The Influence of Climate Variability on flood risk in the //Khara Hais municipality (Upington area) : a GIS – based approach

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SUMMARY

The climate of the continents and the world is controlled by complex maritime and terrestrial interactions that produce a variety of climates across a range of regions and continents. Climate influences agriculture, environment, water and even the economy of countries all over the world. The climate of the world varies from one decade to another and a changing climate is natural and expected. However, there is a well-founded concern that the unprecedented human industrial and development activities of the past two centuries have caused changes over and above natural variation. Climate change is the natural cycle through which the earth and its atmosphere accommodate the change in the amount of energy received from the sun.

A hazard is a physical situation with a potential for human injury, damage to property, damage to the environment or some combination of these. It is important to distinguish between the terms *disaster* and *hazard.* A disaster is seen as a serious disruption of the functioning of a community or society, causing widespread human, material or economic losses which exceed the ability of the affected community to cope, using its own resources. Disasters can be either natural, for instance a flood, or human induced, such as a nuclear accident. Disasters may furthermore be classified as slow-onset disasters, such as a drought, or sudden disasters, such as an earthquake . The word *risk* is one of the most notable examples of words with multiple and disparate meanings that may not be commonly acknowledged. Risk may have a technical meaning, referring to a chance or probability, such as risk from exposure, a consequence or impact, an example being the risk from smoking, or a perilous situation like a nuclear power plant that creates a risk.

This study examines the influence of climate variability on flood risk in the //Khara Hais Municipality in the Northern Cape. The area that was investigated included the entire Orange River and Vaal River catchment areas where monthly rainfall data, as well as runoff data were used to produce a flood model for predicting a flood event within a two-month period, giving enough warning time to farmers and the inhabitants of the areas that may be influenced by this flood event.

Maps were produced to show the high and low rainfall amounts in the these two catchment areas where randomly selected years and months were taken, as well as showing the one-month and two-month periods before these selected dates. Examples of the highest rainfall recorded, which was in 1988, the medium amount in 1977, and the lowest amount in 1997 were selected. Furthermore, five other such examples were taken to examine the rainfall and climate variation between the years and months ranging from 1950 to 1999.

KEYWORDS

Climate variability, climate change, risk, vulnerability, hazard, flood model, El Niño-Southern Oscillation (ENSO)

OPSOMMING

Die klimaat van die kontinente en die wêreld word beheer deur komplekse maritieme en aardse wisselwerkings wat ʼn verskeidenheid klimate oor ʼn reeks streke en kontinente veroorsaak. Klimaat beïnvloed landbou, die omgewing, water en selfs die ekonomie van lande regoor die wêreld. Die klimaat van die wêreld wissel van een dekade tot 'n volgende en 'n veranderende klimaat is natuurlik en te wagte. Daar is egter met rede kommer dat die ongekende menslike nywerheids- en ontwikkelsaktiwiteite van die afgelope twee eeue veranderings buite die natuurlike wisseling veroorsaak het. Klimaatsverandering is die natuurlike siklus waardeur die aarde en sy atmosfeer verandering in die hoeveelheid energie wat van die son afkomstig is, akkommodeer.

'n Gevaar is 'n fisiese situasie wat 'n potensiaal vir menslike beserings, skade aan eiendom, skade aan die omgewing of 'n kombinasie hiervan inhou. Dit is belangrik om tussen die terme *ramp* en *gevaar* te onderskei. 'n Ramp word beskou as 'n ernstige onderbreking van die funksionering van 'n gemeenskap of samelewing wat wydverspreide menslike, materiële of ekonomiese verliese veroorsaak wat groter is as wat die aangetaste gemeenskap deur gebruik van hul eie hulpbronne kan hanteer. Rampe kan natuurlik wees, soos byvoorbeeld 'n vloed, of kan deur die mens veroorsaak word, soos 'n kernongeluk. Rampe kan verder geklassifiseer word as rampe wat stadig begin, soos 'n droogte, of skielike rampe, soos 'n aardbewing. Die woord *risiko* is een van die merkwaardigste voorbeelde van woorde met veelvuldige en uiteenlopende betekenisse wat nie altyd erken word nie. Risiko kan 'n tegniese betekenis hê wat na 'n kans of waarskynlikheid verwys, soos 'n risiko weens blootstelling; of 'n gevolg of impak, soos die risiko weens rook; of 'n doodsgevaarlike situasie wat deur 'n kernkragstasie veroorsaak kan word.

Hierdie studie het die invloed van klimaatswisseling op vloedrisiko in die //Khara Hais-munisipaliteit in die Noord-Kaap ondersoek. Die gebied wat ondersoek is, sluit die hele Oranje- en Vaalrivier-opvanggebiede in waar maandelikse reënvaldata, asook afloopdata gebruik is om 'n vloedmodel te skep om 'n vloed binne 'n tydperk van twee maande te kan voorspel wat boere en die inwoners van die gebiede wat deur hierdie vloedgebeurtenis beïnvloed mag word betyds te kan waarsku.

Kaarte is geproduseer om die hoë en lae hoeveelhede reënval in hierdie twee opvanggebiede te toon waar jare en maande ewekansig gekies is, asook om tydperke van een maand en twee maande voor hierdie gekose datums te toon. Voorbeelde is gekies van die hoogste aangetekende reënval, wat in 1988 plaasgevind het, die medium hoeveelheid in 1977, en die laagste hoeveelheid in 1997. Verder is nog vyf voorbeelde geneem om die reënval- en klimaatswisseling van die jare en maande tussen 1950 en 1999 te ondersoek.

SLEUTELWOORDE

Klimaatswisseling, klimaatsverandering, risiko, vatbaarheid, gevaar, vloedmodel, El Niño-Suidelike Ossillasie (ENSO)

ACKNOWLEDGEMENTS

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

The developing world is a high hazard zone, more than 95 percent of deaths are caused by disasters in developing countries, and losses due to natural disasters are 20 times greater (as a percentage of GDP) in developing countries than in industrial countries, according to the World Health Organisation. The possible explanation for this unequal distribution of disasters could be the result of the three basic needs of man, namely, food, shelter and safety. The best places for man to settle are where these three needs can most easily be accessed and satisfied. Locations where all these needs of man are met are very limited (Zschau & Küppers, 2003).

As the world's human population has grown over the years these ideal locations have become very densely populated, eventually forcing people to move from these sites to areas that are less suitable for human habitation. Since the 1960s the world's population doubled from 3 billion to an estimated 6 billion in 2000 (Skidmore, 2002). When people move into areas that are less suitable for habitation, they will be taking a calculated risk, because the benefits of settling in the specific location will outweigh the drawbacks. Areas that are prone to flooding are often some of the most popular locations for human settlement. This is due to the advantages of food production, in spite of an ever present danger of flooding (Blaikie, 1994).

Humans therefore put themselves at risk, knowingly living in an environment that is not always entirely safe. They also put themselves at risk by not even being aware of a hazard in the environment where they live. Dormant volcanoes are a very good example of areas that might seem to be a good place to settle, especially as the slopes of these mountains are very often rich in fertile soil and ideal for food production. When this volcano erupts, the community around it is taken by surprise and the consequences are usually much worse than in cases where a hazard has been identified and disasters are expected to occur from time to time (Zebrowski, 1997).

In modern times people have come to know their environment much better and can take mitigating measures to minimise the impact of hazards. However, as populations grow, more people move into hazardous areas and today more people are at risk of disaster than was the case in the past.

Moreover, with the alarming increase in the world's population, people are forced to live in hazardous areas because of economic, environmental and demographic reasons. Another reason is the work opportunities that exist in certain areas and cities (Blaikie, 1994). Many of the locations of the cities are very often not ideal and the result is a high concentration of people in a hazardous environment. Even after a disaster has struck, it is impossible for survivors to relocate, because their livelihood is restricted to that hazardous area (Zschau & Küppers, 2003).

Unfortunately, nowadays more people are living in hazardous areas, threatening more people with a disaster. The impact of the disasters is also much greater than it was in the past, because a greater number of people are exposed to the hazards. During the last decade, a total of 3 750 wind storms and floods were recorded worldwide, accounting for two-thirds of all disaster events globally (Skidmore, 2002). On a global scale the impact of natural disasters is very limited; less than 12% of deaths from disaster events between 1900 and 1990 can be attributed to natural disasters, although a natural disaster can have a greater impact on a local scale. It is thus important to bear this in mind for the purpose of this study (Blaikie, 1994).

The impact that any disaster has on the environment is always noticeable and gets far more attention from the media and scientists studying the cause and effects of such events. In our society there are far more hazards that do not have a huge impact in such a short time frame or across a large geographical area, but they are still a threat to the community. Over a longer period of time many more people are killed and affected by day-to-day events such as car accidents and diseases that might be the result of the pollution and degradation of our environment (Miller, 2004).

In the long run these lesser events have a much greater impact on our society than natural disasters, but we cannot exclude natural disasters completely. It is therefore important for disaster management to consider all possible hazards and not only the greater events to be able to create a safer living environment for the entire community.

Many of the current natural disasters worldwide have been linked to climate change or the more plausible climate variability. Climate variability and change profoundly influence social and natural environments throughout the world, with a consequent far-reaching impact on natural resources and industry.

For example, seasonal-to-interannual climate fluctuations strongly affect the success of agriculture, the abundance of water resources and the demand for energy, while the long-term climate change and variability may alter agricultural productivity, land and marine ecosystems and the resources that these ecosystems provide. Recent advances in climate science are beginning to provide information for decision makers and resource managers to better anticipate and plan for potential impacts of climate variability and change.

1.2 PROBLEM DESCRIPTION

In 2002 a study was conducted by NETGroup (Pty) Ltd (NETGroup, 2002) on disaster management in the //Khara Hais local municipality in the Upington area in the Northern Cape. Here, all the hazards were identified that can/would influence the area; the risks and vulnerability of each of the hazards were also identified and mitigation techniques were provided. Floods were identified as one of the hazards which could affect the //Kahara Hais municipality. So, with the aid of Geographic Information Systems (GIS) and engineers, a flood line was predicted which indicated where the flood waters would reach and what damage would be done. This is illustrated in Figure 1.1. Proper planning and mitigation strategies were consequently conducted and explored to deal with the risks and vulnerabilities of the hazard. It was known where the flood waters would be and would reach, although it was never known when it would occur, which would be more helpful in making farmers and other residents aware of the approaching hazard. This study is therefore centred around the purpose of prediction because of the ever changing and variable climate.

In the past disaster management had a reactive function; organising and managing relief and rescue efforts after a disaster struck. Today it is recognised that a pro-active approach is far more important to limit loss of life and economic losses, although the reactive function is still important. In South Africa the Act on Disaster Management has been introduced that will focuses on this new approach.

The new act, Act Number 57 of 2002 (RSA, 2002), states that all municipalities should provide for “an integrated and co-ordinated disaster management policy that focuses on preventing or reducing the risk of disasters, mitigating the severity of disasters, emergency preparedness, rapid and effective response to disasters and post-disaster recovery”.

It is thus important to identify areas that are at risk for any disaster and to introduce mitigating measures to ensure that any foreseeable impacts on the community are limited as far as possible. A great deal of information needs to be gathered and analysed in the risk and vulnerability assessment process. GIS provides the ideal platform from which to analyse large quantities of environmental, demographic, cadastral and infrastructural data and to represent it spatially in a format that is easily understood (Greene, 2002).

