The Impact of Climate Change on Water Services Delivery – A case study of Ekurhuleni Metropolitan Municipality

Report to the
Water Research Commission

by

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EXECUTIVE SUMMARY

BACKGROUND

Water resource management is likely to be one of South Africa's most complex problems for municipalities in the future. There is a strong link between water resources and climate variability around the country. Trends towards greater urbanisation and densification, coupled with environmental changes such as climate change are likely to exert pressure on water resources. It is necessary for strategic planning at a local government level to avoid water supply challenges in the future. The risk that climate change poses to water supply and demand is growing both globally and locally. Incorporating climate change projections and their implications into municipal management is gaining support in cities around the world (e.g. London, New York). Projected climate change is important for various planning horizons, particularly those that aim to address climate and development issues in the short and longer term. Improving the understanding of current storm risks is not purely for the benefit of the science-policy dialogue, but for the affected communities. Efforts also need to be made to understand how flood risk is framed and perceived by those most affected by such storms.

OBJECTIVES AND AIMS

The purpose of this study was to evaluate the impact that climate change is likely to have on water services management for a local authority in South Africa by:

a) Modelling future climate scenarios for South and southern Africa.
b) Identifying the risks associated with the expected consequences of the predicted changes in climate.
c) Evaluate the impact on water management using a hydrological model.
d) Identify challenges and limitations of current water management practices as experienced by communities in Ekurhuleni Metropolitan Municipality (EMM).
e) Assess the awareness of water sectors managers in EMM to the risks posed by climate change.

APPROACH

The outcomes of this study have been based on a four-pronged approach. In the first instance it was considered essential to understand the current knowledge and attitude of water services managers within the EMM to climate change and its potential implications. Interviews were conducted with the decision making role players within the EMM. In addition, communities and stakeholder interviews were conducted to gauge the level of understanding and perceptions of the risks of climate change with specific reference to flooding.

Second, it was important to identify all the areas within the EMM boundaries that are vulnerable or prone to flash flooding events currently and into the future. This was done using vulnerability assessment which included a risk assessment model as well as a vulnerability analysis. The areas that were identified were mapped and combined with EMM managers responses, and were then targeted for further investigation.

As this study was interested in the implications of climate change on flash flooding events, the third section included modelling of future climate scenarios for EMM, using the CCAM climate model and future climates for 2011-2040, 2041-2070 and 2071-2100.

The final stage of the study used the predicted changes in extreme rainfall events and modelled the hydrological responses within various vulnerable catchments in EMM, using the hydrological model PCSWMM 2011.

Combining the four components of the study has resulted in a good assessment of the challenges facing EMM in light of the predicted changing climate, as well as current shortcoming of management and maintenance practices that exacerbate the risks to extreme rainfall events now and in the future.

KEY FINDINGS

Climate change scenarios

An ensemble of high-resolution projections of future climate change over southern Africa has been performed at the CSIR using the regional climate model CCAM. In this project, these simulations were analysed in order to investigate the potential impact of enhanced anthropogenic forcing on the frequency of occurrence of extreme rainfall events over the South African Highveld. The analysis of the projections indicates that significant increases in the annual frequency of extreme rainfall events are plausible over the mountainous regions of eastern South Africa – including the Highveld regions of Mpumalanga and Gauteng. Drastic rises in surface temperatures are projected for the southern African region. This is associated with an increase in the intensity of the heat low over the western and central interior of South Africa – a circulation change that would promote the more frequent occurrence of thunderstorms over central and eastern South Africa. Thus, projections of increases in the frequency of occurrence of extreme rainfall events over the Highveld region of South Africa are plausible and physically defensible. At a grid-box resolution of 50x50 km^2, the model simulations represent area-averaged rainfall values that cannot be directly related to point-scale observations of rainfall. That is, the simulations cannot be applied at their native resolution for the purpose of forcing hydrological models calibrated at the point-scale. Sophisticated bias correction methods, that relate the probability density function of the simulated data to that of rainfall observations at the point scale, are needed to obtain simulations that are useful to force hydrological models that are calibrated at the point scale. It may be noted that the regional downscaling of African climate, both locally and internationally through the Coordinated Regional Downscaling Experiment (CORDEX), are typically performed at resolutions of about 0.5° in the horizontal. In order for these simulations to find application is flash-flood modelling, such sophisticated bias-correction methods need to be developed.

Flood risk assessment

This study has attempted to examine the intersection of various factors that enable the identification of possible areas prone to risks of flash flooding. It is evident from that the most vulnerable communities in Ekurhuleni are those that have been forced to situate themselves on land which is predisposed to flash flooding within the urban context as a result of their financial and social status. The only land available to the poor is in regions that are not considered to be suitable for development. Many aspects of informal settlement within flash flood prone areas exacerbate the vulnerability of the communities within these regions. These can be attributed to the compaction of land due to settlement, thus decreasing infiltration and increasing surface run-off. The structures within informal settlements are not able to withstand any form of hazard, especially flash flooding. Poor and unjust planning practices of the past have also placed poorer communities in the heart of high risk areas. These areas have subminimum infrastructure that has not been upgraded even though the population have increased way beyond the carrying capacities of the associated infrastructure. The introduction of infrastructure such as roads, roofs and buildings in areas that are already exposed to flash flooding hazards tend to enhance the impact of the hazard by reducing infiltration and channelling surface run-off. Thus increasing the chance of ranging torrents, this may have a higher degree of devastation.

Hydrological analysis

- The hydrological analysis was based on the application of a 140 mm rainfall event applied to the current design storm profile for Atlasville, and to the storm profile adjusted for the 2071-2100 time slabs. The future storm profile has higher rainfall intensity by 5%, but the greater area of difference lies in the recession limb of the storm profile where intensities are close to double the present day design storm intensities.
- The effect of this change in storm profile has been tested on three different urban catchments:
    - A small urban catchment (Phomolong, 0.56 ha, less than 15 minute response time), which showed very little change in peak flow, supporting the comment in Section 6.3.1 that small catchments, including roads and project sites, would not need any special adaptation for climate change.
    - A medium catchment (Tswelopele, 575 ha, response time up to an hour) shows proportionately small changes in peak runoff and maximum flood depth, but a clear likelihood of longer and deeper flood inundation, thereby increasing flood damage costs.
    - Large urban catchment (Atlasville, 25.4 km^2, response times in excess of 3 hours) shows proportionately larger increases in peak flow which are considered to be very likely to have consequences in terms of flooding and river management.
- The increased intensity is also seen to have an effect on storm volumes and in runoff response times that need to be considered in the design of attenuation facilities. The significance of this is likely to increase with catchment size following the observations above.
- This outcome also points to how infiltration drainage facilities will need to be designed under a changing climate. Increasing infiltration at source and within the catchment is central to sustainable urban drainage systems, and the infiltration surfaces will need to have the capacity for the higher intensities. The performance of at source infiltration systems (e.g. at a development site scale) is probably best demonstrated by the Phomolong results where the very high, short duration, intensities dominate the catchment response. But this perhaps also points to the increasing importance of wider catchment attenuation and infiltration systems (e.g. wetlands, park land areas, swales, etc.).

Stakeholder engagement

Municipal managers highlighted the fact that issues associated with water services and resources are complex and are associated with management of other sectors and local government priorities. Climate change is only one of many issues and is not currently very high on the planning and or strategy agenda of Ekurhuleni. Given the aforementioned it is necessary that municipalities view the different aspects of water resource management as linked and not in isolation. In addition local government needs to understand that high-level decisions, or lack thereof, have an impact on the ability to at every level of management to deal with the day-to-day challenges of water services delivery and water resource management. A concerted effort at interdepartmental coordination is necessary and imperative for effective management. Development and water service delivery must not be carried out at the expense of water resources or the environment. Considering these factors will help prevent further water insecurity in the future.

CONCLUSIONS

Climate change is now an undisputed fact that needs to be taken into account when planning for future development, service delivery and resource management. Water resources in South Africa are under severe stress under present day climatic conditions. Human interventions have had to be introduced to ensure that water resources are sustainable and secure for the foreseeable future. The purpose of this project was to provide insight into the implications of climate change on water services delivery into the next century at a local government level.

Four aspects of water services have been considered in this study:

1. The current and future climatic conditions that affect water resources and services using a GCM.
2. The hydrological response in small areas to changes in the rainfall and types of rain events.
3. Identifying the nature of areas within local governments (Ekurhuleni Metropolitan Municipality (EMM)) that are at risk to changes in rainfall, especially extreme rainfall events or flash flooding.
4. Perceptions and strategies of water resource and services managers within EMM to climate change and associated water related challenges.

The study has shown that there will be an increase in extreme rainfall and drought events over South Africa by the turn of the century. The impact that this will have on water services links directly to security of supply and use. These can be managed by interventions which reduce and control the usage of water.

The potential for an increase in high intensity short duration storms is going to have significant flooding impact on storm water, sewerage and drainage infrastructure which in turn is going to have a serious impact on roads, housing and water resources. Water services sector must put in priority action plans, to mitigate against these future climate factors. The poorest sectors of the population will be most vulnerable to these incidences. This is as a result of their financial ability to cope with a disaster such as a flood as well as the fact that these communities have been forced, politically or financially, to inhabit areas that are highly prone to flooding as a result of high intensity rainfall.

ACKNOWLEDGEMENTS

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ACRONYMS

CCAM – Conformal-Cubic Atmospheric Model
CSIR – Council for Scientific and Industrial Research
EMM – Ekurhuleni Metropolitan Municipality
NDMA – National Disaster Management Act
NEMA – National Environmental Management Act

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1 INTRODUCTION

Water resource management is likely to be one of South Africa's most complex problems for municipalities in the future. There is a strong link between water resources and climate variability around the country. Trends towards greater urbanisation and densification, coupled with environmental changes such as climate change are likely to exert pressure on water resources. It is necessary for strategic municipal planning to start addressing these factors now in order for municipalities to avoid not being able to provide the necessary water related services. Attention focussed on climate change is growing both globally and locally. Incorporating climate change projections and their implications into municipal management is gaining support in cities around the world (e.g. London, New York). Projected climate change is important for various planning horizons, particularly those that aim to address climate and development issues in the short and longer term. Improving the understanding of current storm risks is not purely for the benefit of the science-policy dialogue, but for the affected communities. Efforts also need to be made to understand how flood risk is framed and perceived by those most affected by such storms.

The water sector is the focus of this activity since this sector has been identified one that may be most at risk to climate change (Christensen *et al.*, 2007). The purpose of study was to evaluate the impact that climate change is likely to have on water services for a local authority in South Africa by:

a) Modelling future climate scenarios for South and southern Africa.
b) Identifying the risks associated with the expected consequences of the predicted changes in climate.
c) Evaluate the impact on water management using a hydrological model.
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e) Assess the awareness of water sectors managers in EMM to the risks posed by climate change.

The aim was to ultimately assist decision makers in improved management of the risks that arise with current climate variability and those that may occur with future climate change. In order to manage the risks associated with climate change through adaptation measures, it is important to identify the priority risks to focus on. Effective adaptation to climate events combines measures to reduce the impacts of *current* climate hazards and *future* risk identified in climate projections to prevent hazards becoming disasters.

1.1 Water Resource Management

Before analysing how climate change might affect water resource management, it is necessary for this concept to be defined. Water resources management ensures the distribution of sufficient water at the required quality to meet the required demand. This can be broken into 3 key areas where challenges can be faced by all levels of government.

1. Availability
2. Quality
3. Distribution

In order to ensure that the management of these factors is maintained, it is important to understand the *current* and future risks and challenges in each of these areas, and these areas combined. Assessing the hydrological cycle is the obvious way of addressing water management, particularly with respect to the impacts of climate change. This approach provides a systemic view of water resources and it allows focussing down to individual aspects of the cycle that need to be addressed with respect to any of the three key areas.

The idea of Integrated Water Resource Management (IWRM), is "widely endorsed over the alternative and it has emerged as the dominant paradigm for water management in rich and poor countries" (Anderson *et al.*, 2008). The National Water Act (1998) and the National Water Resource Strategy (2004) is based on the principles of an integrated approach. IWRM requires co-operative governance, which includes linkages between national, provincial and municipal level management as well as interdepartmental connections. This approach is appropriate for water resource management because of how complex the water sector and how many other sectors are affected by and affect water resources. If implemented effectively, IWRM should ensure effective, viable and sustainable" water resource management (EMM, 2006, 1).

The role of water service delivery networks in South Africa

Municipalities are charged in South Africa legislation with the role of managing water resources and services (see Annex 1 for details of legislation related to water). They are obligated to provide water security for the needs of people, food, industry, the environment and other water users. It is important for municipalities to consider equity and include marginalised and previously disadvantaged communities in the provision of water resources and services. Environmental sustainability and economic efficiency are both vital issues that need to be taken into account (Anderson *et al.*, 2008). Good environmental resource management ensures that maximum efficiency, sustainability and equity are reached which requires that water resources be managed well. This includes protection and conservation of water resources and controlled use and development thereof. On the side of water service provision, municipalities control the extraction, treatment, transport and delivery of water, as well as wastewater removal, treatment and disposal (IWRM).

South Africa has achieved its Millennium Development Goals with respect to water service delivery. There remain, however, many people without this infrastructure and dealing with this backlog needs to be a top priority. The Department of Water and Environmental Affairs aims to have accomplished this by 2014 (Water for growth framework). Water provision is not restricted to domestic usage. Table 2 shows the distribution of water users in South Africa, all of which need to be taken into account when municipalities conduct water resource planning. The South African population is predicted to grow to 53 milllion by 2025 which will shift the proportion of water use in the domestic sector to between 30 and 35%. Table 3 provides a breakdown of where water is being drawn from to supply this demand, as well as how this is predicted to change in the mid to long term.

Table 1. The distribution of water usage in South Africa (IWRM)

Water user/ sector	Proportion of allocation
Agriculture 62%	62%
Domestic	27%
Urban	23%
Rural	4%
Industrial	3.5%
Afforestation	3%
Mining	2.5%

Table 2. South Africa's current and projected future water source usage (IWRM):

Water source	2008	2025 – Mid term	2040 Long term
Surface water	77%	72%	65%
Ground Water	8%	9%	10%
Re-turn flows (irrigation, treated effluent and mining)	15%	17%	22%
Desalination	<1%	2%	3%

Water Service Challenges faced by Municipalities

Primarily the biggest issue regarding water in South Africa is its scarcity. In addition to this, municipal areas do not correspond with water drainage boundaries, which make water abstraction and disposal a complex issue. As a result, South Africa has some of the most complex water resource infrastructure in the world (IWRM). Urban areas such as Gauteng have to bring water in from areas hundreds of kilometres away. The difficulty of bringing water to isolated communities or those in high elevations, has added to the large backlog of water provision in South Africa.

Although the backlog of water service provision has been reduced to meet the Millennium Development Goal targets (halving this backlog in both 2005 and 2008), there remains a large portion of the population that does not have access to basic water service delivery. Many of the issues regarding water service delivery which are currently being faced by municipalities stem from our recent history, where municipalities were highly separated and they were treated unequally in terms of service delivery and provision. The rapid growth of urban areas after 1994 resulted in a dramatic increase in demand for potable water and waste removal in those areas. This increased the chance of waste water and effluent overflows which cause surface and ground water pollution. Rapid growth in these urban centres was often unplanned which makes infrastructure development and service provision difficult (Nealer and Raga, 2008).

The Department of Water and Environmental Affairs has highlighted the need for behavioural change with respect to water usage in South Africa. Water use behaviour has a direct impact on water quality and quantity. Changes are necessary through the range of users from individual domestic users to the mining, agriculture and industrial sectors. Behavioural change that minimises the overall demand on the scarce water resources will allow the current infrastructure and plans to be more sustainable. The major aim is to increase water use efficiency by increasing output and minimising water usage.

It is vital that water management and service delivery are viewed as a part of a greater environmental system. The impact of water use on surrounding environments and possible risks need to be taken into account during planning and management. To achieve this, the whole water cycle needs to be considered. Factors such as runoff, underlying geology, surface soil type, climate variability, climate change and consumer demands are but a few factors which are affected and in turn affect water management in local municipalities. Municipalities struggle to put their water resource needs and impacts into the context of a greater system.

Pollution is another major problem in Municipalities. Mining related pollution has drastic effects on water quality as well as the whole surrounding environment. Similarly, water treatment plants which are poorly maintained result in polluted water seepage into the ground and often pollute underground water reservoirs. Many waste water plants in South Africa are old and have reached or are reaching their design capacity. This has severe implications for health and environmental systems as well as future water management planning and provision. It is not sufficient to supply areas with new wastewater removal services if the treatment and disposal infrastructure cannot handle the additional load. Upgrading the current infrastructure is of high priority.

Storm-water management has become an increasing issue in many urban areas, particularly in Highveld regions where rain comes typically from thunderstorms. Storms of this nature often result in flash floods. Blocked storm water drains and drains too small to cope with the volume of water both lead to urban flooding which creates traffic issues as well as risk for people near flowing water. People who live on flood plains are particularly vulnerable and often do not have high levels of adaptive capacity. In such situations, it is crucial for local municipalities to provide mechanisms of reducing the external risk and the internal sensitivity to rainfall and flooding events. Risks to such events are indicated to increase with climate change (e.g. IPCC, 2007).

The WRC has identified a list of systemic issues that provide great challenges for water governance, these include:

- Change and maturity in the governance systems
- Institutional change and decentralisation
- Participation and democratisation
- Changing management paradigm
- Transformation
- Institutional memory
- Complexity and integration
- Information, communication and uncertainty
- Technical and management capacity
- Financial resources

Illegal and marginalised water users are often excluded from planning and infrastructure and thus provision cannot accurately be planned or monitored (Anderson *et al.*, 2008). Planners and managers often do not have the technical understanding of integrated water networks and the influences of urbanisation and climate change (to name but a few) and thus effective training is necessary to specifically equip these people as well as the public. In this way there can also be a greater interaction and communication between water managers and climate scientists. This will help both sides to better use and integrate new information for research as well as infrastructure planning. This does however require a system which is flexible and allows adaptation in the face of changes in understanding as well as associated conditions.

Potential risks of extreme weather events to effective water service delivery
The most profound effects of climate change are likely to arise from changes in frequency and intensity of heavy rainfall events. These are likely to increase vulnerability and risk for city dwellers (Satterthwaite *et al.* 2007). Communities that are already vulnerable to the effects of heavy rainfall events are likely to be worst affected by an increase in frequency and intensity of these events (Adger, 1996). The concentration of people in urban areas often exacerbates vulnerability (Bates *et al.*, 2008).

Hard impenetrable surfaces increase the amount of runoff and thus the potential for flooding. Flooding risks are influenced by local factors such as topography, drainage, population distribution, infrastructure and rainfall (Douglas *et al.*, 2008; Satterthwaite *et al.*, 2007). It is very difficult to predict the effects of intense storm events because of the complex interaction between the large numbers of contributing factors. These projections are complex in light of the expected changes in rainfall variability as well as the level of uncertainty associated with these changes.

In 2009, a statistical analysis was conducted on historical weather data from the OR Tambo weather station, located in close proximity to the City of Johannesburg. Significant trends were identified in the frequency and intensity of thunderstorms for 1960-2009. This preliminary assessment concurs with possible climate change projections that suggest that heavy rainfall events may become more frequent and intense. While the study is in no way substantive and few wider generalizations can be drawn for other areas, the study does provide a useful starting point for planning interventions (Fatti and Vogel, unpublished).

Southern Africa has a highly variable climate, particularly between droughts and floods (Reason *et al.* 2004). Information used for storm water drainage systems planning and infrastructure design depend on the historical range and averages in rainfall variability. An increase in intensity and frequency of storms is likely to have an effect on surface runoff and flooding as well as the spread of waterborne disease. Projected future changes in rainfall variability, thus need to be taken into account when designing infrastructure (Denault *et al.*, 2006). For example, an increase in rainfall intensity requires an increase in storm water drain capacity which then reduces flooding (Bates *et al.*, 2008). More extreme wet and dry cycles as projected for much of South Africa will require a far more in depth and planned response to water storage and provision than is currently in place. Although total rainfall is likely to remain similar for parts of South Africa, the temporal distribution is likely to change and this will affect infrastructure and planning. There will however be places where less total rainfall is expected.

Global climate projections provide little practical guidance for city and regional planners as the projections give no insight into how climate changes will affect local scale climate, drainage or flooding (Denault *et al.*, 2006). To minimise the risk of increased flooding, factors such as transport networks and storm water infrastructure need to be improved (Bates *et al.*, 2008). The cost of these improvements is likely to be high, particularly in areas where infrastructure is already insufficient in dealing with current flood risks. Despite these costs, the benefits of anticipatory planning and development far outweigh the cost of repairing damage incurred by flooding events (Bates *et al.*, 2008; Stern, 2008).

Warmer temperatures are likely to increase the rate of evaporation, which means that more water will be lost through this means and it needs to be accounted for in planning. Suggestions have been made to increase the use of underground reservoirs, as they are far less susceptible to water loss through evaporation.

1.2 Ekurhuleni Metropolitan Municipality

The Ekurhuleni Metropolitan Municipality (EMM) was formed in 2000 from the joining of several local municipalities of the former East Rand Region (See Figure 1). It includes the geographical areas of Germiston in the west, to Springs and Nigel in the East and covers a total surface area 1923 km^2 (EMM SOER, 2004). The industrial nature of Ekurhuleni is one of its most formidable or infamous aspect, including the OR Tambo International Airport. The estimated population of the Municipality is about 2.7 million people (although figures range from between 2.55 million and 3.2 million, (CES, 2006)), with three quarters who are Black Africans. The municipal population makes up about one third (28%) of Gauteng's population, with a population density of approximately 1 400 people per square kilometre (EMM, 2010). Population densities are high especially in the former "township" and informal residential areas. Approximately 22% of the population resides in informal and inadequate housing. Despite having a large percentage of the population of working age, the rate of unemployment is high, approximately 40% (EMM SOER, 2004).

The municipality, being a conglomeration of nine previously separate municipalities, has no identifiable core and also has an interesting equity profile; where 'low development densities with historically disadvantaged communities [are] situated on the urban periphery' (about 24% of the population live in poverty and the current estimated unemployment rate is 35%) (EMM, 2010, 9). There is currently (at the time of preparation of the 4th review) a great housing backlog with an estimated 135 000 shacks in informal settlements and 36 000 backyard shacks.

Water services for EMM are supplied by two major bulk water services providers, namely Rand Water and East Rand Water Care Company, which cater for water supply and waste water respectively (CES, 2006). Water is also purchased from neighbouring Water Services Authorities such as the City of Johannesburg. Bulk water is drawn mainly from the Vaal River System. There were, at the time of writing the CES report in 2006, an estimated 133 Rand Water and 3 Johannesburg Water connection points (CES, 2006). Water service provision generally meets the requirements for all houses, but more sustained efforts are needed to ensure water access (CES, 2006)

Summers in Ekurhuleni are considered mild with temperatures seldom above 300C (EMM SOER, 2004 and EMM EMF, 2007). Ekurhuleni falls within the summer rainfall region of South Africa and the experience of hot wet summers and cool dry winters are normative. More than 80% of the rainfall occurs from October to April. Average rainfall for the region is between 715 mm to 735 mm annually. The region is prone to intense rainfall events in terms of thunderstorms, which generally fall in the late afternoons. These storms account for the major flooding and heavy rainfall events that affect Ekurhuleni and can cause much damage to livelihoods and infrastructure (Tyson and Preston-Whyte, 2000). A number of recent studies have examined daily rainfall in and around Gauteng over the past few decades to gain a better understanding of rainfall variability and change (CoJ, 2009; Dyson, 2009; Fatti and Vogel, 2009).

The convergence of the Limpopo and Vaal river catchments is observed within the EMM region. The terrain is generally flat with elevations ranging from 1460 m to 1760 m. The following topographical features are prominent within the landscape of Ekurhuleni i.e. plains with pans; undulating plains with pans; strong undulating plains; superimposed river valley (i.e. Blesbokspruit) on plains with pans and ridges (EMM SOER, 2004 and EMM EMF, 2007).

The occurrence of groundwater in EMM is prominent, due to the underlying geology within EMM, which is dominated by dolomite of the Chuniespoort Group and tillites of the Dwyka group, both of which are formidable for the water carrying capacity, (EMM EMF, 2007).

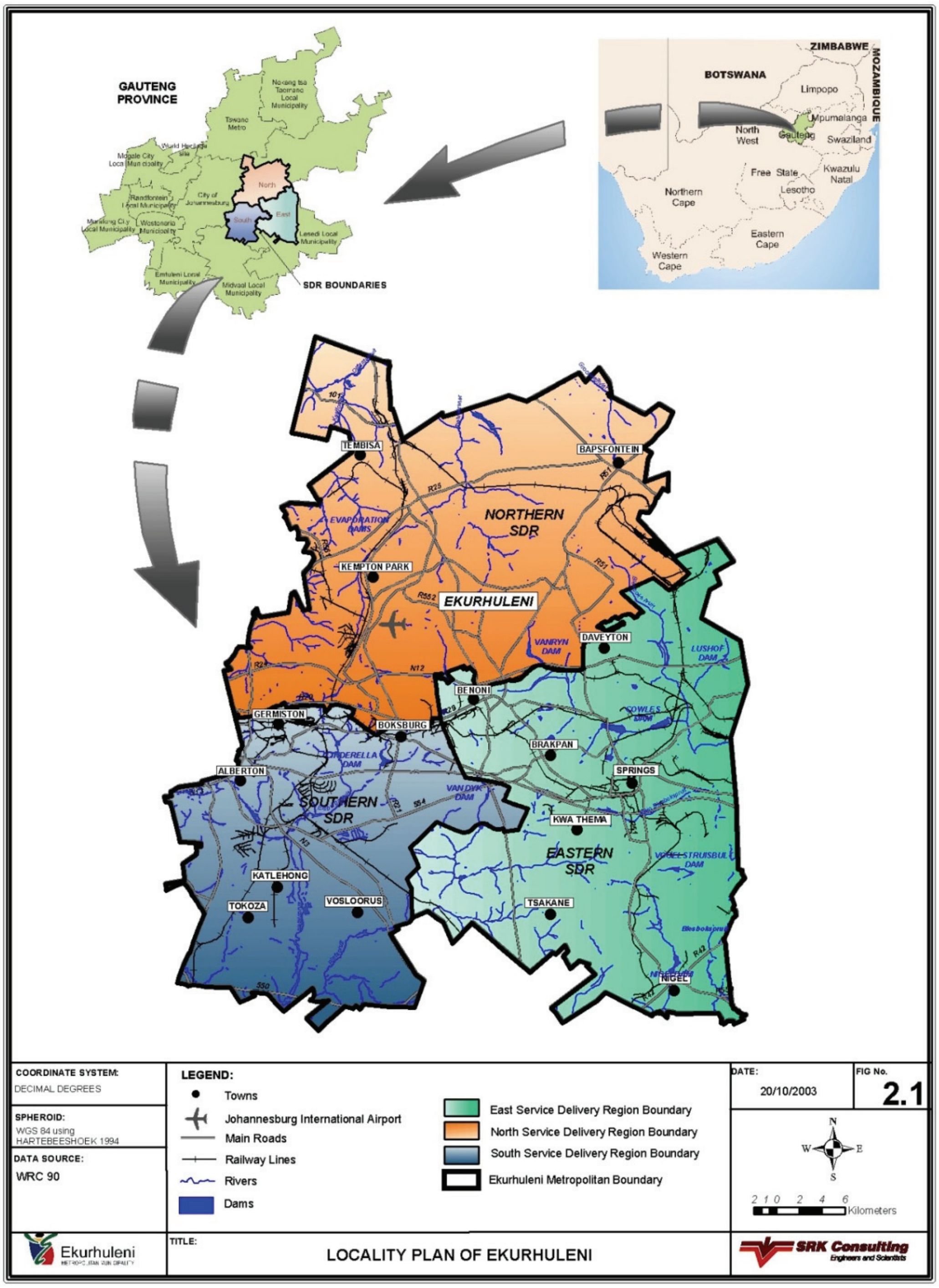


Figure 1. Locality of Ekurhuleni Metropolitan Municipality, including the three managerial districts

The surface hydrological system consists of 6 river or spruit systems (See Figure 2). The Blesbokspruit, is a system that originates to the north of Benoni and Daveyton and flows southwards through Springs and Nigel towards the Vaal river. The eastern part of the catchment contains extensive natural wetlands, while the western part is highly modified by agriculture and human settlements. Key industrial sites including mine dumps and slimes dams, waste disposal sites, intensive agriculture, and sewage works all impact negatively on water quality. The second river system is the Klip River and its tributaries. The Riet spruit originates in the south-west of the Benoni area and joins the Klip River outside the EMM boundary. The Natalspruit, another tributary of the Klip Riverm, rises in and around the Germiston and Boksburg areas. The upper reaches of the Klip River can be found to originate within Kathlehong. The pollution within these spruits can be attributed to human settlements, agricultural practices and industrial activities. Although these rivers join the Vaal River, they do so downstream of the Vaal dam, thus the effects of this pollution on the EMM quality of drinking water is not problematic. However, the pollution affects both the aesthetic and natural aspect of the Vaal River. The third river system includes both the Kaal and Olifant Spruits. These originate in Kempton Park and Tembisa, and flows north to join the Hennops River in Centurion. There is serious pollution in this system, which is attributed once again to human settlements and agricultural activities. The Jukskei Spruit is the fourth system and has a number of small tributaries within the system, which drain to the western region of EMM around Edenvale. This system takes control as it leaves Ekurhuleni through parts of Alexandria. The fifth river system is the Bronkhorst Spruit, which is located in the eastern region. This area is drained by two small spruits namely Os spruit and Kofffie spruit, which feed the Bronkhorst Spruit. The sixth and final system is the large Rietvlei Spruit. This system starts in the smallholdings area of Kempton Park and flows northwards past the OR Tambo International Airport to Rietvlei Dam. This dam is a high contributor of water supply in Tshwane. The primary supply of this water originates from agricultural and industrial surface runoff. The Grootvlei River in the Bapsfontein area is a tributary of this system.

An impressive feature of the EMM region is the prevalence of a number of pans, which is directly linked to flat topography. They cover a total area of 3 559 ha and are mostly seasonal. A few perennial pans are found within the agricultural areas. A number of lakes are situated within the municipal region and are primarily a creation of the Gold Mines in the area. The Germiston, Benoni and Boksburg lakes are prime examples of this and are utilised as recreational parks. However, the water quality of these systems is under severe stress due to problems associated with water hyacinth, mine dust pollution and storm water drainage (EMM EMF, 2007).

The water quality is generally poor in all river/stream systems within Ekurhuleni (details provided below). The poor management of storm water, sewage treatment plant, industries and agricultural activities all contributes greatly to the negative impacts on river/stream systems (EMM SOER, 2004)

The damming of most of river and spruit systems is a common problem associated with the agricultural activities in the region. Many of the rivers have been canalised, mostly for storm water control in urban areas or for agricultural purposes. The ever-increasing human pressures in the area have caused many of the natural systems in the area to a downward cycle of deterioration.

As described above the natural systems in EMM are overshadowed by contributions from sewage works and mining. The increase in urbanisation has resulted in an increase in the surface water runoff of almost 300%. The higher river flood peaks and levels pose serious threat to all developments (mainly informal housing) within designated flood zones. Many parts of Tembisa, Katlehong, Tsakane and Nigel are at particular risk (EMM SOER, 2004).

