.

- The Stormvoël stormwater by-laws provide excellent protection against property damage and loss, especially in terms of formal residential, commercial and industrial developments. No guidance is provided in terms of informal settlements presently at risk from flooding and no process is in place to reduce this risk or to relocate the affected population of these informal settlements.

Future contracted studies:

- Standardization of methods for the determination of floodlines and discharge data. These methods should be determined by the JRA and communicated to consultants involved in flood line determination and related work done for the City of Johannesburg.

- Development of a centralised disaster management and reporting database for the recording of flood events, disasters and emergency situations. This should be done in conjunction with the NDMC, SAPS, SAWS, local fire departments and private paramedic services.

- Improvement of the reliability of meteorological stations under the control of the City of Johannesburg for accurate and reliable data recording in order to improve data on rainfall and extreme weather events.

- Development and maintenance of a central database of accurate digital elevation models, river and stormwater reticulation system data, cadastral information, aerial photographs and associated GIS data that may be accessed by all departments in the City of Johannesburg. The existence of such a database and the contents thereof needs to be communicated to all departments within the City of Johannesburg.

- GIS data currently available requires a visual verification process using high resolution aerial photography. This will allow for the identification of errors in recording various data types. Much of the GIS data may be corrected using this method which will negate the need for costly field investigations.

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11. REFERENCES

Bates, B.C., Kundzewicz, Z.W., Wu, S., and Palutikof, J.P.. 2008: Climate Change and Water. Technical Paper of the Intergovernmental Panel on Climate Change, IPCC Secretariat, Geneva, 210 pp.

Boko, M., Niang, I., Nyong, A., Vogel, C., Githeko, A., Medany, M., Osman-Elasha, B., Tabo, R. & Yanda, P.. 2007. Africa in Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J. & Hanson, C.E. (eds.), *Climate Change 2007: Impacts, Adaptation and Vulnerability; Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge.

Brooker, C.. 2009. Personal communication. CBA Associates. Fourways. Johannesburg. South Africa. Tel: +27 11 465 0510.

Cameron, D., Beven, K., Naden, P.. 2000. Flood frequency estimation by continuous modelling under climate change (with uncertainty). Hydrology and Earth System Sciences, 4(3), 393 – 405.

COJ. 2008. Assessment of Johannesburg's vulnerability to the global threat of climate change. Department of Environmental Management, Metropolitan Centre, 158 Loveday Crescent, Braamfontein, South Africa.

COJ. 2009. Integrated Development Plan Revision. Metropolitan Centre, 158 Loveday Crescent. Braamfontein. South Africa

Erasmus, P.. 2006. Topographical LIDAR survey. Corporate GIS Department. Metropolitan Centre. 158 Loveday Crescent. COJ. South Africa

Hewitson, B.C. & Crane, R.G.. 2006. Consensus between GCM climate change projections with empirical downscaling: Precipitation downscaling over South Africa, *Int. J. Climatol.* 26: 1315–1337.

Klein, R.J.T. and Tol, R.S.J.. 1997. Adaptation to climate change: Options and technologies. Institute for Environmental Studies. Vrije Universiteit. Amsterdam.

Kovacs, Z.. 1988. Regional maximum flood peaks in Southern Africa. Technical Report TR 137. Department of Water Affairs and Forestry, Directorate of Hydrology, Pretoria, South Africa

Mason, S.J., Waylen, P.R., Mimmack, G.M., Rajaratnam, B. & Harrison, J.M.. 1999. Changes in Extreme Rainfall events in South Africa, *Climate Change,* 41, 249-257.

Pistrika, A., Tsakiris, G.. 2007. Flood risk assessment: A Methodological Framework. Centre for the Assessment of Natural Hazards & Proactive Planning, National Technical University of Athens, Greece.

Poolman, E.. 2009. Implementing a new flash flood warning system for South Africa. South African Weather Service. 442 Rigel Avenue South, Erasmusrand, Pretoria, South Africa.

Trenberth, K.E., Jones, P.D., Ambenje, P., Bojariu, R., Easterling, D., Tank, A.K., Parker, D., Rahimzadeh, F., Renwick, J.A., Rusticucci, M., Soden, B., Zhai, P.. 2007. IPCC Fourth Assessment Report – Chapter 3 Observations: Surface and Atmospheric Climate Change. Intergovernmental Panel on Climate Change. p 237 – 336.

Tyson, P.D., Dyer, T.G.J. & Mametse, M.N.. 1975. Secular changes in South African Rainfall: 1880-1972, *Quarterly Journal of the Royal Meteorological Society*. 101, p 817 – 833.

Van Zyl, K. 2006. A Study on a risk disaster management plan for the South African agricultural sector. Report compiled for Agri SA, TAU SA, NAFU SA, Total SA.

Department of Environmental Affairs and Tourism. 2007. State of the Environment. http://soer.deat.gov.za/themes.aspx?m=519

Encyclopedia Britannica 2009: Johannesburg http://www.britannica.com/EBchecked/topic/304472/Johannesburg

Limpopo Game Reserves. 2009. Nylsvlei Nature Reserve. http://www.sa-venues.com/game-reserves/np_nylsvley.htm

South African Weather Service. 2009. Climate Data for Johannesburg. http://www.weathersa.co.za/Climat/Climstats/JohannesburgStats.jsp

Vogel, C., Landman, W., Poolman, E., Fatti, T.. 2009. Extreme rainfall events in Johannesburg: physical and social dimensions. ReVAMP Study Group, University of the Witwatersrand, Johannesburg, South Africa.

Wordtravels. 2007. Johannesburg Climate and Weather. http://www.wordtravels.com/Cities/South+Africa/Johannesburg/Climate

12. APPENDICES

Appendix A - Applicable legislation affecting floodplain management

Appendix B - Results of catchment discharge volume calculations for the City of Johannesburg