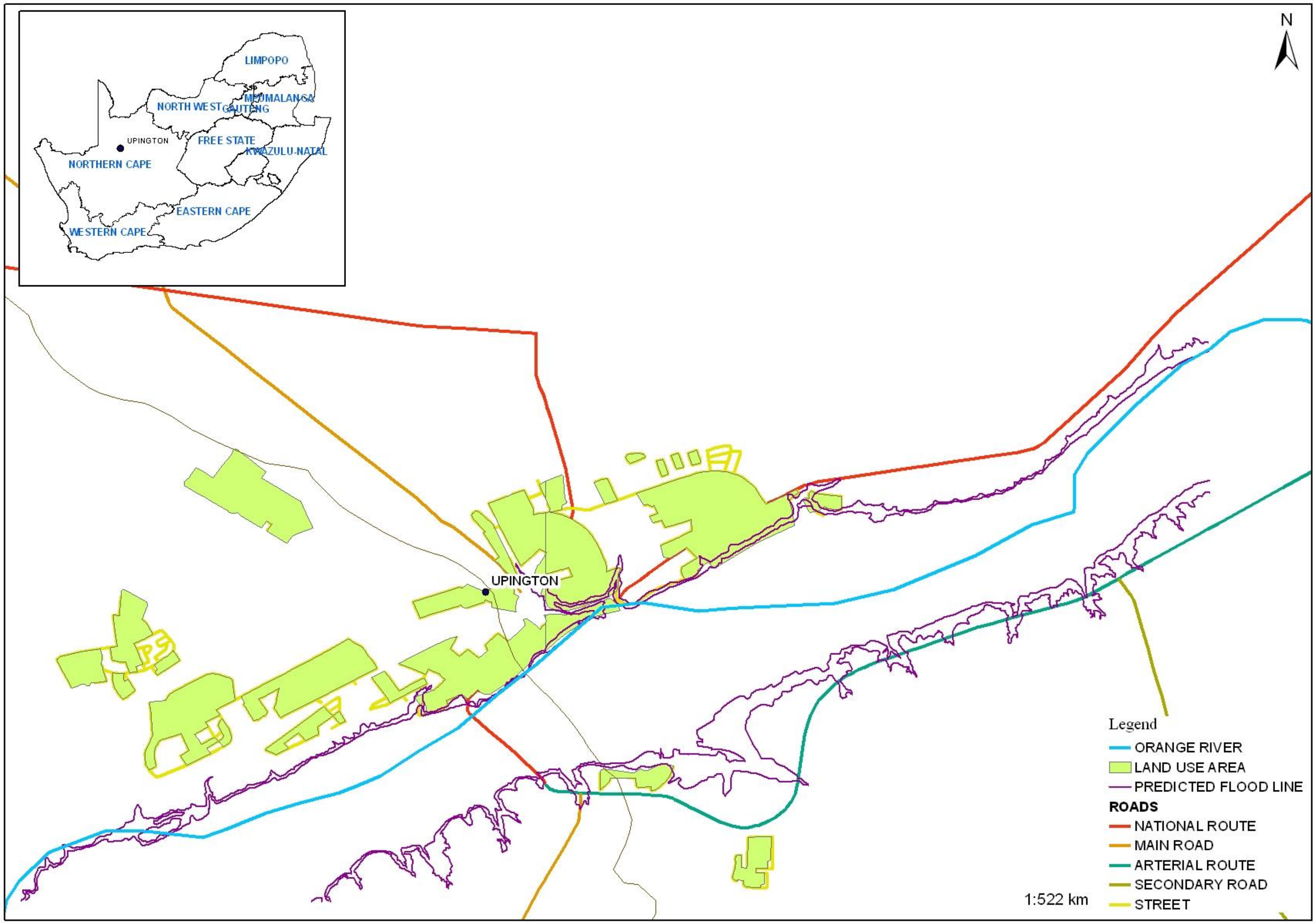


Figure 1.1 Predicted Flood Line in the Upington Region (NETGroup, 2002)

1.3 STUDY AREA

The study area in question is not only the //Khara Hais local municipality. When taking climate variability into account a large study area is needed for the results and predictions to be more plausible and correct; the Orange River and the Vaal River catchment areas were therefore used in the study as illustrated by Figure 1.2. Tertiary catchment areas were used to represent the different catchments and the quaternary catchment areas were used as an overlay on the map.

The Northern Cape is the largest province in South Africa and it shares its border with Namibia. A portion of the Kalahari Desert falls into this province and the areas skirting the desert are either arid or semi-arid. Most parts of the province receive below 400 mm of rainfall per year and the climate in the Northern Cape is mostly hot and dry. However, this does not mean that the Northern Cape consists only of sand and sun. The province is large and there is adequate space for diversity, especially in the western regions of the Northern Cape. As one moves further east, the heavy rainfall dries up somewhat and takes the form of early evening thunderstorms which are a regular feature of the late summer months. These are somewhat more dramatic than anywhere else in the country as the wide semi-arid plains are often hit by bolts of lightening as they replenish the soil’s nutrients. The climate in the eastern parts of the Northern Cape is by far the hottest and most extreme in Southern Africa (South African Weather Service, 2009).

The highest temperatures occur along the Namibian border and summer temperatures can soar above 40 ºC in extreme cases. The highest temperature ever recorded was 47.8 ºC in 1939 at the Orange River. In winter the weather conditions make a complete reversal with frosty, cool to cold weather. Temperatures in the southern parts of the province may drop as low as –10 ºC and snow often falls here (South African Weather Service, 2009).

Upington is the main commercial, agricultural and educational centre of the Green Kalahari and Gordonia regions in the Northern Cape Province of South Africa. This Southern Kalahari Desert town is situated in the fertile Orange River valley, which brings life-giving water from the Lesotho Highlands and snakes across the semi-arid Northern Cape landscape.

The Orange River that flows through Upington is the result of the confluence of the Orange and Vaal Rivers at the town of Douglas, approximately 300 km upstream. Upington is a holiday destination with all the amenities required for the many tourists who stay or travel through, as well as being an agricultural hub for one of the most intensive sultana grape farming areas in the country.

The economy of Upington relies heavily on agriculture, tourism and the services industry and many large South African companies dealing in wine, table grapes, dried fruit and livestock farming have their head offices in the town. Upington is situated on the banks of the Orange (Gariep) River in the Southern or Green Kalahari, which forms part of the 900 000 square kilometre Kalahari Desert. The geography of the town varies from sandy red dunes, rock faced 'koppie' hills, African veld and extremely fertile agricultural areas. The Orange River is a perennial, bedrock-controlled river which has been prone to severe flooding in the past. Upington is generally accepted as the hottest town in South Africa, with summer temperatures varying between 30 °C and 40 °C. Winter temperatures during the day usually reach around 25 °C, while the night temperatures, although averaging between 4 °C and 10 °C, can drop to 0 °C or below. The climate is generally dry; however, in summer, due to the town being situated on the banks of the Orange River, varying levels of humidity have been recorded. The annual average rainfall is less than 200 mm (South African Weather Service, 2009).

Records of floods that have previously occurred in the Northern Cape and Free State date back to 1954, 1976 and the last in 1988. According to the Dartmouth Flood Observatory researchers in Hanover, USA, an archive number is assigned to any flood that appears to be ‘large’: where significant damage to structures or agriculture, long intervals since the last similar event and/or fatalities occur. The severity assessment is on a scale of 1-3.

- Class 1: large flood events, significant damage to structures or agriculture, fatalities and/or 1-2 decades interval since the last reported similar event.
- Class 2: very large events, greater than 20 years but less than a 100 year recurrence interval.
- Class 3: extreme events, with an estimated recurrence interval greater than 100 years.

The flood event that occurred in 1988 in central, northern and north-western South Africa was a class 1 flood event. It lasted for 22 days, there were 24 casualties and it was due to heavy rain in the Orange River and the Vaal River.

The flood line was also higher than the level that was reached in 1974. The affected regions combined were 51 000 square kilometres (Nghiem & Brakenridge, 2003). The Vaal River joins the Orange at Douglas in the Northern Cape. In wet years the Orange and the Vaal Rivers can flood simultaneously, causing major flooding in the lower reaches. This was the situation in 1988 when the flow rate of the water measured 7.8 million cubic metres/second, but it did rise to 11 million cubic metres/second in the past. Dams have played a large role in determining the flow of the Orange River. Before they were built, the river was reduced to a trickle in the dry season, but the water regulations placed on the dams upriver now ensure a constant flow. Today there are two dams in the Orange River, namely the Vanderkloof Dam which was built in 1977 and the Gariep Dam built in 1972.

1.3.1 Orange River Catchment area

The Orange River basin is the largest river basin in South Africa with a total catchment area in the order of 1 000 000 km^2 of which almost 600 000 km^2 is inside the Republic; the remainder being in Lesotho, Botswana and Namibia (Swanevelder, 1981).

The effective catchment area is difficult to determine since it includes many pan areas and also several large tributaries which rarely contribute to flows in the main river channel. The Orange River originates high in the Lesotho Highlands some 3 300 m above sea level where the average annual precipitation can exceed 1 800 mm, with a corresponding average annual potential evaporation of 1 100 mm.

The river stretches 2 300 km from the source to Alexander Bay where the average annual precipitation drops to below 50 mm while the average annual potential evaporation rises to over 3 000 mm (Swanevelder, 1981).

According to various sources, the average natural runoff from the total basin is more than 12 000 million m^3/a. This represents the average river flow that would occur if there were no developments of any kind in the catchment. This value can, however, be very misleading since the basin is now heavily developed with the result that the current average annual runoff reaching the river mouth at Alexander Bay is less than half the natural runoff. The precise catchment is difficult to determine since it includes many pan areas and several large tributaries the runoff of which rarely, if ever, reaches the main river channel. The Orange River catchment includes the whole of Lesotho and several large river basins such as the Vaal River basin and the Fish River basin in Namibia (Swanevelder, 1981).

There are three main storage reservoirs on the Orange River, namely the Gariep Dam and Vanderkloof Dam in South Africa and the Katse Dam in Lesotho on the Senqu River. The Gariep Dam forms the largest reservoir in South Africa with a capacity in excess of 5 000 million m^3 while the Vanderkloof Dam forms the second largest reservoir with a storage of more than 3 200 million m^3. Although the storage of the Katse Dam reservoir is lower at a modest 1 950 million m^3, it has the highest dam wall in the Southern Hemisphere with a height of approximately 185 m above the foundation. The Vanderkloof Dam is currently the last main storage structure on the Orange River and it effectively controls the flow of water along the 1 400 km stretch of river between the Dam and Alexander Bay on the Atlantic Ocean (Swanevelder, 1981).

The banks of the Orange River downstream of Vanderkloof Dam are heavily developed in many areas, principally for irrigation purposes. Both the Gariep and Vanderkloof Dams are used to regulate the river flow for irrigation as well as to produce hydro-electricity during peak demand periods. Very little Orange River water is used for domestic or industrial purposes, with the exception of that used in the Vaal River basin. The Orange River basin is by far the most important river basin in South Africa and includes the Vaal River basin which is the largest and most important tributary of the Orange River. The Vaal River in turn supplies water to the industrial heartland of southern Africa, including the Pretoria and Gauteng areas.

The industrial areas supported from the Vaal River produce more than 50% of South Africa's wealth as well as more than 80% of the country's electricity requirements - more than 50% of all the electricity generated in Africa. From the Vaal River water is also supplied to some of the largest gold and platinum mines in the world, as well as to many of the world's largest coal reserves. No less than six of the nine provincial regions in South Africa are affected by the Orange River basin to some degree and some of the largest and most ambitious water projects to be undertaken in Africa are situated in the Orange River basin (Swanevelder, 1981).

1.3.2 Vaal River catchment area

The Vaal River is the largest tributary of the Orange River. The river has its source in the Drakensberg Mountains in Mpumalanga and east of Gauteng at a source known as the Ash River. It then flows southwest to its confluence with the Orange River southwest of Kimberley in the Northern Cape.

It is 1 120 km in length and forms the border between Mpumalanga, Gauteng and North-West Province on its northern bank, and the Free State on its southern bank. The Vaal River system, covering 196 438 km^2 and supports about 37% of the country’s economic activity. The greatest demand for water in this catchment is for irrigation, followed by mining and industrial use, with a similar proportion going to urban and domestic use (Basson *et al.,* 1997). The river is controlled through the Vaal Dam, the Vaal Barrage and the Bloemhof Dam. It provides water to the Crocodile and Olifants Rivers, while receiving water from the Assegaai, Buffalo, Tugela, Orange and Senqu Rivers.