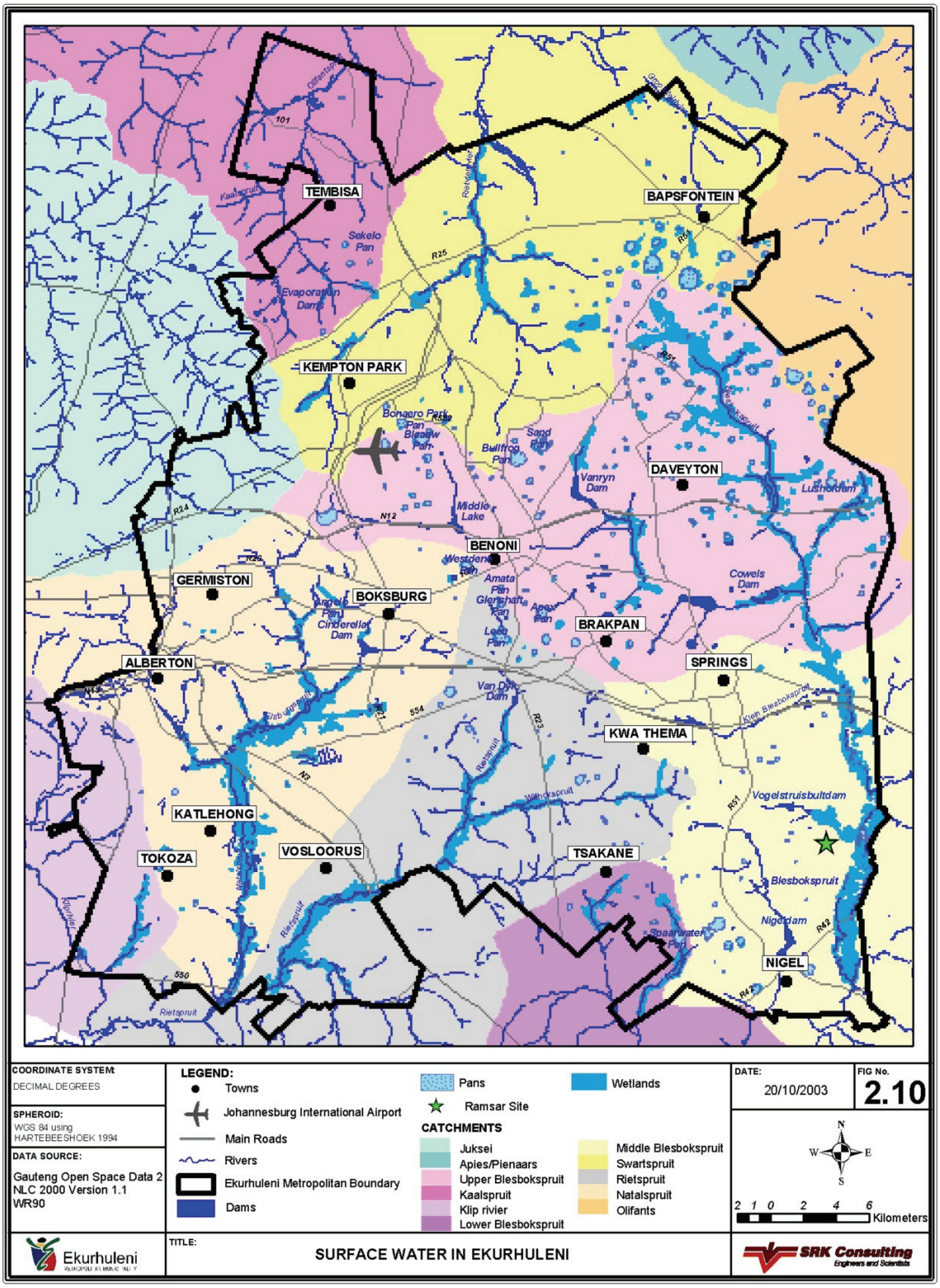


Figure 2. Surface Water in Ekurhuleni Metropolitan Municipality

EMM Water service delivery baseline

According to the EMM State of Environment Report (2004), water provision and quality are variable across the municipality. Water quality here is assessed in terms of both riverine and surface water quality in terms of potable and/or drinking water quality.

Riverine water quality

In some of the major rivers associated with EMM, water quality has been described as generally poor (e.g. the water of the Klip, Natalspuit and Blesbokspruit rivers). The quality of water however, improves as some of these watercourses make their way through the significant wetlands in Ekurhuleni (EMM, 2004). The Belsbokspruit recorded low water quality with respect to salt load (associated with impacts from mining) and some of the rivers and dams in the wider EMM showed evidence of bacterial contamination coupled to sanitation problems (EMM, 2004). In an overview assessment in 2004, the water quality for the various rivers in the EMM was as follows:

- Upper Klip River – Poor;
- Natalspruit – Poor;
- Lower Klip River – Fair;
- Upper Besbokspruit – Poor;
- Mid Blesbokspuit – Poor;
- Lower Blesbokspruit – Poor (EMM, 2004, and River Health Programme)

These rivers all discharge into the Vaal River between the Vaal Dam and the Vaal Barrage. The water quality of the rivers affects that of the Vaal Barrage, downstream. Because of declining water quality, the Barrage is no longer used for water supply, but it remains an important source for the future. Even though it does not supply water, a minimum water quality is maintained by diluting the polluted water through releases of water from the Vaal Dam upstream (van Wyk, 2010). Therefore, drainage from Johannesburg and Ekurhuleni does affect water resources, and the situation may become more severe if urban drainage discharges and rainfall seasons change.

At the time of writing the State of Environment Report (2004), several strategic priorities were outlined. These include attention being paid to: improving flood management (with respect to settlement development in the 1:50 year flood line); developing wetland and water resource policy, in association with relevant authorities; the involvement of the Working for Water Programme in water developments in the municipality; the dewatering of mines; the control of discharges from the mines and industry; the assessment of dumping from informal settlements and townships; and the co-ordination of water resource management with disaster management (EMM, 2004).

Potable water quality

Water quality, in terms of potable water, is measured by EMM and Rand Water. In a very recent assessment, the municipality of EMM received a positive Blue Drop assessment (Department of Water Affairs and the Blue Drop Report, 2010). The assessment focuses on the quality of tap water for drinking purposes, based on various parameters including microbiological assessments and water management (e.g. water safety plan; process control and maintenance competency; efficiency of drinking water quality; credibility of dirking water sample analysis; compliance with South African National Standard etc). Of the 10 Top performers in the recent assessment, the City of Ekurhuleni, with Rand Water, was placed

6th in the performance rankings. Based on 12 months data assessment, the EMM scored 99.28% on microbiological indicators, 99.82% on chemical indicators and overall Blue Drop score of 96.83%. Areas for possible improvement included finalisation of the risk assessment process, documented in the water safely plan.

In EMM, Water quality levels can be impacted by changes in rainfall and poor urban drainage management. In February 2006, for example, rapid filling of the Vaal Dam (from 46%-100%), resulted in large areas of land and vegetation being submerged under water and caused discoloration of water. During summer months, chlorine levels in the water at some of the EMM sampling points have also shown changes, with chlorine levels dropping presumably because of rainfall periods (CES, 2006). Geosmin, a by-product of blue-green algae is also favoured during warm summer spells.

Changing rainfall patterns and intensities also places strain on urban drainage networks. Sediment loads and E. coli contamination are already a problem in many parts of EMM. These result from increased erosion of stream banks, overland runoff and the flooding of sewer systems. Poor development planning is part of the problem, but the situation may be exacerbated by changing weather patterns and in particular by increasing rainfall intensities.

Planning and management of water services

Various plans, including several Integrated Development Plan plans and strategies, have been drawn up for EMM. Some of these that have bearing to the research being planned for this WRC project are profiled below:

a) Ekurhuleni Municipality Integrated Development Plan (EMM, 2010)

As part of their EMM Integrated Development Plan (IDP), the Municipality, is committed to ensuring that all communities have access to clean water and basic sanitation by 2014 (EMM, 2010). As with most cities, the EMM does not operate in a vacuum when trying to realize its planning objectives. The EMM follows a planning layout that includes national and provincial guidelines, ward priorities, IDP, various budgetary opportunities and constraints, as well as performance assessments. As per these overarching guidelines, the City notes in their 4th review that:

"All people will have access to potable water by 2014 – This target has been achieved. All communities in EMM have access to potable water according to the minimum level of service" (EMM, 2010, 7).

According to the Ekurhuleni Growth and Development Strategy (2005) however, potable water supplied by Rand Water is distributed to approximately 666 000 domestic, 6 400 industrial and 1 600 business customers with the backlog of those not having access to potable water being estimated at around 45 000 connection points, mostly in the disadvantaged township areas (EMM, 2005, 17).

b) Growth and Development Strategy 2025 (EMM, 2005)

The City has engaged in a Growth and Development Strategy 2025*.* This includes key focus areas such as striving for a clear city identity; an integrated and equitable city; high quality infrastructure and promotion of urban renewal; and a high quality and well-maintained services throughout the city including that all people have access to potable water by 2008 (a goal already achieved as indicated above). Of interest to this project, there is a focus on improved storm water management (a storm water master plan to be in place by 2007 and storm water backlogs to be eradicated by 2020) (EMM, 2010, 15-16; EMM, 2005).

c) Water Services Development Plan

Linked to the planning focus, especially around water in EMM, a specific Water Services Development Plan (WSDP) has been prepared (CES, 2006). This document states that "the main objective to ensure effective, viable and sustainable water and waste water services". To ensure integration of water management, a WSDP Forum (established by the Water Services Division was established and comprises of representatives from all departments, including the IDP co-ordinator (CES, 2006). Linked to the Plan are a range of issues e.g. water supply and water services infrastructure, which may prove to have relevance to this project. For example, in 2006 there were 63 water reservoirs and 28 water towers, providing a total storage of 934 Ml. The water demand as of 2006 was estimated to be 793 Ml/d. A Strategic Environmental Management Plan has also been completed that also makes reference to water management issues.

d) Water Demand Management Strategy (EMM, 2005)

Water demand has increased by 2.6% per annum for the period July 2004 to 2006 (CES, 2006). Several factors can affect water demand, including HIV/Aids, water conservation and demand management strategies. Water restrictions, usually linked to periods of reduced water availability (e.g. as occurred in 1996) and that may occur with changing climate, also have 'significant' impacts on water consumption triggering steep declines in water consumption (CES, 2006).

Some of the issues that were highlighted in this document have relevance for this project, including the need for:

1. Greater attention to be given to issues of information availability and validity
2. Transversal responsibility of water issues e.g. across and between departments
3. Water quality issues requiring further investigation e.g. fluctuating chlorine levels and the influence of sewerage and blocked storm water drainage systems
4. Improved monitoring of ground water

e) Disaster Management Policy (EMM, 2002)

The Disaster Management Policy for EMM, much like those for several other cities in South Africa, has the potential to be a critical policy for the effective management of climate risks and the promotion of an overarching climate risk management approach. In the EMM Disaster Management Policy, as part of the Key Performance Indicators, several activities could greatly assist in climate risk reduction. Among others, these include:

1. Enhancing information and the communication thereof (3.1; 3.1.4);
2. The use of vulnerability assessments and hazard and risk analysis to enable the 'prioritisation of determined hazards and vulnerable communities (3.2);
3. Ensuring that highest risk areas receive priority attention (3.2.3);
4. Effectively planning and managing disaster risk (see objective 3.3.1)

The Policy highlights that it is important "to identify various plans and sub-plans that can address identified risk, vulnerable communities and structures and hazards" (Disaster Management Policy, 2002, 7).

Several, if not all, of the aspects raised in the Disaster Management Policy can be linked very closely to climate change and climate variability, for example, the use and provision of useful and accessible information – daily and seasonal weather information; the identification of hazards and vulnerable areas and communities; and plans for improved risk assessment and reduction etc.

1.3 Climatology context

It is less likely for changes in climate (in this case, thunderstorms) to be detectable in seasonal trends or annual averages. Instead, changes in climate variability will be more obvious through heavy rainfall trends (New *et al.*, 2006; Williams *et al.*, 2008). These events are predicted and observed on regional scales and thus require climate models that have a higher resolution than the GCMs. A recent study (Engelbrecht *et al.*, 2009) for example, revealed that total rainfall in the south western region of South Africa is likely to decrease; the eastern regions should also become drier; and the central interior is expected to receive increased total rainfall (Engelbrech *et al.*, 2009). The rainfall season is likely to shorten with increasing intensity of rainfall events, particularly where convective rainfall occurs (Engelbrech *et al.*, 2009; Mason *et al.*, 1999).

Available large-scale assessments show that since the beginning of the 20th century, annual rainfall over South Africa has remained relatively constant. Some increases in the extremes in rainfall variability have been observed (Kruger, 2006). Similar results have also been found in a countrywide study of the long-term changes in extreme rainfall events in South Africa for the periods 1931-1960 and 1961-1990 (Mason *et al.*, 1999). An increase in rainfall intensity was identified over significant parts of the country over the assessed time periods. The spatial resolution of this study is, however, quite coarse and gives little detailed insight into heavy rainfall events in localized areas.

1.4 Hydrology context

Stormwater management

With the anticipation of changing rainfall patterns, urban hydrology will be one of the key interfaces between a changing climate and municipal service delivery. Runoff responses to storm rainfall affect more than just the size of storm drains:

- It is the cause of surface flooding that has far reaching impacts; property damage, stream stability, loss of life, traffic disruption, loss of business, to name a few.
- Impacts on sewerage systems. Surcharging storm systems flood sewer systems that in turn surcharge into the receiving environment, for example.
- Urban runoff pollutes streams and water supply sources, and can even change the water balance of a catchment, placing strain on both treatment and supply services.

Each of the above are problems experienced by Ekurhuleni Metropolitan Municipality, but are also typical problems faced by urban environments in developing countries. They are exacerbated by rapid expansion in metropolitan and large urban areas experienced in many developing countries, often leading to uncontrolled development and widening areas of informal settlements, the most vulnerable of urban communities.

Despite the close relationship between water supply, drainage and waste water management, historically they have been designed and managed independently of each other. Traditionally stormwater runoff is treated as a waste product, to be removed as efficiently as possible. This has led to significant gaps in the urban planning process which are now inherent in all of our major urban centres in South Africa, as it is globally. As the land and water demands of urban communities continue to increase in tandem with diminishing resources, the gaps in the planning processes become more evident through increased flooding problems and the impact on receiving streams and water resources.

Internationally, this has led to initiatives such as SUDS (Sustainable Urban Drainage Systems) in the UK and Europe, LID (Low Impact Development) in the United States, and WSUD (Water Sensitive Urban Design) in Australia. These are based on a central principle of stormwater volume control in urban environments (as opposed to peak flow control), and set out a range of Best Management Practices (BMPs) that may be employed to reduce the effect urban environments have on increasing storm runoff. The BMP include stormwater retention, infiltration, groundwater recharge and reuse. But there is also an important requirement to manage stormwater on a catchment scale, a critical requirement for large or rapidly increasing urban areas.

The difference between a focus on peak flow control and one on volume control is significant in the context of this study as it signifies a change in urban development management that may become central to the adaptation strategies for municipalities in response to climate change. By managing peak flow from urban sites, storm runoff is treated as a waste product with the aim to get it off site as efficiently as possible. Some attention is given to preventing the neighbour from flooding, but the extent to which systems further downstream are not flooded is usually limited. This is the approach widely adopted in Ekurhuleni and mainly on a site by site basis. Planning at a catchment scale is only recently being reintroduced and is not yet implemented, but it is still focussed on peak flow control.

Managing stormwater volume instead of only peak flow would see urban runoff treated more as a resource. There is more retention on site, either through storage or infiltration, but more often a combination of the two. This makes stormwater more available for use by both natural systems and human requirements. Flash floods from urban areas generally pass too quickly (and with a lot of force) and are generally unavailable for use, whereas water retained within a urban catchment is released more slowly and it therefore more available for habitat and water supply. BMPs for retention and infiltration also inherently improve water quality through both settlement and filtration, thereby generally improving stormwater from a waste product to something more useable.

Changing rainfall patterns may lead to changes in design rainfall depths and intensities which in turn will result in adjustments to stormwater design requirements. However, with the anticipated increase in rainfall and intensities it is likely emphasise the need to plan stormwater runoff at catchment level and apply BMPs for stormwater volume control.

Water supply security

Municipalities are Water Service Authorities in terms of the Water Services Act No 108 of 1997 (WSA). The act places the responsibility on the municipality for ensuring access to water services (water supply and sanitation). Many of the Water Service Authorities use Water Service Providers to provide water to consumers and they often have responsibility for planning and securing water resources. Rand Water is Ekurhuleni’s Bulk Water Services

Provider and has been central to Ekurhuleni achieving the highest Blue Drop score in Gauteng in 2012 (Dept. Water Affairs, 2012[1]). Rand Water plays a key role in Ekurhuleni's Water Safety Planning which is one of the performance areas of the Blue Drop score. Water Safety Planning includes catchment planning, and as Rand Water is on the Strategy Steering Committee of the Vaal River System, it is central to all planning decisions on water resources security into the future.

Rand Water therefore fulfils Ekurhuleni's responsibility for water resources planning, as is the case for many municipalities in the country. This means that Ekurhuleni, and other municipalities in the Gauteng province, benefit from a number of inter-basin transfers into the Vaal River catchment, including an international transfer scheme from Lesotho. At the same time Ekurhuleni is reported as one of a number of Gauteng municipalities who do not report on unaccounted for water (UAW) (Dept. Water Affairs, 2012). In a province averaging 25% UAW, it is not clear how the Water Safety Planning performance factor is measured for the Blue Drop Score but suggests that viewing stormwater runoff as a potential resource is some way off.

1.5 Adaptation context

There are two types of responses to climate change, namely mitigation and adaptation. Mitigation involves minimising the impact that people have on the environment that is causing climate changes. This involves, amongst others, measures to reduce greenhouse gases. Adaptation involves dealing with the impacts of climate change and trying to minimise the extent of damage caused.

"prevent the impacts that we can't manage and manage the impacts we can't prevent"

Mitigation projects have been the focus of efforts by municipalities to combat climate change. The fruit of these projects will only be realised many decades in the future and do little to prepare countries and municipalities for the projected impacts of climate change. The day-to-day effects of climate change will be borne by local communities and municipalities. It is the municipalities' role to reduce the impacts of climate change, through local specific adaptation projects (Roberts, 2008).

Adaptation is understood as the process by which a system copes with and responds to changes to that system (Gallopin, 2006). The IPCC (2009) refers to adaptation as the "process of adjustment that moves towards resilience, even when the dynamics of risk is changing". Adaptive capacity is the ability of a community to adapt, and the process of learning, which can be seen as one way that resilience can be developed. Resilience "is the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks" (Walker *et al.*, 2004). In order to plan and prepare effective adaptation, it is important to understand the risks that are to be addressed and the changes that are to be adapted to. Adapting to climate change should be fundamentally linked to issues of societal resilience including

[1] Department of Water Affairs, 2012. 2012 Blue Drop Report. Department of Water Affairs, South Africa. www.dwaf.gov.za/dir_ws/dwqr/subscr/ViweCompDoc.asp?Docid=375 (downloaded 12 July 2012).

development and other issues, particularly in developing contexts (Rayner and Malone, 1998).

Only a few urban areas in the South have placed a strong focus on analysing the impacts of climate change and incorporating adaptation approaches into policies and planning (Janjua, 2010). Much of the research undertaken to improve local understanding of vulnerability and adaptation, has not been transferable into policy responses (Burton *et al.*, 2004).

Approaches to Adaptation

The IPCC fourth assessment report (2007) separates adaptation into 'spontaneous adaptation', 'anticipatory adaptation' and 'planned adaptation'. Spontaneous adaptation consists of non-deliberate responses to changes in the natural systems (e.g. ecological) as well as human systems (e.g. market related) (IPCC, 2007). Anticipatory adaptation lies on the other extreme consists of proactive measures taken against changes before these changes are observed. When the adaptation response is due to the observation of changes in an attempt to return the system to a desired state, it is termed planned adaptation. This often comes in the form of policy response and behaviour change (IPCC, 2007). Municipalities need to incorporate a combination of planned and anticipatory adaptation to ensure the safety and wellbeing of the environment and society into the future.

Climate change adaptation involves three approaches, which can be divided into three categories including:

1. Modifying the human element
2. Adapting policy
3. Modifying human behaviour (WSP, 2009)

Modifying the human element involves planning infrastructure and buildings (including houses) in areas where there is low risk from climate change. It involves physical changes to the environment that will reduce the risk and vulnerability to extreme climate events. Adapting policy to accommodate climate change, involves changing strategic plans, local policies and engineering standards. This relies on a good understanding of how local municipalities will be affected in the short, medium and long-term future (eThekwini, 2010, WSP, 2009). The last and crucial approach is modification of human behaviour. This involves education, awareness campaigns and development of early warning systems. This aspect is dependent on well-structured public participation and governance (Carmin *et al.*, Roberts, 2010, WSP, 2009). Working with local communities and building adaptation into current issues and priorities is the best way to get public and political buy-in.

Many issues, related to climate change, are complex and thus it is important to adopt a combination of responses to combat the projected impacts. It is necessary to create a strategic framework, which ensures that individual projects all work together for a common goal (WSP, 2009). Adaptation options need to be in line with sustainable development as well as national priorities (Burton *et al.*, 2004). Often adaptation projects are not labelled as such but fall under the banner of service delivery and infrastructure development, for example.

Adaptive Capacity and behaviour

Adaptive capacity (in relation to climate change impacts) can be described as "the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences" (EU, 2010). Governance structures are often also indicated as components that determine

the adaptive capacity of communities, but here we argue that governance structures (or institutions) themselves can also be assessed on adaptive capacity.
Components of adaptive capacity are listed as:

1. **Asset base**: availability and interplay of key assets needed to respond to evolving circumstances in a changing climate – assets being financial, physical, natural, social, political and human capitals;
2. **Institutions and entitlements**: an institutional environment that allows equitable access and entitlement to key assets;
3. **Knowledge and information**: the system has the ability to collect, analyse and disseminate knowledge and information in support of adaptive activities;
4. **Innovation**: the system creates an enabling environment to foster innovation, experimentation and the ability to explore niche solutions in order to take advantage of new opportunities; and
5. **Flexible, forward-looking governance**: the system is able to anticipate, incorporate and respond to changes with regard to its governance structures and future planning.(Jones *et al.*, 2010 and ACCRA, 2010)

As for the last component on this list, Jones *et al.* (2010) indicates that this indeed revolves around capacity of the governance system to anticipate change, and prioritisation and incorporation of initiatives in future planning. Of importance are also informed decision making and transparency. And "…flexibility to allow for systems, and the institutions that govern them, to evolve and adapt to a changing environment is a crucial characteristic of adaptive capacity" (Adger *et al.*, 2007 and Smith *et al.*, 2003; in Jones *et al.*, 2010).
However, besides the above emphasis on adaptive governance as part of adaptive capacity, one can also investigate the governance structure or institution as a "community" that needs to adapt. Hence, the above components can be assessed from a livelihoods and community point of view, but also from an organisational or institutional point of view, e.g. municipal entities managing risks such as floods.
This particular deliverable aims to shed more light on components a) through e) from the point of view of local government, though it must be acknowledged that this investigation will probably not be able to map the full complexity of issues at institutional level: they are inherently complex and would require a separate, larger investigation.

In practice, actual behaviour (of individuals, communities and organisations), is also influenced by more subjective matters such as framing, perceptions, opinions, experience and knowledge. Jasanoff (2010) poses that "scientific facts never take root in a neutral interpretive field" which can be interpreted in the widest sense possible: cultural differences between countries, cities, organisations, and individuals, influence the perception of scientific facts. Jasanoff (2010) argues that it is necessary to link the processes of understanding the science and facts, and creating meaning from these. In other words, to turn data into knowledge that can inform action.

The focus of study is to understand how local government can potentially adapt to challenges placed on the water services sector as a result of climate change. In order for local municipalities to place the required emphasis on adaptation, it is necessary that the impacts of climate change be framed from a local, rather than global, perspective (Janjua, 2010, Roberts, 2008). Stakeholders are unlikely to be motivated to change approaches towards adaptation if they do not understand the implications of climate change on their specific sector. In order to implement adaptation policies effectively, good governance and public participation is necessary (Janjua, 2010).

Institutional context – local government

Institution is defined by Turner (1997, 6) as "a complex of positions, roles, norms and values lodged in particular types of social structures and organising relatively stable patterns of human activity with respect to fundamental problems in producing life-sustaining resources, in reproducing individuals and in sustaining viable societal structures within a given environment". In this case, we will be looking specifically at the institution of local government.

Local government acts as the bridge between policy and implementation, even if implementation is done by communities or stakeholders, there is often a need for an enabling environment. Understanding the local institutional context assists in determining not only which risk management options are technically available, but also which ones are most viable in the context in which they need to be implemented.

Individuals work within institutions and give meaning to the functions that are being executed. Despite the existence of routines (e.g. procedures), there are still many instances where individuals, knowingly or unknowingly, influence the way an institution functions. Also, individuals work and live within the previously mentioned context, and they are in a position to influence each other (knowingly and unknowingly). All these aspects contribute to attitudes, framing, perceptions and meaning- or sense-making of each individual. In addition, individuals have individual experiences – which are either different all together, or they are interpreted differently.

A shift within institutional frameworks and strategic approaches is necessary if adaptation is to be effectively incorporated into policy (Carmin *et al.*, 2009). A full commitment to adaptation includes providing opportunities for decision-makers and managers to support and encourage adaptation approaches. This is accomplished through allocating appropriate budget and resources, and the space for creativity and innovation (Janjua, 2010). Creating environment in the municipality that encourages the incorporation of adaptation into policy has proven to be dependent on a climate change 'champion', who drives this vision (Janjua, 2010, Roberts, 2008).

When considering institutions and organisations, two aspects are of importance which largely influence the functioning of the institutions, but over which the institutions rarely has (enough) control: the context within which they operate, and the individuals that constitute the institution. Context refers to the external environment within which an institution operates, most notably those related to markets and policy. Also for this investigation these need to be assessed as they also form drivers of water services planning.

Many communities depend on local municipality and expect them to provide risk reduction strategies to enable adaptation and recovery from the effects of flood events, and ultimately climate change. Several other dimensions also need consideration when gearing up for and ensuring resilience to periods of potential climate stress. These include assessing the governance structures and processes of various institutions designed to intervene. Governance structures need to have a level of flexibility in their approach to managing climate change and disasters, as the extent and type of risks are likely to be different between communities and areas, and from one disaster to the next (Dietz *et al.*, 2003; Fatti and Vogel, 2011).

Municipal Examples

A risk management approach has been adopted in New Zealand as the primary approach to climate change adaptation. This approach aims to manage the uncertainty of climate change projections to assist decision-making, and use climate information to guide climate risk management (Jones, 2010). Risk management involves establishing risk and its importance, and the strategies that are needed to avoid or minimise the impact of the particular risk. This process can be referred to as the development of adaptation options. Typically, risk assessments, which are used in risk management, rely heavily on technical information. It is however also important to understand the institutional framework within which “risk managers” operate, their challenges and constraints, as well as their views and opinions of the risk.

eThekwini

eThekwini is a South African example of where adaptation has been well incorporated into long term planning strategies so that actions that are taken now to deal with current problems also take long term projections into account (eThekwini, 2009). Short and medium term plans and projects have also been laid out to ensure that the long-term goals are met (WESSA, 2010).

A participatory approach was taken by eThekwini in formulating adaptation plans and priority areas. The relevant stakeholders were consulted and they gave insight into current understanding and misconceptions of climate change, as well as the areas that these stakeholders believed to be important areas to focus resources on now and into the future. The process also allowed the municipality to gauge the level of empowerment of the different stakeholders (WESSA, 2010). Transparency and good communication are two key aspects that proved important in this case (WSP, 2009).

The eThekwini Municipality has worked to encourage participation on issues of climate change through a range of stakeholders in society. A number of projects have been initiated to encourage climate change adaptation and awareness. A few such projects are detailed below.

A partnership has been established to support and encourage industries to mitigate their environmental and climate change impacts. An easily accessible website and database was set up to support this (WESSA, 2010). Although this may seem to be an effort focussed more on mitigation than adaptation, there is a argument that effective mitigation is the best form of adaptation (Bartlett *et al.*, 2010).

Another initiative to encourage civil society to engage with climate change issues is through a schools’ competition where learners were required to create a poster about one of the issues associated with climate change and the local area (WESSA, 2010).

Community initiatives, such as “adopt a spot”, where people are encouraged to take responsibility for the environmental wellbeing of an area encourage participation from communities in maintaining the environment. This can have positive effects of reducing flood risks. Other actions taken by the municipality to reduce the threat of flooding include:

- Maintenance issues and prevention
- Regular clearing of stormwater drains
- Raise awareness around existing technologies- many people are not aware of what is available (WESSA, 2010)

Marking flood lines and including forecasts of future projections of high flood lines will help communities and decision makers ensure the safety of people living in high-risk areas (eThekwini, 2010).

2 DESIGN CRITERIA AND METHODS

2.1 Vulnerability assessment

Mapping Vulnerability

The methodology has been designed around three steps using the developed risk assessment model. The first step is to understand the hazard of flash flooding and determine the areas within the region that may be most prone to this hazard. This may be due to a number a number of natural factors, based primarily on the natural environment i.e. topography and flood plains. The second step integrates the concept of vulnerability into the study. It quantifies the vulnerability of a particular area in terms of its four key dimensions, which will be discussed in more detail below. The final step involves the mapping of the risk within in the region. This will essentially incorporate the areas prone to flash flooding with the areas that are vulnerable, thus allowing the study to identify those zones within the region that may suffer the most if any form of flash flooding hazard were to occur.

The risk assessment model

The risk analysis model that will be used, can be represented by the equation of

$$Risk = Hazard \times Vulnerability$$

where *risk* is the probability that a negative event has to affect and individual in a given time and space; *hazard* is a natural or human-made event that threatens to adversely affect human life, property or activity to the extent of causing a disaster. This will be simplified in this case to represent a potential flash flood event. *Vulnerability* is the predisposition to suffer damage due to external events. This equation has been adapted from Kumpulainen, 2006.

The equation uses the following determination of the hazard variable:

$$H = HP \times SI;$$

where *HP* is the hazard probability factor, which in this case will be taken as 1 to enable the assumption that a hazard of this nature will occur due to the effects of climate change; *SI* indicates the severity index of the hazard, this will essentially be regarded as high due to the nature of impact of the flash flooding within the region. Thus the severity index will be set at 1 for areas that are prone to flash flooding within the region, and 0 for areas that are not.

Other variations of the risk assessment equation include variables which represent manageability and capacity i.e.

$$Risk = \frac{(Hazard \times Vulnerability)}{(Manageability \times Capacity)}. ;$$

where *manageability* is the degree to which authorities can intervene and manage the risk and *capacity* is the degree to which individuals or communities themselves can intervene and manage the risk. These variables can drastically change the outcome of the risk assessment. However, since these factors are variable in space and time, and there is no data available to adequately describe these factors and their impact on the risk assessment, they will not be included in this simplified risk analysis. Thus the risk analysis will evaluate the hazard of flash flooding without any interventions.

Vulnerability analysis

The vulnerability assessment will involve identifying zones of high, medium and low vulnerability. A number of key factors will influence the vulnerability of a particular area. These will factors will incorporate elements from a number of spheres. These generally include aspects of social vulnerability, economic vulnerability, environmental vulnerability and structural vulnerability. The equation used to attain vulnerability is described as:

$$V = [SoV + EcV + EnV + StV];$$

Where *SoV* is the social vulnerability variable which is a measure of the level of well-being/predisposition to risk + level of literacy + population Density (according to 2001 Census data); EcV is the economic vulnerability which identifies the income level according in accordance with the 2001 Census data; the variable EnV is the environmental vulnerability and looks at ecological resources within the area (i.e. natural open space, wetlands); and finally StV is the structural vulnerability and is valued by the understanding of the structural robustness of a particular area.

A guideline to contextualise the vulnerability of the region based on the specific underlying homogenous zone was used (Mahlangu, 2009). This effectively depicts the current dominant use within a particular areas and based on this specifies a unique set of values for each of the variables represented in the equation above. The table is specifically designed for the South African urban context and was used to assess vulnerability. Thus the total of the different variables stipulates the total vulnerability for the different homogeneous zones within the Ekurhuleni region.

The proposed weightings are presented in table format. The numbers that are allocated ranges between 0.1 and 1. This is the range that is usually used for probability analyses. The indices indicate how vulnerable the areas are over each sphere in the vulnerability equation.

The sum total over the four fields will essentially give the vulnerability of the particular homogeneous zone. The total will range from 0.55 (for land use associated with degrade land e.g. mine dumps) to 2.7 (for land use associated with residential e.g. informal settlements and high population densities).

Stakeholder Engagement

Consideration of vulnerabilities includes not only assessing physical factors, but also social and economic circumstances. This section of the research aims to understand the institutional elements of managing water resources within a municipality. This was done initially through attending the Spatial Planning Forum and subsequently through a series of interviews with municipal managers from the different levels of management. The investigation included managers operating on various scales in the decision-making structure of the municipality namely, strategic, regional, local operations and maintenance managers. The focus here is on the strategic level however, the insights gained from the managers in lower positions are nonetheless important in assessing governance structures.