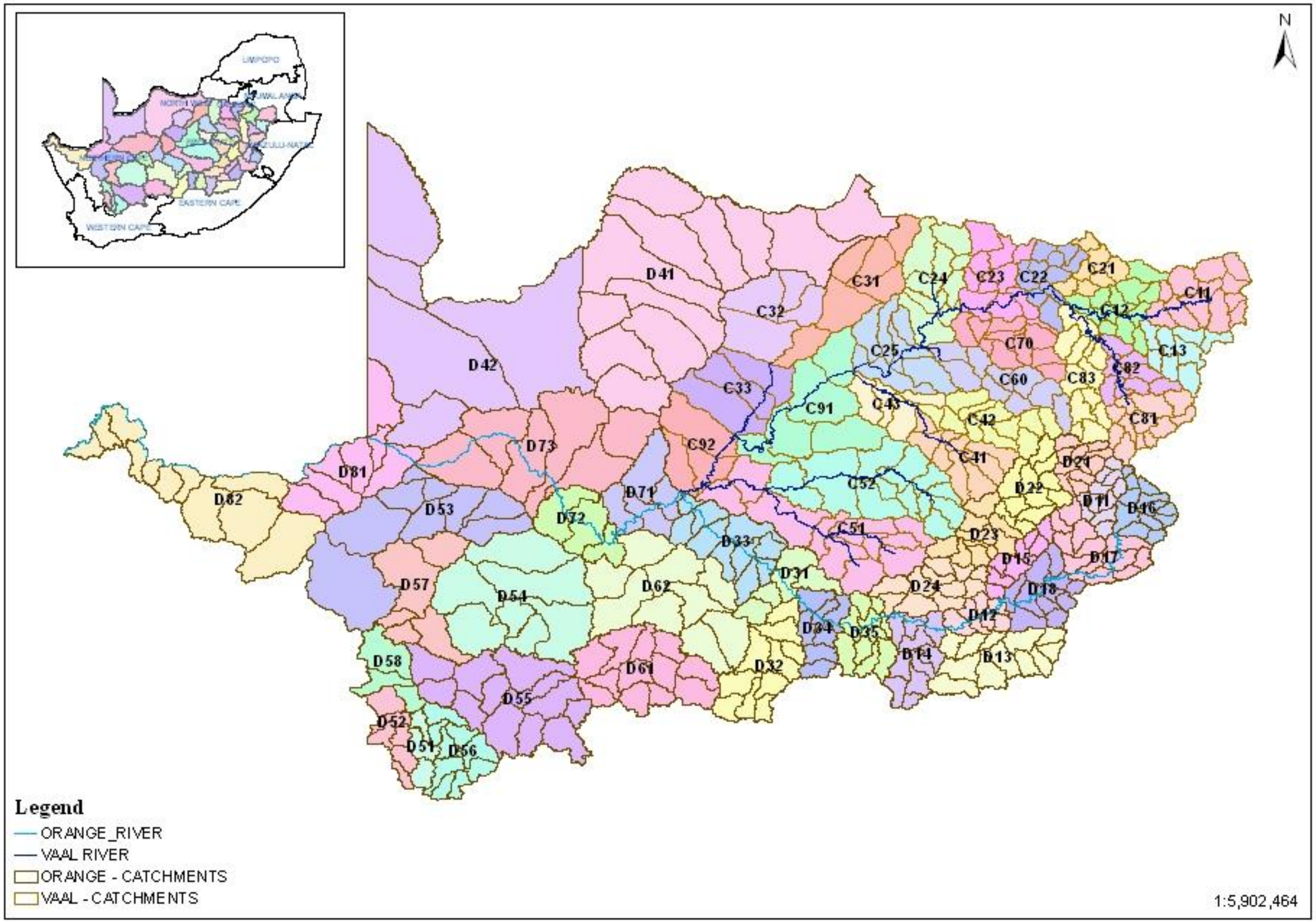


Figure 1.2: Study Area of the Orange River and Vaal River Catchment Areas

1.4 OBJECTIVE OF THE STUDY

The objective of the study was to investigate the effect and the impact of climate variability on flood risk in the //Khara Hais Municipality by applying GIS techniques. One might think that there cannot possibly be a flood risk in this part of the country, particularly because of the dry climate in the Northern Cape throughout much of the year. As mentioned earlier, a disaster management report was conducted in 2002 and floods were one of the hazards identified. Although the flood risk would only affect a few wards in the Municipality, the risk exists. For the purpose of this research project, climate variability is included in the factors contributing to the possibility of flood risk. The use of GIS techniques such as spatial analysis was used to determine the results. With the aid of statistical analysis a two-month prediction window will also be conducted using rainfall and runoff data to aid the planning and preparation of the event which may be likely in the area.

The information provided in this study will also be used to assist in building a useful information basis for future studies, as well as useful geographic knowledge about the rainfall and runoff patterns. The study also tested the effectiveness of applying GIS to prediction situations and forecast modelling. If this was successful, the hazard information would then be very useful for the Municipality to use effectively in the logical steps for prioritising hazard mitigation initiatives which were provided in the disaster management report. From this data it will be possible for decision makers to apply resources where they are most needed, whether for further research on hazards or mitigating actions in vulnerable areas. It also provides the community with information that will empower them to protect themselves from hazards in their environment.

The main aims or objectives of this study were:

- To investigate the effect and impact of climate variability on flood risk in the //Khara Hais Municipality.
- To generate maps of the catchment areas, rainfall patterns and runoff in the Orange and Vaal River areas.
- To use statistical analysis for problem solving in the study.

- With the aid of GIS and spatial analysis, to help solve the spatial problem and represent the results.

1.5 METHODOLOGY

As regards the research design, a number of the results and terms obtained from the disaster management report conducted in 2002 was used in the research, as well as new results and terms obtained from other scholars and researchers in the same or adjoining fields of study. This applies mainly to climate variability. Information is provided on climate change versus climate variability and then takes a closer look at the varying climate of South Africa over roughly the past 5 to 10 years, focusing on the Northern Cape area.

Moreover, the rainfall patterns as well as the runoff data would be mentioned. El Niño-Southern Oscillation (ENSO) is discussed as this is also an ever present factor that influences the climate in South Africa and globally. The flood plain and the surrounding dams in the neighbouring provinces were also be taken into consideration, as they also form part of the factors contributing to the flood risk in the //Khara Hais Municipality.

With the aid of GIS techniques spatial analysis will be conducted, using rainfall and runoff data. Together a conclusion and/or result would be obtained for the flood risk hazard, although it is very unlikely to reach a conclusion for this study, owing to the single factor of climate variability. *Variability* speaks for itself; always changing. So not a single conclusion will be reached, but possibly a number of possibilities or even none might be concluded. Not all research projects end in success and with an airtight conclusion, but they do contribute to other research projects, providing information that others might use.

CHAPTER 2

HAZARDS, RISK AND VULNERABILITY

2.1 HAZARDS

A hazard is a physical situation with a potential for human injury, damage to property, damage to the environment or some combination of these. It is important to distinguish between the terms *disaster* and *hazard.* According to Allen (1992) a potential damaging phenomenon, which is seen as a hazard only has the potential of becoming a disaster event when it occurs in populated areas where it can cause loss of life or major economic losses. A disaster is seen as a serious disruption of the functioning of a community or society, causing widespread human, material, economic or material losses which exceed the ability of the affected community to cope, using its own resources. Disasters may be either natural, for instance, a flood, or human induced such as a nuclear accident. Disasters may further be classified as slow-onset disasters, such as a drought, or as sudden disasters, such as an earthquake (RAVA, 2002).

2.1.1 Types of Hazards

Hazards may be classified in a number of different ways. The first distinction is between natural and human induced hazards. This method of classifying hazards may vary on a gradual scale from purely natural hazards to those of purely human origin. This classification is given in Table 2.1 which illustrates the effects humans have on their environment and *vice versa*. For example, it may be a landslide which can be purely natural due to heavy rainfall or an earthquake, but it may also be human induced as a result of the removal of vegetation or due to excavation reasons (Skidmore, 2002).

A methodology that combined two approaches was used to identify possible hazards in //Khara Hais Municipality. The first one was to use information that was provided by local stakeholders and secondly the study team's experience was used to identify common hazards.

Hazards may be classified into three categories, namely natural, environmental and human induced. These categories are than further divided into smaller classes that were used to identify all hazards in the //Khara Hais Municipality.

Workshops were held with representatives of the //Khara Hais Municipality and local councillors to gather the necessary information on hazards and historic disaster events. Individual visits to relevant disaster management personnel were also a valuable source of hazard and disaster related information.

During the workshops, brainstorming sessions were held with personnel from the municipalities and stakeholders from relevant organisations, thus ensuring that indigenous knowledge was utilised to identify potential hazards in the study area. From experience gathered in previous projects and research, it was decided that the spatial dimensions of the Municipality would be studied and if possible general hazard identification would be undertaken. The two methods (information from respondents and the consortium's experience) were combined to present a hazard identification figure. See Figure 2.1

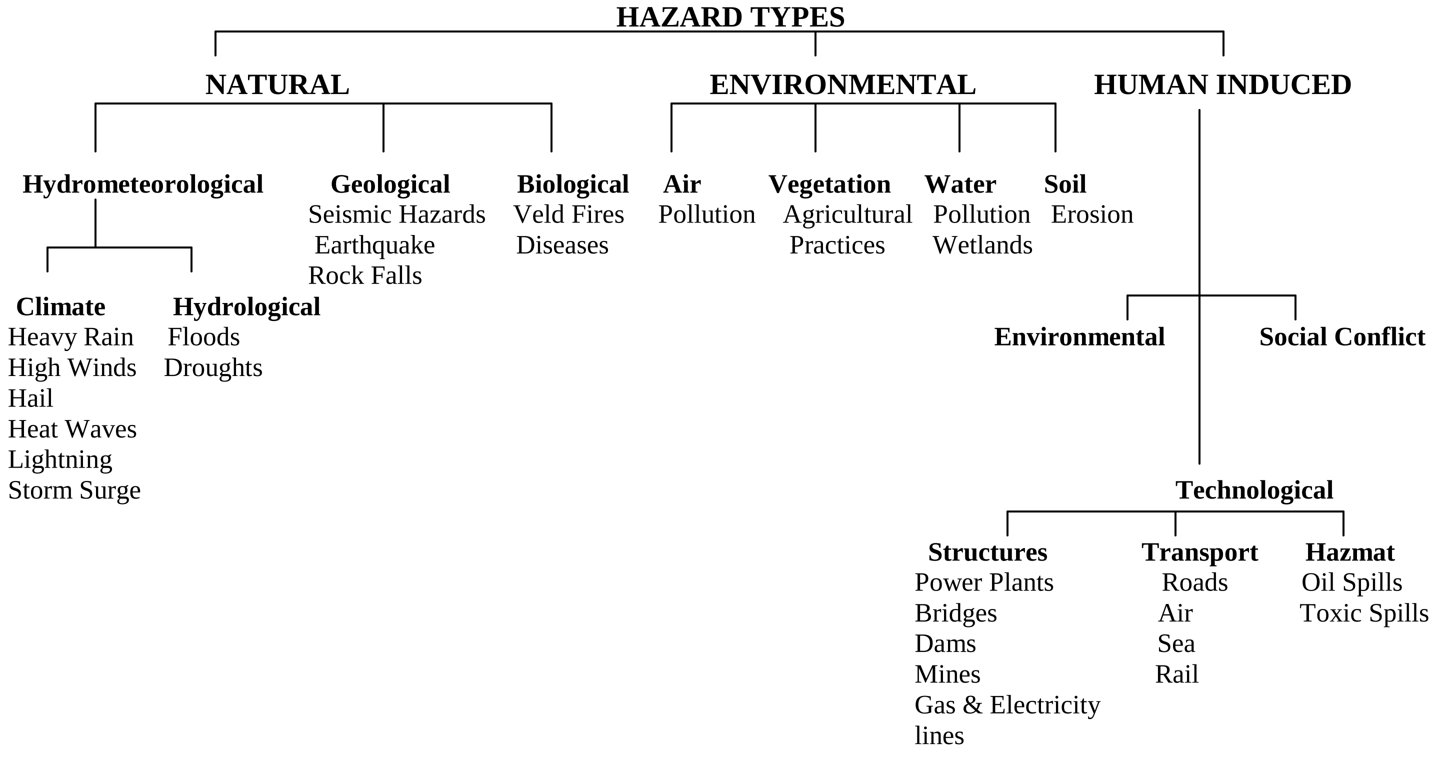


Figure 2.1: Hazard Identification in //Khara Hais Municipality (NETGroup, 2002)

2.1.2 Hazard Assessment

There are three different methods of identifying natural and human induced hazards (Miller, 2004).

- The first is by reviewing past occurrences of hazards and their impacts through historical records.
- The second is to develop hazard scenarios with the help of scientific models that can predict a specific hazard scenario.
- The auditing of historical records can provide insights into past experiences and impacts associated with hazardous events. A good example is the identification of areas where there are high road accident rates, where historical data is used to identify high hazard areas for road users.

Hazard Profile

The hazard profile was compiled using available data on hazards that could cause major disasters in a short space of time in //Khara Hais, namely fire, floods, hazardous materials, and aircraft accidents. The extent of areas vulnerable to the different hazards was overlaid to create Figure 2.2.

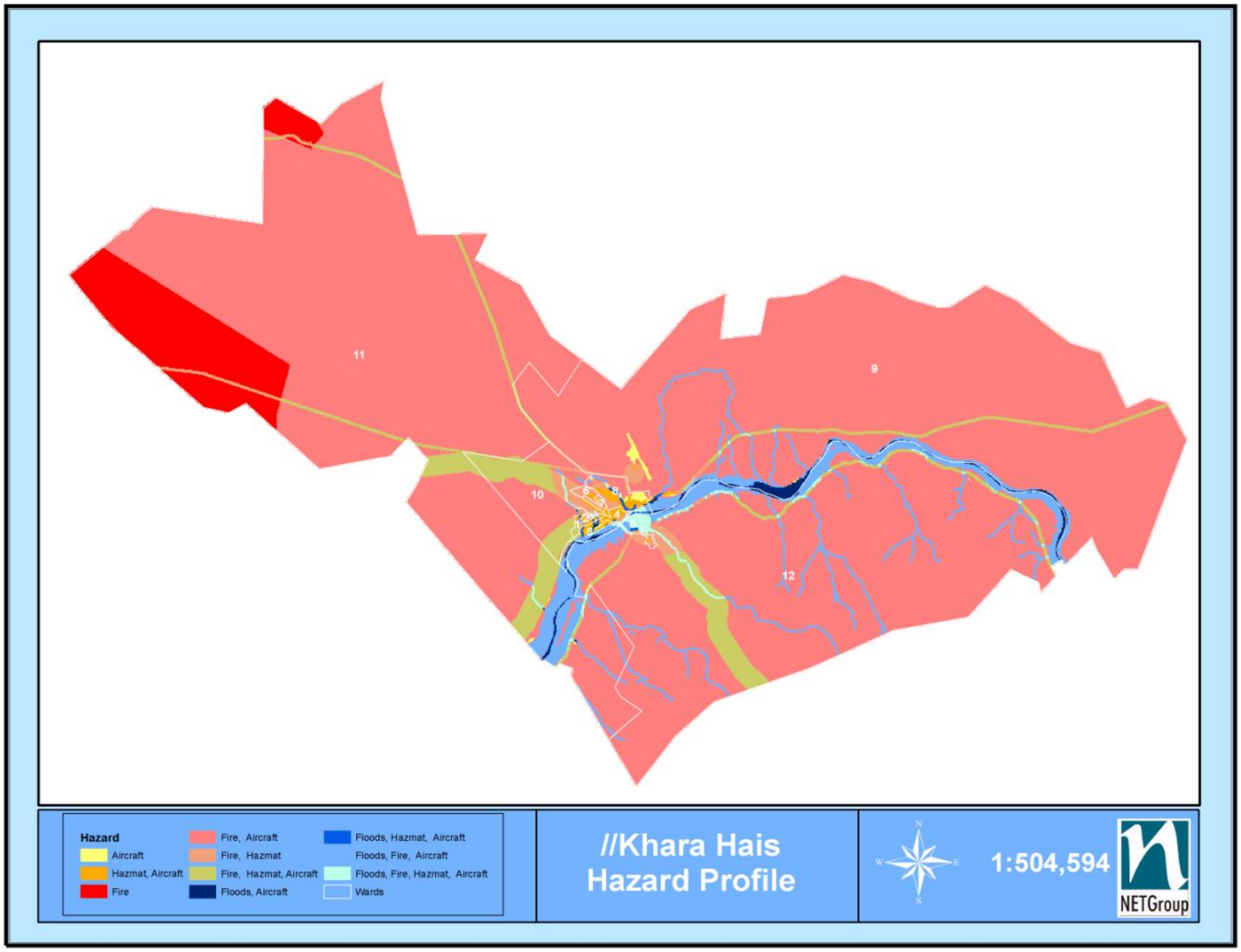


Figure 2.2: //Khara Hais Local Municipality hazard profile

2.2 RISK

Risk is defined as the possibility of suffering harm from a hazard that can cause injury, disease, economic loss or environmental damage. Risk can be expressed in terms of:

- A probability: a mathematical statement about how likely it is that some event or effect will occur
- Or frequency: the expected number of events occurring in a unit time (Miller, 2004; Allen, 1992).

The word *risk* is one of the most notable examples of words with multiple and disparate meanings that may not be commonly acknowledged. Risk may have a technical meaning, referring to a chance or probability such as risk from exposure, a consequence or impact, an example being the risk from smoking, or a perilous situation like a nuclear power plant that creates a risk (Gerrard, *et al*., 2001).

Usage of the word *risk* in the context of this study incorporates two concepts:

1. That the situation being discussed has the potential for undesirable consequences and there is some uncertainty associated with the circumstances.
2. There is uncertainty whether a hazardous event will occur, when or where it will occur, who or what will be affected and the magnitude of the consequences.

Risk in this sense includes both the probability and the character of the undesirable event. Risk as a simple definition then refers to uncertain events that can damage the wellbeing of an individual or group (Scoones, 1996).

2.2.1 Sources of risk

Risks can be either natural or human induced. Nature is the source of many risks, including earthquakes, fire and floods. Human actions very often amplify the consequences; for example, houses built in a floodplain are more likely to be damaged than houses built on higher ground (Gerrard, *et al*., 2001).

Three primary sources of risk are generated by human action:

1. *Lifestyle choices* are voluntary choices we make ourselves that put us at risk, for example excessive drinking and smoking can be a health risk, or exceeding speed limits when driving increases the risk of a traffic accident.

2. *Contractual arrangements* normally have some economic influence, especially for people working in hazardous circumstances. Police officers, for example, knowingly put themselves at risk through their career choice, but expect some offset. Another example would be a person purchasing a house near a busy airport. The person puts himself at risk of noise pollution and the danger of an aircraft accident in exchange for a lower real estate value.
3. *Externalities from choices by others* means that actions by one party create risks or costs for another. Water and air pollution by factories and an accident due to a drunken driver are good examples of externally imposed risks (Gerrard, *et al*., 2001).

2.2.2 Ordinary versus Catastrophic Risks

For the purposes of disaster management, a reasonable objective would be to target risk regulation efforts to maximize the expected numbers of lives saved for the resources spent. Such an approach would treat two situations equally:

1. Where one person faces a risk of 1/1000
2. The other where 100 people together face a risk of 1/100 000

In each case the number of expected casualties would be the same over a given period of time, but the death of 100 people in an aircraft accident or flood event would typically receive much more attention than the separate deaths of 100 individuals in non-related events such as vehicle accidents. Society is particularly concerned with large-scale catastrophes (Gerrard, *et al*., 2001). Extensive media coverage also leads people to overestimate certain risks and place undue importance on catastrophic events. For example, the thousands of lives lost to the HIV/Aids pandemic should merit the same preventive efforts as those that will be lost in a highly visible catastrophe such as a major aircraft accident (Gerrard, *et al*., 2001).

2.2.3 Risk assessment

Risk assessment involves determining the types of hazards involved, estimating the probability of each hazard occurring, estimating how many people are likely to be exposed to it and how many may suffer serious harm. The risk assessment process involves the use of data, hypotheses and models to estimate the probability of harm to human health, to society or to the environment that may result from exposure to specific hazards (Miller, 2004).

Risk assessment emphasises the estimation and quantification of risk to determine acceptable levels of risk and safety; in other words, to balance the risk of a technology or activity against its social benefits to determine its overall social acceptability (Cutter, 1993).

There is considerable disagreement over the use of risk assessment. Most of these conflicts centre on scientific issues of measurement, inference and use of quantitative data. In theory, risk assessments are objective attempts to numerically define the extent of human exposure to all the hazards they face. Unfortunately we know that science is not always objective; scientists tend to disagree on the interpretations of the quantitative evidence, depending on their own personal points of view. The question of whether the glass is half-full or half-empty lies at the centre of many debates on risk assessments (Lofstedt & Frewer, 1998).

2.3 VULNERABILITY

Because the risk that people face is a complex combination of vulnerability and hazard, it is most important that the term *vulnerability* is well understood. Vulnerability is a central theme in hazard research, yet there is very little consensus on its meaning or exactly how to assess it. Questions of geographical scale and social referent (individual, household, community, society) add to the confusion. Are we talking about vulnerable people, places or societies, and at what scale: local, national, regional or global? (World Bank, 2000).

Most of the vulnerability research to date focuses on natural hazards or global change and either examines vulnerable places based on biophysical or environmental conditions, or vulnerable people governed by political and economic conditions. Vulnerability must be viewed as an interactive and dynamic process that links environmental risks and society (Cutter, 1993).

In the dimensions of income and health, vulnerability is the risk that an individual or household will experience an episode of loss of income or health over time. But vulnerability also means the probability of being exposed to a number of other risks (violence, crime, natural disasters, etc.) (United Nations Development Programme, 1992).

In the context of this study, vulnerability may be described as a set of conditions and processes resulting from physical, social, economic and environmental factors, which may increase the susceptibility of a community or location to the impacts of hazards. It is also important to remember that vulnerability is dynamic, not static; the vulnerability of a community changes because of improvements or degradation of social, environmental and economic conditions, as well as interventions specifically aimed at reducing vulnerability, such as disaster mitigating actions (Zschau & Küppers, 2003).

2.3.1 Exacerbating circumstances

Poor people and poor communities are frequently the primary victims of natural disasters, in part because they are priced out of the more disaster-proof areas and live in crowded makeshift houses. The incidence of disasters tends to be higher in poor communities, which are more likely to be in areas vulnerable to hazards such as flooding. And there is evidence that the low quality of infrastructure in poor communities increases their vulnerability (May, 1998).

While natural disasters harm everyone affected by them, poor families are hit particularly hard because injury, disability and loss of life directly affect their main asset, their labour. Long-term disabilities and the destruction of assets can trap people in chronic poverty, while it also has been proved that malnutrition impairs children’s learning ability. Moreover, disasters destroy poor households’ natural, physical and social assets, and disrupt social assistance programmes (Zschau and Küppers, 2003).

In Ecuador, El Niño may have increased the incidence of poverty in affected areas by more than 10 percentage points. In the 1984 drought in Burkina Faso the income of the poorest third of the rural population dropped by 50 percent in the Sahelian zone (United Nations Development Programme, 1992).

2.3.2 Risk perception

According to Scoones (1996) individuals, scientists, farmers, public service personnel, aid workers, politicians – all see the hazards of the everyday world through different eyes. The way that risks are perceived and responded to is based on education background, gender, age, historical and personal experience, attitudes and behaviours derived from peers, friends and family, etc. For example, a study conducted by Scoones (1996) in the south of Zimbabwe found that the most common reason given for the occurrence of drought by farmers in the area is moral decline.

A lack of respect and changes in the moral order were seen as retribution from God or the ancestors. In contrast, scientists blamed the El Niño effect for a rise in average temperature that led to a decline in precipitation in the area.

2.3.3 Risk Management

Once an assessment of the risks in an area is made, decisions must be made on how to address these risks. Risk management includes the administrative, political and economic actions taken to decide whether and how to reduce a particular risk to a certain level and at what cost (Miller, 2004).

According to Miller (2004), risk management involves deciding:

- Which of the vast number of risks facing society should be evaluated and managed and in what order of priority with the limited funds available.
- How reliable the risk assessment performed is for each risk.

- How much risk is acceptable.
- The cost of reducing a risk to an acceptable level.
- How much each risk can be reduced using available funds.
- How the risk management plans will be communicated to the public.

Once the risk manager has decided what risks have to be reduced and by what margins, the following methods can be implemented to achieve the desired targets.

Methods of reducing an identified risk include the following:

- Avoiding the risk altogether. (Closing a factory that produces hazardous materials eliminates the risk of pollution from that facility).
- Regulating or modifying the hazard to reduce the associated risk. (Lowering speed limits might reduce the number of fatal accidents).
- Reducing the vulnerability of exposed persons or property. (Providing proper infrastructure reduces a community’s vulnerability to disease, as members then have better access to clean drinking water, health facilities and electricity).
- Developing and implementing post-event mitigation and recovery procedures. (Providing fire fighting equipment, training volunteer search and rescue teams, e.g. the NSRI).
- Instituting loss reimbursement and loss distribution schemes. (Insurance, drought relief programmes, etc.) (Gerrard, *et al*., 2001).

2.3.4 Risk communication

As a consequence of our understanding of the divergence in perceptions of risk between the public and experts, and the ensuing debates on the acceptability of such risks, a whole new area of study developed, called *risk communication*. Risk communication is a process that develops and delivers a message from the experts to the public. This one-way flow is designed to enable the public to better understand the risk of a particular hazard.

The assumption is that, if the public understands the hazard and the method of calculating the risk associated with such a hazard, they would be more accepting of any risks involved (Cutter, 1993). Unfortunately many problems are experienced with risk communication, such as the credibility of either the message or its source, self-serving or selective use of information in the message and contradictory messages from other highly regarded sources. Messages must also be understandable to the general public, without losing too much of its scientific content.

Issues of uncertainty should be expressed in terms that are easily understood, rather than numerical or probability terms (Cutter, 1993). Risks need to be measured against something to be meaningful. Depending on the analytical technique used, risk comparisons can produce very different conclusions on the relative magnitude of the risk under investigation. While messages from the experts are important, it is the general public that should provide the values to assess the scientific facts and their acceptance or rejection. Nuclear facilities are a good example where the benefits of a nuclear power plant by far outweigh the risks, according to experts, but the general public has a different perception of the risks associated with such a facility and they do not necessarily value the benefits in the same way (Barrow, 1997).

2.3.5 Geography in risk assessment

The relationship between people and their environment is viewed as a series of adjustments in both the human use and natural events systems. A change in the natural environment, such as a major flood, would have an immediate effect on the distribution of settlements in that area. On the other hand, the construction of a dam would alter the natural river system (Coch, 1992).

Hazards are connected to the geophysical processes that initiate them; for example, stress in the earth’s crust can cause solid rock to deform until it suddenly fractures and shifts along the fracture, producing a fault. The faulting or a later abrupt movement on an existing fault can cause an earthquake. It is the interaction of this extreme event with the human conditions in particular places that produce the hazard and influences responses to it (Miller, 2004). Risk is synonymous with the distribution of these extreme events or natural features that give rise to them. Much of the early hazard work mapped the locations of these extreme events to delineate risks.

These early studies also mapped the human occupancy of these hazard-prone areas and could thereby study the relationship between hazards, such as the natural environment, and risk, for instance human occupancy (Foster, 1980). These early hazard identification, assessment and risk assessments were therefore pure Geography applications.

With new advances in Geography, particularly in Geographic Information System (GIS) and the availability of digital environmental, demographical and economic data, hazard and risk assessments have become an important geographical application (Greene, 2002).

2.4 GIS IN RISK ASSESSMENT

There are many alternative definitions of a Geographic Information System (GIS), but a simple definition is that a GIS is a computer-based system for the capture, storage, retrieval, analysis and display of spatial data. GIS is differentiated from other spatially related systems by its analytical capacity, thus making it possible to perform modelling operations on the spatial data.