Interviews were structured and assessed according to a KAP approach, which aims to understanding three dimensions that influence adaptation, namely knowledge, attitude and practice allows a project to track changes in them over time, and may enable the project to customise activities to the needs of a particular community. Although this project is not able to assess changes over time, it will be a good basis from which to test changes in the future.

Knowledge

This aspect assesses the actual knowledge that people have of different factors such as:

- Knowledge of planning processes, including resources availability (assets)
- Knowledge of (climate change) science and the risk/threat posed

- Knowledge of risk reduction or risk management options (adaptation)
- Knowledge networks (i.e. where do people get their information/knowledge from, what do they generate themselves, and what do they pass on, and how) – which should also address inaccessibility of information and the possible existence of intermediaries
- Knowledge of challenges and strengths

Attitude
This dimension specifically investigates feelings that people have towards certain subjects, as well as any preconceived notions. Here meaning-making as opposed to fact-finding is being addressed.

- How do people feel about water services delivery planning and decision-making processes, and why (is there room for innovation and flexibility).
- What are general feelings about climate change:
- Its existence
- The data or information that is available
- What do people think is important or relevant about climate change for their jobs or for the functioning of the municipality (why/why not)?
- When making decisions about climate change, what information is regarded as important or relevant, and why?
- What aspects of risk reduction people think is important, and why?

Practice
This dimension assesses ways in which people demonstrate their knowledge and attitudes through their actions.

- How do people or units respond to certain conditions – for instance on difficult decision-making processes, or flood events. Here, hypothetical questions or mini-case studies can be posed (e.g. how did they respond to previous flood events, both technically as well as in terms of decision-making)?
- What are some of the routines for typical activities (both decision-making as well as technical aspects) – including codification?
- How is information from different sources used and integrated in the local government's systems?

2.2 Analysis of extreme rainfall events

SAWS provided climatic data for this study from the OR Tambo Weather Station, for the period of 1960-2009 for use in this research. This period is used because it comprises the full set of observation data available. Due to the requirements of the airport there is always a human observer monitoring the weather at the station so cloud and weather data are available for the entire period. This information is crucial for identifying storms, as thunderstorm occurrence is associated with a combination of specific weather. The weather and cloud data comprised three daily-recorded observations, at 08h00, 14h00 and 20h00. Rainfall data are stored as daily totals. For the purpose of this study, a thunderstorm is identified by the fulfilment of three criteria at a specific time on a day, namely cloud type being cumulonimbus, the human observation of a thunderstorm and the occurrence of rain during that day. A maximum of one thunderstorm is counted per day due to the availability of only one value for daily rainfall. This minimises the data inconsistencies between rainfall, cloud and weather types. This method also prevents a single storm, which extends across observation times, from being counted more than once.

This study focuses on the summer season, from October to March, in line with other summer rainfall studies in the region (e.g. CoJ, 2009; Dyson, 2009). Following the identification of thunderstorms during this period, the frequency of these events is investigated. The total number of storms per season is calculated by summing the storms identified during each year's rainfall season. Further analysis of the data includes assessments of storm frequency, total rainfall, total storm rainfall, average storm rainfall and heavy storm frequency. In line with Dyson's (2009) rainfall study and a study from the Krugersdorp Weather Station, heavy rainfall is classified as the top 10% of daily rainfall, which equates to a daily rainfall of at least 10 mm. The greatest potential inaccuracy in this study is underreporting of storm events.

Uncertainties and Limitations

Uncertainties and limitations are inherent in climatic studies of this nature. A key uncertainty in the study relates to the classification of thunderstorms and significant rainfall events. Three criteria were used to make this classification and were based on the available information from the SAWS. The SAWS data is assumed correct and thus this study indicates the minimum number of storms for the period. The data included cloud type, rainfall and the observation of a thunderstorm by an observer. Cloud type and thunderstorm observations are both subject to error. There might have been occasions where a storm or the cloud type was not recorded due to a more dominant weather event at the time of observation. Storms may have been missed if one occurred between observation times but was not present at the recorded time. Both situations imply the possibility that more storms occurred than were recorded. The results from these datasets were tested by dropping the cloud type and thunderstorm observation respectively from two tests and the resulting trends were essentially the same in all situations.

2.3 Detailed climate change scenarios

The southern African region is thought to be highly vulnerable to anthropogenically induced climate change (e.g. Meadows, 2006). Indeed, a robust signal from the coupled global climate model (CGCM) projections described in Assessment Report Four (AR4) of the Intergovernmental Panel on Climate Change (IPCC), is that the region may be expected to become generally drier in response to enhanced anthropogenic forcing (Christensen et al., 2007). However, the CGCM projections described in AR4 and elsewhere are of coarse horizontal resolution, and therefore to some extent inadequate to describe the regional details of climate change. Only a few detailed projections of regional climate change over southern Africa have been obtained to date using dynamic regional climate models (e.g. Tadross et al., 2005; Engelbrecht et al., 2009; Engelbrecht et al., 2011; Engelbrecht et al., 2012). These experiments have indicated that the central and eastern parts of South Africa may become wetter during summer, with an associated increase in the frequency of occurrence of convective rainfall events. Annual rainfall totals have, consistent with the CGCM projections, been projected to decrease over most of the subcontinent in response to a general strengthening of the subtropical high-pressure belt (Engelbrecht et al., 2009) – despite the projected increase in summer rainfall totals.

The plausibility of the central and eastern parts of South Africa becoming wetter during summer, with an associated increase in the frequency of occurrence of extreme rainfall events, may be of great relevance to the metropolitan areas of the South African Highveld. The high-altitude Highveld region is prone to the occurrence of thunderstorms, which are the main cause of flash-flooding within the cities. Should enhanced anthropogenic forcing lead to an increase in intensity or the frequency of occurrence of thunderstorms, their impact on storm-water drainage systems may be expected to correspondingly increase. Also of interest to the occurrence of flood events within cities, is the occurrence of wet-spells (prolonged rainfall events that last for two or more consecutive days). Wet-spells may lead to surface areas gradually becoming saturated, which then induces increased run-off and eventually the occurrence of flood events. Changes in the attributes of rainfall over this region may additionally impact on the average rainfall, stream-flow and surface water reservoirs.

In order to gain more insight into the potential impact of enhanced anthropogenic forcing on flood-producing rainfall events over eastern South Africa, there is a need for larger ensembles of high-resolution regional projections of climate change to be obtained for this region. Ensembles of projections also allow to some extent a description of the uncertainties associated with the projections. Now that super-computing facilities are becoming more generally available in South Africa, primarily through the computer clusters of the Centre for High Performance Computing (CHPC) of the Meraka Institute of the CSIR, there is the potential to perform more of these computationally expensive regional climate modelling experiments. In this project, a large ensemble of dynamically downscaled climate scenarios recently performed at the CSIR (using the computer clusters of the CHPC) are analysed to gain insight into the potential impacts of enhanced anthropogenic forcing on the frequency of occurrence of extreme rainfall events over the South African Highveld. Downscaling from a number of CGCMs used within the IPCC's AR4, these simulations are analysed to reveal the projected climate change signal in metrics such as the frequency of occurrence of extreme rainfall events and the underlying changes in circulation dynamics.

High-resolution regional projections of climate change

A variable-resolution atmospheric global circulation model, the conformal-cubic atmospheric model (CCAM) of the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Australia, was used to obtain the ensemble of regional climate projections that are analysed as part of this project. The model is highly suitable for the purpose of regional climate modelling, due to its computational efficiency and variable-resolution formulation that allows great flexibility in downscaling CGCM data, through the application of a multiple nudging technique (McGregor, 2005). The model's ability to simulate the present-day characteristics of regional climate has been investigated rigorously over southern Africa (e.g. Engelbrecht et al., 2009; Landman et al., 2010; Engelbrecht et al., 2011; Engelbrecht et al., 2012) and for various other climatological regions (e.g. Nunez and McGregor, 2007; Lal et al., 2008).

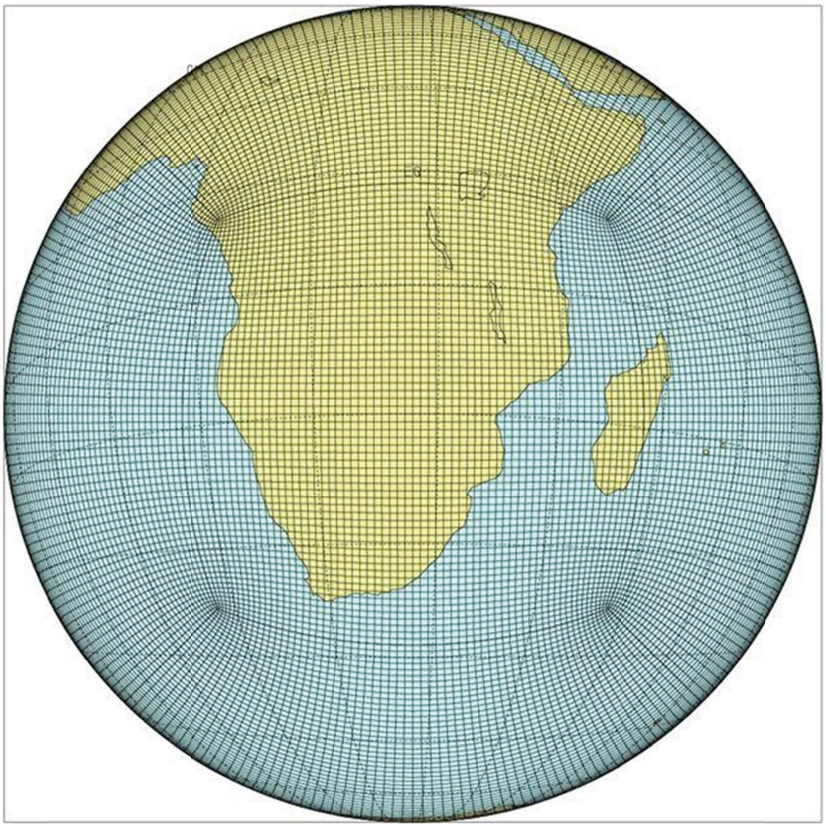


Figure 3. Stretched C64 CCAM grid, having a horizontal resolution of about 0.5° over southern Africa.

In order to obtain the ensemble of regional projections of climate change, the model was forced with the bias-corrected sea-surface temperature (SST) and sea-ice output of six different CGCMs used in AR4 of the IPCC, for the period 1961-2100. All six of these projections performed are for the A2 emission scenario of the Special Report on Emission Scenarios (SRES). A multiple-nudging strategy was followed, by first integrating CCAM globally at quasi-uniform C48 resolution (about 200 km in the horizontal, that is, about 2° in latitude and longitude), forcing the model with the SSTs and sea-ice of each host model, and with CO2, sulphate and ozone forcing consistent with the A2 scenario. In a second phase of the downscaling, CCAM was integrated in stretched-grid mode over southern Africa and the southwestern Indian Ocean, at C64 resolution (about 0.5° in latitude and longitude, or 60 km, over the area of interest). The high-resolution grid is centred at 28° E and 25° S (Figure 3). The higher resolution simulations were nudged within the quasi-uniform C48 simulations, through the application of a digital filter (Thatcher and McGregor, 2009) using a 4000 km length scale. The filter was applied at six-hourly intervals and from 900 hPa upwards. More details on the experimental design are provided by Engelbrecht et al. (2011). Model output for the 60 km simulations were written at hourly intervals, in order to provide forcing to the hydrological modelling to be performed as part of the project.

Projected changes in extreme rainfall events

Wet-spells and widespread flooding over the South African Highveld may result from a number of different weather systems (or from a combination of different weather systems). These include tropical-temperate cloud bands, mesoscale convective complexes (that typically reach the Highveld via Botswana) as well as cut-off lows from the westerly wind regime. The Highveld is also prone to the occurrence of intense thunderstorms – these may either occur in isolation (heat thunderstorms) or embedded within larger cloud bands or cloud complexes. Slow moving thunderstorms are a primary cause of flash-floods within cities on the Higveld of South Africa. Climate change over South Africa may manifest itself not only in a change in the long-term mean seasonal rainfall, temperature and circulation patterns, but also through an increase in the frequency of extreme weather events. This component of the project therefore focused on analysing the ensemble of projections to obtain insight into potential changes in the frequency of occurrence of extreme rainfall events that may impact on the metropolitan areas of the Highveld.

Figure 4 shows the ensemble-average projected change in the annual frequency of occurrence of extreme rainfall events over South Africa. Here an extreme rainfall event is defined as 20 mm of rain falling within 24 hours over an area of 0.5°x0.5°, that is, an area of about 50x50 km^2. Rainfall events of this magnitude rarely occur over the South African Highveld (Dyson, 2010) and are likely to be associated with flooding over the region. A general increase in extreme rainfall events is projected for South Africa. Rainfall events are projected to increase over the mountainous regions of eastern South Africa in particular – including Lesotho and the Highveld regions of Mpumalanga, Gauteng and the Free State. There is strong correspondence between the different ensemble members regarding the projected future increase in extreme rainfall events (Figure 5), which strengthens confidence in the projections.

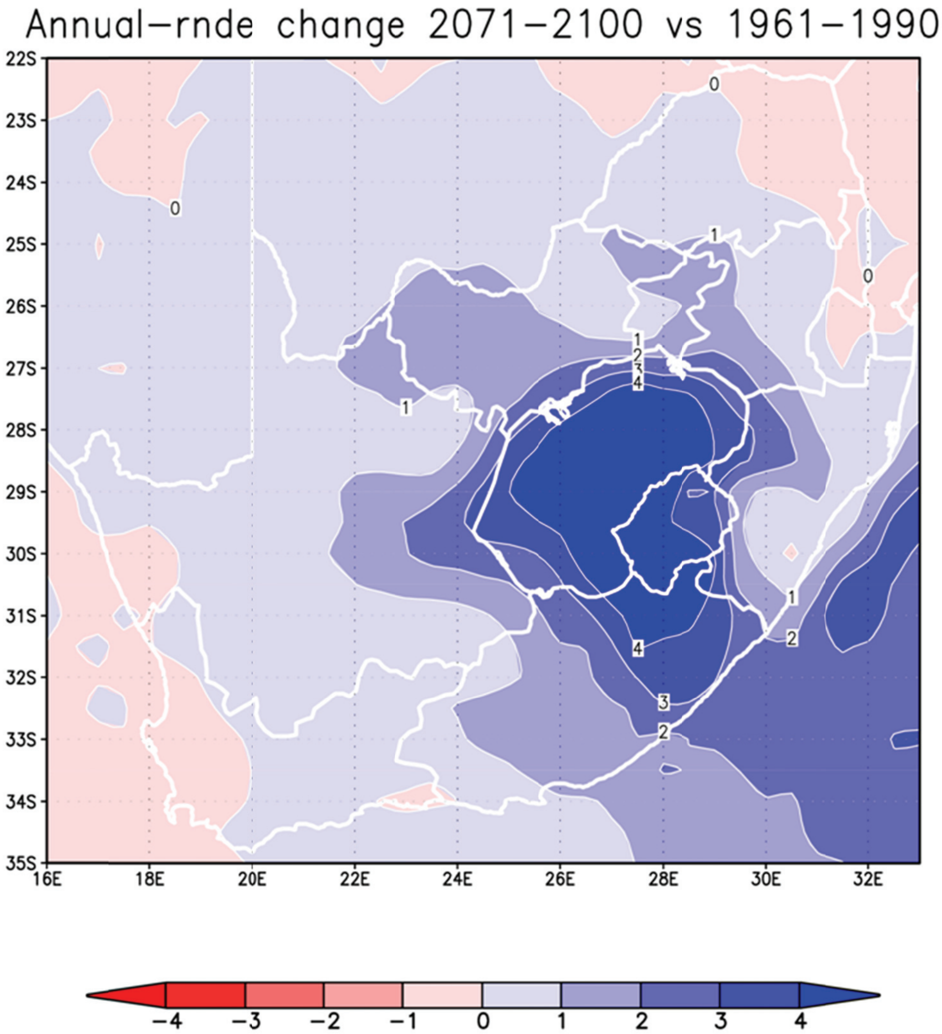


Figure 4. Projected change in the annual frequency of extreme rainfall events (defined as 20 mm of rain falling within 24 hours over an area of 0.5°x0.5°) over South Africa, for the period 2071-2100 vs 1961-1990 (units are number of events per model grid box per day). The figure shows the ensemble average of the set of downscaled projections, obtained from six CGCM projections of AR4 of the IPCC, all for the A2 SRES scenario.

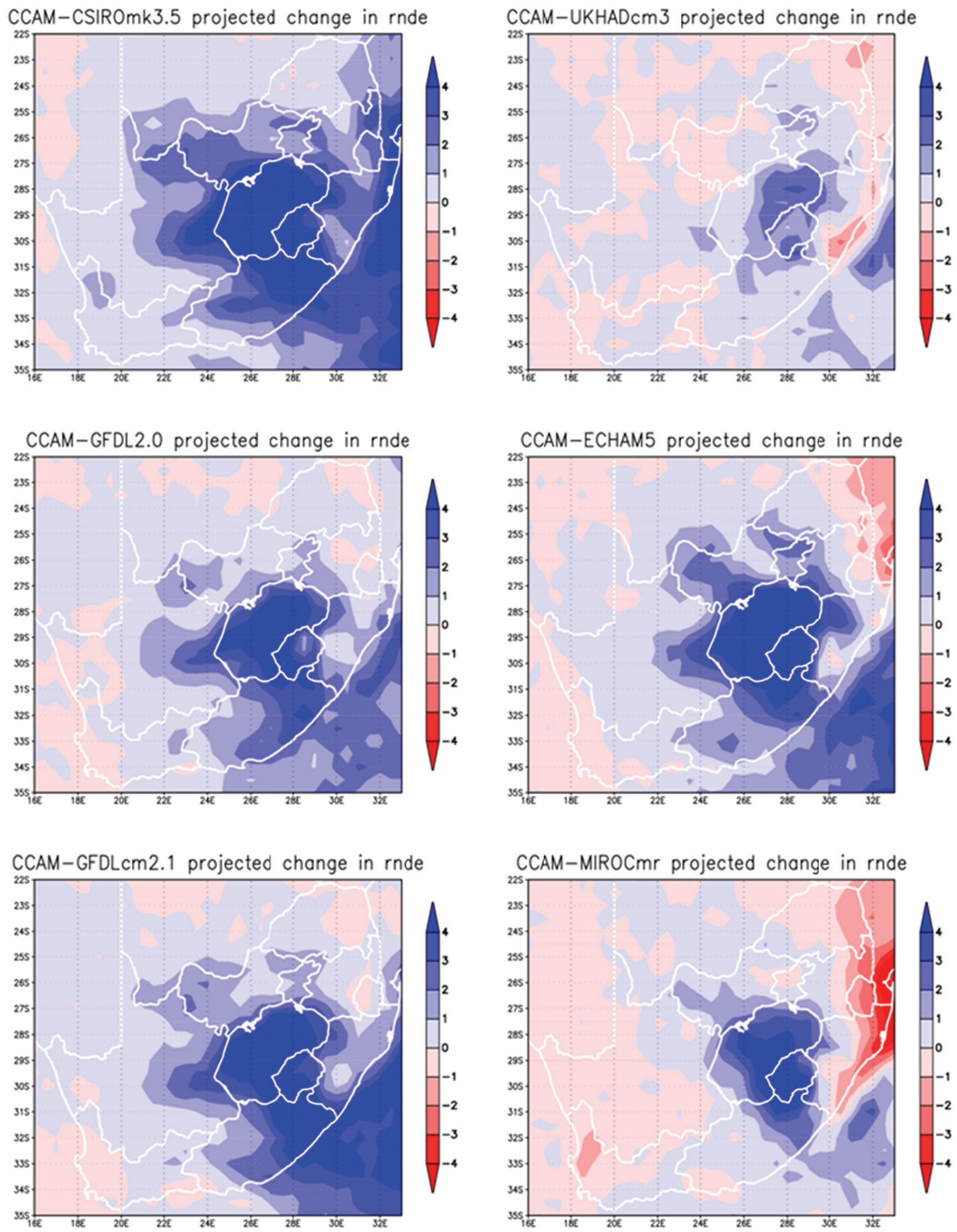


Figure 5. Projected change in the annual frequency of extreme rainfall events (defined as 20 mm of rain falling within 24 hours over an are of 0.5°x0.5°) over South Africa, for the period 2071-2100 vs 1961-1990 (units are number of events per model grid box per day). The figure shows the six ensemble members of the set of downscaled projections, obtained from six CGCM projections of AR4 of the IPCC, all for the A2 SRES scenario.

Underlying physics and circulation changes

The projected change in maximum temperature (ensemble average of the six projections) during the summer half-year (October to March, ONDJFM) for the period 2071-2100 relative to 1961-1990 is shown in Figure 6. The projections obtained from the six individual ensemble members are shown in Figure 7. Strong warming is projected for the southern African region under the A2 emission scenario. The pattern of drastic increases in maximum temperature over southern Africa, of more than 4 °C over large parts of the interior regions, is robust across ensemble members. The particularly strong warming of the western and central interior is associated with an increase in the intensity of the heat low over this region (Figure 8). This Figure shows the projected change in the geopotential height for the six different ensemble members, for the period 2071-2100, relative to the period 1961-1990. A robust pattern of falling geopotential is consistently projected across the different ensemble members. Such a change in circulation is favourable for the more frequent formation of thunderstorms to the east of the heat-low axis, that is, over the central and eastern interior of South Africa.

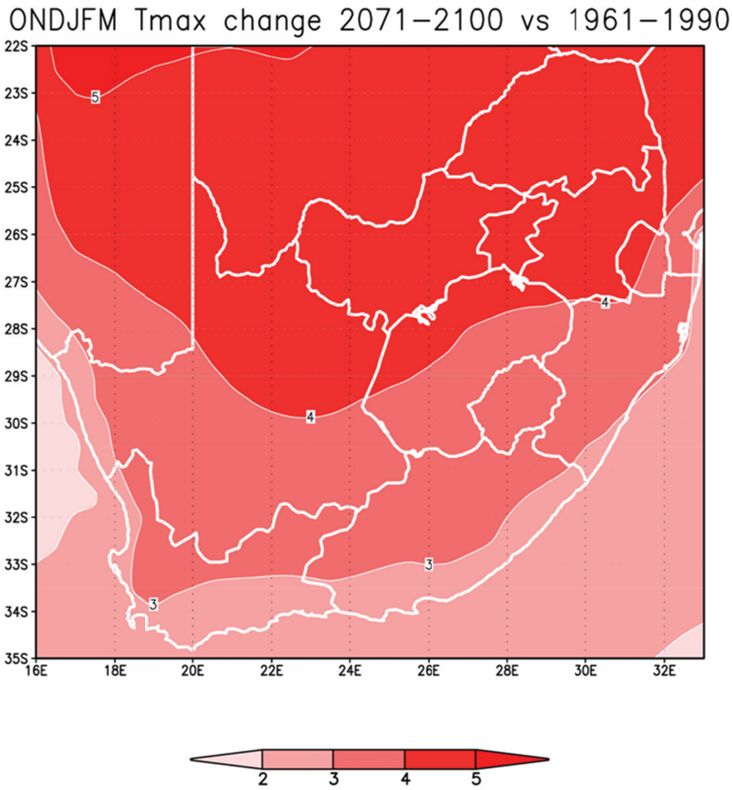


Figure 6. Projected change in maximum temperature (°C) during the summer half-year over South Africa, for the period 2071-2100 vs 1961-1990 . The figure shows the ensemble average of the set of downscaled projections, obtained from six CGCM projections of AR4 of the IPCC, all for the A2 SRES scenario.

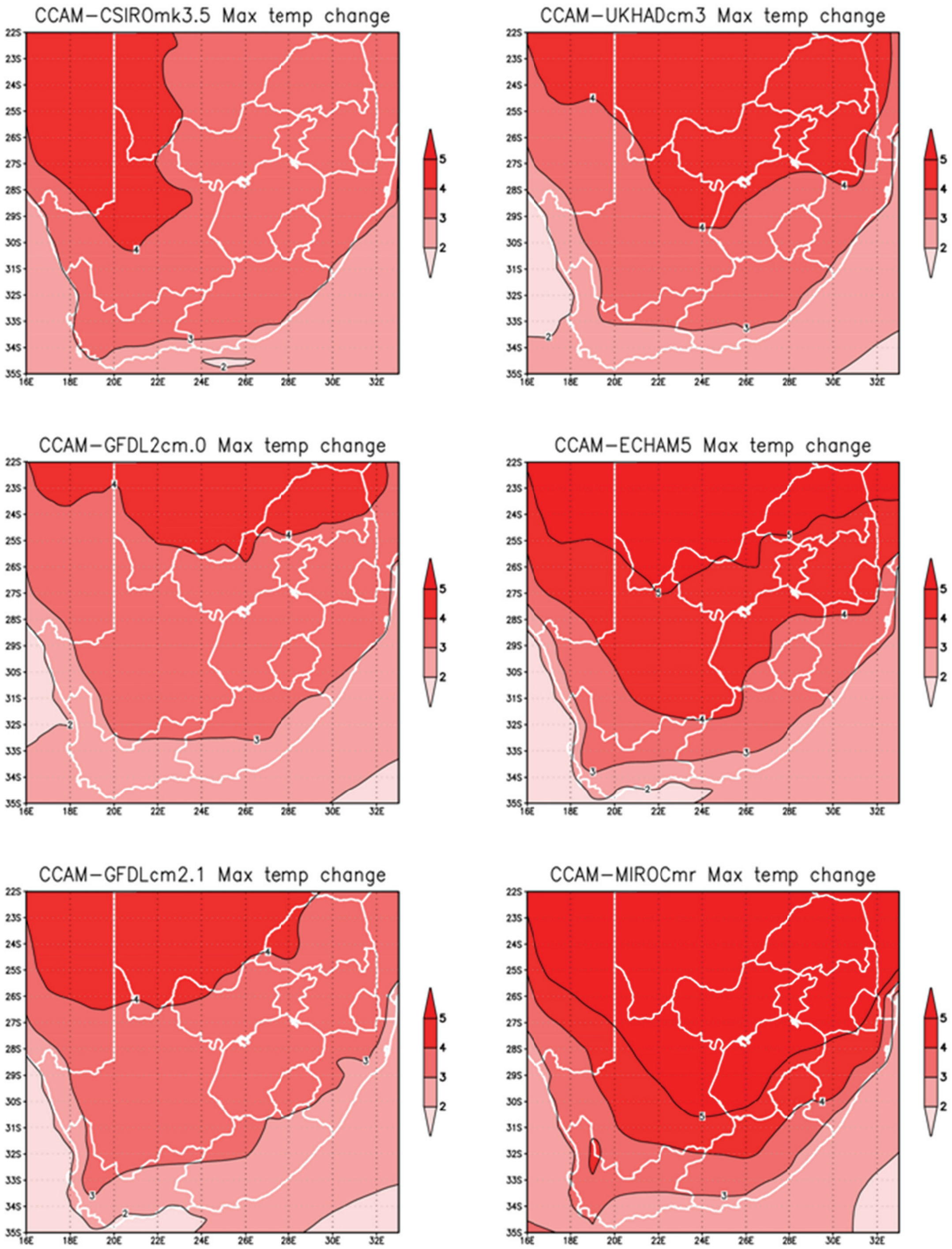


Figure 7. Projected change in maximum temperature (°C) during the summer half-year over South Africa, for the period 2071-2100 vs 1961-1990. The figure shows the six ensemble members of the set of downscaled projections, obtained from six CGCM projections of AR4 of the IPCC, all for the A2 SRES scenario.

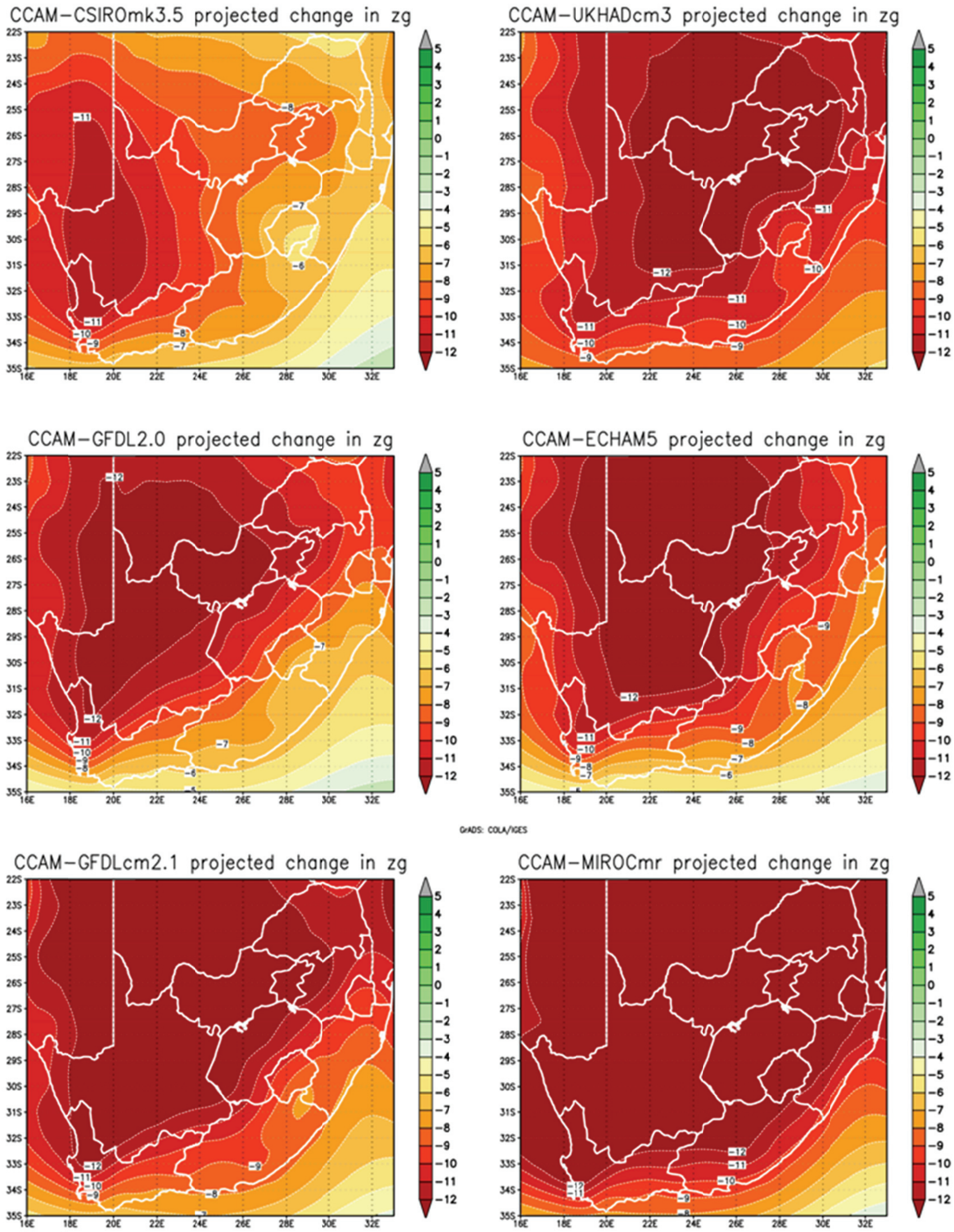


Figure 8. Projected change in 1000 hPa geopotential height (gpm) during the summer half-year over South Africa, for the period 2071-2100 vs 1961-1990. The figure shows the six ensemble members of the set of downscaled projections, obtained from six CGCM projections of AR4 of the IPCC, all for the A2 SRES scenario.

Application of the projections of future climate change within hydrological models – shortcomings and potential

CCAM simulations have been applied to force hydrological models in order to obtain simulations of streamflow over southern Africa (Ghile and Schulze, 2009). However, simulations at a resolution of about 0.5° are still too course to be of direct value in forcing hydrological models calibrated using data at the point scale (that is, weather station data). Experienced gained in this regard during the course of the project has indicated the need for the development of a probability density function based method of bias-correction of the hourly model data, in order to relate the area-averaged model data (in this case rainfall averages 50x50 km^2 grid boxes) to the attributes of observed hourly rainfall at the point-scale. Such a methodology is currently under the development at the CSIR. A future alternative for obtaining model simulations at the point-scale, would be to downscale the model projections dynamically to a resolution of about 1 km. Recent advances in supercomputing in South Africa have made feasible obtaining such simulations over relatively small areas (e.g. Engelbrecht et al., 2011), but significant investments in computer time and disk storage space are still required.