Geographic Information System (GIS) technology was originally developed as a tool to aid in the organisation, storage analysis and display of spatial data. The ultimate goal, however, was its application in geographical analysis. GIS has since been linked to environmental models, decision support systems and expert systems to make these systems applicable to a wide variety of spatial explicit planning and decision-making activities (Skidmore, 2002).

GIS allows a user to:

- Import geographic data, such as maps.
- Manipulate geographic data and update maps.
- Store and analyse attributes associated with geographic data.
- Perform queries and analyses to retrieve data.
- Display the results as maps or graphs.

- GIS allows users to overlay different kinds of data to determine relationships among them. Maps produced with GIS can help explain hazard events, predict the locations of hazard events, predict outcomes, visualise different scenarios and support planning strategies (Federal Emergency Management Agency, 1997).

GIS is a tool used for improving the efficiency and effectiveness of a project where geographical knowledge is of prime importance. The information in a GIS consists of two elements: spatial data represented by points, lines and polygons or grid cells, and attribute data or information that describes the characteristics of these spatial features. The spatial data is referenced to a geographical spatial co-ordinate system and is stored either in a vector or raster format (Burrough & McDonnell, 1998). Some communities and regional planning authorities maintain GIS databases for urban planning and utility management purposes.

This land use and infrastructural data provides the baseline information for a hazard assessment, as it is possible to map the extent of a hazard and compare it to this data. It is possible to profile the geographic extent of hazards because they very often occur in predictable locations. Once the possible extent of a hazard is known, it is then possible to identify communities, resources and infrastructure at risk (Zschau and Küppers, 2003).

Knowledge of how the world works is more important than knowledge on how the world looks, because such knowledge can be used to predict. The characteristics of a specific location are unique, whereas processes are very general. For example, the environmental conditions and landscape in //Khara Hais would differ drastically from Perth, Australia, but in the case of veldfires the same fuel type and quantity would burn similarly in both areas under the same climatic conditions.

These assessments are in some sense ideals, as no assessment can anticipate every eventuality, nor is such an assessment ever really finished, since hazard conditions are constantly changing. It is also important that the information gathered in such an assessment is communicated in an uncomplicated yet accurate format, easily understandable to experts and laymen alike (Greene, 2002).

GIS allows us to put the accurate physical geography of a hazard event on a computer monitor and then overlaying other relevant features, events, conditions or threats on that geography. Combined with scientific models it enables the scientist to predict the extent and impact of a hazard event on the specific location. GIS can display the location, size, value and significance of assets. It can also show the kinds of environmental, atmospheric and other conditions that give rise to particular kinds of natural hazards.

This enables disaster management, police, medical, fire and other managerial personnel to make decisions based on data they can see and judge for themselves. This spatial or geography-based method presents essential information in a way far more real and understandable than any other method (Greene, 2002).

CHAPTER 3

DISASTER RISK MANAGEMENT

3.1 DISASTER RISK MANAGEMENT CONCEPTS

The terms *hazard*, *risk* and *vulnerability* have already been defined and mentioned in the previous chapter as they are used by various authors. There are many different definitions used and understood by authors, therefore it is necessary to define what is understood by these terms. For the purpose of this study, the international definitions defined by the United Nations International Strategy for Disaster Reduction (UNISDR) 2002 are defined below and used as such.

3.1.1 Definitions and terminology

Not all hazards lead to disasters and not all incidents are regarded as disasters. A **hazard** is a potentially damaging physical event, phenomenon or human activity, which may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation.

A **disaster** is defined as a serious disruption of the functioning of a community or a society causing widespread human, material, economic or environmental losses that exceed the ability of the affected community or society to cope using its own resources. The possibility or chance of harmful consequences, or expected loss (of lives, people injured, property, livelihoods, economic activity disrupted or environment damaged) resulting from interactions between natural or human induced hazards and vulnerable conditions are defined as the disaster **risk**.

The saying, prevention is better than cure, has never been more relevant than when it is used in the case of disaster management (Vermaak & Van Niekerk, 2004). **Disaster risk reduction** is seen as the science of reducing risks to which vulnerable communities are exposed through appropriate risk reduction measures. Disaster risk reduction reflects a new global approach to the management of disasters and disaster risk. It can also be seen as the systematic development and application of policies, strategies and practices to minimise vulnerabilities and disaster risks throughout a society, to avoid (prevent) or to limit (mitigate) the adverse impact of hazards, within the broad context of sustainable development (Vermaak & Van Niekerk, 2004:556).

Not all disasters impact directly on a community. The terms *primary* and *secondary impact* are used to describe the different causes and scales of potential damage and/or impacts by a hazard event. Primary impacts are also termed *direct impacts*, such as loss of housing through flooding. If an outbreak of disease such as cholera follows a flood, the cholera outbreak is then a secondary or *indirect impact*. A flood, for example, can result in the malfunctioning or complete unavailability of sewage systems. This does not only lead to the spreading of disease via untreated sewage, but can also lead to a series of environmental conditions.

Disaster management is defined by the Disaster Management Act No. 57 of 2002 (RSA, 2002) as a continuous and integrated multisectoral, multidisciplinary process of planning and implementation of measures aimed at:

- Prevention or reduction of the risk of disasters
- Mitigation of the severity or consequences of disasters
- Emergency preparedness
- A rapid and effective response to disasters
- Post-disaster recovery and rehabilitation

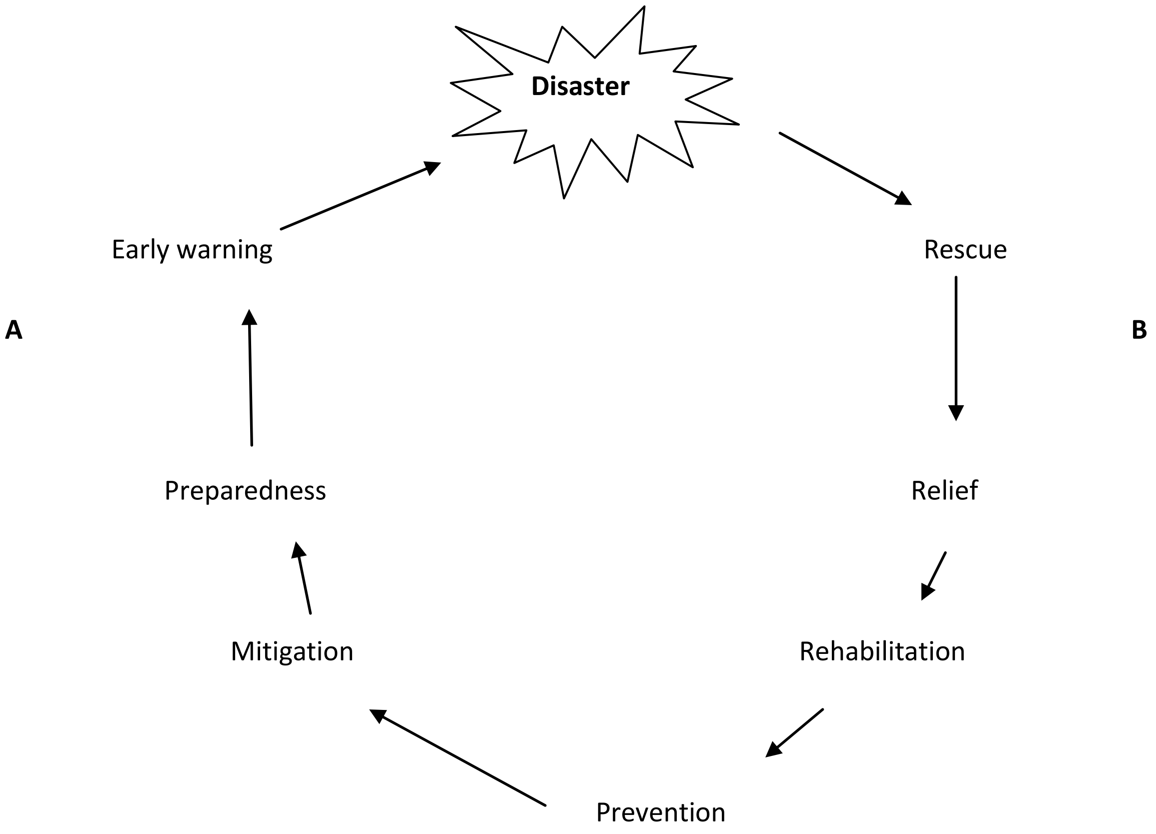


Figure 3.1: The disaster management cycle (Vermaak & Van Niekerk, 2004:557)

Notes: A = Pre-disaster reduction phase; B = Post-disaster recovery phase

Disaster management internationally entails the integration of pre- and post-disaster activities to safeguard lives and property against possible disasters. One significant problem with disaster management as a discipline and the application of the cycle as illustrated in Figure 3.1, is that it still has a disaster oriented focus. All the activities are drawn towards a disastrous event. In most cases, the underlying causes of these disasters are not considered, or are the product of ignorance.

Another weakness in the application of the cycle is that a number of practitioners view its implementation as a phased approach where the activities follow a sequential path.

It is often not recognised that each of the cycle's processes occurs simultaneously (Vermaak & Van Niekerk, 2004).

It is also important to acknowledge that not all disasters are natural. Previously, the terms *natural* and *man-made* were commonly used. Now, however, it is a recognised practice to use the classification by the UNISDR (2002), as given below.

Natural hazards are natural processes or phenomena occurring in the biosphere that may constitute a damaging event. Natural hazards are typically classified as:

- Geological hazards: Natural earth processes or phenomena in the biosphere that include geological, neo-tectonic, geo-physical, geo-morphological, geo-technical and hydro-geological nature.
- Hydro-meteorological hazards: Natural processes or phenomena of atmospheric, hydrological or oceanographic nature.
- Biological hazards: Processes of organic origin or those conveyed by biological vectors, including exposure to pathogenic micro-organisms, toxins and bioactive substances.

Technological hazards are dangers originating from technological or industrial accidents, dangerous procedures or certain human activities, which may cause loss of life or injury, property damage and social and economic degradation.

Environmental degradation involves processes induced by human behaviour and activities (sometimes combined with natural hazards) that damage the natural resource base or adversely alter natural processes or ecosystems.

3.1.2 Disaster Risk Assessment: Methodology

3.1.2.1 Disaster Risk Management and the Integrated Development Plan (IDP)

The Disaster Management Act (Act 57 of 2002) (RSA, 2002) requires that a Disaster Management Plan of an area form an important part of the Integrated Development Planning (IDP) process. The National Spatial Development Perspective (brought forward in May 2006) has broadened the functionality of the IDP (Act 32 of 2002).

It focuses on development planning in a spatial content, not a managerial entity, irrespective of the sphere of government responsible for certain functions. Two of the most profound processes of development planning at municipal level in South Africa are the development of land development objectives and Integrated Development Plans (IDPs) for all municipalities.

The IDP is a legislative requirement, which has legal status and therefore supersedes all other plans that guide development at local government level. The development of a disaster management plan therefore forms an integral part of the IDP. The aim of a disaster management plan is to enhance the capacity of the municipality to assess risks, prevent and deal with hazards and avoid developments that are subject to high risk and possible disaster.

Such a disaster plan should include and outline the following:

- Likely types of disasters or hazards and specific locations or communities at risk;
- Prevention and mitigation strategies for each of the likely types of disaster;
- Contingency plans and emergency procedures that ensure maximum emergency preparedness, under consideration of available capacities; and
- Roles and responsibilities of all role-players.

The guidelines for the preparation of IDPs suggest that rather than taking possible disasters into consideration, municipalities must focus on likely risks. Disaster management officials at government level are, however, not knowledgeable about the IDP process or the elements that should be included in a comprehensive disaster management plan. They thus approach outside authorities and/or scholars who are more knowledgeable about the process and the elements. There is also apparent confusion about the difference between disaster management plans and contingency plans (Vermaak & Van Niekerk, 2004).

Until the National Disaster Management Centre (NDMC) gives clear guidance on these issues to local authorities, one can expect that risk assessment will be a haphazard and a somewhat tedious exercise.

3.1.2.2 Assessing disaster risk: general methodological approach

Disaster risk is defined as the possibility or chance of harmful consequences or expected loss (of lives, people, injury, livelihoods, economic activity disrupted or environmental damage) resulting from interactions between natural and human induced hazards and vulnerable conditions (UNISDR, 2002). In general it is agreed that risk is a function of hazard, vulnerability, resilience, capacity to cope and exposure. In mathematical terms it is expressed as:

$$R = f(H, V, CC, E, R, \ldots)$$

Where: R = Risk

H = Hazard

V = Vulnerability

CC = Coping capacity

E = Exposure

R = Resilience

The exact mathematical relation between the variable is however unknown, although many scholars agree on a basic equation where Risk = Hazard x Vulnerability (Villagran de Leon, 2006). The same author suggests that Risk = Hazard x Vulnerability x Deficiencies in Preparedness. This definition is similar to the basic definition of risk defined by Botha and Louw (2004) where

R = Hazard x Vulnerability / Manageability.

Manageability is generally referred to as ‘capacity to cope’. It should therefore also be taken into account when quantifying risk in any manner. Care should be taken, due to the fact that a certain variable may be over- or under-emphasised. When approaching disaster risk, there are a few steps to be followed. A brief description of the steps is given below.