Summary of projected climate change scenarios

An ensemble of high-resolution projections of future climate change over southern Africa has been performed at the CSIR using the regional climate model CCAM. In this project, these simulations were analysed in order to investigate the potential impact of enhanced anthropogenic forcing on the frequency of occurrence of extreme rainfall events over the South African Highveld. The analysis of the projections indicates that significant increases in the annual frequency of extreme rainfall events are plausible over the mountainous regions of eastern South Africa – including the Highveld regions of Mpumalanga and Gauteng. Drastic rises in surface temperatures are projected for the southern African region. This is associated with an increase in the intensity of the heat low over the western and central interior of South Africa – a circulation change that would promote the more frequent occurrence of thunderstorms over central and eastern South Africa. Thus, projections of increases in the frequency of occurrence of extreme rainfall events over the Highveld region of South Africa are plausible and physically defensible. At a grid-box resolution of 50x50 km^2, the model simulations represent area-averaged rainfall values that cannot be directly related to point-scale observations of rainfall. That is, the simulations cannot be applied at their native resolution for the purpose of forcing hydrological models calibrated at the point-scale. Sophisticated bias correction methods, that relate the probability density function of the simulated data to that of rainfall observations at the point scale, are needed to obtain simulations that are useful to force hydrological models that are calibrated at the point scale. It may be noted that the regional downscaling of African climate, both locally and internationally through the Coordinated Regional Downscaling Experiment (CORDEX), are typically performed at resolutions of about 0.5° in the horizontal. In order for these simulations to find application is flash-flood modelling, such sophisticated bias-correction methods need to be developed.

2.4 Hydrological model and pilot sites

Hydrological model

The hydrological component of the project intended to look at trends in hydrological responses to the time series of hourly rainfall predicted in each of CCAM models described above. The approach of continuous simulation of catchment responses is preferred as assumptions on antecedent conditions are avoided, and a direct analysis of frequency of occurrence of, say, peak flow or water level can be undertaken without assumptions on joint probabilities.

The software used for this study was the PCSWMM 2011 software. This allows simulation of both hydrological and hydraulic function of components of the catchment. It is suitable for both site design and catchment wide analysis and planning, and it is also able to run long time-series of rainfall data. The software is gaining wider application in South Africa.

The software was to be applied to a number of pilot catchments that were identified in consultation with Ekurhuleni Roads and Stormwater staff based on existing drainage problems. These are outlined below.

Tembisa – Tswelopele

Located in the north-western part of Ekurhuleni, the community of Tswelopele comprises both formal and informal housing divided by a tributary of the Kaalspruit which has been adapted and stabilised into a formal urban drainage line. The point of interest is just upstream of the confluence with the Kaalspruit regular flooding of properties occurs. The main aspects of the catchment and the site are summarised as follows:

- Total catchment area is 575 ha.
- Land use is residential with approximately 27% of the area covered by roofs (roads are a mix of paved and unpaved).
- Urban green space is generally limited to the drainage channel.
- The main channel has been stabilised with a series of gabion weirs at some stage in the past, possibly in response to an increasingly developed catchment. There is no evidence of attenuation structures, only channel stabilisation.
- Upstream stormwater management initiatives include a bulk stormwater main (approx. 1.2 m dia.) that was partially installed until the scheme was halted by residents in a section of informal housing who were unwilling to allow the main to cross their section. The scheme now appears to be abandoned, with materials still standing on site.
- As a result, the drainage into the upstream sections of the main had to be blocked to prevent the flooding of the installed section of main. This included the bricking up of kerb inlets (KIs) along the roads feeding the stormwater main. Surface runoff is now understood to run as sheet-flow through the community and informal housing area until it joins the main drainage line.
- The site selected for this analysis is downstream of this scheme. The stabilised channel is approximately 15 m wide and 1.5 m deep at its lowest point. On the right bank is formal housing which floods annually, ponding in gardens and inside houses until the floodwaters recede. On the left bank is informal housing which also floods, though the floodwaters generally run as sheet flow into the Kaalspruit.

- At the time of the site visits, the dry weather flow in the main channel was raw sewage. The sanitation services in the formal housing area were not investigated, but chemical toilets in the informal housing area were located directly on the bank of the stream.

EMM is clearly aware of these issues. The Tembisa Urban Management Plan (EMM, 2009[2]) reflects many of the issues raised above, in particular sewer contamination, inadequate solid waste systems, inadequate maintenance and an inadequate stormwater management system. An action plan set for the first six months of 2010 was not in evidence during the field work undertaken in the second half of 2011.

Phomolong – Tswelopele
Although the Phomolong site exhibited a case of poor drainage design, it offered an example of a small urban catchment and the general area presented example of a number of factors that affect efficient stormwater management:

- The estimated stormwater catchment area is around 1 ha (the stormwater network was not surveyed in detail).
- Land use is formal housing on small stands (~300 m^2), but many of the sites are almost entirely developed as residents seek extra income from room rentals in out buildings. Hence average roof coverage is around 34%.
- On-site stormwater management frequently included a direct connection of the roof downpipe with the sewer line (thus minimising on-site surface water during a storm).
- In the general area most stands were clean and litter free. However, along main roads, and particularly at stream crossings, litter and solid waste build-up was severe. This was explained as being the norm for members of the household to take a plastic bag of daily waste and deposit it at a general dumping area on the way to the taxi rank in the mornings. Many of these dumping areas are located at stream crossings, resulting in loads of solid waste rolling into the watercourse daily. It was explained that this was done because waste collection systems were inadequate.
- Sediment and debris build up in the stream was noticeable at a number of bridges and culverts with overtopping of the structures and resulting failure of the structure (mainly downstream scour and erosion, but in one case the entire bitumen surface of the road had been lifted off the bridge and deposited in the channel below). It was observed at one location that a six month old stormwater channel had silted to the point that it no longer functioned.
- Raw sewage was observed in most of the streams and appeared to comprise a substantial component of the dry weather flow.
- Both Tswelopele and Phomolong were identified by the Roads and Stormwater department as examples of problem areas. Many of the critical issues were noted by the assistant engineer and a number of local schemes were pointed out where

[2] Ekurhuleni Metropolitan Municipality, 2009. Tembisa Urban Management Plan. Prepared by: Urban Management Directorate, City Development Department.

drainage and river stability works were recently undertaken. All the schemes were site specific and reactive to a local problem.

Atlasville – Kempton Park

This is the site of a new flood relief scheme to address flooding of properties along the main stream feeding Homestead Lake. This was selected due to the availability of the hydrological model, the large catchment size (~25 km^2) and the multiple land uses within the catchment, including a portion of OR Tambo International Airport. Key features included:

- The area at flood risk was previously a wetland in the 1970s. It was apparently drained for residential development in the 1980s when the present day spruit was excavated in the wetland.

- The surrounding catchment has developed over time, with rapid changed in recent years. As a result, the residents in Atlasville experienced severe flooding in 2006, and had a number of similar events since then.

- Impervious areas average at 31% in the catchment, but vary from zero to 49%. The areas of greater imperviousness included the airport and light industrial areas. Residential areas varied between 30 and 40%. Of interest is that although the roof areas appeared to comprise a lower proportion of the catchment area than the Tswelopele and Phomolong catchments, there were more formal hard surfaces (e.g. driveways and paved roads) in Atlasville.

- The hydrological model identified a number of important natural attenuation features in the catchment – three natural pans and a large wetland area – immediately upstream of the area of flood risk. One of these, Blaauwpan, is used in this study for testing the effects of changing rainfall patterns on attenuation features.

- Maintenance of the stormwater systems around the Atlasville area is known to have decreased in recent years with silt build-up due to upstream development being mentioned as a particular concern by residents. Furthermore, reed infestation of the spruit has become a problem in recent years and is seen a primary cause of the flooding problems. The reeds have reduced the capacity of the spruit to cope with flood flows. However, it is noted that municipal engineers are wary of environmental legislation (NEMA) being used against the municipality to prevent the removal of the reeds as has occurred in the recent past.

The Roads and Stormwater department has been sensitised to the problems of the area since 2006 and have been reactive in reed maintenance and implementing local works to divert surface flooding and has undertaken a catchment study to analyse and design a flood relief scheme for the Atlasville community. There doesn’t appear to be any catchment management plan other than implementation of a standard requirement for on-site attenuation for new development.

Thintwa – Thokoza

A fourth site recommended by Ekurhuleni Metropolitan Municipality was chosen as an example of a site with a formal attenuation facility but where a combination of catchment development and a very flat topography still resulted in flooding of the formal and informal residential areas immediately adjacent to the attenuation pond. Unfortunately, only limited data on the attenuation pond were made available and the system could not be modelled. However, a couple of important issues were noted about the site during local consultation:

- Flooding had been a problem for many years. Flood waters would inundate properties for many hours, with standing water in houses (suggested to be up to 200 mm depth in any event).
- Emergency services arrive and offer to remove residents to emergency centres, but many residents prefer to remain to protect their household goods and personal effects.
- The Ward Councillor complained residents were unwilling to relocate to sites offered by the municipality, though an interview with an affected resident (who had been there for more than 20 years) suggested she would be willing to move.
- At a meeting with the Roads and Stormwater department (who recommended the site be included in the study), there was no apparent plan to address the flooding.

Comment on Stormwater Management

No catchment management or stormwater management plans were in place at any of the sites considered in this study. Ekurhuleni Metropolitan Municipality is in the process of finalising a municipality wide stormwater management planning system, but until then work in the catchment in this study is largely reactive. This is particularly evident where local drainage projects were often seen to be compromised by sedimentation, litter or erosion, shortening the design life to a few months or years.

Applying the bylaws also appears to be limited. Although the connection of rainwater downpipes from roofs to sewers was known to the assistant engineer who showed the project team the Tembisa sites, there was no apparent intent to rectify the situation. No doubt budget limitations are at the centre of this problem.

There is a guideline for developers that set out attenuation requirements for new developments. It is not clear that these are widely applied in the Atlasville catchment and residents did make claims that recently developed sites were not providing attenuation facilities. However, even if attenuation structures were provided in all cases, they would be designed in the absence of any stormwater master plan and without any particular consideration of downstream conditions. Additionally, around the study catchments, it appears that the development of new residential areas (by the municipality itself) appears to be done without any provision of attenuation facilities.

3 VULNERABILITY ASSESSMENT

3.1 Vulnerability Assessment of EMM

The areas within the Ekurhuleni region that may be prone to flash flooding have been identified (Figure 9). This may be due to a number of factors which include mostly: the proximity to a watercourse or pan and low lying topographic depression which are superimposed on inadequate infrastructure. The extent of these zones can be represented as a percentage of the total area of Ekurhuleni, which is approximately 12.46%.

Much of these areas are found as part of the natural flood plains of watercourse and pans, however some of these areas are found as depressions within the land surface. These areas may form part of the catchment areas for some of the water course, however due to anthropogenic change, as well as, changes in the natural environment have become stagnating collection points. A first contribute to the water collection is the impermeably of the ground and the changes of land use in the surrounding areas. The changes associated with urbanization i.e. roads, roofs, building and concrete, all enable and assist water collection in these areas. The area in Figure 1 below highlights these factors in the context of the region and assists in amplifying the point above. The areas may have under natural conditions, even though found in low lying areas, not flooded due to the permeability of the ground and the natural dispersion of water. However, under these modified conditions, the area becomes a potential flood zone.

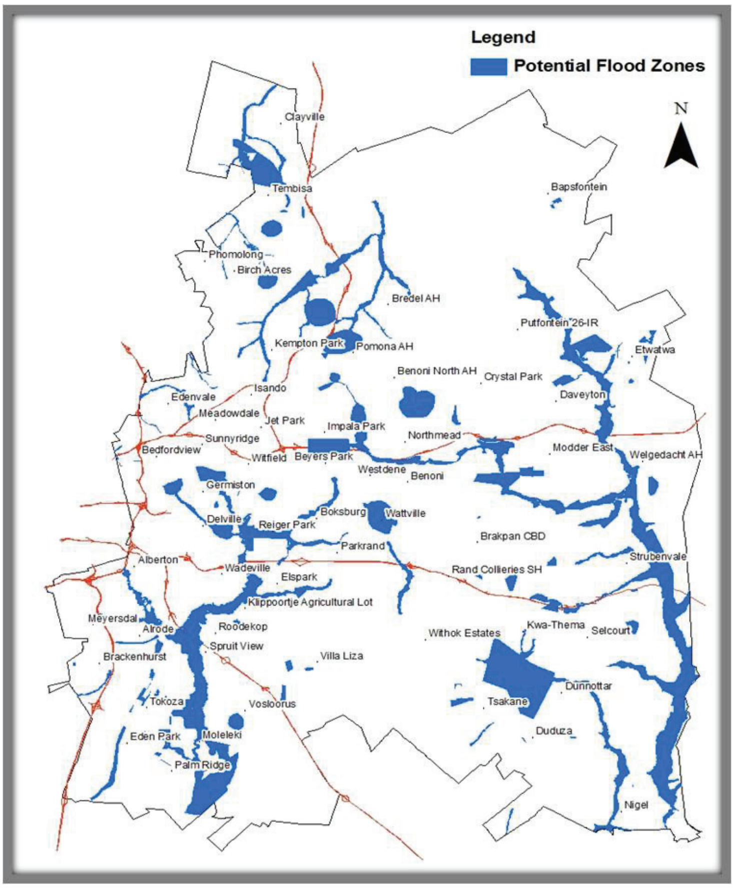


Figure 9. Hazard analysis – areas that are prone to flash flooding in Ekurhuleni.

The vulnerability analysis for the region is depicted in Figure 10. The verification of this map lies in the understanding of what the homogenous zones represent. In general the Very High homogenous zones are areas with high social value (e.g. high population density), high structural value(e.g. informal housing, shacks or commercial buildings), high economic value associated with the potential to generate income in these areas and low environmental value due to the demand for development and the built environment in these areas. While the Very Low homogenous zones are those that have a minimal population, mostly open space with high environmental value, a low economic value and structural associated with no infrastructure or economic use. These areas are typically natural open space, such as koppies and ridges and even old mining land and mine dumps.

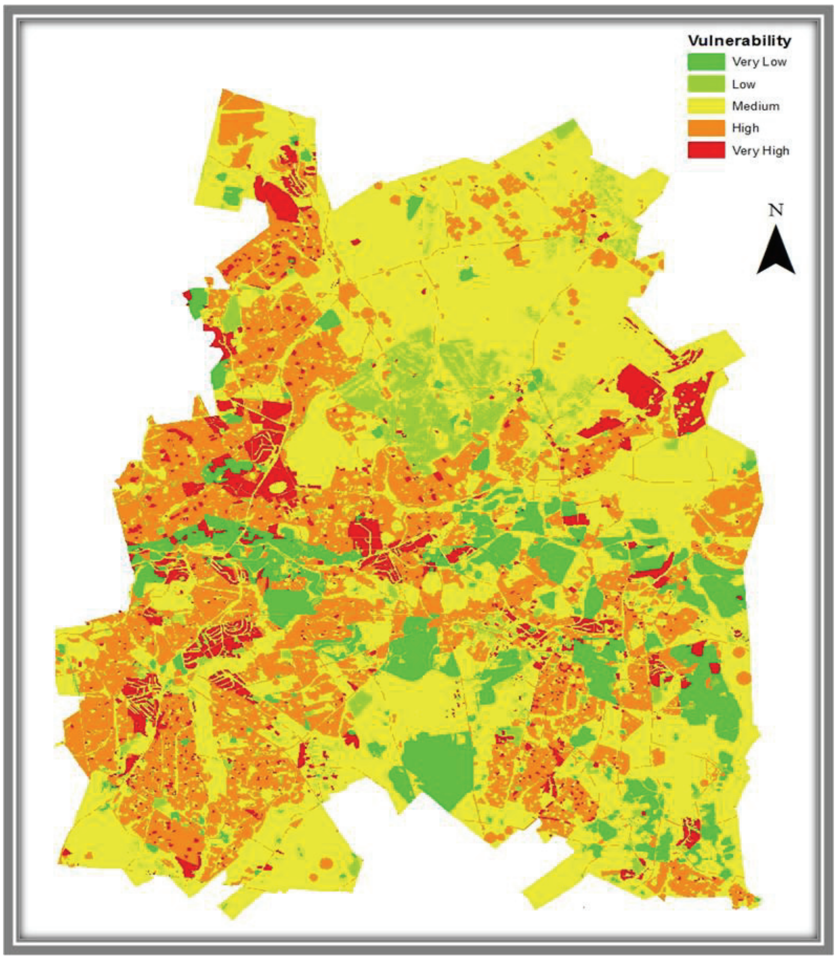


Figure 10. Vulnerability analysis – Highlighting the regions that are most vulnerable to flash flooding in Ekurhuleni.

Outcome of risk mapping process

The risk mapping analysis for Ekurhuleni is depicted in Figure 11 in which the areas vulnerability to flash flooding have been classified into five impact categories, namely, very low impact, low impact, medium impact, high impact and very high impact. Of most concern is the very high impact zones which have been analysed in more detail. It is important to explain that some of the areas may be observed as low impact zones presently, however, if land use change occurs, these areas may be changed and need to be re-evaluated. An example of this was found and will be highlighted in the section below.

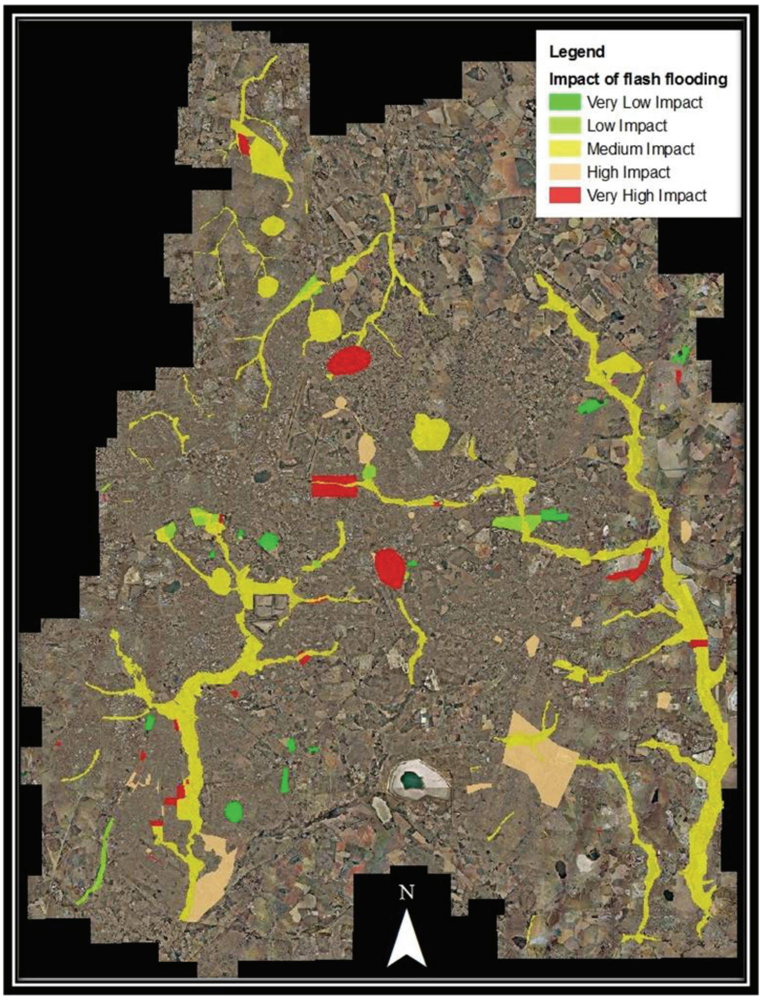


Figure 11. Indication of the flash flooding risk zones within Ekurhuleni.

A series of random areas categorized as very high impact zone were selected and a brief explanation and interpretation made of some of the factors that attribute to them being at considerable risk during a flash flood event. An additional component of the analysis was the use of 2010 aerial photography, which will assist in viewing current land uses of the areas being analysed below. It will also enable a form of change analysis between the vulnerability measure based on 2001 census data and land use mapping of Ekurhuleni from 2007.

The first selected area can be found in the North West corner of Ekurhuleni in the town of Tembisa which is illustrated in Figure 12. The area depicts an informal settlement area with no formal infrastructure, in terms of drainage systems. Furthermore the area represents the part of the main catchment area for the Kaalspruit, which can be seen to the west of the very high impact zone. The zones around the area have been categorised as medium impact due to the level of infrastructural services provided within this region. However, it is clear that these are also within the key catchment of the Kaalspruit. The infrastructure that does exist in these formal areas may be the cause of the informal area being at considerable risk during a flash flood event. This is simply due to the fact that surface runoff is increased in urban areas as a factor of anthropogenic change.

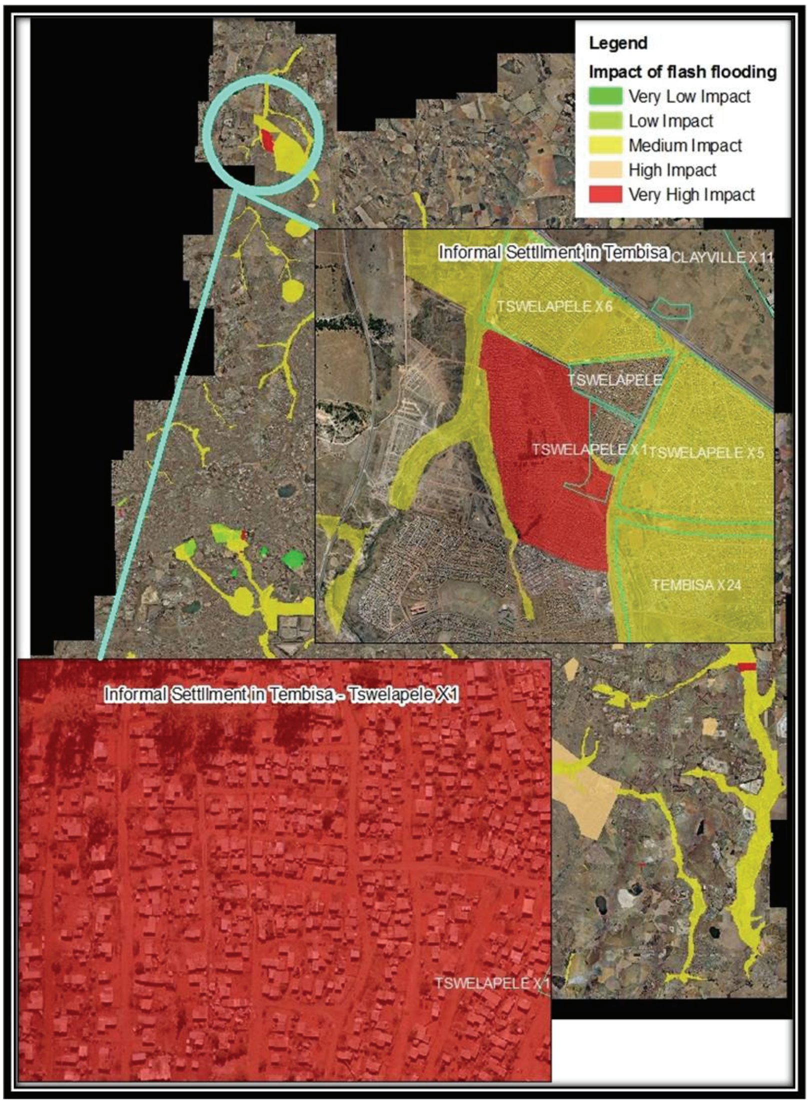


Figure 12. Flash flood risk zone, categorized as very high in risk mapping process, representing an informal settlement in the town Tembisa.

The second area that is shown in Figure 13. The area represents a high impact zone found in the formal residential town of Tokhoza, Ekurhuleni. This area represents a formal residential suburb with established storm water infrastructure. However, as depicted by the contour lines on the map, this area is flat with a change of 20 m over a distance +/- 2 km. The area should have been preserved as a natural area which would assist with flood water retention during periods of high rainfall. However, be it poor planning or the historical unjust planning practices of the apartheid era, this area can be found to be at high risk of a flash flooding event. The need for adequate storm water management within this region is important to ensure that the communities are protected against and that, no further in justice is served by marginalising these people.

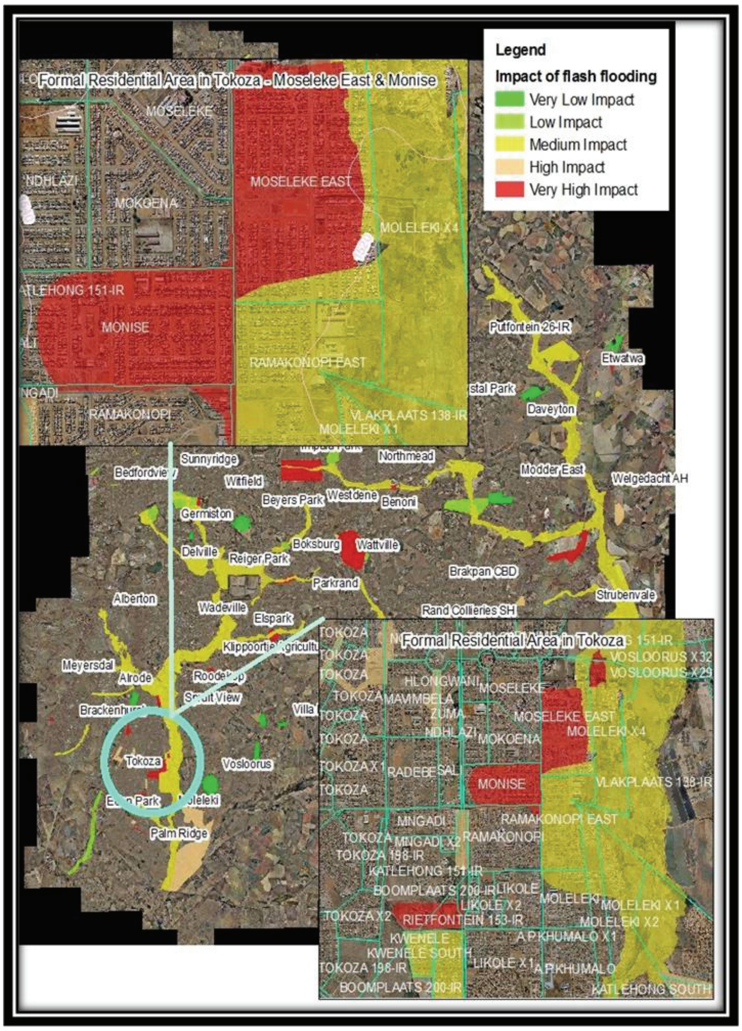


Figure 13. Formal residential area found in flood plain of Natalspruit – Tokoza, Ekurhuleni.

Summary of risk assessment

This study has examined the various factors that enable the identification of possible areas prone to risks of extreme events, specifically flash flooding. The results have confirmed the body of literature around risk, vulnerability and flash flooding hazards. The most at risk have been found to be those communities which due to their social status and location have been forced to situate themselves on land which is predisposed to flash flooding within the urban context. This predisposition was found to be predominantly due to the general status of urban environments, where the only lands available to the poor are in regions that are not considered to be suitable for development. Many aspects of informal settlement within flash flood prone areas exacerbate the vulnerability of the communities and include

a) Compaction of land due to settlement, thus decreasing infiltration and increasing surface run-off.

b) The structures within informal settlements are not able to withstand any form of hazard, especially flash flooding.

c) Poor and unjust planning practices of the past have also placed poorer communities in the heart of high risk areas e.g. Benoni area. These areas have subminimum infrastructure that has not been upgraded even though the population have increased way beyond the carrying capacities of the associated infrastructure.

d) The introduction of infrastructure such as roads, roofs and buildings in areas that are already exposed to flash flooding hazards tend to enhance the impact of the hazard by reducing infiltration and channelling surface run-off.

The region of Ekurhuleni needs to rectify, reduce and mange the risk and exposure to flash flooding within the region. This can be achieved by evaluating each of the areas identified as vulnerable and interventions implemented to reduce and alleviate the risk.

3.2 Stakeholder engagement

The initial discussions with the Ekurhuleni municipal managers were at their bimonthly strategic planning forum meetings and subsequently individual semi-structured interviews were done with a number of the departmental managers. . In each interview, managers were asked to discuss the major issues that exist in their departments, how these are being or planned to be addressed, and if and how they believe climate change will affect planning and management. The following comments came out of these interviews.

Climate change

The comments, specifically related to climate change, have been assessed according to the KAP approach; however, the broader themes that were revealed in the interviews will be dealt separately.

Knowledge

There is a general sense that there is a growing knowledge about climate change and that there may be implications on municipal management from associated changes. The managers felt that there was a reasonably good level of awareness with managers in the strategic level, however, there remains little understanding of what this means for day-to-day management. The link between awareness and practical understanding is lacking.

The managers seem to obtain information about climate change from a number of sources, including, but not limited to, Municipal documents, their experience and observations, and conferences. Climate change has been included in the EMM Spatial development frameworks. This inclusion shows that the Municipality is committed to addressing the impacts of climate change.

Attitude

The general attitude of managers is that they acknowledge climate change is a reality and although they may not be able to trace back to it precisely in recent past, there is a general belief that it is likely to have an impact, to some degree, on the municipality in the future. Some managers did mention that they have noticed changes in the timing of the seasons and they believe that climate change has impact the seasons such that winter carries on longer than it did before, and summer temperatures and rainfall extend into April (the start of autumn). Other observations are that rainfall patterns have shifted, which has meant that wetlands that used to be dry are now wet. One of the managers observed that the thunderstorms seemed to have gained intensity, and the consequences of these storms have had increasing impacts.

Details of the risks that *may* be caused by climate change are not generally well understood, which means that there is less emphasis placed on making climate change a priority. There are however, mixed attitudes towards climate change. Some managers believe that it will have a big effect and there needs to be a move to prioritise the inclusion of actions aimed at minimising the potential impacts, but this attitude is based on an intellectual understanding of climate change and not a practical idea of how this could be done, or where the greatest risks are concentrated.

Some managers believe that climate change is going to cause a big problem, particularly in the areas that are already experiencing problems. There are other managers who believe that although climate change is likely to have some impact, it is likely to be a side issue and not worth focusing on. The focus in their eyes should be a case of managing properly, and "people doing their jobs". One of the managers believes that climate change is made into a big issue, and is used as a scapegoat for poor management and planning. He was very cautious to link disasters and issues in the future to climate change, and made a strong point that if departments are able to manage properly, the impact of climate change will be negligible.

Practice

Because of the gap between awareness of climate change and understanding the consequences it will have on the water sector, there is very little that managers feel they can do to change practices and behaviours in response to climate change.

"Climate change is too abstract. You can't stop development because of climate change because there are no facts" *(EMM Manager, 2012)*

There are a number of things that the town planning departments have already started including to address climate change. They have restricted development within the not only the 50-year flood line, which was the standard before, but now they also prevent development in the 100-year flood line.

Some of the managers believe that creating bylaws to address possible climate change impacts, such as the shift in flood lines, may be the most effective way of including climate information into day-to-day management. A difficulty with this is the lack of capacity to monitor and enforce these bylaws, as current bylaws are not currently being enforced. There was a suggestion that perhaps the best way to encourage behaviour change might be to identify the problem areas and address them as such, and avoid linking them to 'climate change'. This would avoid situations where the urgency of potential impacts is ignored by people who do not believe climate change is going to cause problems.

The Municipality's environmental department organised a climate change summit at the end of 2010, to try to engage the municipal councillors and managers on climate change implications, and the incorporation of these into governing Ekurhuleni. However, due to political issues at that time, only a couple people arrived to attend this summit and it was called off. Municipal attendance at COP-17 was similarly affected by political factors, which resulted in budget not being available for people to attend the conference, when they had originally been given permission to attend.

Through looking at climate change through knowledge, attitude and practice, it is clear that although climate change has been acknowledged as a potential risk for the municipality in future, the lack of detailed understanding has resulted in a low level of attitude and behaviour change. Nevertheless, there is consensus that climate change has the potential to help solidify priority areas, which will possibly mean that sufficient budget and focus is applied to the things that are currently causing major problems.

Strengths

Some of the strengths that were identified by the various managers include being on the continental divide. Most watercourses in the municipality start there and flow on to either the Atlantic or Indian Ocean. This means that the water that in the municipality starts clean and only processes that occur in the EMM pollute the water. This provides the EMM with an opportunity to maintain the quality of its water.

Another strength of EMM water resource management is that there is an up to date plan of water pipes and infrastructure. This means that the managers are able to argue for budget because they are able to document how much it costs to maintain and upgrade the infrastructure that is already in place.

One of the managers made the comment that considering the range of challenges that the municipality faces, they are doing a very good job!

Some of the departments identified the use of GIS as a strength that allows departments to combine different factors to obtain knowledge about different priority or sensitive areas. This has been effectively used in creating the Ekurhuleni Biodiversity and Open Space Strategy.

Challenges

Some of the major challenges that were identified by the managers are detailed below. The lack of capacity, both financial and human capital, was identified by every manager as the major challenge to effective management.

The capacity of much of the infrastructure was identified as a major challenge to managing both water and wastewater services. Nearly all of the wastewater plants are hydraulically overloaded and thus chemical treatment is required. The addition of new developments often does not address the need for new bulk infrastructure. Developments are allowed by council without provision to increasing the required infrastructure capacity. The housing backlog for the region puts further pressure on infrastructure and service provision.

The size and spatial extent of the municipality was also highlighted as a challenge to management. Because of this spread, there are many areas where population density is very low, and thus providing these groups with sufficient services is expensive and very difficult. The decentralised nature of the municipal area requires very good infrastructure, in order for things to work well, and this infrastructure is just not there!

Although there is some communication across departments there is no unified effort to manage in an integrated way. Many departments feel that they do not have the capacity to do more than the bare minimum and thus cooperating and coordinating across departments is not seen as high priority.

Institutional Governance

From the municipal perspective, the issues seem to be centred on reactive management. The two major causes for this type of management are the lack of budget and information.

Legislation

Although South Africa has some of the most progressive environmental laws, the problem that occurs often is the lack of enforcement. This is the case not only for government legislation, but also for municipal bylaws. The departments that should be responsible for enforcing the adherence of these bylaws are already so stretched that they do not have the extra capacity to police on top of other, more critical, responsibilities. In some cases, the Ekurhuleni Metropolitan Police Department (EMPD) has been charged with the enforcement of water bylaws. However, the EMPD is also working under capacity and their focus is on other criminal activity. The enforcement of environmental law is not a high priority for them.

The laws around Environmental Impact Assessments (EIAs) and Water Use Licences (WULs) seem to have caused some large backlogs in the system and have delayed many projects. Managers did however, note that cooperation between departments has improved and EIAs have become better understood. As a result, there seems to be less frustration due to EIA requirements. The Environmental Department has worked with some of the departments to help them understand the EIA requirements, and how to streamline these processes. For example, in the initial EIA for a project, a management plan should be included, which will cover all maintenance of the site in the future. In the past, this section was not added to the EIA applications. Thus, when maintenance was needed, a new EIA had to be drawn up, which delayed the sometimes urgent maintenance. These problems seem to have been sorted out.

Dealing with the delays in obtaining WULs has however, not been as successfully addressed. WULs are sent to the DWA, which means that it is not as easy for managers to fast-track urgent projects. A concern that some of the managers highlighted was that the DWA works on different timelines and with different procedures than the municipality and thus projects that should not be delayed, can end up with delays of up to a year.

A number of the managers commented that the communities that kick up a fuss about the situation and the bylaws that are not being adhered to by the municipality, are the areas that get attention. One of the managers spoke about the need for communities and individuals to keep the municipality and water users accountable to the laws and bylaws, because there is capacity for communities to police the areas that they live in. This was identified as an area where, by taking responsibility for their areas, communities can provide capacity that the municipality and police departments lack.

The managers noted that there are challenges in marrying the requirements from different national legislation, namely the National Disaster Management Act (NDMA) and then National Environmental Management Act (NEMA). The implementation of NEMA in disaster situations sometimes restricts the emergency services from doing what they need to do to reduce the impact of disasters.

Operations and Maintenance

Activities are constrained by the financial operational budget and capacity to plan to be more proactive. Stormwater drains, for example, are usually cleared before the summer rains start, and from there onwards, they are cleared when required. Most of the operations and maintenance that is required to ensure that systems work well are not done. Many of the managers complained about not having the budget that would allow them to monitor and maintain the systems in a way that would allow them to identify problems before they occur.

Much of the current stormwater operations and maintenance in the municipality is reactive and very little routine maintenance or forward planning is done. In some of the informal and semi-formal housing areas in the municipality, pollution and solid waste are the main causes of blocked drains. Some of this is due to poor waste removal services. A difficulty that was mentioned by an operations manager was the number of extra people living on each property. The extra people, such as those living in backyard shacks, are not included in infrastructure and service provision. As a result, in some areas where solid waste removal is insufficient, people dump their rubbish next to the banks of rivers. This waste often clogs the streams and stormwater ways. The problem cannot only be blamed on the lack of service provision because there are dumps in most areas, but managers commented that people are too lazy to make the effort to dump their waste in the allocated areas and it is easier to leave it in vacant land (particularly building rubble).

In some areas, the failure of stormwater systems has caused much further damage to roads and other infrastructure. In many cases sewage flow into watercourses and stormwater systems. In some areas, lack of maintenance has resulted in flooding into roads and houses. Other areas are flooded because the storm water system has been intentionally blocked up with bricks. There are many social issues that also enhance flooding, for example, in Tswelopele there are many informal settlements, some of which are right on the banks of the river and others located at the planned outlet for the stormwater system.

Capacity

A number of the managers made strong reference to the social capacity that they lack in their departments. There are issues between labour unions and the municipality, such that neither of these stakeholders is happy and thus the municipality is unable to fill critical vacancies. The inability to gain new employees means that as staff leave, they cannot be replaced and the pressure and load on the remaining people becomes heavier. As a result, many of the departments are losing people because they are not able to progress or see job growth potential, as vacancies are not being filled and there is a lack of training people up to be equipped for other jobs.

Lack of capacity is not restricted to the number of people that are needed, but in many cases, there is a lack of the required skills, such as specific engineers. In some situations, the expertise needed come at a premium and thus the municipality can’t hire such skills on a full time basis, and instead they outsource to consultants. The lack of skills in the municipality has a knock-on effect on departmental ability to plan and implement major projects. In order to spend the allocated budget, they need skilled people, such as engineers with specialised skill sets. As a result departments (such as water management) sometimes struggle to use their allocated budget.

The disaster management plan is not strongly enforced, and there is no one on standby over weekends, evenings and holidays. This is due to a lack of human resources and capacity.

As mentioned above, reference was made to the potential for communities and individuals to provide some capacity in holding the municipality and other stakeholders accountable to the laws and bylaws. This however requires that people have the knowledge of the constitution, the laws and bylaws. The municipality, in fulfilling DWA requirements, are conducting awareness campaigns particularly around the blue drop report. Currently the blue drop report is acting as an effective incentive for water provision to sort out the problems that exist. There does not seem to be the same incentive from the green drop report. This may be due to the relative difficulty in sorting out problems raised by the green drop report.

Budget

In some of the regional and operations level departments in charge of stormwater management, there have been budget cuts each year for the last four years. This has put increasing pressure on the operations and maintenance.

As mentioned above, in some cases, the lack of skilled personnel in the municipal departments prevent major projects and plans from being implemented, and thus budget can be difficult to spend. An example of this was in one of the departments, the allocated annual budget for capital expenditure is about R400 000. In order to achieve the plans which have been set out by strategic plans and developmental trajectories, they require an annual budget of between R600 000 and R700 000, but due to the lack of skilled staff, the department struggles to even spend R100 000 of their capital expenditure budget.

Geopolitical challenges

Political complications also arise from the mismatch between drainage basins and municipal areas. A few catchments, for example, flow between Ekurhuleni and the City of Johannesburg. Although the catchments are similar and processes in the separate areas generally affect the same watercourses, there is apparently little effective communication between the City of Johannesburg and Ekurhuleni management, even though the catchments affect each other.

Political interference

Managers highlighted that in a disaster situation, there is great pressure from more senior managers and councillors. There is often a lot of pressure to sort problems out in the timeline created by senior managers and not necessarily related to what can be done from a technical perspective. "There is political interference", which makes it difficult for managers to do their job in the way that they see fit, and instead they have to comply with external pressure, which can sometimes have severe consequences and possibly affect the efficiency and effectiveness of the responses to disasters. "Let the technical guys do the technical things".

The management of stormwater systems is also affected by the political context, particularly with respect to budget allocation. In some areas, where budget has been allocated for infrastructure development, there appears to be some political motivations driving infrastructure development. For example, in Tembisa, there was sufficient budget to tar the roads but not to build the associated stormwater system alongside it. Tarring the roads was a 'visible' development whereas the drainage system would have been less visible as it is an underground network. In this way some service delivery is noted (this supposition is to be tested further and is only a preliminary assumption at this stage).

Some of the managers commented that decisions about developments were often made at a political level and sometimes do not take environmental concerns into account. In some cases this means that developments are built in areas where they should not be in the first place. This has caused many issues in areas such as Atlasville and Tembisa. Such situations cause maintenance and upkeep of these areas very difficult and costly. In some cases, it causes the residents to be in danger of flooding or other disasters.

Expectations and possible outcomes for this study

There is a great need to quantify what will happen in the future because of climate change, before they can devise and implement mitigating factors. Managers feel a great need to have concrete information about what the impacts of climate change may be. From this information would allow sensitive and priority areas to be identified and the appropriate budget and attention can be placed on preparing these areas.

There is a strong sense that climate change may be able to give weight to things that need to be done but are being neglected (e.g. fast-tracking stormwater and sewage plans, identifying priority areas). These things need to be done anyway for effective management, irrespective of climate change.

Summary of the Stakeholder engagement

Many of the issues that were highlighted by municipal managers that relate not only to climate change but to general management are complex issues that impact other sectors. It is thus necessary that municipalities view the different aspects of water resource management as linked and not in isolation, and that high-level decisions, or lack thereof, have an impact on the ability to manage and deal with the day-to-day aspects of water resource management on every level of management. To ensure this, coordination between different departments is necessary. Development and water service delivery must not be carried out at the expense of water resources or the environment. Considering these factors will help prevent further water insecurity in the future.

We want to prevent situations where "despite the potential utility, managers do not use climate forecasts except for background information." (Callahan *et al.*, 1999, 269).

3.3 Challenges and Concerns from Water Service Provision – Rand Water

The predicted changes in weather patterns caused by climate change will possibly introduce a number of new challenges to water utilities i.t.o their ability to provide safe, reliable potable water at the lowest possible cost. Although technology to deal with most of these challenges is available, the cost of implementation may seriously hamper the cost-efficiency of water delivery into the future (personal communication van Wyk, 2012)

Some of these challenges include:

1. Soil Stability
   Increased rainfall and flooding may cause soil to become water logged and unstable. This may result in pipelines being under severe stress, causing cracks and bursts.
2. Water temperature fluctuations
   Increased surface temperatures may affect the temperature of water in the distribution system. This in turn will lead to increased rates of chemical reactions, causing changes in the water quality that will have to be corrected before final delivery. (For instance, Chlorine decay increases at higher temperatures.)
3. Storage Capacity
   Increased frequency and severity of droughts may force utilities to invest in increased storage capacity to overcome prolonged periods of drought. This will cause a significant capital burden, as the additional infrastructure might not be utilized optimally (only during drought periods).
4. Flood damage
   All infrastructure linked to raw water storage and abstraction facilities will have to be secured against the increased possibility of flooding, and the consequential damages.

5. Changes in Treatment Processes
   As a result of increased water temperatures, algal blooms will be experienced more frequently and also for longer periods. This will required utilities to introduce new technologies to remove algae from raw water sources. The increased flow rates as result of floods will also cause changes in turbidity levels of the raw water, which will also require additional treatment, either i.t.o chemicals dosed or new technology.
6. Increased demand
   The combination of higher temperatures and prolonged droughts will significantly affect the daily demands on water. Consumption will increase during these periods, stressing utilities to run its facilities at maximum capacity for extended periods of time.
7. Diseases
   A changing climate will bring with it changes in habitat, resulting in various organisms expanding their natural boundaries as conditions become more favourable. Water-borne diseases such as bilharzias, malaria etc will spread into new raw water sources, requiring additional technologies to ensure that the water is safe to drink.

4 ANALYSIS OF EXTREME RAINFALL EVENTS IN EMM

A statistical analysis of historical weather data from the OR Tambo Weather Station was conducted. Significant trends in the frequency and intensity of thunderstorms for the period 1960-2009 were identified. This work was published in Water SA in 2011 (Fatti and Vogel, 2011).

For the purpose of this study, a thunderstorm is identified by the fulfilment of three criteria at a specific time on a day, namely cloud type being cumulonimbus, the human observation of a thunderstorm and the occurrence of rain during that day. This study focuses on the summer season, from October to March, in line with other summer rainfall studies in the region (e.g. CoJ, 2009; Dyson, 2009). Following the identification of thunderstorms during this period, the frequency of these events is investigated. The total number of storms per season is calculated by summing the storms identified during each year's rainfall season. Further analysis of the data includes assessments of storm frequency, total rainfall, total storm rainfall, average storm rainfall and heavy storm frequency.

Storm frequency

Figure 14 shows the trend of summer thunderstorms for 1960-2009. The distribution across the period shows a decreasing trend. A Poisson regression model is applied to the distribution as shown in Figure 14. The regression indicates a highly significant ($P<0.0001$) decreasing trend over time in the frequency of storms. At the beginning of the period, storm count is roughly between 30 and 45 per year. By the end of the period, the range has decreased to between 10 and 25 storms per year.

Total Storm Rainfall

The rainfall produced by individual thunderstorms is extracted from the daily rainfall data and plotted as a time series as shown in Figure 15. The range of total storm rainfall for the summer season over the period of the study lies between 150 mm and 450 mm. The total rainfall produced by thunderstorms showed a slightly decreasing trend over time, which is just significant at the 5% level ($p=0.04$).

Average Storm Rainfall

The average rainfall per storm is analysed by dividing the total storm rainfall by the number of storms in the respective season. These values are then plotted on a graph, as shown in Figure 16. A linear regression fitted to the series indicates a highly significant ($p<0.0001$) increase in the average rainfall per storm over the period. In the 1960s, the average rainfall per storm ranges between 5 mm and 12 mm. By the 2000's, this has increased to between 10 mm and 16 mm per storm.

Heavy Storm Frequency

Due to the highly significant increase found in the average rainfall per storm over the period 1960-2008, heavy storms are also analysed to determine if this relates to an increase in the frequency of heavy storms. A key challenge in studying past heavy rainfall events is defining what constitutes a heavy rainfall event (classified here as the top 10% of rainfall events, i.e. when 10 mm or more fell in a 24 hour period). These storms are extracted from the total storm count and their frequency is plotted over the period as shown in Figure 17. The Poisson regression model is applied to this distribution. The number of heavy storms averaged around 10 per year over the whole period. The season with the greatest number of heavy storms is 1986/1987 where 16 heavy storms are noted.

Total Rainfall

The final analysis conducted is of total rainfall (thunderstorms and other rainfall) for the summer season across the period as shown in Figure 14. A regression model is applied to the distribution. The model showed no significant statistical trend over the period.

Although these changes cannot be explicitly attributed to anthropogenic climate change, the results of this study link well with some climate change projections. Nevertheless, the findings of the investigation into thunderstorms variability in Gauteng reveal some very interesting and potentially significant changes over time.

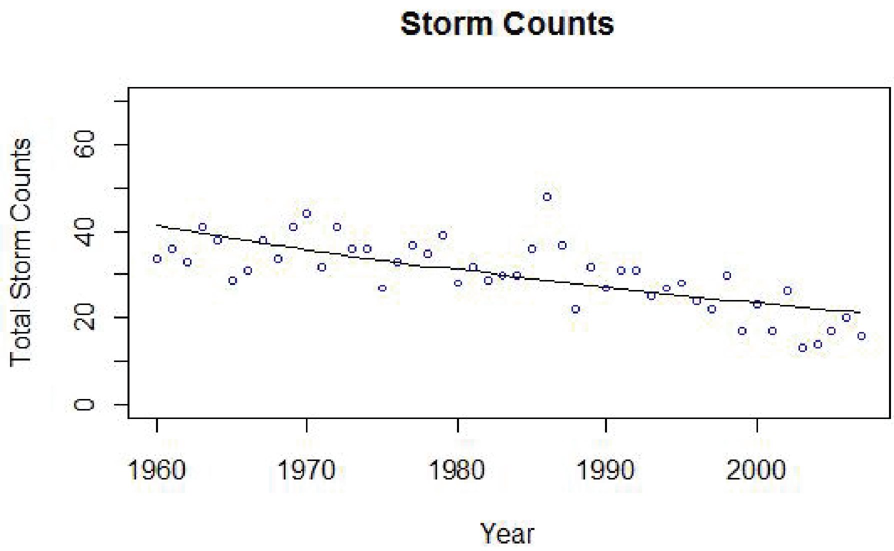


Figure 14. Total Thunderstorm Frequency for OR Tambo International Airport, summer 1960-2009

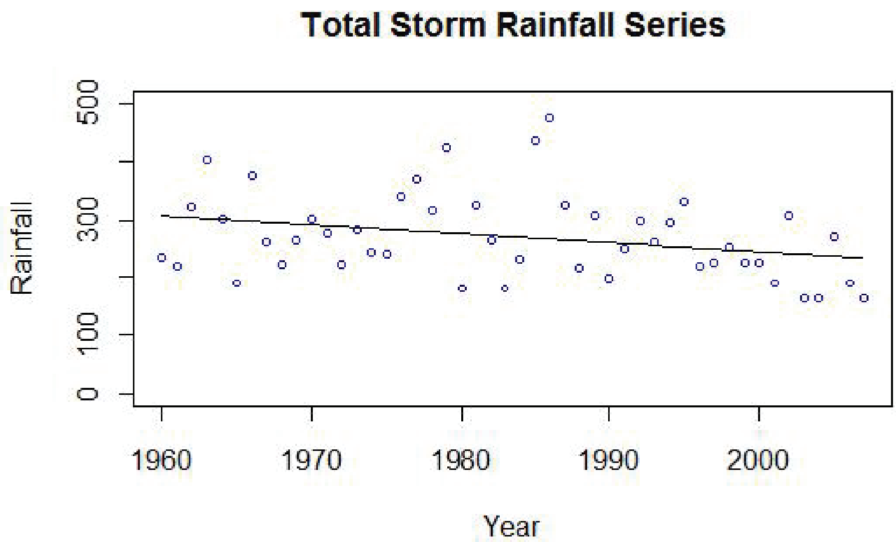


Figure 15. Total Rainfall from Thunderstorms, OR Tambo International Airport Summer 1960-2009

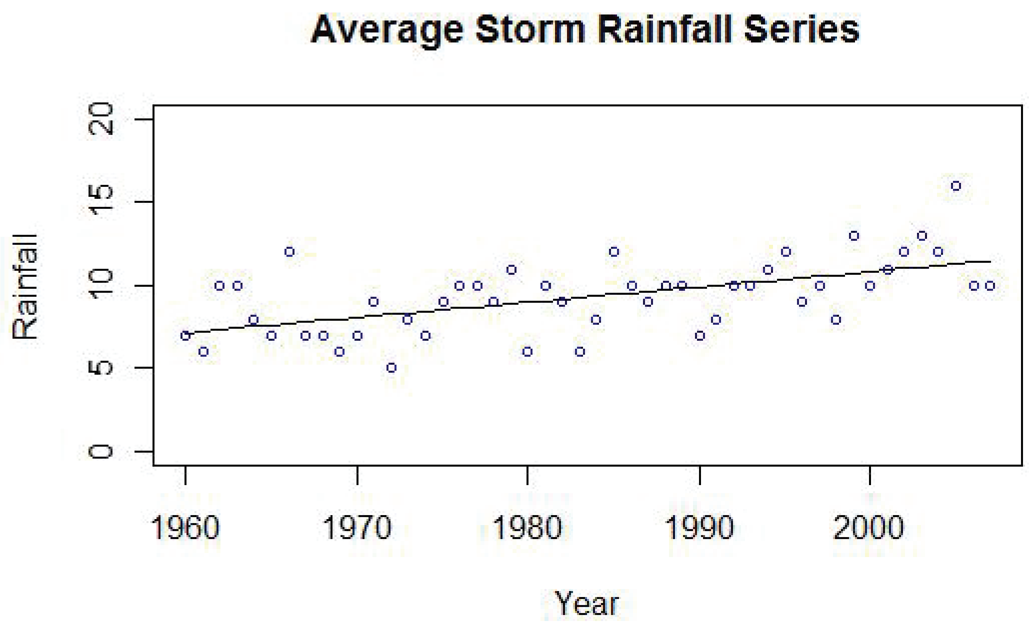


Figure 16. Average Rainfall from Thunderstorms, OR Tambo International Airport Summer 1960-2009

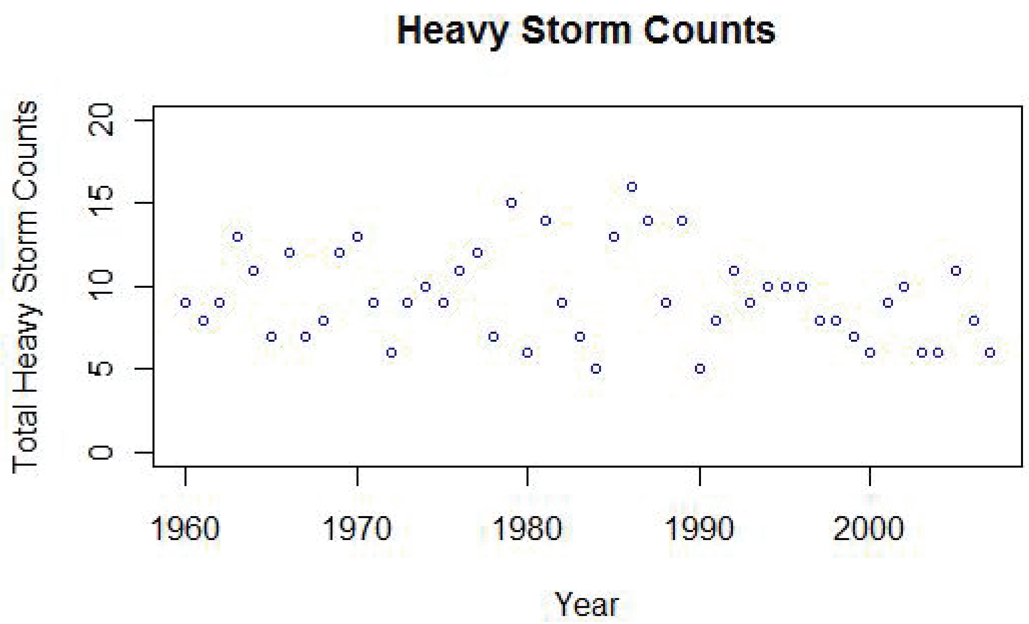


Figure 17. Frequency of Heavy Thunderstorms, OR Tambo International Airport Summer 1960-2009

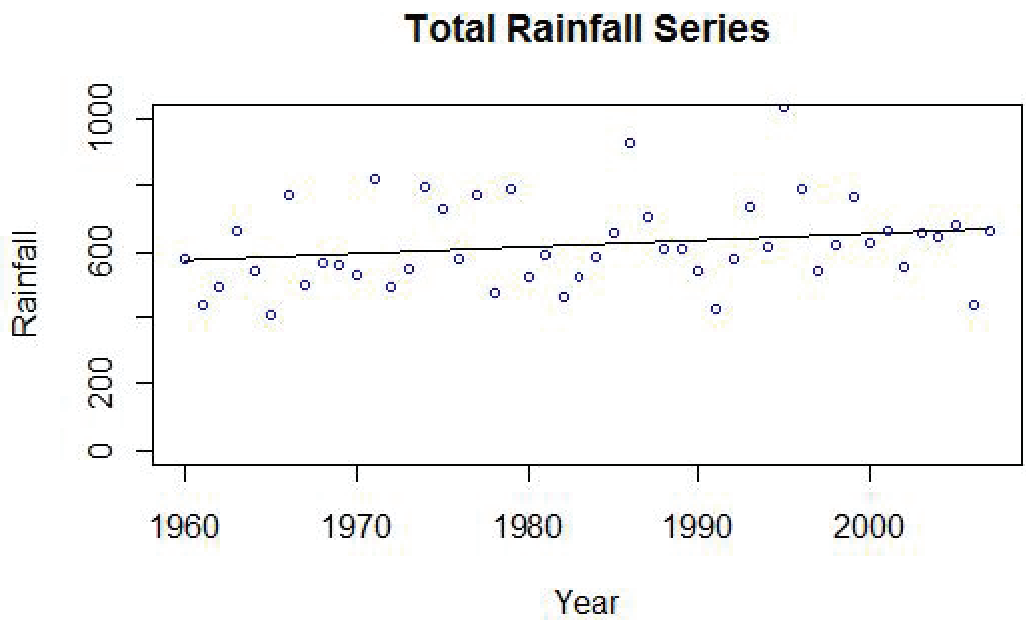


Figure 18. Total Rainfall in millimetres, OR Tambo International Airport Summer 1960-2009

4.1 Design Rainfall

Urban drainage design uses design rainfall that reflects storm depth, duration and even a storm intensity profile appropriate to the location and size of catchment. Storm rainfall for different durations have been published for South Africa (Smithers and Schulze, 2002), and the applicable design rainfall depths (mm) for Atlasville, Kempton Park, are shown in Table 3.

Table 3. Storm rainfall depths (mm) for Atlasville, Kempton Park (After Smithers and Schulze, 2002).

		Duration			
		1h	4h	24h	7d
Return Period	2y	25.2	38.3	60.1	92.4
	5y	34.7	52.9	82.9	127.5
	10y	42.0	63.9	100.3	154.2
	20y	49.7	75.6	118.7	182.5
	50y	61.0	92.7	145.5	223.7
	100y	70.4	107.1	168.0	258.4
	200y	80.8	122.9	192.8	296.5

Storm intensity is a critical component of urban drainage design. In 1987, Schmidt and Schulze (1987) presented a set of typical 24 hour storm profiles for the country. The profile for the Ekurhuleni area is Storm Type 3 shown in Figure 19. This was compared with an analysis of rainfall distribution of all storm events greater than 10 mm recorded at OR Tambo International Airport. The analysis used 5 minute recorded data available from October 1994 to January 2010. Figure 19 suggests the Storm Type 3 is still relevant for drainage design in Ekurhuleni.

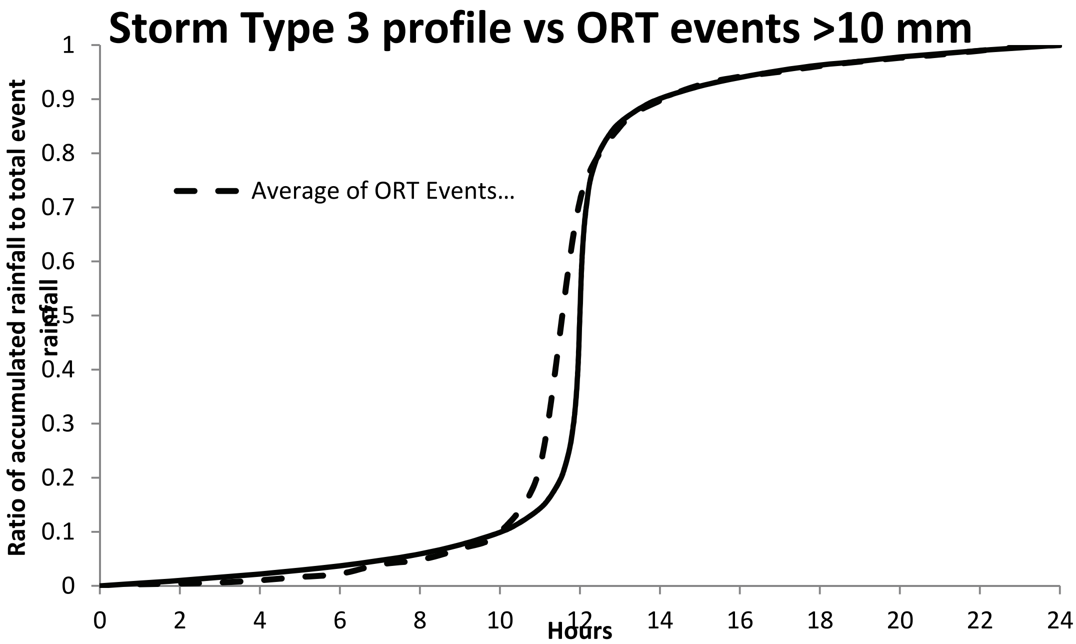


Figure 19. Comparison of storm profiles of rainfall events > 10 mm at OR Tambo (1994-2010) against the Storm Type 3 profile for Ekurhuleni area.

5 HYDROLOGICAL MODEL BASELINE

The downscaling of the CCAM model output was a point of discussion at the start of the project. The rainfall output would be averaged over an approximate 50x55 km area and needed to be scaled to suit applications at municipal scale. Both spatial and temporal scaling needed to be considered, but the CCAM model output was provided at an hourly time-step in an attempt to minimise assumptions on temporal rainfall distribution.

The analysis of the CCAM output began with an overall comparison with local records up to 2010. In this case the analysis was done using the output from the CSIRO climate model.

5.1 CCAM Model Yield

An analysis of monthly rainfall yield from the CCAM-CSIRO model is compared with a similar analysis of the OR Tambo data from 2001-2010. The results are summarised in Table 4. The results are considered to show a reasonable comparison of average monthly rainfall and standard deviation and suggest that from water resources planning perspective the CCAM-CSIRO model gives a reasonable representation of present day conditions.

Table 4. Comparison of average monthly rainfall between CCAM-CSIRO and OR Tambo station

		Total hours with rainfall 2000-2010	Statistical Analysis: Average Monthly Rainfall (mm) – OR Tambo and CCAM – 2001-2010											
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
ORT	Average	3156	122.7	81.9	76.1	26.5	13.0	5.8	3.4	7.6	33.0	79.0	91.5	104.2
	Std.dev		57.7	64.9	43.9	16.0	13.1	7.8	4.9	11.2	45.4	60.8	52.4	47.9
CCAM	Average	23831	150.1	94.6	76.0	53.9	12.0	5.1	4.3	3.6	18.1	96.8	114.5	110.5
	Std.dev.		66.1	32.1	34.0	27.1	7.4	3.8	3.8	2.0	10.6	48.2	20.4	20.8

However, the third column in Table 4 hints at the problem of areal averaged results. The OR Tambo data shows a total of 3156 hours of rainfall in the assessment period (approximately 330 hours of rain per year) while the CSIRO model simulates almost eight times this duration (23831 ~ 2500 hours per year). Figure 20 and Figure 21 give insight to the reasons for this. Figure 20 shows the CCAM-CSIRO rainfall seldom reaches much more than 3 mm in an hour, while the recorded data at ORT shows storm regularly exceeding 10 mm in an hour, reaching as much as 40 mm in an hour. Figure 21 shows the rainfall distribution of the CCAM-CSIRO output to be far more than the high intensity, but more infrequent recorded events at the ORT station.