Step 1: Information collection

Information regarding all existing hazards and prevailing conditions in the area needs to be collected. Information collection should not be limited to climate-related information and a thorough literature search on existing and threatening hazards should be conducted at the same time. Information is also collected on the demography, groundcover, land use, infrastructure and topography of the area or the municipality.

Step 2: Hazard Assessment

The purpose of the hazard assessment is to assess current and future hazards. The assessment involves the listing of hazards that occurred in that area in the past, as well as the incidence and impacts of these hazards. Future hazards are also researched during this step.

Using questionnaires, the assessment is ideally initiated in a workshop environment, in consultation with disaster management role-players in that area (Botha & Louw, 2004).

Step 3: Risk Profiling Assessment

The risk profiling assessment is conducted spatially and qualitatively and uses the information collected in the information collection and hazard identification phases to complete the following steps:

Primary Impact Mapping: The primary areas of incidence for each identified hazard should be mapped. This is followed by a vulnerability analysis to determine the impacts of the identified hazard on society, the environment, the economy and critical facilities.

Societal Vulnerability Analysis: The focus of this step is to identify those areas where individual resources are minimal.

Environmental Vulnerability Analysis: The purpose of this analysis is to identify locations where there is a potential for secondary environmental impacts from natural hazards and to target vulnerable locations for risk reduction activities.

Economic Vulnerability Analysis: Economic vulnerabilities to hazard impacts are to be identified.

Critical Facilities Vulnerability Analysis: This analysis focuses on determining the vulnerability of key individual facilities or resources within an area.

Step 4: Risk Prioritisation

The South African National Disaster Management Framework (RSA, 2005) gives certain guidelines on the execution of a disaster risk assessment and specifically instructs that the level of risk associated with a hazard is estimated to determine whether it is a priority or not.

When several hazards (threats) are present in an area, it is then necessary to conduct a process called *risk evaluation*. This is done because it is unlikely that there will be enough budgets and resources to deal with all of the threats simultaneously. The prioritisation of risks therefore assists in the allocation of budgets across the various areas in a municipality.

This methodology uses the term *risk prioritisation* to comply with the stipulations in the national framework and is based on methodologies used by the United States Federal Emergency Management Agency (FEMA), the United Nations Disaster Management Training Programme (UNDMTP) and the Cranfield Disaster Management Centre (Botha & Louw, 2004).

Step 5: Inclusion in Sectoral Plan

Once the mapping of the risk profiles for communities in the district has been completed, the spatial information is submitted to the municipality with the recommendation that is should be included in the Spatial Development Framework (SDF), the Local Economic Development Plan and the Medium Term Expenditure Framework. This enables intersectoral and interdepartmental planning practices.

Such a disaster management plan with all its aims and methodologies was conducted for the //Khara Hais Municipality. The disaster management plan was conducted by NETGroup, together with WATEES and several hazards were identified in the Municipality, namely lightning, floods, drought, geological hazards, air pollution, water pollution, environmental degradation and soil erosion. For each of these hazards, maps were provided to illustrate where the hazards occurred in the municipal area. Then a vulnerability assessment was conducted on the income levels of the population, the basic needs approach, as well as for the health facilities and police stations.

Then hazard, vulnerability and risk profiles where illustrated and conducted of the effects on the community and the environment. After this had been done, possible planning and mitigation scenarios were given and examined for the area affected by the hazards and this report was submitted to the //Khara Hais local government for them to use and plan accordingly.

CHAPTER 4

FLOODS

4.1 INTRODUCTION AND BACKGROUND

South Africa is not prone to spectacular, destructive and media-attracting disasters such as volcanic eruptions, massive earthquakes and tsunamis. South African disasters are localised incidents of veld fires, informal settlement fires, seasonal flooding in vulnerable communities, droughts and human-induced disasters such as oil spills and mining accidents. Of late, the impact of HIV/Aids on the economy of South Africa has increasingly become under a watchful eye all over the world.

For the purpose of this study, the disaster of the hazard, floods, was examined in the //Khara Hais Municipality, commonly known as Upington in the Northern Cape Province. The overview of this region was given in chapter one; the flood problem globally and nationally, as well as the common flood prediction methods employed by hydrologists in South Africa, is therefore further discussed. Some disadvantages of these methods will be mentioned and the recommendations will also be discussed in this section.

Estimating the probabilities of extreme floods is a significant and challenging problem. It is important because the stakes are high: very large floods kill people, destroy property and the cost incurred in attempting to avoid these damages can be great. The probabilities that such floods will occur during the life of a particular project are a crucial part of the analytical input for making decisions about that project (Water Science and Technology Board, 1988, p. viii). The enormity of the flood problem was acknowledged by the American Meteorological Society (1978) who stated that flash floods now rank as the most destructive weather-related natural hazard in the USA. This contention is supported by statistics indicating that between 1973 and 1979, 80% of the 193 declared national disasters by the US President were flood related (Lundgren, 1986). Worldwide losses when measured in terms of deaths as a result of floods are staggering. A selection of this is presented in Table 4.1.

Table 4.1: A selection of major flood disasters (Zawada *et al*., 1996:2)

YEAR	REGION	DEATHS
1642	China	300 000
1887	Hwang – Ho River, China	800 000
1889	Johnstown, Pennsylvania	2 100
1911	Yangtze River, China	100 000
1939	Northern China	2 000
1953	Northern Europe	2 000
1960	East Pakistan	10 000
1963	Vaoint, Italy	2 600
1966	Arno Valley, Italy	113
1970	Bangladesh	300 000 – 500 000
1972	Eastern United States	118
1972	Rapid City, South Dakota	232
1976	Big Thompson Canyon, Colorado	139
1981	Laignsburg, South Africa	104
1987	Natal, South Africa	200
1988	Bangladesh	2 000
1988	Southern Thailand	373

Although South Africa has not experienced floods of the magnitude that other countries experience and that lead to large numbers of deaths as represented in Table 4.1, it has experienced severe floods. An example is the period between 1973 and 1988, when more than 1000 deaths were flood related (Alexander, 1988). These floods include the Laingsburg floods mentioned in the table above, and the flood in Upington which occurred in 1988.

4.2 FLOOD MODELLING

The term *risk* in the context of natural hazards is interpreted in many different ways. For the purpose of this study, the term *risk* is defined in chapter two. *Hazard* in the study is defined as a characteristic of, or phenomenon from, the natural environment which has the potential for causing damage to society (Kelman, 2002).

Estimating flood hazard involves estimating two types of probability, namely the probability of an event exceeding a given magnitude and the probability of inundation during any particular event. There is a wide variety of flood models that can be used to this end. Many of these current models are erroneous because some of the models are applied to areas where there is a shortage or no historical data available; therefore assumptions that the available data is correct are then erroneously applied. Moreover, many of these models have been designed for large scale applications, although their results are also used on a local scale to determine flood hazard and/or risk (Pappenberger, *et al*., 2007).

It is clear that although floods have always posed a threat to man in terms of loss of life and damage to property, many believe that floods occur randomly with seemingly little hope to predict their magnitude and when they will occur both spatially and temporally. Although much research has gone into the development of sophisticated techniques, there is still a large number of deaths and damage to property due to catastrophic floods. Despite the realisation by hydrologists that there is great difficulty in assessing the risk of large magnitude flood events, it is nonetheless a vital requirement in South Africa that this assessment be done in all cases where development is potentially at risk from flooding.

Increasing development in flood prone areas has identified the need to improve our understanding and predictive abilities (Zawada, Hattingh & Van Bladeren, 1996). Design flood estimation in South Africa is generally based on empirical and deterministic models such as the rational method, unit hydrograph and the SCS model (Alexander, 1990). The other types of flood models are those known as statistical methods.

4.2.1 Types of Flood Models

Design flood estimation in South Africa is generally based on empirical and deterministic models, such as the rational method, unit hydrograph and the SCS model (Alexander 1990). Statistical and regional techniques are described and applied to some areas, but little effort has been devoted to the development and application of regional estimation techniques. According to Chetty and Smithers (2005), flood estimates are often required by engineers, hydrologists and even agriculturalists for the design of hydraulic structures, namely dams and bridges. An under- or over-design of these structures can occur and there is then a waste of resources; it is therefore important to have accurate design flood estimates. On the humanitarian side, the loss of life, property and infrastructure also leads to the importance of improving the ability to predict the magnitude and frequency of floods.

As described in the previous section, there are three different types of flood estimation methods, namely deterministic methods, empirical methods and statistical analysis. The use of regional flood frequency analysis has two advantages. The first is that the reliability of the estimated design events increases because of the inclusion of additional spatial information. The second is that the design events can be estimated at ungauged sites, i.e. sites where no measurements of floods exist (Kjeldsen, Smithers & Schulze, 2001:315).

A popular and widely used regional method is the index-flood method. To use this method for estimation at ungauged sites, a relationship, based on regression models, between the index-flood which is often the mean annual flood (MAF) and the corresponding catchment characteristics has to be developed. However, it should be noted that the reliability of the estimation is significantly lower than the estimate made from a gauged site. This leads to the construction of gauging weirs in the areas where flood estimation was needed. This notion was prompted by the NERC (1975).

Cordery and Pilgrim (2000) suggest that research in design flood estimation is declining and there is a significant gap between design flood research and practice. This needs to be addressed if design flood estimation practice is to be improved. Generally speaking, the approach to the type of design flood method and estimation varies due to the availability of the data needed.

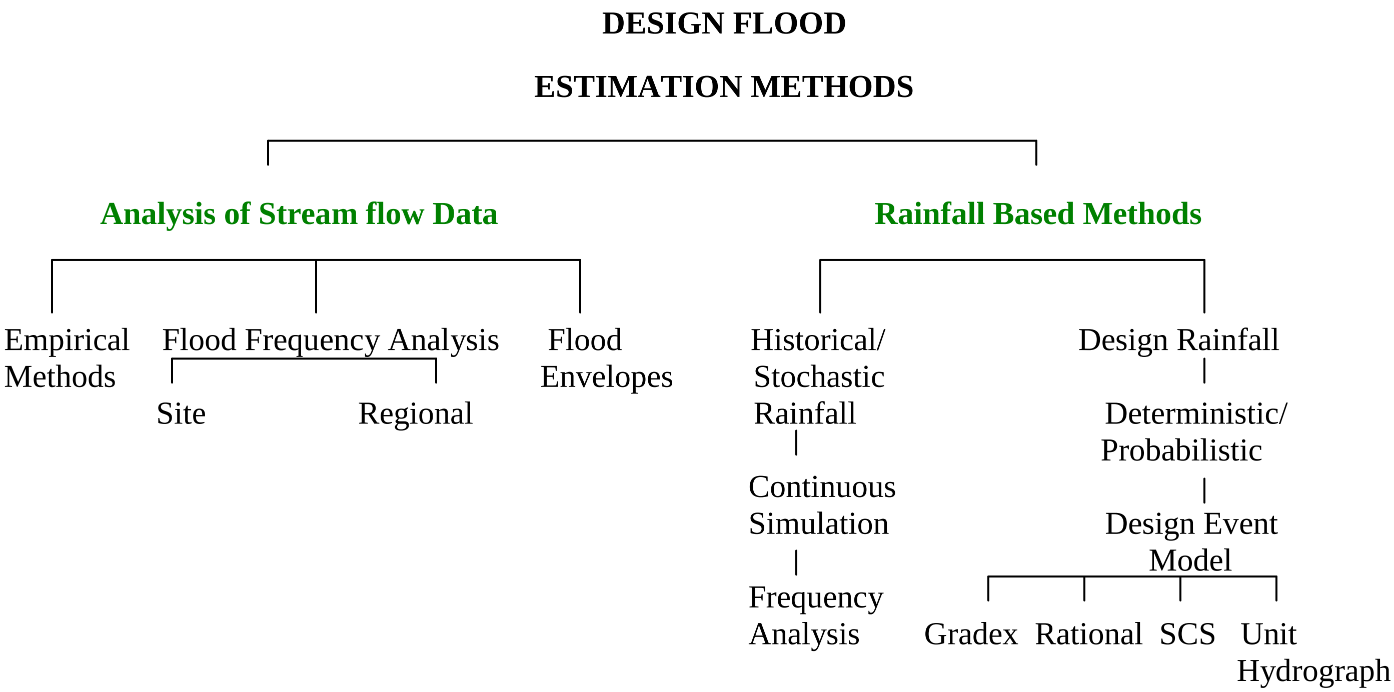


Figure 4.1: The general approaches to design flood estimation (Smithers & Schulze, 2000)

A number of studies and reviews have shown that regional analyses are advantageous (Hosking & Wallis, 1997). There is also very often inadequate stream flow data available owing to the scarcity of recorded flow data, or flow records which are too short for frequency analyses. If this is the case, rainfall-runoff models are often used instead, as more data is available. These rainfall-runoff models make several simplifying assumptions which are significant in design flood estimation.