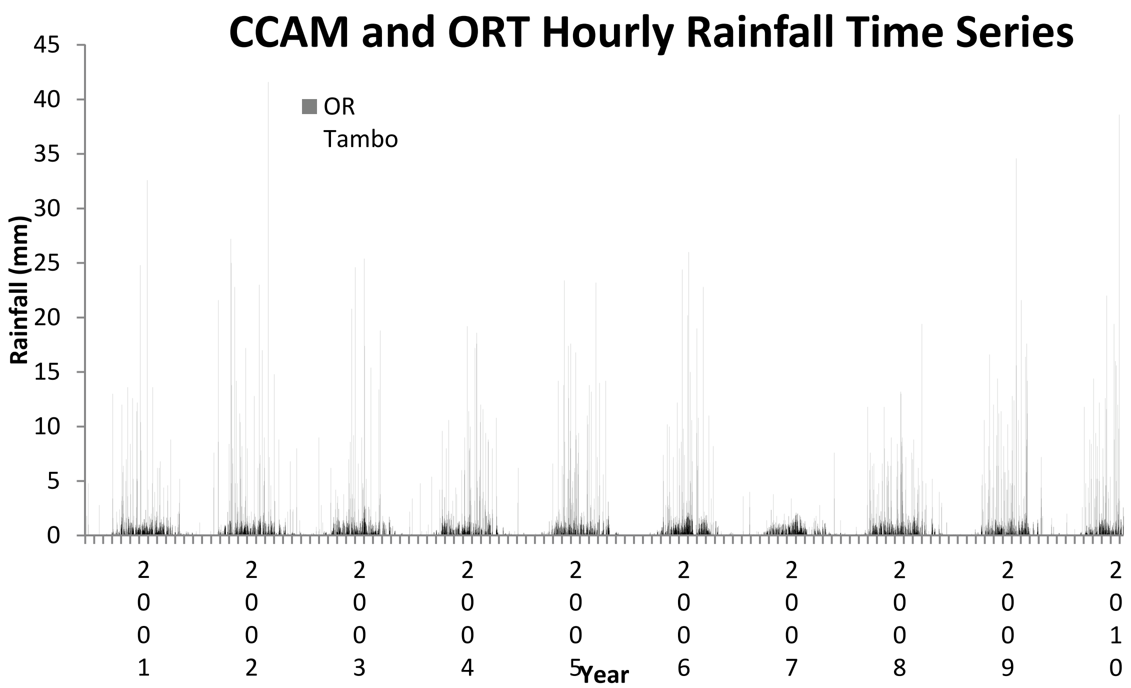


Figure 20. A sample set of the hourly time series of rainfall from the CCAM-CSIRO model and OR Tambo International Airport.

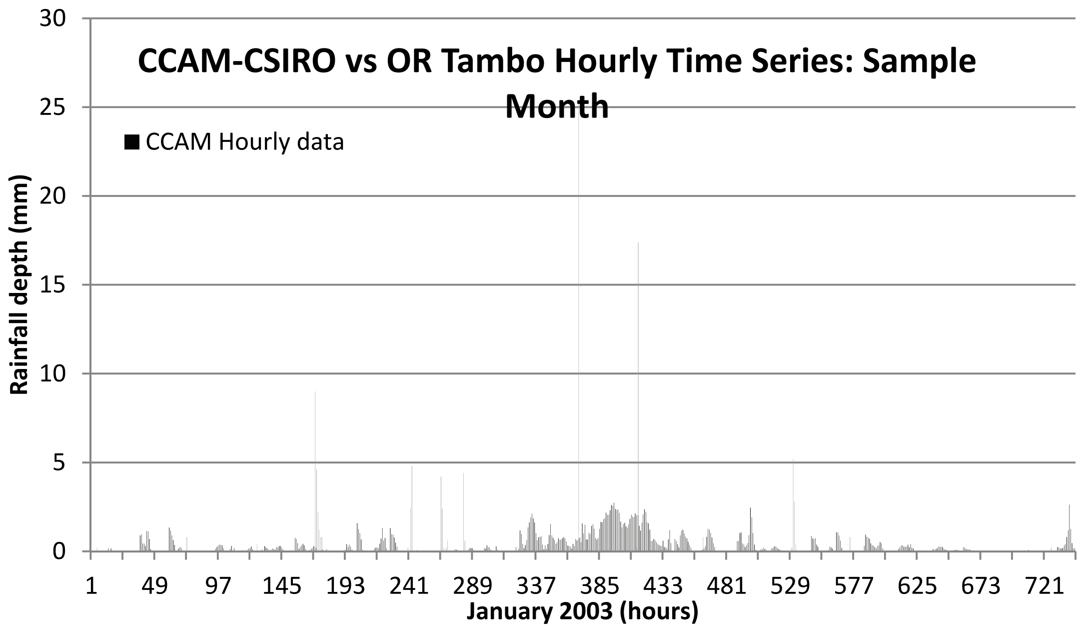


Figure 21. A sample month the hourly time series for CCAM-CSIRO model and ORT.

Correcting the scale of the CCAM model output will require more than the application of an area reduction factor. This is usually applied to point rainfall (e.g. at a weather station) to get an estimate of the average rainfall over a wider catchment area (Wilson, 1990), and it may have been applied in reverse to this data set had the rainfall patterns in Figure 21 been similar.

This result required that, although the overall rainfall yield of the CCAM-CSIRO model is representative of the Ekurhuleni area, the rainfall patterns on an hourly and daily scale are not yet suitable for conventional application at municipal scale. Another approach to the analysis had to be adopted. This involved the analysis of trends in the CCAM model simulations and applying these trends to present day design storm applications.

Trends in CCAM Model Rainfall Output

The analysis of trends in the CCAM model rainfall output is based on a similar approach that would be adopted for statistical analysis of large rainfall events for municipal applications. This focuses on analysis of Annual Maximum Series (AMS) of peak (daily and hourly) rainfall, and analysis of events above a threshold.

The analysis was done on the output of each of the six CCAM models and was broken down into the following "time slabs":

- 1961-1990 (reference period)
- 1991-2010
- 2011-2040
- 2041-2070
- 2071-2100

Procedure
The following steps in the analysis were taken:

I. The first assessment looked at changes in MAP (mean annual precipitation) and numbers of rain days in each time slab. This would give an indication of predicted long-term changes in overall precipitation, and the frequency of rain events.

II. Design rainfall events are central to much of the design and planning requirements for municipal operations. Design rainfall is typically described in terms of return periods (2 year, 5 year, 100 year, etc.) in accordance with the level of risk being considered, and storm durations (1 day, 1 hour, 30 minute, etc.) as appropriate to the catchment size and runoff response. The basis for the statistical analysis to determine these is the Annual Maximum Series (AMS) of recorded 1-day rainfall. The CCAM mode output provides a very useful data set for this so the next stage of this analysis was the extraction of the AMS from each CCAM model. A linear trend was then applied to the AMS from each model.

III. To get an indication whether there is a predicted change in the frequency of the larger events, an analysis of daily rainfall events above a given threshold was done. The threshold levels were selected on the basis of the range of area averaged rainfall simulated by the models. The average annual maximum rainfall from all the models was 18.8 mm in a day, with only rare events exceeding 30 mm, and only one exceeding 45 mm in a day.

IV. The analysis was taken a step further by looking at maximum hourly rainfall simulated by the six CCAM models. Analysis of both Annual Maximum Series of hourly maximum and events over a threshold was undertaken as for the analysis of daily events.

V. Finally, an analysis of trends in changing rainfall intensities was undertaken, focussing on the hourly data provided by the CCAM models. The trends observed were then applied to a standardised design rainfall distribution (Storm Type 3) applicable to the location of Ekurhuleni (Schmidt & Schulze, 1987). A comparison is made between the Storm Type 3 distribution (applicable to the reference period of 1961-1990) and the projected design storm distribution for 2071-2100 derived in this analysis.

VI. Application of the changed rainfall distribution to the hydrological models. A standard 100 mm, 24h rainfall event was applied to the Storm Type 3 and the 2071-2100 design rainfall distributions, and these were run on the catchment models at each pilot site. Differences in runoff response and peak flows are presented. (Refer to Section 6.4)

Trends in mean annual precipitation (MAP)
Trends in overall mean annual precipitation (MAP) from the six CCAM models range from an overall increase of 5% by 2100 to an overall decrease of 19% (see Table 6). A combined average suggests a general decrease in MAP after 2040 and a drop of around 4% by 2100. These results appear to concur with the total rainfall analysis for OR Tambo International Airport (1960-2009) presented earlier in Figure 20.

All models show a decreasing number of rain days per year up to 2100 (Table 7). The range is a decrease by 4% to 11% by 2100, with an average at 9%. This implies that the same rainfall will fall in fewer days. This appears consistent with other predictions for this part of South Africa.

Trends in maximum daily rainfall

Trends in maximum daily rainfall are surprisingly flat (Table 5). The projected change in average annual maximum rainfall ranges from an increase of 6% to a decrease of almost 9% by 2100. The average of all models shows negligible change over all time slabs.

Figure 22 (a)-(f) shows the AMS trends for each of the CCAM models. Half of the models predict slight increases in annual maximum rainfall over time, while the other half predict slight decreases.

Looking deeper than the AMS, Table 5 presents rainfall events over given thresholds. This is an attempt to consider a broader range of storm events. However, the flat trend is still evident, and in fact at least four of the models imply the rarer events will decrease in magnitude.

Table 5. Analysis of the Annual Maximum Series (AMS) of daily rainfall. (Analysis of percentage change in average AMS compared to the reference time slab 1961-1990.)

CCAM	**AMS trend *(y=mx+c)***		***x***				
	M	***c***	**2010**	**2020**	**2040**	**2070**	**2100**
CSIRO	-0.0049	29.687	19.84	-0.25%	-0.74%	-1.48%	-2.22%
MPI	0.0119	-6.02	17.90	0.66%	1.99%	3.99%	5.98%
GFDL20	-0.0037	26.978	19.54	-0.19%	-0.57%	-1.14%	-1.70%
GFDL21	0.0016	15.851	19.07	0.08%	0.25%	0.50%	0.76%
MIROC	-0.0185	56.275	19.09	-0.97%	-2.91%	-5.81%	-8.72%
UKMO	0.0093	-1.2725	17.42	0.53%	1.60%	3.20%	4.80%
AVERAGE			**18.81**	**-0.02%**	**-0.06%**	**-0.12%**	**-0.18%**

Average annual max. rain =	18.80

In Table 8 the threshold levels were selected according to the range of rainfall observed in the model output. However the number of events per year shown gives some indication of the design equivalent. For example, for the CSIRO model the occurrence of events greater than 20 mm was once every three years. This increases to almost once a year between 1990 and 2040 and then drops again to once every two to three years. A more detailed breakdown is given in Table 9. The trends are not conclusive, but there is a suggestion that there will be a small increase in the number of events above 20 mm (i.e. the average return period decreases), while the frequency of events above 25 mm will decrease (as the average return period increases).

Comparison with trends observed from recorded events at OR Tambo International Airport over the 50 year period between 1960 to 2009 shows reasonable correlation with these results. The analysis by Fatti and Vogel (2011) shows a trend of decreasing number of storm events per year (Figure 14) over the observation period. This is reflected in the results of four of the CCAM models for the same period as shown in Table 8. Here the number of storm events over a threshold of 2.5 mm show a decrease in four of the six models up to 2010.

However for the larger storm events, the results by Fatti and Vogel in Figure 17 suggests a trend of fairly constant storm counts per annum. This too is seen as the general trend in the results for events over 10 mm shown in Table 8.

The main difference between the two analysis appears to be in the size of the storm events over time. Figure 21 suggests storm events recorded at OR Tambo have been getting larger up to 2009. Instead, the analysis of the CCAM model data suggests that the size of the events are fairly consistent over time and that the large order events may actually decrease over time (Table 9). The data warrants further detailed analysis, but the discrepancy may point to a short-term trend at OR Tambo being different to the long-term trend. For example two of the CCAM model predictions (the GFDL20 and MPI model results for events above 25 mm) suggest increasing event rainfall for the period 1990-2010 (i.e. reduction in return period). Certainly, the CCAM output shows that most of the models suggest some variability from the overall long-term trends will occur between time slabs. Hence the period of record of 1960-2009 at OR Tambo International Airport may not necessarily point to long-term trends arising from changing climate conditions.

Alternatively the discrepancy between the results may also point to the problem associated with comparing a trend in area averaged rainfall to a trend in point rainfall depths. While other results suggest it is reasonable to assume the trends in the CCAM model output can be transferred to point rainfall trends, this result points to the need to further analyse this assumption.

Table 6. Assessment of change in Mean Annual Precipitation (MAP) in each time slab (reference period is 1961-1990).

	CSIRO		GFDL20		GFDL21		MIROC		MPI		UKMO		Average
	MAP	% change	MAP	% change	MAP	% change	MAP	% change	MAP	% change	MAP	% change	% change
1961-1990	677.68		677.74		677.45		677.52		677.65		677.78		
1991-2010	740.24	9.23%	677.99	0.04%	676.97	-0.07%	684.30	1.00%	663.67	-2.06%	651.06	-3.94%	0.70%
2011-2040	717.15	5.82%	683.81	0.89%	697.68	2.99%	656.34	-3.13%	644.56	-4.88%	674.26	-0.52%	0.20%
2041-2070	687.84	1.50%	683.62	0.87%	707.57	4.45%	604.83	-10.73%	612.81	-9.57%	626.38	-7.58%	-3.51%
2071-2100	713.54	5.29%	675.32	-0.36%	683.75	0.93%	546.70	-19.31%	645.87	-4.69%	622.72	-8.12%	-4.38%

Table 7. Assessment of average number of annual rain days in each time slab (reference period is 1961-1990).

	CSIRO		GFDL20		GFDL21		MIROC		MPI		UKMO		Average
	rain days	% change	rain days	% change	rain days	% change	rain days	% change	rain days	% change	rain days	% change	% change
1961-1990	226.27		223.83		218.37		219.37		227.43		226.63		
1991-2010	225.90	-0.16%	217.95	-2.63%	217.40	-0.44%	218.55	-0.37%	220.10	-3.22%	221.05	-2.46%	-1.55%
2011-2040	222.23	-1.78%	217.00	-3.05%	218.43	0.03%	205.53	-6.31%	216.97	-4.60%	224.70	-0.85%	-2.76%
2041-2070	219.77	-2.87%	211.40	-5.55%	215.97	-1.10%	198.73	-9.41%	208.83	-8.18%	207.47	-8.46%	-5.93%
2071-2100	217.13	-4.04%	198.83	-11.17%	203.87	-6.64%	179.17	-18.33%	206.63	-9.15%	212.33	-6.31%	-9.27%

Table 8. Trends in occurrences in daily rainfall events over a given threshold.

Threshold (mm)		2.5		5		10		15		20		25	
	yrs	no.	no./yr	no.	no./yr	no.	no./yr	no.	no./yr	no.	no./yr	no.	no./yr
CCAM – CSIRO													
1961-1990	30	2988	99.6	1398	46.6	278	9.2	50	1.6	11	0.3	0	0.00
1991-2010	20	2073	103.6	1059	52.9	228	11.4	57	2.8	17	0.8	6	0.30
2011-2040	30	3043	101.4	1510	50.3	332	11.0	80	2.6	25	0.8	10	0.33
2041-2070	30	2970	99.0	1422	47.4	311	10.3	73	2.4	11	0.3	1	0.03
2071-2100	30	3104	103.4	1534	51.1	336	11.2	61	2.0	13	0.4	3	0.10
CCAM – GFDL20													
1961-1990	30	2932	97.7	1357	45.2	279	9.3	59	1.9	20	0.6	5	0.17
1991-2010	20	1983	99.1	954	47.7	174	8.7	35	1.7	8	0.4	5	0.25
2011-2040	30	2926	97.5	1468	48.9	299	9.9	61	2.0	14	0.4	5	0.17
2041-2070	30	2895	96.5	1454	48.4	324	10.8	61	2.0	17	0.5	9	0.30
2071-2100	30	2864	95.4	1482	49.4	347	11.5	77	2.5	14	0.4	1	0.03
CCAM – GFDL21													
1961-1990	30	2952	98.4	1421	47.3	286	9.5	66	2.2	13	0.4	4	0.13
1991-2010	20	1934	96.7	938	46.9	208	10.4	38	1.9	7	0.3	2	0.10
2011-2040	30	2980	99.3	1475	49.1	330	11.0	69	2.3	16	0.5	6	0.20
2041-2070	30	2982	99.4	1490	49.6	348	11.6	77	2.5	19	0.6	7	0.23
2071-2100	30	2904	96.8	1483	49.4	357	11.9	78	2.6	16	0.5	3	0.10
CCAM – MIROC													
1961-1990	30	2961	98.7	1344	44.8	282	9.4	52	1.7	15	0.5	5	0.17
1991-2010	20	1959	97.9	931	46.5	209	10.4	37	1.8	10	0.5	1	0.05
2011-2040	30	2776	92.5	1352	45.0	307	10.2	76	2.5	22	0.7	6	0.20
2041-2070	30	2591	86.3	1216	40.5	257	8.5	53	1.7	9	0.3	2	0.07
2071-2100	30	2376	79.2	1108	36.9	239	7.9	43	1.4	13	0.4	1	0.03
CCAM – MPI													
1961-1990	30	2995	99.8	1393	46.4	245	8.1	41	1.3	6	0.2	2	0.07
1991-2010	20	1924	96.2	923	46.1	173	8.6	25	1.2	7	0.3	5	0.25
2011-2040	30	2815	93.8	1310	43.6	258	8.6	50	1.6	8	0.2	1	0.03
2041-2070	30	2629	87.6	1233	41.1	257	8.5	54	1.8	14	0.4	2	0.07
2071-2100	30	2765	92.1	1314	43.8	296	9.8	54	1.8	11	0.3	2	0.07
CCAM – UKMO													
1961-1990	30	2978	99.2	1393	46.4	247	8.2	40	1.3	10	0.3	3	0.10
1991-2010	20	1857	92.8	873	43.6	185	9.2	28	1.4	4	0.2	1	0.05
2011-2040	30	3010	100.3	1347	44.9	253	8.4	45	1.5	5	0.1	1	0.03
2041-2070	30	2702	90.0	1261	42.0	256	8.5	54	1.8	12	0.4	3	0.10
2071-2100	30	2671	89.0	1221	40.7	261	8.7	47	1.5	11	0.3	4	0.13

Table 9. Changes in approximate return periods (years) of select threshold events.

Threshold (mm)		20 mm			
Model	**1961-1990**	**1991-2010**	**2011-2040**	**2041-2070**	**2071-2100**
CSIRO	2.7	1.2	1.2	2.7	2.3
GFDL20	1.5	2.5	2.1	1.8	2.1
GFDL21	2.3	2.9	1.9	1.6	1.9
MIROC	2.0	2.0	1.4	3.3	2.3
MPI	5.0	2.9	3.8	2.1	2.7
UKMO	3.0	5.0	6.0	2.5	2.7
Average	**2.8**	**2.7**	**2.7**	**2.3**	**2.3**
Threshold (mm)		**25 mm**			
Model	**1961-1990**	**1991-2010**	**2011-2040**	**2041-2070**	**2071-2100**
CSIRO	-	3.3	3.0	30.0	10.0
GFDL20	6.0	4.0	6.0	3.3	30.0
GFDL21	7.5	10.0	5.0	4.3	10.0
MIROC	6.0	20.0	5.0	15.0	30.0
MPI	15.0	4.0	30.0	15.0	15.0
UKMO	10.0	20.0	30.0	10.0	7.5
Average	**8.9**	**10.2**	**13.2**	**12.9**	**17.1**

The first half of Table 9 may be compared model results. The projected change in the annual frequency of extreme rainfall events (>20 cmm in 24h, over a 50x50 km grid area) shows a slight increase in the frequency of these events over the Gauteng area for the period 2071-2100, compared to the 1961-1990 reference period (Figure 5). This is also reflected in Table 9 where the average return period for events greater than 20 mm drops from once every 2.8 years to 2.3 years (i.e. they become more frequent). The trend of the average is consistent over time, though it is not a sharp increase in frequency.

However, analysis of events above 25 mm shows a different trend. The average return period increases from once every 8.9 years to over 17 years (i.e. a notable decrease in frequency). Apart from the UKMO model, all the other model projections show decreasing frequency. This outcome may have important bearing in the determination of design events for municipal planning and design. If the lower order events (e.g. 5 year, 10 year) are seen to be increasing, this may not substantially increase hazard levels but mat substantially increase economic cost of damage. On the other hand, if the extreme events are generally decreasing in magnitude, this could improve general flood hazard levels, lower flood risk and even improve property values. However, this remain speculative until the data is analysed in more detail.

Trends in Maximum Hourly Rainfall

Analysis of annual hourly maxima presents a different result. There is clearly a trend of increasing maximum hourly rainfall shown by all the CCAM models (Figure 22 (a)-(f)).

Table 10 looks at the frequency of events over given thresholds, and here the results suggest increasing rainfall intensities over time, and a corresponding strong trend of reducing hours of rainfall. The latter result reinforces the observation above. Hence, a clear suggestion from all the models that future storms will be shorter and more intense.

This result is in line with trends anticipated by climate specialists in recent years. However, this is the first time that sufficient detail is available to quantify the extent of the change and then the potential implications thereafter.

Table 10. Analysis of occurrence of hourly extremes in each time slab.

		Hourly rainfall greater than:				Ave. rain hrs per year
		2.5 mm	3 mm	4 mm	5 mm	
CSIRO	1961-1990	15	0	0	0	2403
	1991-2010	39	10	0	0	2480
	2011-2040	47	19	0	0	2372
	2041-2070	45	12	2	0	2290
	2071-2100	102	15	0	0	2302
MPI	1961-1990	13	1	0	0	2510
	1991-2010	6	0	0	0	2356
	2011-2040	4	0	0	0	2321
	2041-2070	21	5	0	0	2152
	2071-2100	70	16	2	0	2070
GFDL20	1961-1990	22	3	0	0	2371
	1991-2010	19	6	0	0	2294
	2011-2040	46	15	0	0	2250
	2041-2070	72	13	0	0	2162
	2071-2100	97	30	2	0	1987
GFDL21	1961-1990	21	3	0	0	2304
	1991-2010	17	4	0	0	2266
	2011-2040	31	4	0	0	2255
	2041-2070	46	19	1	0	2238
	2071-2100	117	46	2	0	2004
MIROC	1961-1990	18	3	0	0	2341
	1991-2010	19	11	0	0	2287
	2011-2040	80	22	0	0	2103
	2041-2070	53	11	0	0	1970
	2071-2100	79	20	2	1	1625
UKMO	1961-1990	10	2	0	0	2472
	1991-2010	15	0	0	0	2339
	2011-2040	17	2	0	0	2398
	2041-2070	36	3	0	0	2095
	2071-2100	63	18	0	0	2069

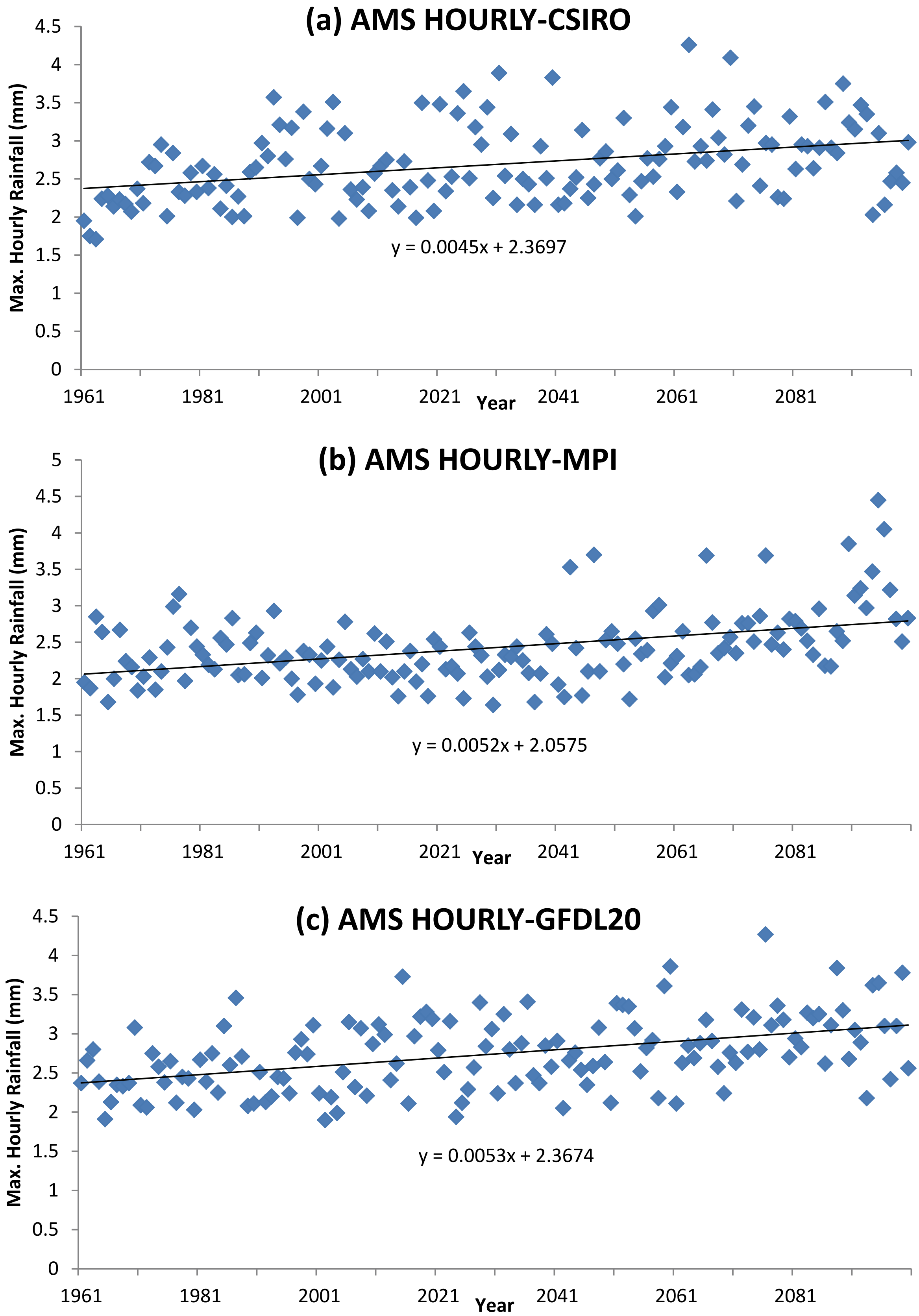


Figure 22. (a)-(c): AMS of maximum hourly rainfall.

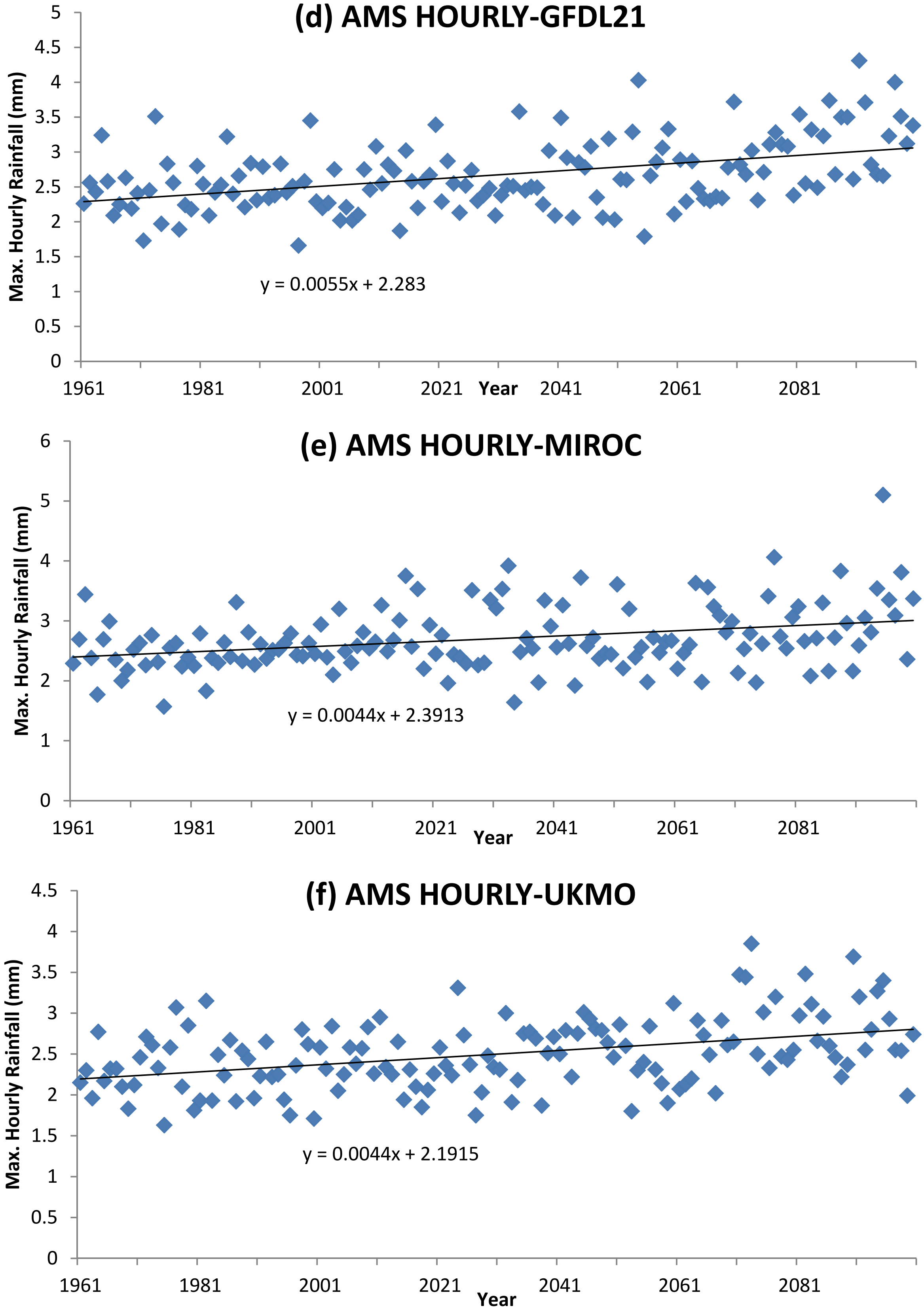


Figure 22. (d)-(f): AMS of maximum hourly rainfall.

5.2 Potential Change in Rainfall Intensity

For this reason the analysis was extended to rainfall distribution during these storms of highest intensity in each year, and to compare them to the reference period of 1961-1990. The analysis was limited to comparisons with the last time slab (2071-2100) due to time limitations.

Figure 23 presents the outcome of the analysis for the period 2071-2100 compared to the Storm Type 3 rainfall distribution applicable to Ekurhuleni. The curve represents the cumulative rainfall in a 24 hour period during a typical extreme storm event (i.e. storm events that would typically include the maximum rainfall event in each year). The curve representing the 2071-2100 time slab is based on the results of all the CCAM models. It shows that more of the rain is concentrated in a shorter time period.

Table 11 quantifies the differences by looking at storm durations that would normally be critical to municipal conditions. Storm durations up to an hour would apply to smaller catchments and site drainage design; new roads, site developments, business parks and residential areas (for example). The longer storm durations would apply to larger urban catchments and would likely be considered in urban planning applications; stormwater management plans, catchment management plans, floodplain management and urban stream management. In the instance of Ekurhuleni, this may also include the likes of OR Tambo International Airport as a site on its own.

Table 11 shows an increase in rainfall contribution under all storm durations, but interestingly it is more significant in the longer storm durations (2 to 6 hours). For the shorter storm durations the relative increase is small.

Table 11. Effect of change in storm profile on 100 mm, 24h rainfall. Rain falling in each of the critical storm periods (i.e. about the point of peak intensity) is shown along with the percentage of the total storm rainfall.

	Type 3 (1961-1990)		2071-2100		
Period	Max rain	% of 24h	Max rain	% of 24h	% increase
(hr)	(mm)	event	(mm)	event	
0.25	24.70	24.7%	25.29	25.3%	2.4%
0.5	49.10	49.1%	49.91	49.9%	1.6%
1	61.00	61.0%	63.55	63.5%	4.1%
2	71.40	71.4%	77.67	77.7%	8.8%
3	76.60	76.6%	84.78	84.8%	10.7%
4	80.20	80.2%	90.12	90.1%	12.4%
6	84.80	84.8%	94.82	94.8%	11.8%

Storm event (mm) =	100

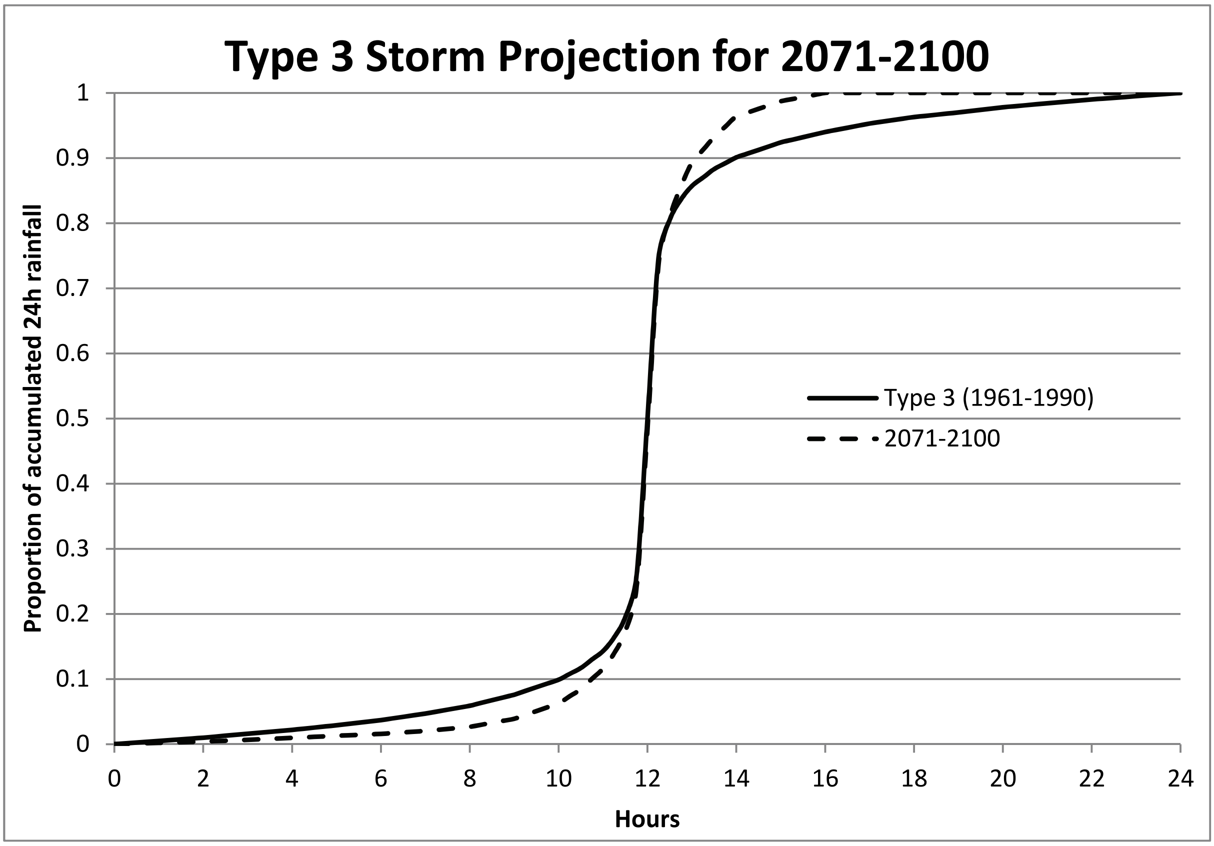


Figure 23. Inferred change to the Storm Type 3 storm profile by 2100, applicable to Ekurhuleni

Comment on Storm Intensity Analysis

The potential changes to storm intensity is based on the assumption that trends in the areal averaged rainfall output from the CCAM models are directly transferrable to present day point rainfall patterns. This will need to be reviewed as the scaling of the climate models improves, but the results presented here are seen to provide a useful insight for engineers and planners to develop adaptation plans at municipal scale.

- The 2017-2100 storm profile moves closer to the Storm Type 4 profile which is reflects the most intense storm rainfall in the country (around the eastern escarpment of the Drakensberg range around Lesotho – Schmidt and Schulze, 1987).
- Yet the results in Table 11 suggests the greater effect of this will be experienced for storm durations greater than 2 hours.
- The direct implication of this is that road design and Site Development Plans (SDPs) for individual site development applications may not need to consider changes for on-site drainage requirements, but municipal catchment management and downstream flood risk will be more critical in the larger urban systems.

This is tested on the hydrological models developed for this project and the results presented below.

5.3 Hydrological Model Results

Initially the CSIRO model output was run as a continuous simulation on one of the catchments. Although this was a test of the software running 140 years of rainfall record, it did confirm that the very low intensities described previously which resulted in minimal runoff. Hence the hydrological models were then used to test the significance of the potential change in storm rainfall distribution as shown in Figure 23.

For this trial, a 1-day, 140 mm rainfall event was tested on both storm profiles[3]. The resulting rainfall intensity distribution is shown in Figure 24. The rainfall intensities at the peak are very similar; the peak 5 minute intensities are 138 mm/hr and 141 mm/hr, but these average out over an hour time-step at 85 and 89 mm/hr for the present day and 2100 scenarios respectively. This increase is equivalent to the average increase proposed in the trends presented in Figure 12(a)-(f).

Figure 24 shows the rising and receding sections of the graph having the greater differences, particularly the receding section of the storm where the projected 2071-2100 intensities remain close to twice the present day Storm Type 3 intensity.

The modelling looks at select aspects of the catchments to assess the impact of the change in storm intensity. These aspects are catchment size and attenuation features.

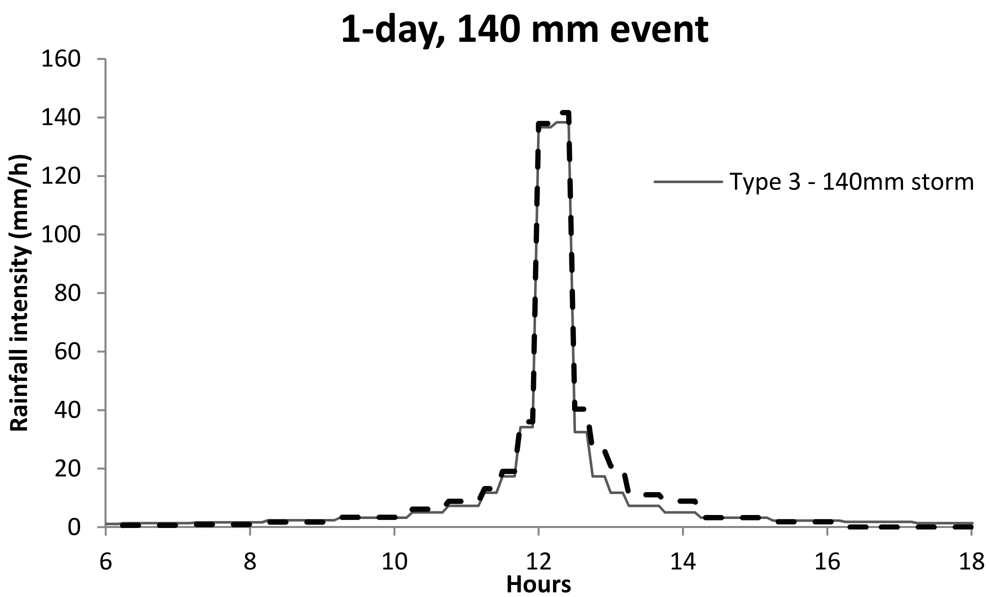


Figure 24. Rainfall intensity for a 1-day, 140 mm event.

Impact on attenuation features – Blaauwpan, Atlasville

Blaauwpan is a natural pan that has been modified with a formal outlet. It is located upstream of the flood risk area of Atlasville, and it receives runoff from a large portion of OR Tambo International Airport. Blaauwpan has been identified as a key stormwater management facility in the Atlasville catchment, as its attenuation function is critical in protecting downstream communities from flooding.

[3] A 140 mm 1-day rainfall event is the 100 year 1-day event for Atlasville. A 1-day event is based on daily rain gauge data measuring, typically from 08:00 to 08:00. This is usually smaller than the 100 year, 24 hour event, which is any consecutive 24 hour period.

The total area of the Blaauwpan catchment is 1223 ha (12.2 km^2), and the impervious area is estimated at 32%. The response time[4] of this catchment estimated at between 1 to 1.5 hours, meaning that critical storm duration will be of that order of magnitude.
The surface area of Blaauwpan is 37 ha and the estimated stormwater storage capacity is just over 1.2x10^6 m^3. The attenuating effect of the pan is seen in Figure 25, where the inflow peak at around 100 m^3/s is reduced to less than 10 m^3/s at the outlet, thereby substantially reducing flood risk to downstream properties.
The effect of the new storm profile initially appears marginal (Figure 25), but the storage facility requires an additional 80,000 m^3 storage to contain the flood. This is a 9% increase on the storm runoff volume and equates to an additional 200 mm storage depth. This is seen as a result of the higher intensity rainfall on the catchment and the resulting lower catchment infiltration.

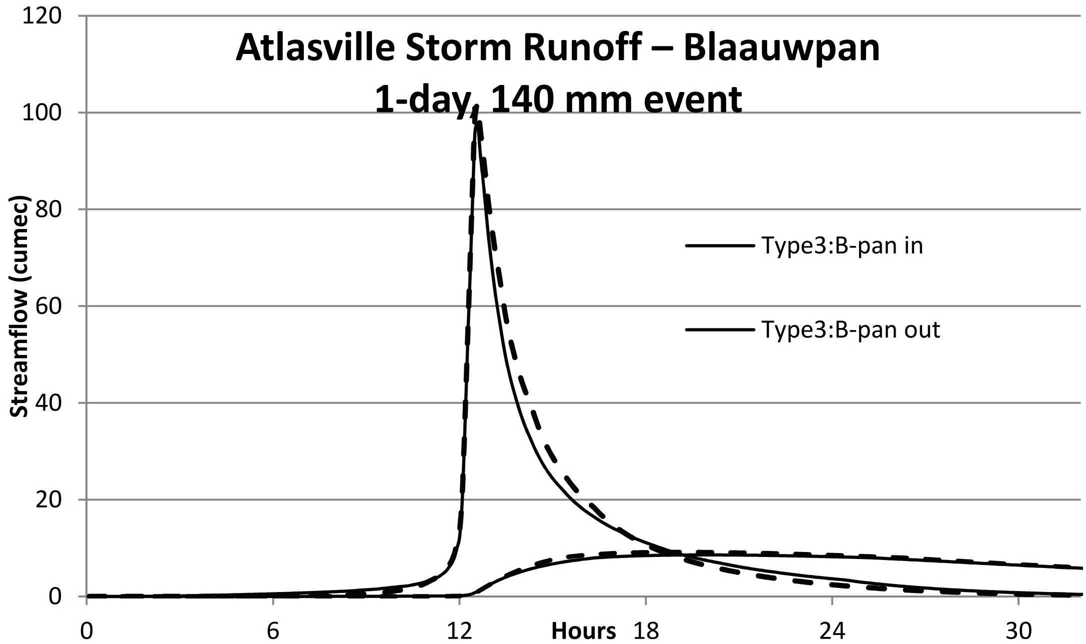


Figure 25. Inflow and outflow hydrographs for Blaauwpan, Atlasville, showing the effect of the 2100 storm profile.

Small Urban Catchment – Phomolong

The Phomolong site is indicative of the drainage situation of a site or a residential block. The catchment area modelled in this instance is 0.56 ha and comprises 34% roof area. There will be additional imperviousness due to some roads being paved, compaction on the other gravel roads and some paving in individual stands, but these were not measured in any detail for this study.
The response time of this catchment will be short – typically less than 15 min, and therefore the very high short-term (e.g. 5 minute) storm intensities indicated in Figure 24 will have a more direct influence on storm peak runoff than for larger catchments. Storm drains will be

[4] Catchment response time is a measure of the time required for the entire area of the catchment to contribute to flow at the catchment outlet. This is represented by parameters such as the Time of Concentration (SANRAL, 2006) and Catchment Lag (Schmidt & Schulze, 1987).

designed for the 2 year or 5 year event (CSIR, 2000). Thus it is expected that surface flow will occur in the roads for events larger than this.

The application of the 140 mm, 1-day storm profile to this catchment results in the storm hydrograph shown in Figure 26. The 200 l/s peak discharge should surcharge the storm drains and there would be flooding in the streets. However of note is that the higher intensity storm predicted by 2100 seems to show little difference at this catchment scale, although total runoff for the event increased from 79.5% to 85.3% of the total rainfall, and infiltration reduced to 11.4% from 15.6%.

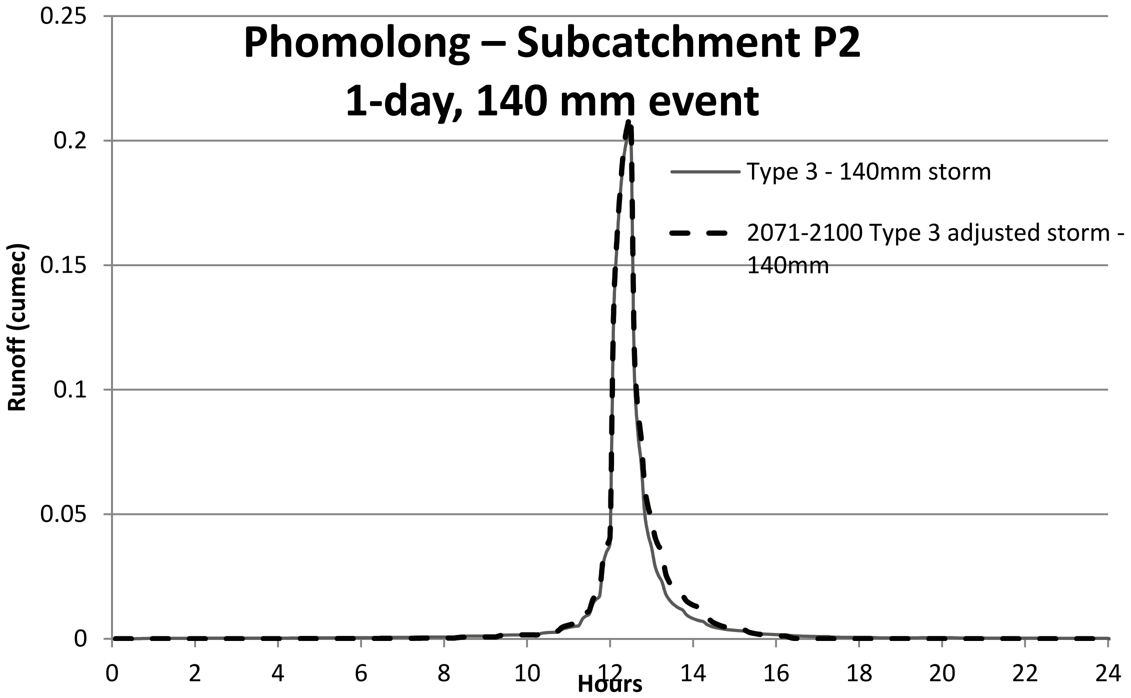
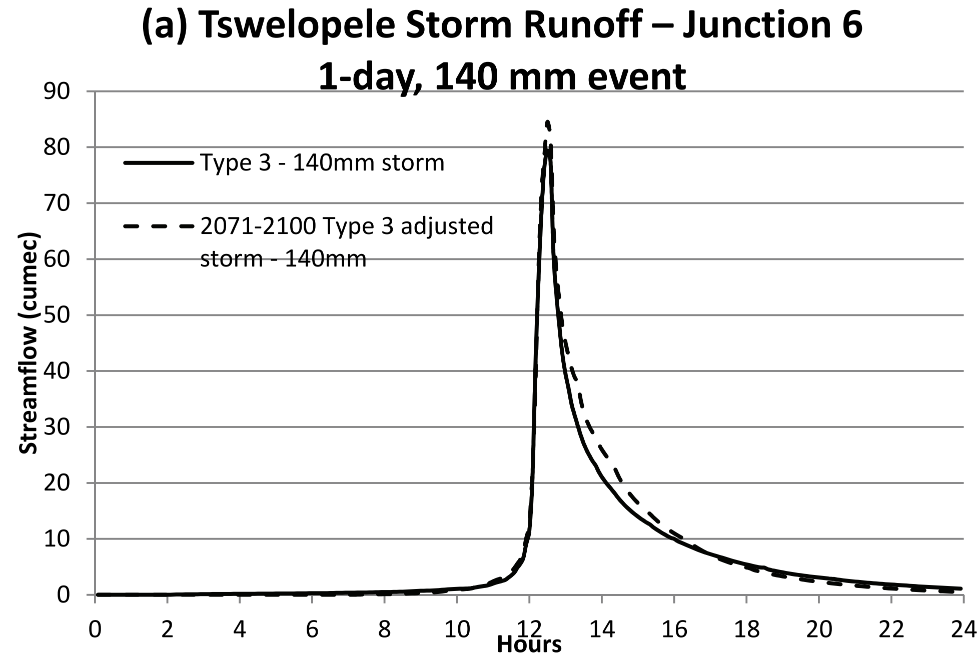


Figure 26. Storm runoff at the Phomolong site.

Medium Urban Catchment – Tswelopele

At 575 ha with a percentage roof area at 27%, the response time for this catchment would be of the order of 45 min to an hour. Hence the hourly rainfall intensities will have the greater influence on peak flows. The results of the simulation are shown in Figure 27 (a) and (b).



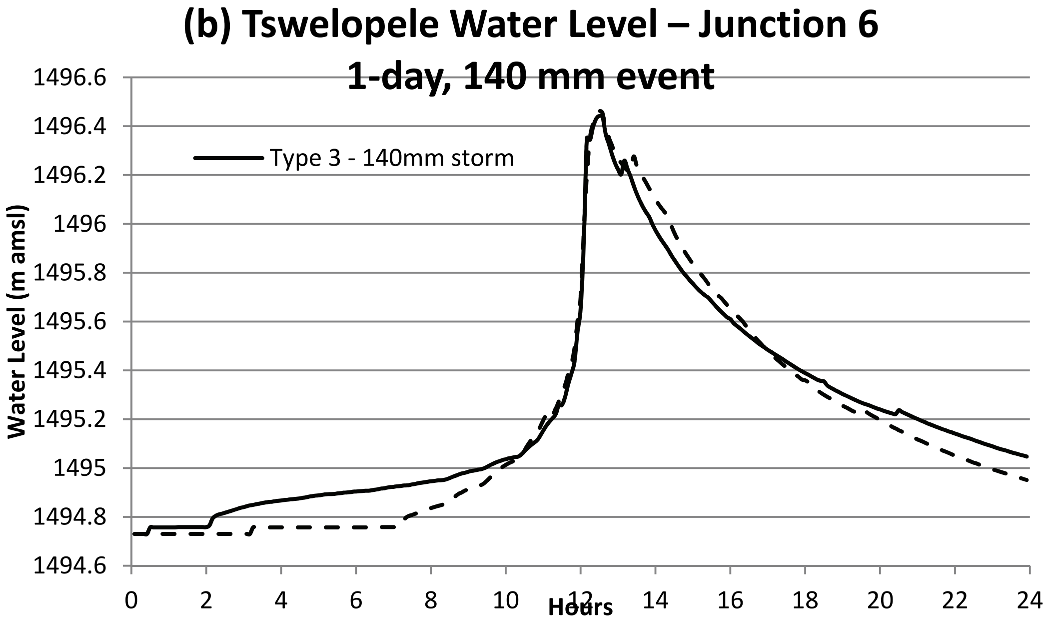


Figure 27. (a) & (b): Storm runoff and water level in the main channel at Tswelopele.

The increase in surface runoff from 68.8% to 69.1% of total rainfall results in an increase in peak flow by 5 m^3/s which appears to have a small impact on flood depth, though this will vary with channel section (as the channel widens into the floodplain, the rate of increase of flood depth reduces). However, if flooding begins at 1495.9 m asl (=1 m depth estimated on site), then the average depth of flooding will be deeper (by up to 100 mm) and longer (by

0.5 hours). This does not account for extended inundation that typically occurs due to ponding in localised depressions in the area. Also, in the urban environment, a 100 mm rise in flood level can result in a substantial increase in damage cost as, for example, water gets into the electrical components of appliances, saturates the lower portions of furniture, etc. Hence at the medium catchment scale of the size of the Tswelopele catchment, the projected changes in storm intensity by 2100 will result in flood responses that are likely to result at least in extended durations of flooding with an increase cost of flood damage.

Large Urban Catchment – Atlasville

The total storm flow responses from the entire 2539 ha (25.4 km^2) catchment is considered here to assess the impact of the change in storm profile on a catchment with a longer response time. The runoff response for this catchment area approximately four hours with the attenuation facilities (e.g. Blaauwpan) in the catchment. The storm flow responses are presented Figure 28.

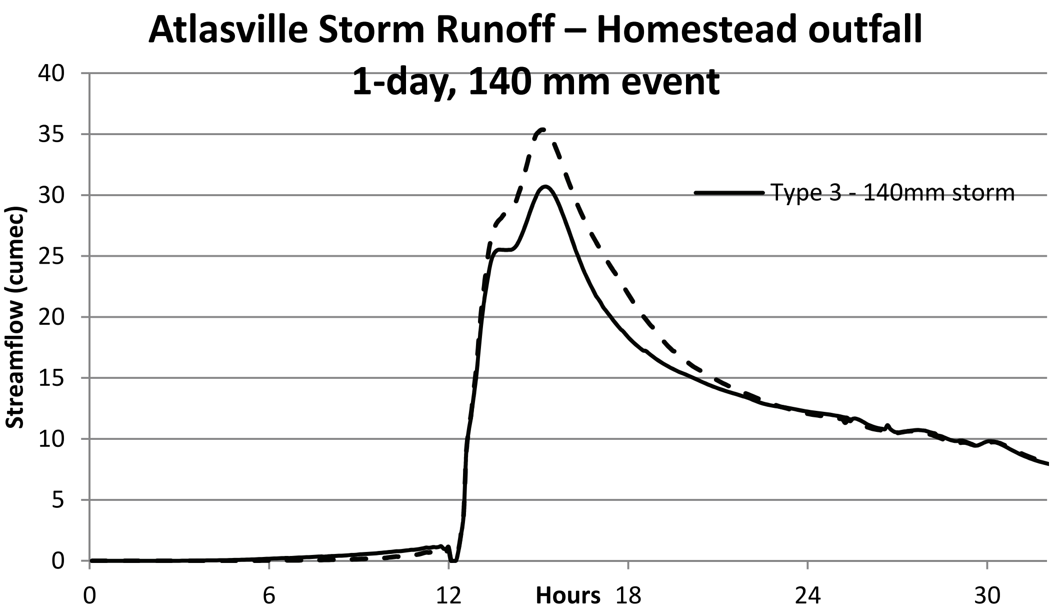


Figure 28. Storm runoff at Homestead Lake at the outlet of the Atlasville catchment.

The total runoff from the catchment increased from 57.3% to 59.6% of total rainfall. As a result, there is a 4.7 m^3/s increase in the peak flow at Homestead Lake, which is an increase of 15% over the present day condition. In the specific case of the Atlasville Flood Relief Scheme, the recently completed design was based on the present day Type 3 design storm profile. The additional 4.7 m^3/s will exceed the design capacity of the scheme and it would reduce the level of service of the scheme from a 100 year return period to approximately the 50 year return period.

Summary of Hydrological Modelling Outcomes

- The hydrological analysis is based on the application of a 140 mm rainfall event applied to the current design storm profile for Atlasville, and to the storm profile adjusted for the 2071-2100 time slab. The future storm profile has a higher rainfall intensity by 5%, but the greater area of difference lies in the recession limb of the storm profile where intensities are close to double the present day design storm intensities.

- The effect of this change in storm profile has been tested on three different urban catchments:
    - A small urban catchment (Phomolong, 0.56 ha, less than 15 minute response time), which showed very little change in peak flow, supporting the comment in Section 6.3.1 that small catchments, including roads and project sites, would not need any special adaptation for climate change.
    - A medium catchment (Tswelopele, 575 ha, response time up to an hour) shows proportionately small changes in peak runoff and maximum flood depth, but a clear likelihood of longer and deeper flood inundation, thereby increasing flood damage costs.
    - Large urban catchment (Atlasville, 25.4 km^2, response times in excess of 3 hours) shows proportionately larger increases in peak flow which are considered to be very likely to have consequences in terms of flooding and river management.
- The increased intensity is also seen to have an effect on storm volumes and in runoff response times that need to be considered in the design of attenuation facilities. The significance of this is likely to increase with catchment size following the observations above.
- This outcome also points to how infiltration drainage facilities will need to be designed under a changing climate. Increasing infiltration at source and within the catchment is central to sustainable urban drainage systems, and the infiltration surfaces will need to have the capacity for the higher intensities. The performance of at source infiltration systems (e.g. at a development site scale) is probably best demonstrated by the Phomolong results where the very high, short duration, intensities dominate the catchment response. But this perhaps also points to the increasing importance of wider catchment attenuation and infiltration systems (e.g. wetlands, park land areas, swales, etc.).

The hydrological analysis undertaken in this study are considered to be very much a first look at the implications of urban catchment responses arising from changing rainfall patterns. However, although the examples are site specific, they begin to give municipal designers, engineers and planners an indication of where best to focus adaptation efforts for climate change.

6 DISCUSSION: COMBINED CLIMATE CHANGE SCENARIOS WITH HYDROLOGY MODEL

The study has shown that for water resources planning where monthly and annual rainfall is required, the global climate models appear to provide useful results for the Ekurhuleni study area. However, design and catchment planning decisions at municipal level, it will be important to downscale the model output such that temporal and spatial rainfall distributions can be analysed. This is necessary to develop guidelines and standards for rainfall depth, intensity and duration needed for effective stormwater management. It is already understood that the global climate models are being run at finer spatial and temporal resolution than was applied for this study. Although run times, computing capacity and the magnitude of the output is still limiting anything other than very site specific applications at smaller scales, there is no doubt advances in technology will make this more accessible to municipalities in the near future.

The outcome of this study is based on a first look at the trends in storm rainfall changes for the period up to 2100. The study was narrowed to looking at the likely shift in rainfall intensities between the present day and 2100. Interim periods that would be more appropriate to most municipal design (e.g. 10, 25 and 50 year design life) have not been assessed. However, the results suggest that, if the transfer of trends observed in the current 0.5°x0.5° scale output from the CCAM models to the present day design rainfall guidelines is reasonable, and if the Ekurhuleni pilot study area is representative of other parts of the country, then are likely to be important changes in catchment responses into the future as rainfall intensities increase. This is particularly so for the medium to large urban catchments and it will place more emphasis on the need for effective catchment planning and maintenance, rather than a focus on site specific interventions as is the current norm.

The study has highlighted that, under present circumstances in Ekurhuleni, the need to do the basics right is far more urgent than implementing changes in stormwater design standards. These would include:

- Developing effective catchment stormwater master plans,
- Maintaining and repairing existing stormwater networks,
- Policing by-laws and illegal connections of stormwater systems to sewer systems,
- Implementing effective solid waste removal systems,
- Sediment management – controlling and policing construction sites, erosion areas and exposed dumps, spoil heaps and bare surfaces.

One outcome – matching the 2 models, spatially and temporally – intellectual conversation about this – are they the best to match each other? Is the current design the best? The hydro model is what is used in planning – standard practice… the question is, is there a better model available or should the hydro model be dumbed down instead of doing the climate downscale. How do we match the time/space issues?-

7 GUIDANCE

This research has identified that an integrated approach to managing climate change risk is necessary, particularly in the local municipal sphere of government. The checklist in Table 12 identifies a possible set of considerations for municipal managers when assessing climate change and the implications at the local level. The checklist comprises of a range of climate change related questions, which are grouped into four categories: Knowledge and Information, Response Strategies, Monitoring strategies, and General Considerations. There are four columns alongside the questions which fall under the 'Considerations' title. These columns represent the information that should be used to guide answering the questions. This checklist aims to incorporate all four approaches that this study used, namely:

1. Perceptions and experience of relevant communities
2. Status Quo of Vulnerability and Management in the municipality
3. Climate change projections (downscaled to a relevant scale)
4. Interpretation of Climate change projections (in this case using hydrological modelling).

As this investigation has attempted to do, this checklist should be used to ensure that a range of information is used to inform different questions related to managing climate change at the municipal level. In addition to guiding municipal responses, this checklist could be used to inform how climate and hydrological scientists conduct their research, so that the information they provide to the municipality is relevant to municipal decisions and strategies related to climate change.

Table 12. Checklist of adaptation options to reduce climate change related flood risk

General Climate Change related questions.	**Considerations**				
	CC	**Hydro**	**Public**	**Present**	**Comment**
Long-term community outcomes of CC projections					
Is strategy clear?					
Can strategy be monitored?					
Is timeframe of CC effects handled effectively?					
Do adaptive responses relate to current assets?					
Are other CC programmes specified and detailed?					
Is a specific budget allocated to:					
a) Development, maintenance and management?					
b) Research and investigation?					
c) Ongoing monitoring?					
Is a monitoring regime identified incl. mechanism, cost, duration?					
Are levels of uncertainty of projections adequately relayed?					
Is an appropriate reporting mechanism detailed?					
If outcomes are not achieved, does this have to be explained?					
Is CC identified as a regional issue requiring response?					
Do considerations comply with the relevant national policy?					
Are the necessary decisions specified with person responsible?					
Is there consistency in CC approaches across regions/adjacent municipalities?					
Is public education encouraged as a response method?					
Do responses allow for spatial variation across areas and communities?					
Are damage and costs due to possible CC effects limited or avoided?					
Is a procedure stipulated to monitor CC?					
Is CC identified as an issue?					
Are any objectives related to climate change explained and integrated adequately with policy?					
Is there a commitment by council to keep up to date with CC projections and their effects?					
Are areas with enhanced risk due to CC been identified?					
Do strategies relating to natural hazards consider CC implications?					
Are provisions and statements relating to managing CC effects appropriate for the long-term					
Do asset management plans consider the effects of CC?					

8 CONCLUSIONS

8.1 Climate change scenarios

An ensemble of high-resolution projections of future climate change over southern Africa has been performed at the CSIR using the regional climate model CCAM. In this project, these simulations were analysed in order to investigate the potential impact of enhanced anthropogenic forcing on the frequency of occurrence of extreme rainfall events over the South African Highveld. The analysis of the projections indicates that significant increases in the annual frequency of extreme rainfall events are plausible over the mountainous regions of eastern South Africa – including the Highveld regions of Mpumalanga and Gauteng. Drastic rises in surface temperatures are projected for the southern African region. This is associated with an increase in the intensity of the heat low over the western and central interior of South Africa – a circulation change that would promote the more frequent occurrence of thunderstorms over central and eastern South Africa. Thus, projections of increases in the frequency of occurrence of extreme rainfall events over the Highveld region of South Africa are plausible and physically defensible. At a grid-box resolution of 50x50 km^2, the model simulations represent area-averaged rainfall values that cannot be directly related to point-scale observations of rainfall. That is, the simulations cannot be applied at their native resolution for the purpose of forcing hydrological models calibrated at the point-scale. Sophisticated bias correction methods, that relate the probability density function of the simulated data to that of rainfall observations at the point scale, are needed to obtain simulations that are useful to force hydrological models that are calibrated at the point scale. It may be noted that the regional downscaling of African climate, both locally and internationally through the Coordinated Regional Downscaling Experiment (CORDEX), are typically performed at resolutions of about 0.5° in the horizontal. In order for these simulations to find application is flash-flood modelling, such sophisticated bias-correction methods need to be developed.

8.2 Flood risk assessment

This study has examined the intersection of various factors that enable the identification of possible areas prone to risks associated with flash flooding events. The results have confirmed the body of literature around risk, vulnerability and flash flooding hazards. The study has shown that most vulnerable communities are those that are forced as a consequence of their financial and social status to occupy land predisposed to flash flooding within the urban environment. The only land available to the poor for settlement has been found to be in regions is not suitable for development. Many aspects of informal settlements within flash flood prone areas exacerbate the vulnerability of the communities and include; compaction of land due to settlement, thus decreasing infiltration and increasing surface run-off; structures within informal settlements are not able to withstand any form of hazard, especially flash flooding; pooor and unjust planning practices of the past have placed poorer communities in the heart of high risk areas; subminimum infrastructure that has not been upgraded even though the population have increased way beyond the carrying capacities of the associated infrastructure and the introduction of infrastructure such as roads, roofs and buildings in areas that are already exposed to flash flooding hazards tend to enhance the impact of the hazard by reducing infiltration and channelling surface run-off.

8.3 Hydrological analysis

- The hydrological analysis is based on the application of a 140 mm rainfall event applied to the current design storm profile for Atlasville, and to the storm profile adjusted for the 2071-2100 time slab. The future storm profile has a higher rainfall intensity by 5%, but the greater area of difference lies in the recession limb of the storm profile where intensities are close to double the present day design storm intensities.
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The hydrological analysis undertaken in this study are considered to be very much a first look at the implications of urban catchment responses arising from changing rainfall patterns. However, although the examples are site specific, they begin to give municipal designers, engineers and planners an indication of where best to focus adaptation efforts for climate change.