4.2.1.1 The index-flood method

The key factor underlying the index-flood method is that the annual maximum series (AMS) of floods from different sites are identically distributed except for a scale parameter, which is termed the *index-flood*. This method requires the identification of homogeneous regions. The T-year event (X_T) at any site within the homogeneous region can be estimated as:

$$X_{T,\mathrm{I}} = \mu_i Z_T$$

Where:

μ_i = MAF at site *i*

Z_T = (1-1/*T*) quintile in the regional frequency distribution of normalised AMS.

The regional growth curve Z_T describes the relationship between the normalised flood magnitude and the corresponding exceedance probability and is considered constant within a homogeneous region (Kjeldsen, Smithers & Schulze, 2001). There has also been recommendations that the General Normal (GNO), the Pearson Type III (P3) or the General Pareto (GPA) distributions are regional distributions of the normalised AMS for floods in the western and north-western parts of KwaZulu-Natal. A study was conducted using the annual maximum series (AMS) of flood flow from relatively unregulated rivers in KwaZulu-Natal.

The study included the identification of homogeneous regions based on cluster analysis of site characteristics and identification of suitable regional frequency distributions. The index-flood method was used. The traditional at-site estimation of design floods considers only the data available from the specific site which is being studied and the reliability of the estimate is directly related to the length of the series available. This method also includes information from nearby stations exhibiting similar statistical behaviour as the site being studied, to obtain more reliable estimates (Kjeldsen, Smithers & Schulze, 2002).

The index-flood method can also be used to obtain estimates at ungauged sites, which is an important factor because it can then be used in countries such as South Africa, where the flow gauging network density is relatively low. For the study conducted in KwaZulu-Natal the AMS were available for 29 gauging weirs.

The AMS were initially abstracted by DWAF from records on contentious water level readings, converted into flow measurements using water level flow rating curves (Van Bladeren, 1995).

Numerous factors went into determining the flood frequency and estimation for the study, namely:

- At-site characteristics – these are the at-site characteristics for each AMS
- Site characteristics – these should be easily accessible from readily available information, mapped values and electronic format or data. Some values include latitude, longitude, mean annual precipitation, rainfall concentration, mean catchment slope, altitude and soil characteristics.
- Identification of homogeneous regions – this includes heterogeneity tests and the clustering of stations.

The concluding remarks were that the index-flood method is one of the most frequently used flood methods for gauged sites and the results are of a relatively high and reliable standard. Although much data and many steps are involved in conducting this method, it is worth the scholar’s while, time and effort to do so, as the ultimate results are of a high quality.

4.2.1.2 Continuous simulation modelling

The continuous simulation modelling (CSM) rainfall-runoff approach to design flood estimation has many advantages and has the potential to overcome many of the limitations of the design event approach.

Rahman, *et al*. (1998) claim that the continuous simulation models are aimed at representing the major processes responsible for converting the input catchment rainfall into streamflow. An important trait of these models is the use of a continuous water budget model for the catchment so that antecedent conditions for each storm are known. The views of several scholars and authors were interesting in their conclusion that CSM is regarded as having the potential for solving the limitations of the current single event approach to design flood estimation. The need for the use of a synthetic storm is null and void when using the actual storm records; this being one of the advantages of CSM. Secondly, selecting antecedent conditions for the land surface is not required, because a water budget is accounted for.

The duration of the storm is also not an issue as antecedent moisture conditions (AMC) and the water budget are specifically modelled for each time step; the assumption that the return period of the output streamflow is the same as the return period of the input rainfall therefore no longer has to be made.

Some of the disadvantages as highlighted by Rahman, *et al*. (1998) are that the CSM includes the loss of ‘sharp’ events if modelling time scale is too large. The extensive data requirements then require significant time and effort to obtain and prepare the input data and the expertise required to determine parameter values so that historical hydrographs are adequately simulated. Despite the limitations, CSM may prove to be the most powerful means of flood frequency estimation by rainfall. This method is proving to be favoured globally, also in the United Kingdom. According to Calver and Lamb (2000) CSM may form the basis for the next generation of flood frequency estimation in the United Kingdom. A pilot study was conducted by the School of Bioresources Engineering and Environmental Hydrology at the University of KwaZulu-Natal to assess the development and outcomes of a continuous simulation modelling system for design flood estimation in South Africa. The Agricultural Catchments Research Unit (ACRU) model was selected and the study was conducted for the Thukela catchment area in KwaZulu-Natal.

According to Smithers, *et al*. (2001), the ACRU model is a physical-conceptual agrohydrological model which operates on a daily time scale. The model simulates all major processes of the hydrological cycle which affect the groundwater budget and is capable of simulating, *inter alia*, streamflow volume, peak discharge and hydrograph, reservoir yield, sediment yield, crop yield for selected crops and irrigation supply and demand. The model can operate as a catchment model or as a distributed cell-type model to account for the spatial variability aspect in climate, land use and soils. The ACRU system is linked to the quaternary catchments database. South Africa is divided into numerous primary catchments, each of these having been further subdivided into secondary, tertiary and quaternary catchments by the Department of Water Affairs and Forestry (DWAF) of South Africa for planning and management purposes. There are altogether 1 946 quaternary catchments and the quaternary catchments database stores information such as location, rainfall, soils and groundcover information for every quaternary catchment, which are in turn used for modelling purposes (Chetty & Smithers, 2005).

To meet the objectives set for the pilot study, the following methodology was used:

- A 253 km² quaternary catchment was selected and sub-divided into 9 sub-catchments according to the topography.
- The Calc-pptcor suite of programmes was used to determine the closest and most representative rainfall station whose daily rainfall values were used.
- All the other input variables for ACRU were obtained from the quaternary catchment database. The model was run from 1950 to 2000.

According to Chetty and Smithers (2005:637), the results obtained from the pilot study on the Thukela catchment indicated that simulated streamflow depths from lumped quaternary scale catchments were much greater than the simulated streamflow depths obtained from dividing the catchment into sub-catchments. This implies that the quaternary catchment scale of modelling is not adequate and the quaternary catchments need to be divided into sub-catchments for realistic results. It should also be noted that the results obtained from the ACRU model are specific to the area in which the study will be/was done.

4.2.1.3 Deterministic Methods

The principal assumption involved in deterministic methods in flood-peak estimation is that the annual exceedance probability (AEP) of the resultant flood is the same or is dependent on the causative rainfall (Alexander, 1990). This relationship may be expressed in the following simple equation:

$$Q = C\ I\ A$$

Where the variable:

Q represents discharge

C represents the runoff coefficient

I represents the rainfall intensity

A represents the area of the catchment

Specifically, the magnitude of a flood is a function of the following variables as suggested by Alexander (1990):

- Storm rainfall properties (variable I) such as the depth-duration frequency relationship of point rainfall and the relationship between point rainfall and rainfall over the catchment.
- Catchment characteristics such as area, slope, soil permeability and vegetation cover (variables A and C).
- Catchment processes which control the conversion of rainfall into runoff such as inception, infiltration and sub-surface movement of water (variable C).
- Antecedent conditions which modify the catchment processes such as antecedent rainfall and antecedent river flow (variable C).

In reality it is difficult to estimate the temporal and spatial variation of storm rainfall across the entire catchment from rainfall gauging data. To calculate the magnitude of a flood for a particular catchment requires records of historical spatial and temporal characteristics over the catchment exhibiting certain characteristics that modify the conversion of storm rainfall to river discharge.

The advantage of deterministic methods in flood-peak estimation is in attempting to understand and integrate the many variables that control runoff. It is an attempt to understand the flood-producing system at a holistic level.

Kovacs (1988) claimed that, although the deterministic methods need to be given merit, some of the variables when used during extreme flood conditions are either imprecisely known and/or represent as yet unverified hypotheses. Hence, the error of flood-peak estimation may even reach the magnitude of the probable maximum flood (PMF) itself. Kovacs (1988) supported this claim by referring to a flood-peak estimation study of over 100 dam sites in South Africa by the Department of Water Affairs and Forestry (DWAF) using deterministic methods, whose results gave grossly unrealistic and inconsistent figures. Other scholars also supported this claim, adding that deterministic methods exhibit the problem of dimensionality, where, unless a precise understanding of the interaction between independent variables exists, the inclusion of additional variables will actually decrease the accuracy of the prediction.

A further problem associated with deterministic methods is the inability to derive the annual exceedance probability of a flood because the depth-area-duration-frequency of the storm rainfall and the probability characteristics of the storm rainfall-runoff process are unknown (Zawada *et al.*, 1996).

4.2.1.4 Statistical Methods

The main objective of statistical methods is to predict the tail of the probability distribution from an annual peak flood series. This is normally done by using flow-gauge data and represented in the form of a graph. The method involves applying a best-fit probability-distribution curve to the relative cumulative frequencies of the annual flood peak series. Although a number of probability distributions exist, the log-Pearson type III is the most commonly applied one for hydrological analysis in South Africa as it seems to fit most hydrological data sets. The log-Pearson type III distribution is also widely used by federal agencies in the United States and is recommended by the US Water Resources Council (1976) and the Water Science and Technology Board (1988) (Alexander, 1990).

The log-Pearson III probability distribution is a log-normal distribution; therefore it is plotted on log-probability paper as a straight line. This makes it theoretically possible to extrapolate the distribution line to ascertain the flood exceedance probabilities and discharges of large magnitude flood events. The statistical method is, however, dependent on three main assumptions:

Assumption 1: Each annual flood-peak value in the annual series is independent of the previous and subsequent one.

Assumption 2: The data is comprehensive and free of measurement error. Currently, most of the flow-gauge data in South Africa is managed by the DWAF using the Hydrological Information System. The accuracy of the flow-gauge record is dependent on four main factors, namely the continuity of the time series; the range of readings covered by the record; how well the readings have been recorded; and how well the flow-gauge station is calibrated (Van Wyk, *et al.*, 1990).

Unfortunately there can be possible data errors in flow-gauge data. Alexander (1990) claims that it is particularly important to check for systematic errors where the design of a major structure is involved. It is difficult to assess the quality of flow-gauge data because there has never been an in-depth quality analysis of the data in South Africa, which could be problematic.

Assumption 3: The annual flood-peak series is a reliable and representative sample of random and homogenous events. This is a very important assumption which hydrologists have made in order to justify stochastic models as predictors of flood magnitude and frequency. Furthermore, the conventional flood record may not be representative of all the major flood-producing weather systems. In addition, climate is not constant through time. These two variables also play an important part in the third assumption in statistical methods (Zawada *et al*., 1996).

4.2.1.5 Empirical Methods

Owing to the limitations in statistical analysis and a deterministic method in flood-peak estimation, there has been a recent tendency to apply empirical techniques using maximum recorded flood-envelope curves on a worldwide basis.

Kovacs (1990) suggests that stochastic models imply that the concept of an absolute maximum flood, which is important to the design structures, defies an acceptable scientific definition because in theory a catchment area does not exhibit an upper limiting flood. The reason for developing an empirical approach in estimating the regional maximum flood (RMF) is contained in the contrasting definitions of the RMF and the PMF. The RMF is defined as an upper envelope of floods that have occurred in a region. The RMF is also a realistic lower limit of the maximum flood that can be reasonably expected. It is important to note that the RMF is based on observed maximum floods. The PMF, however, is an estimate of the largest flood that could occur based on modelling maximum rainfall events over a catchment region. An important advantage of the RMF method is the emphasis on recording and documenting the tail of the peak-flood probability distribution from which an empirically derived maximum flood limit can be defined (Alexander, 1990).

It was observed that when plotting the peak-discharge values against catchment area on a log-scale, an envelope curve for a hydrologically homogenous region was identified. These envelope curves may be defined as a function with a K-value which is calculated using the following equation:

$$K = 10\{1 - (\log Q - 6) / (\log A - 8)\}$$

Where the variable

Q represents the largest flood (m^3 / s) observed at a site.

A represents the effective catchment area in km^2.

Studies were done by Kovacs in 1980 and revised in 1988 using the RMF calculations. This method was applied to 519 southern African maximum floods from South Africa, Lesotho, Swaziland, Namibia, Botswana, Zimbabwe and Mozambique and the concluding remarks were that the southern African maximum flood database is sufficiently comprehensive to enable the application of RMF calculations (Zawada *et al*., 1996). The advantage of this empirical approach is its dependency on a large peak-flood database for the southern African region. Consequently it is independent of an unverifiable probabilistic or stochastic model.

However, the disadvantages are that there are uncertainties in defining the homogenous regional maximum flood boundaries and the inapplicability of the method to either very large or very small catchments because of unusual hydrological conditions. A criticism levelled at the RMF method, which is also applicable to the deterministic and statistical methods, is its reliance on historical records that will be exceeded over time (Alexander, 1988).

4.3 OPERATIONAL FLOOD METHODS IN OTHER COUNTRIES

4.3.1 Australia

The main system used in Australia is the Continuous Simulation System (CSS) for design flood estimation (Boughton, 2001). This system uses the AWBM for continuous simulation of losses and a non-linear runoff routing model for hydrograph simulation at hourly time steps. Furthermore, the relationship between daily runoff and a stochastic daily rainfall generator is used to estimate flood frequency characteristics. In Australia, event-based approaches are generally used and are dominant over the other methods.