8.4 Stakeholder engagement

Many of the issues that were highlighted by municipal managers that relate not only to climate change but to general management are complex issues that impact other sectors. It is thus necessary that municipalities view the different aspects of water services management as part of an integrated management system and not in isolation. Water services managers should be conscious that strategic decisions or the lack thereof, have an impact on the ability to manage and deal with the day-to-day aspects of water resource management on every level of management. Development and water service delivery must not be carried out at the expense of water resources or the environment. Considering these factors will help prevent further water insecurity in the future.

The following issues are ones that need to be addressed by further studies, but have not been included in this report:

- Acid mine drainage
- Biodiversity, and areas that are biodiverse sensitive
- Dolomite and sinkholes
- Vectors (e.g. rats/mosquitos) and their impacts

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ANNEXURE 1: SOUTH AFRICAN WATER-RELATED LEGISLATION (POST 1994)

Table 13: Examples of water-related legislation in SA since April 1994 (Nealer and Raga, 2008)

Year	Act	Summarised purpose and/or goal
1994	White Paper on Water Supply and Sanitation Policy.	This document is dedicated to the millions of SA's citizens who struggle daily with the burden of not having the most basic of services
1995	National Sanitation White Paper	It recognises that all South Africans have equal rights to a healthy environment and that this should be addressed. Unfortunately DWAF cannot do it alone. Assistance from other role-players is needed in an integrated approach to management of additional aspects from the economic, social and environmental environments
1995	White Paper on the Transformation of Public Service.	To establish a policy framework to guide the introduction and implementation of new policies and legislation aimed at transforming the South African public service
1996	Constitution of the Republic of South Africa, 1996.	This is the supreme law of the Republic, which embraces the human rights principles and sets forth the right of access to water as part of a lengthy list of social and economic rights. These include, *inter alia*, the right to a healthy environment, housing, health care, food, social security, education and culture
1996	'Water law principles.'	A set of principles submitted by various role-players and stakeholders which guided DWAF in drafting a new water act
1997	Local Government Green Paper.	This puts forward a vision for a developmental local government system in SA
1997	White Paper on Transforming Public Service Delivery (better known as the *Batho Pele* White Paper).	This seeks to introduce a fresh approach to service delivery: an approach which puts pressure on systems, procedures, attitudes and behaviour within the Public Service and reorients them in the customer's favour, an approach which puts the people first
1997	Water Services Act 108 of 1997	To provide for, *inter alia*, the rights of access to basic water supply and basic sanitation, the setting of national standards and of norms and standards for tariffs, water services development plans, establishment of water boards, monitoring of water services, and financial assistance to water services institutions
1998	Local Government White Paper.	This establishes the basis for a new developmental local government system, which is committed to working with citizens, groups and communities to create sustainable human settlements which provide for a decent quality of life and meet the social, economic and material needs of communities in a holistic way
1998	Local Government: Municipal Demarcation Act 27 of 1998.	To provide for criteria and procedures for the determination of municipal boundaries by an independent authority
1998	National Water Act 36 of 1998.	This Act replaced the old inherited Water Act 54 of 1956 and now for the first time recognises that water in SA is a scarce and unevenly distributed national resource which belongs to all its inhabitants and that the National Government is responsible for the nation's water resources and their use. This should be attained in a sustainable manner by means of, *inter alia*, integrated water catchment management of all aspects of water resources and, where appropriate, the delegation of management functions to a regional or catchment level so as to enable everyone to participate
1998	National Environmental Management Act 107 of 1998.	To provide for co-operative, environmental governance by establishing principles for decision-making on matters affecting the environment, institutions that will promote co-operative governance and procedures for coordinating environmental functions exercised by organs of state

1998	Local Government: Municipal Structures Act 117 of 1998.	To provide for the definition and establishment of municipalities in accordance with the requirements relating to categories and types of municipalities and provide for an appropriate division of functions and powers between the categories of municipalities
2000	Local Government: Municipal Systems Act 32 of 2000.	To enable municipalities to move progressively towards the social and economic upliftment of local communities, and ensure universal access to essential services that are affordable to all
2003	Strategic Framework for Water Services	To map out a vision for how the water sector as a whole will work in providing water services.
2004	Local Government: Municipal Finance Management Act 56 of 2003.	To secure sound and sustainable management of the financial affairs of municipalities and other institutions in the local sphere of government
2005	Intergovernmental Relations Framework Act 13 of 2005	To secure sound and sustainable management of the financial affairs of municipalities and other institutions in the local sphere of government

ANNEXURE 2:

A CLIMATE CHANGE PRIMER FOR THE WATER SERVICES SECTOR IN SOUTH AFRICA

by

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FOREWARD

Water services are currently under strain in South Africa due mostly to ageing infrastructure and insufficient planning and maintenance. Anthropogenic induced climate change is now inevitable fact with the only remaining question being the extent to which the atmosphere will warm over the next century and what the consequences will be for the weather and the environment in general. Climate modelling conducted for this research indicates that one of the impacts will be an increasing number of extreme rainfall events over central and eastern South Africa. The extreme rainfall events will be accompanied by flash flooding if proper planning and maintenance of the water services infrastructure is not improved. This document outlines the outcomes from an investigation of changing climates over the next century and evaluates the impacts on water services for Ekurhuleni Metropolitan Municipality. The methodology and results are a good indicator for local government throughout the country of what can be expected and the actions that need to be undertaken and planned to ensure uninterrupted water services over the next 100 years in South Africa.

10 INTRODUCTION

Water services management is likely to be one of South Africa's most complex problems for municipalities in the future. There is a strong link between water resources and climate variability around the country. Trends towards greater urbanisation and densification, coupled with environmental changes such as climate change are likely to exert pressure on water resources. It is necessary for strategic planning at a local government level to avoid water supply challenges in the future. The risk that climate change poses to water supply and demand is growing both globally and locally. Incorporating climate change projections and their implications into municipal management is gaining support in cities around the world (e.g. London, New York). Projected climate change is important for various planning horizons, particularly those that aim to address climate and development issues in the short and longer term. Improving the understanding of current storm risks is not purely for the benefit of the science-policy dialogue, but for the affected communities. Efforts also need to be made to understand how flood risk is framed and perceived by those most affected by such storms.

This document aims to provide an easily accessible framework to water resource managers, urban planners and storm water managers at all spheres of government dealing water related issues and especially the challenges of managing increased risk of flooding and flash flooding. Only a few urban areas in the South have placed a strong focus on analysing the impacts of climate change and incorporating adaptation approaches into policies and planning (Janjua, 2010). Much of the research undertaken to improve local understanding of vulnerability and adaptation, has not been transferable into policy responses (Burton *et al.*, 2004). This guideline will assist decision makers to improve their understanding of the challenges and risks that arise with current climate variability and those that may occur with future climate change. The guideline should enable effective adaptation planning for climate stresses both now and in the future. The water sector is the focus of this activity since this sector has been identified as one that may be most at risk to climate change (Christensen *et al.*, 2009). Effective adaptation to climate events combines measures to reduce the impacts of *current* climate hazards and *future* risk identified in climate projections to prevent hazards becoming disasters.

11 WATER RESOURCES MANAGEMENT

Water Resource management is a crucial activity for all spheres of government in South Africa and across the globe. It is an accepted fact the fresh water resources in many parts of the world are under pressure, vulnerable and potentially significantly impacted on by climate change (Bates *et al.*, 2008). Water resources managers have to consider on a daily basis the things that influence both the water quality and quantity within their particular sphere of government. The aforementioned are both impacted on by the source strength of the water, rainfall and river or stream flow, as well as by human activities such as agriculture and land-use change, construction and pollutants (Miller and Yates, 2006 and Bates *et al.*, 2008). Given the aforementioned it is vital that water resources are managed holistically. Brekke *et al.* (2009) have listed the various water resource sectors that are likely to be impacted by climate change in the foreseeable future. These can be subdivided into direct effects on water resources and also effects that will arise indirectly (Table 14).

Table 14. Direct and indirect impacts of Climate change on water resource related sector (Miller and Yates, 2006).

Direct effects	Indirect effects
Water availability	Wildland fires (Veld fires)
Water demand	Ecosystems
Water quality	Sea-level changes
Storm and wastewater infrastructure	Navigation
Flood risk reduction	Energy

In general terms water resource management have many challenges to deal without taking into account climate change concerns. From discussions with a small community on EMM as well as the water resources management team the key challenges have been identified (Table 15). These challenges are not unique to EMM and similar issues have been raised in other studies in South Africa as well as in other parts of Africa (Mukheibir and Sparks, 2006; Mukheibir, 2007; Douglas, *et al.*, 2007).

Table 15. Non-climate change challenges identified in the water resources management in local authorities.

Challenges	Description
Human capacity	A shortage of staff as well as the availability of skilled personnel adversely affects the effective management of water resources.
Infrastructure capacity	Infrastructure maintenance and development is a cornerstone of providing services associated with water. This challenge is closely linked to financial resources made available by the local authority to look after and develop infrastructure in existing and new areas.
Financial constraints	Budgets to develop and maintain infrastructure are constantly under pressure from other activities within the municipalities and metropolitans authorities. Insufficient funding is made available to maintain and develop the infrastructure required for effective water resources delivery. Little or no money is allocated to the monitoring of existing systems that would assist with effective management and inform decisions.
Institutional communication	Water resources management is not an activity that is undertaken by a single department. Inter-departmental communication is required for better water management
Political interference	The priorities of politicians frequently detract from effective water resource management

The predicted changes in weather patterns caused by climate change will possibly introduce a number of new challenges to water utilities in term of their ability to provide safe, reliable potable water at the lowest possible cost. Although technology to deal with most of these challenges is available, the cost of implementation may seriously hamper the cost-efficiency of water delivery into the future. Some of these challenges are summarised in Table 16..

Table 16. Climate change related challenges to water resource management

Climate related challenges	Description
Pollution of streams and water sources	Increased flash flooding will lead to higher sediment and pollutant loads in the river systems, leading to increased treatment costs.
Water temperature fluctuations	Increased surface temperatures may affect the temperature of water in the distribution system. This in turn will lead to increased rates of chemical reactions, causing changes in the water quality that will have to be corrected before final delivery. (For instance, Chlorine decay increases at higher temperatures.)
Storage Capacity	Increased frequency and severity of droughts may force utilities to invest in increased storage capacity to overcome prolonged periods of drought. This will cause a significant capital burden, as the additional infrastructure might not be utilized optimally (only during drought periods).
Flood damage	More intense rainfall will lead to more surface flooding and therefore more likelihood of impact on sewer systems. This would occur either through stormwater ingress during flood inundation, or due to direct connection of rainfall downpipes with waste water sewers as evident in Ekurhuleni.
Flood damage	Increased erosive potential of rainfall leading to increasing sediment loads in stormwater and river systems. This leads to increased blockage of storm infrastructure and flood risk, as well as increased maintenance costs.
Flood damage	Increased storm flows and longer duration at higher flows will increase erosion risk of stream and rivers, resulting in increasing channel instability.
Changes in Treatment Processes	As a result of increased water temperatures, algal blooms will be experienced more frequently and also for longer periods. This will required utilities to introduce new technologies to remove algae from raw water sources. The increased flow rates as result of floods will also cause changes in turbidity levels of the raw water, which will also require additional treatment, either i.t.o chemicals dosed or new technology.
Increased demand	The combination of higher temperatures and prolonged droughts will significantly affect the daily demands on water. Consumption will increase during these periods, stressing utilities to run its facilities at maximum capacity for extended periods of time.
Diseases	A changing climate will bring with it changes in habitat, resulting in various organisms expanding their natural boundaries as conditions become more favourable. Water-borne diseases such as bilharzias, malaria etc will spread into new raw water sources, requiring additional technologies to ensure that the water is safe to drink.
Litter management	Litter management is a problem in many South African urban areas. Increased storm intensity will increase litter transportation, affecting water quality, flood risk and maintenance costs.

Climate change is particularly important to water resource planners for the following reasons:

1. Future reliability of water supply depends on decisions made in the near term
2. Long term planning is a standard practise in water resources management (Miler and Yates, 2006).

The impacts of climate change on water will depend on the predicted changes in variables such as surface temperature, total precipitation and intensity and frequency of precipitation. The next section aims to look at what the expected changes over South Africa are expected to be until the end of this Century.

11.1 Climate Change and Water Resources challenges

The first question that many managers may ask at the outset is “Is climate change a real issue” or “ Is the climate changing in response to anthropogenic activities?” This is probably a fair question given the fair amount of debate that rages in the media today. Scientific evidence to date indicates that anthropogenic induced climate change is a real phenomenon that is currently occurring and is likely to gather momentum towards the middle of this century. Although the climate is known to vary over time, a reconstruction of the Earth’s climate for the past 2000 years has revealed an unprecedented change in the global mean surface temperatures over the last century (Brekke *et al.*, 2009). Measurements of atmospheric temperatures also show the Earth’s system steadily heating, especially over the past few decades (Figure 29) (Trenberth *et al.*, 2007)

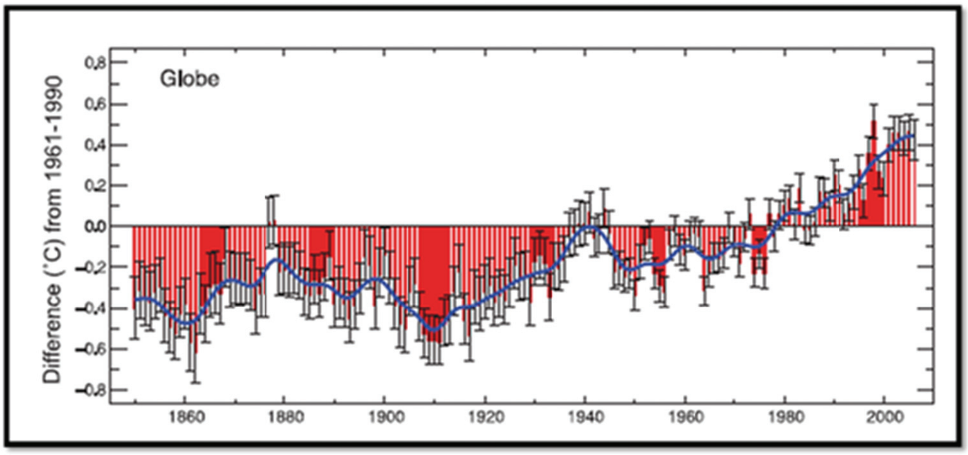

Figure 29. Global combined land surface air temperature anomalies for 1850 to 2006 relative to the mean from 1961 to 1990. The 5 to 95% error bar ranges are displayed as well as the decadal variations (blue line) (after Trenberth *et al.*, 2007).

Of course of most interest in this document is what the implications of climate change will be for water resources at a local and regional scale. Climate factors that are significant for water resources are not the same for all sites around the globe or even in South Africa. In general the major drivers will be changes in surface temperature, and precipitation. Other important factors that may be important are global sea level rise. It is crucial that climate change impacts on rainfall and therefore the consequences for water as a resource need to be modelled for future scenarios where possible at the appropriate spatial scales to inform decision making processes for example at local government level (Bates *et al.*, 2008).

In a WRC study, K5/1953/3, a General Circulation Model (GCM), conformal-cubic atmospheric model (CCAM), was utilised to simulate future climates over southern Africa over the next 100 years (Engelbrecht *et al.*, 2011). The model results indicated a few important findings that are crucial for any consideration of future water resource management. The first is that maximum surface temperatures over southern Africa are going to increase significantly towards the end of this century (Figure 30). Maximum daily temperatures increase by as much as 4°C over the northern parts of South Africa including over Gauteng. These increases are higher than the projected global increases and highlight the need for careful planning.

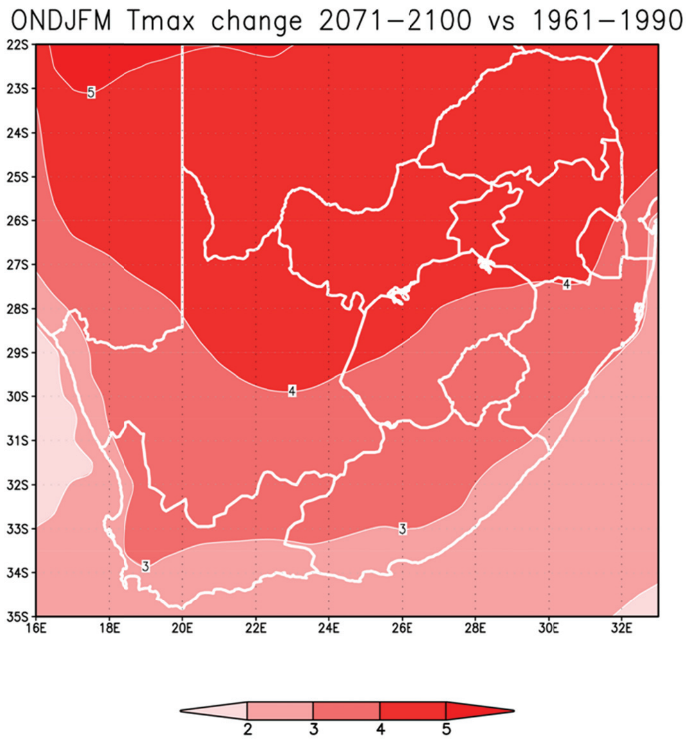

Figure 30. Projected change in maximum temperature (°C) during the summer half-year over South Africa, for the period 2071-2100 vs 1961-1990. The data are an ensemble average obtained from six CGCM projections of AR4 of the IPCC, all for the A2 SRES scenario (Piketh et al, 2012).

Surface temperature increases will impact on the supply and quality of water in a region. Higher surface temperature will result in higher evaporation and evapotranspiration. Although there are a complex set of mechanisms and feedback mechanisms that drive the aforementioned some studies have indicated that a 2-4°C change in surface temperature could results in a reduction in runoff of between 4-12% and 9-21% respectively if precipitation stayed constant (Nash and Gleick, 1993 and Miller and Yates 2006).

In addition to the increases in temperature, specific attention was given in this research to the predicted changes in rainfall over the country for the same modelling period. Although there it is expected that some changes will occur on eth quantities of precipitation that is received over South Africa. In addition to the changes in actual precipitation amounts it is also been shown that the precipitation frequency and intensity is likely to change significantly over South Africa (Figure 31).

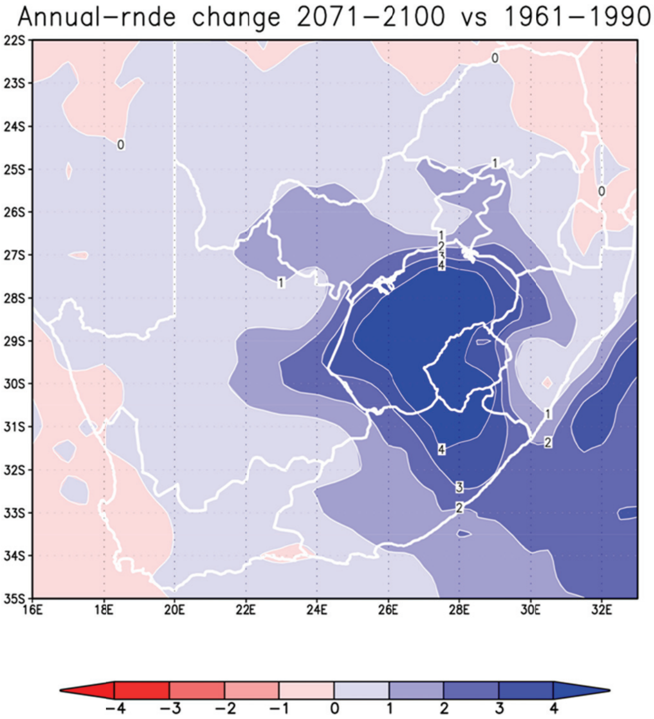

Figure 31. Projected change in the annual frequency of extreme rainfall events (defined as 20 mm of rain falling within 24 hours over an area of 0.5°x0.5°) over South Africa, for the period 2071-2100 vs 1961-1990 (units are number of events per model grid box per day). The figure shows the ensemble average of the set of downscaled projections, obtained from six CGCM projections of AR4 of the IPCC, all for the A2 SRES scenario.

Figure 4 shows the ensemble-average projected change in the annual frequency of occurrence of extreme rainfall events over South Africa. Here an extreme rainfall event is defined as 20 mm of rain falling within 24 hours over an area of 0.5°x0.5°, that is, an area of about 50x50 km^2. Rainfall events of this magnitude rarely occur over the South African Highveld (Dyson, 2010) and are likely to be associated with flooding over the region. A general increase in extreme rainfall events is projected for South Africa. Rainfall events are projected to increase over the mountainous regions of eastern South Africa in particular – including Lesotho and the Highveld regions of Mpumalanga, Gauteng and the Free State.
The increased surface temperature and the likelihood of more intense rainfall episodes possibly leading to flooding and flash flooding has direct implications on the water resource management of local governments. Associated management issues include: disaster management for especially floods but also droughts, water storage and demand changes.

11.2 Climate change and Stream flow consequences

Urban streams typically exhibit flashy stream flow characteristics with generally low base flow conditions unless a catchment management plan is in place which addresses this. Under climate change conditions of increasing intensity and decreasing rain hours, this flashy nature of stream flow is expected to increase. Preliminary hydrological analysis in this study suggests it will be streams in medium to large catchments that will experience this effect the most. Some of the anticipated stream flow consequences include:

- Higher velocities and increased depths during storm flow.
- Lower base flow due to a decrease in catchment infiltration during storm events and longer dry periods.
- A likely increase in sediment loads, with increased deposition in places, especially at stream crossings (bridges, culverts, etc.). This may change the geomorphology of streams and rivers, potentially affecting both urban open space areas and flood risk.
- Potential changes in habitat, and particularly vegetation cover. This may vary according to location; in steeper channels where there will be minimal sediment deposition with an associated decrease in vegetation cover, and in flatter channels there may be a build-up of sediment with the likely ingress of dense vegetation such as reeds.
- In areas of decreasing habitat, a lower resistance to the erosive flow velocities, resulting in increasing stream instability.
- In areas of reed infestation there will be an increase in flood risk.
- Increased hazard risk during storm flow due to increased velocity and depth.
- Increased disruption of transportation systems sue to flood inundation.

The anticipated changes in rainfall patterns will place more emphasis on the need for catchment planning and catchment scale solutions to urban drainage problems.

11.3 Managing flooding and flash flooding

Management issues associated with flash flooding in the South African context can be ascribed to actual physical environment, governance and perception (Fatti and Patel, 2012). Each of these three components are closely linked to a certain extent. Environmental aspects, allocation of budgets in the metropolitan or municipality and lastly political agendas that do not address on the ground issues associated with the management of the local government.

Management of flash floods by local governments typically occur directly after a flooding event as a immediate response to the crisis that has just occurred or slowly between events. The latter is typically low on the priority list with slow to no action over periods of time (Colombo *et al.*, 2002) Sufficient planning has to be the corner stone to minimise loss of life and property from flash flooding events.

In established urban areas, there are basically three components to managing extreme rainfall events at a local scale. These include:

a) **Identifying the risk of a flash flood event**. Develop stormwater master plans for each urban catchment which, in the process, will develop areas at higher risk of flooding.

b) **Developing prevention and mitigation strategies (structural and non-structural) (Colombo *et al.*, 2002).** These are likely to be a combination of measures. Structural interventions should include short and long-term strategies, the latter including progressive conversion of paved surfaces to permeable surfaces, converting culverts to swales, etc. Non-structural interventions in South African municipal areas would include maintenance of stormwater systems, vegetation management and litter management.

c) **Developing a flood action plan in conjunction with the communities.** Community awareness and action is an important part of stormwater and flood management. Stormwater master plans should both highlight risk areas and give residents an understanding of flood behaviour (warning signs, sequence of events, consequence of disaster actions, etc.). It will also empower residents to look out for problem areas (blockages, reed growth, etc.). However, this needs to be supported by clear responsibilities actions on the part of municipalities. These will include regular maintenance programmes, effective solid waste management strategies (i.e. more than just litter management), and enforcement of by-laws.

11.4 Checklist of adaptation options to reduce climate change related flood risk

An integrated approach to managing climate change risk is necessary, particularly in the local municipal sphere of government. The checklist in Table 12 identifies a possible set of considerations for municipal managers when assessing climate change and the implications at the local level. The checklist comprises of a range of climate change related questions, which are grouped into four categories: Knowledge and Information, Response Strategies, Monitoring strategies, and General Considerations. There are four columns alongside the questions which fall under the 'Considerations' title. These columns represent the information that should be used to guide answering the questions. This checklist aims to incorporate all four approaches to evaluate climate change associated water services risks, namely:

5. Perceptions and experience of relevant communities
6. Status Quo of Vulnerability and Management in the municipality
7. Climate change projections (downscaled to a relevant scale)
8. Interpretation of Climate change projections (in this case using hydrological modelling).

This checklist should be used to ensure that a range of information is used to inform different questions related to managing climate change at the municipal level. In addition to guiding municipal responses, this checklist could be used to inform how climate and hydrological scientists conduct related research, so that the information they provide to the municipality is relevant to municipal decisions and strategies related to climate change.

Table 17. Checklist of adaptation options to reduce climate change related flood risk

General Climate Change related questions.	**Considerations**				
	CC	**Hydro**	**Public**	**Present**	**Comment**
Long-term community outcomes of CC projections					
Is strategy clear?					
Can strategy be monitored?					
Is timeframe of CC effects handled effectively?					
Do adaptive responses relate to current assets?					
Are other CC programmes specified and detailed?					
Is a specific budget allocated to:					
d) Development, maintenance and management?					
e) Research and investigation?					
f) Ongoing monitoring?					
Is a monitoring regime identified incl. mechanism, cost, duration?					
Are levels of uncertainty of projections adequately relayed?					
Is an appropriate reporting mechanism detailed?					

General Climate Change related questions.	Considerations				Comment
	CC	Hydro	Public	Present	
If outcomes are not achieved, does this have to be explained?					
Is CC identified as a regional issue requiring response?					
Do considerations comply with the relevant national policy?					
Are the necessary decisions specified with person responsible?					
Is there consistency in CC approaches across regions/adjacent municipalities?					
Is public education encouraged as a response method?					
Do responses allow for spatial variation across areas and communities?					
Are damage and costs due to possible CC effects limited or avoided?					
Is a procedure stipulated to monitor CC?					
Is CC identified as an issue?					
Are any objectives related to climate change explained and integrated adequately with policy?					
Is there a commitment by council to keep up to date with CC projections and their effects?					
Are areas with enhanced risk due to CC been identified?					
Do strategies relating to natural hazards consider CC implications?					
Are provisions and statements relating to managing CC effects appropriate for the long-term					
Do asset management plans consider the effects of CC?					

11.5 Recommendations

Table 18 outlines a range of actions that can be taken or approaches that should be fostered to minimise and prepare for the impacts of climate change on the water resource sectors at the local level and have been adopted and augmented from Kicker (2000).

Table 18. Water Adaptation Measures (after Kicker, 2000).

Plan and Coordinate Use of River-Basin. Comprehensive planning across a river basin will support coordinated solutions to problems of water quality and water supply. Planning can also help to address the effects of population, economic growth, and changes in the supply of and demand for water.	The Water Act of 1998 requires that water use should be conducted in a sustainable and equitable manner. The Act mandates the creation of Catchment Management Authorities to manage the water resources and demands
Make Marginal Changes in Construction of New Infrastructure Now. In planned construction, consider marginal increases in the size of dams or marginal changes in the construction of canals, pipelines, pumping plants, and storm drainages. This change may be much less expensive than adding capacity in the future.	The very preliminary assessment of pilot catchment in Ekurhuleni suggests that a guideline 10% increase in capacity of attenuation ponds, river conveyance and culvert sizes would be reasonable design safety factor. However, site specific assessment should still apply and new development should be scrutinised for level of risk.
Conserve Water. Reducing demand can increase excess supply, creating a greater margin of safety for future droughts. Demand for water may be reduced through a range of measures that encourage efficient water use including education, voluntary compliance, pricing policies, legal restrictions on water use, rationing of water, or the imposition of water conservation standards on technologies.	In the municipal environment there generally seems to be better control of industrial and commercial use than there is for municipal/residential use. For the latter we have • very high unaccounted for water in municipal systems, • wasteful use of potable water (garden irrigation, car washing, driveway cleaning, etc.) • poor grey water re-use and use of potable water for toilet flushing, etc. very limited rainwater harvesting.
Control Pollution. Polluting water so that it is unfit for drinking or other uses can, in many respects, have an effect that is similar to reducing water supply. Reducing water pollution effectively increases the supply of water. In turn, a larger water supply increases the safety margin for maintaining water supplies during droughts. In addition, reduced runoff from climate change will most likely increase concentrations of pollutants in the water column.	The polluter pays principle should be applied to South African municipalities. This will not only improve their own management and maintenance efforts, but will also improve their policing of individual polluters within the municipal area. The Department of Water Affairs should be given the mandate to inspect not only industrial and WWT outfalls but also spot checks of urban streams and rivers.
Allocate Water Supplies by Using Market-Based Systems. Market-based allocations are able to respond more rapidly to changing conditions of supply and also tend to lower demand, thus conserving water. Consequently, market-based allocation increases both the robustness and the resiliency of the water supply system.	Maintain a regular review of tariff structures in line with international good practice. However, these should be supported by sound public information campaigns to ensure understanding and support from the public. Where possible, include rebates or discounts for proven water saving.
Adopt Contingency Planning for Drought. Plans for short-term measures to adapt to water shortages could help mitigate droughts. Planning could be undertaken for droughts of known or greater intensity and duration. The cost of developing contingency plans is relatively small compared with the potential benefits.	Municipalities generally delegate the responsibility for provision of water services to a Water Services Provider and can therefore become disassociated from the problem of droughts. Typical measures include water conservation measures mentioned above, but these should be complimented with wider catchment strategies: • improving water quality in receiving streams and rivers, • preservation of natural storage areas (wetlands, pans, shallow aquifers, etc.). • treating stormwater as a resource rather than a waste product. • Including drought mitigation in catchment management plans (including measures for volume control for stormwater runoff, introduction of infiltration systems, etc.). • Reduce or remove alien vegetation and promote

	water wise landscaping. Develop and maintain public awareness campaigns so that communities are aware of the risks, frequencies of events, severity and consequences, as well as the current disaster action plans..
Use Interbasin Transfers. Transfers of water between water basins may result in more efficient water use under current and changed climate. Transfers are often easier to implement than fully operating markets for water allocation. Transfers also can be an effective short-term measure for responding to regional droughts or other problems of water supply.	From a water resources planning perspective inter-basin transfers are usually a last resort, though they will still be required from time to time, especially for larger municipalities in water stressed areas. Municipalities have a responsibility to engage directly in water resource planning and participate in decision making for developing new resources such as inter-basin transfers. In particular, municipalities should be accountable for their water demand and the motivation for new resources
Maintain Options to Develop New Dam Sites. Keep options open to develop new dam sites, should they be needed. The number of sites that can be used efficiently as reservoirs is limited, and removing structures once an area has been developed may be very costly or politically difficult.	As for the role of municipalities in decision making on inter-basin transfers, they should be equally active and accountable in the planning and decision making for new reservoirs.
Improve Monitoring and Forecasting Systems for Flood and Droughts. Climate change is likely to affect the frequency of floods and droughts. Monitoring systems will help in coping with these changes and will be beneficial without climate change (IPCC, 1995).	Municipal activities for this should include: • Utilise climate model predictions to provide a baseline of frequency and magnitude ot floods and droughts for the area. • Develop and maintain contingencies for coping with floods and droughts (e.g. spare flood storage capacity, spare water resource reserves). These will vary with population and urban area growth. • Include disaster management in catchment management plans. • Develop flood warning systems according to good practice and in line with budgets. Ensure the public remain well informed.
Coordinate and Integrate Across Departments and Levels. Effective adaptation requires coordination and integration across municipal and provincial boundaries, and thus relationships between different levels and jurisdictions need to be encouraged and developed. *All* departments and levels need to take responsibility for disaster management and preparation, as well as climate change	

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