4.3.2 United States of America

Several major continuous simulation systems are used in the USA. The most frequently used and best known model is the Hydrocomp model (Boughton & Droop, 2002). The other model used by the United States Geological Survey (USGS) is the Precipitation-Runoff Modelling System (PRMS). It is a continuous simulation distributed parameter model for use in small forested headwater catchments. Losses are modelled using the Green and Ampt infiltration formula and hydrographs are modelled by using a minematic wave approach.

The National Weather Service River Forecasting System (NWSRFS) uses a variety of hydrological models, including snow pack/melt, two soil moisture accounting models, variants of the API approach, the unit hydrograph method and storage behaviour routines.

4.3.3 United Kingdom-Europe

TOPMODEL is a simple semi-distributed model that calculates runoff from a combination of variable saturated surface areas and subsurface runoff (Quinn & Beven, 1993). The TATE model continuously simulates the water balance of a single soil and vegetation store to estimate runoff, which is then divided into ‘quick’ and ‘slow’ flow components. Then an area-distance relationship is used to estimate the hydrograph of runoff at the catchment outlet (Calver, 1996).

4.3.4 South Africa

The Agricultural Catchments Research Unit (ACRU) model is a modified USDA SCS Curve model where the soil moisture deficit, computed from a daily water balance, is used as a replacement for a curve number. Peak discharges are estimated from the calculated daily runoff using a triangular-shaped unit hydrograph. Also, daily rainfalls are broken into shorter time intervals and the rainfall excess is routed through the sub-areas of the catchments to estimate the flood hydrograph at the outlet (Schulze, 1995).

4.4 PARTIAL MODEL FAILURE

The problem with many models is that they perform well at one location and then poorly at the next. Research has been done by Freer, *et al*. (2004) that rainfall-runoff models exhibit the same problem and Pappenberger, *et al.* (2006) found the same problem for flood inundation models.

Pappenberger, *et al*. (2006) make five suggestions if there is a failure in model calibration:

1. Investigate the regions of the flow domain where there are consistent anomalies between model predictions and range observations;
2. Avoid using data that seems somewhat doubtful;
3. Introduce local parameters if there are particular local anomalies;
4. Where data is doubtful, make error bounds wider in some way; and
5. Resort to local evaluations in assessing local uncertainties.

A sixth suggestion was made by Pappenberger, *et al.* (2006) where a vulnerability weighted global measure is used in an attempt to ensure that the behavioural models give more accurate predictions in those locations where accurate predictions are important. The choice to use the vulnerability weight remains subjective by many scholars, but the possibility remains that even vulnerability weighted measures will result in the rejection of all models tried, thereby suggesting that the model structure or the data is inadequate for the study.

In this study some elements of all of the models discussed above were used, particularly the deterministic method where antecedent conditions that modify the catchment processes, like antecedent rainfall and antecedent river flow are important variables, and empirical methods where the model estimates the largest flood that could occur based on modelling the maximum rainfall over the catchments, specifically the RMF calculations. Although the exact variables and equations were not used, an adapted version was used and formulated which took flow and rainfall as the only two variables in the equation and the study. A statistical analysis was conducted were a two-month prediction period was determined, using data provided by the Department of Water Affairs in Pretoria. Spatial analysis was also conducted to represent the previous months' flow in the catchment areas. The results of both of these techniques are discussed in detail in Chapter 5.

CHAPTER 5

CLIMATE CHANGE VS CLIMATE VARIABILITY

5.1 INTRODUCTION

To various degrees, individuals, communities and even nations have had to cope with and adapt to climate variability and change for many years, even centuries (Tyson, *et al*., 2002). Being able to adapt to climate change and variability may be linked closely to vulnerability, with the ability to withstand shocks and stresses to livelihoods being considered particularly important. High levels of vulnerability and low adaptive capacity in the developing world have been linked to certain factors, including reliance on natural resources, a limited ability to adapt financially and institutionally, a low per capita GDP and a lack of safety nets. According to Klein, *et al*. (2003) the opposite of vulnerability is resilience, with growing evidence that people may act positively to enhance their resilience if wider dimensions of livelihood change permit it. In subtropical areas of Africa climate variability, uncertainty and events such as drought are phenomena that some societies have coped with for many generations and even centuries. However, Sokona and Denton (2001) claim that many groups in the developing world are among the most vulnerable and helpless in the face of climate change, in part because of their vulnerability to changes in the natural resource base.

Given the paradox between views of present day helplessness and historic adaptability, it is vital to investigate how exposure to climatically driven changes in the environment can affect both its use and people's livelihoods. Such an understanding could make a contribution to facilitating and more widely informing reactions to developing changes and uncertainties within climate systems. Arguably it is becoming increasingly important to recognise the limits of our scientific knowledge and interrogate our understanding of what uncertainty and variability mean to how people live their everyday lives. Research was conducted in the summer rainfall zone of South Africa as part of a larger project investigating the adaptive capacity of natural resource dependent societies to future climate changes (Thomas, *et al.*, 2007).

The results revealed that the initial climate data analysis and the subtleties of climate change in terms of precipitation parameters, provided information that allowed aspects of the climate-led changes in livelihoods to be recognised. Livelihoods change and people adapt to the pressures and opportunities provided by many variables operating at a range of scales, of which climate is only one.

5.2 CLIMATE CHANGE – THE SCIENTIFIC BASIS

This section gives a brief overview of the scientific basis as summarised by the Intergovernmental Panel on Climate Change in its 2001 synthesis report (IPCC 2001, 2007). The IPCC is an international body that was jointly established by the World Meteorological Organisation and the United Nations Environment Programme in 1998. Its present terms of reference are to:

- Assess available information on the science, the impacts and the economics of and the options for mitigating and/or adapting to climate change,
- Provide, on request, scientific/technical/socio-economic advice to the Conference of Parties to the United Nations Framework Convention on Climate Change (IPCC 2001).

Since its establishment, the IPCC has produced a series of Assessment Reports, Special Reports, Technical Reports and methodologies that have become standard works of reference, widely used by policymakers, scientists and other experts and scholars.

The prediction made in the IPPC reports is internationally recognised as a benchmark and is certainly regarded as such by leading researchers in South Africa. It is not the intention of this study to question the methodologies and predictions of this body of leading scientists, but merely to share and become acquainted with them. Many uncertainties do, however, exist and will be discussed further along in this chapter. The IPCC defines climate as the average weather over periods of longer than 20 years. Variations in climate are normal. The earth’s climate has never been stable over extended periods. These variations may be ascribed to variability of energy emitted from the sun, changes in distance between the earth and the sun and even the presence of volcanic pollution in the upper atmosphere (Appleton, 2003).

Fluctuations are also produced by internal variations through feedback processes that connect various components of the climatic system.

Variability is defined as the range of values that the climate at a particular location can take over time. It is an inherent feature of the natural climatic system (IPCC, 2001). The United Nations Framework Convention on Climate Change (UNFCCC) defines climate change as a change in climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods, as suggested by Appleton (2003).

Paleoclimatic records obtained from Antarctic ice cores for periods as far back as 4 000 years show natural variability in temperature, carbon dioxide and methane levels. The latter two are considered the most important greenhouse gases in terms of radiative forcing. The composition of the atmosphere has, however, through human activities, been progressively altered since the expansion of agriculture and the Industrial Revolution. Human activities have increased the emissions of greenhouse gases; and aerosols, which, according to recent observations, have given rise to a projection of a warmer world (IPCC, 2007).

Most greenhouse gases reached their highest levels in the 1990s. Greenhouse gases retain heat and help maintain an increased temperature on earth. Burning fossil fuels and changes in land-use through deforestation are responsible for nearly 75% of the increase in carbon dioxide. An increase in methane levels could be identified emanating mainly from emissions from energy use, livestock, agriculture and landfills. Fossil fuel combustion is also directly responsible for increased concentration in tropospheric ozone, the third most important greenhouse gas. The indicators of human influence on the atmosphere during the industrial era are illustrated in Figure 5.1.

The IPCC also states that:

- The sea-level has risen (on average) by 1 to 2 mm per year.
- Temperature in the lowest 8 km of the atmosphere has increased during the past 40 years.
- Ocean heat content has increased surface precipitation (rain, snow, hail) continuing to show an increase of 0.5% to 1% per decade over much of the middle and high latitudes of the Northern Hemisphere.
- More pronounced increases in heavy and extreme precipitation events also occurred.

The UNFCCC approach is adopted in many studies and scenarios; it therefore restricts the use of the term *climate change* to projected future conditions of climate under various greenhouse gas emission scenarios.

According to the IPCC (2001), climate change is an integrated framework which includes climate change and how mankind and the environment need to adapt to the changing climate. This also leads to different mitigation processes; socio-economic development paths are also created to adapt; this process acts both ways. With all of these adaptations and mitigations occurring, green house gases are emitted and have a vast effect on the climate. Figure 5.2 illustrates this concept.

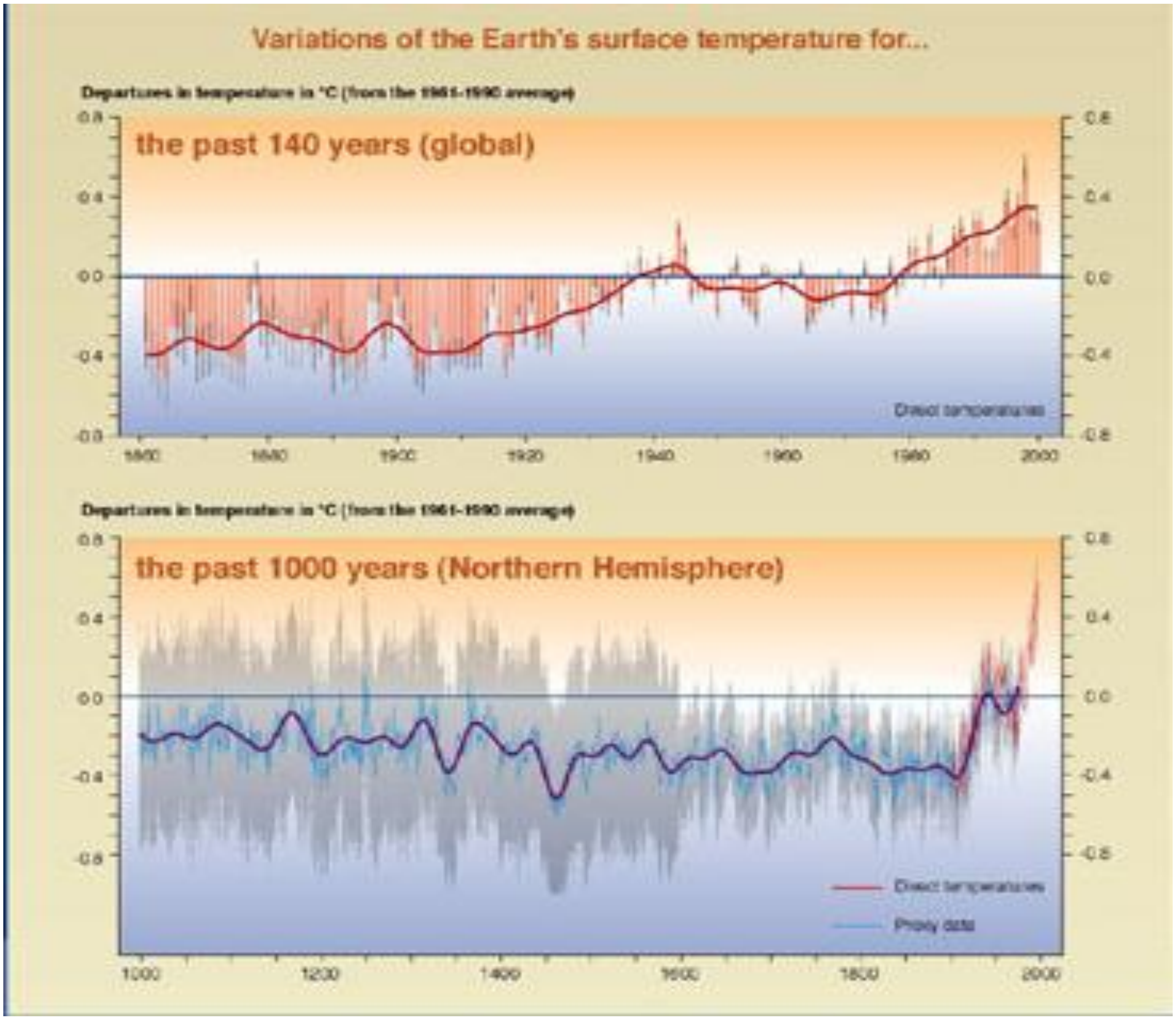


Figure 5.1: Variations of the earth's temperature (IPCC, 2001).

The top panel represents changes in the earth's surface temperature over the period of direct temperature measurements (1860 – 2000). The departures from global mean surface temperature are shown each year by the red bars and decade-by-decade by the continuous red line. The bottom panel represents the proxy data merged with the direct temperature measurements (red line) for the Northern Hemisphere. The proxy data consists of tree rings, corals, ice cores and historical records that have been calibrated against thermometer data (IPPC, 2001).

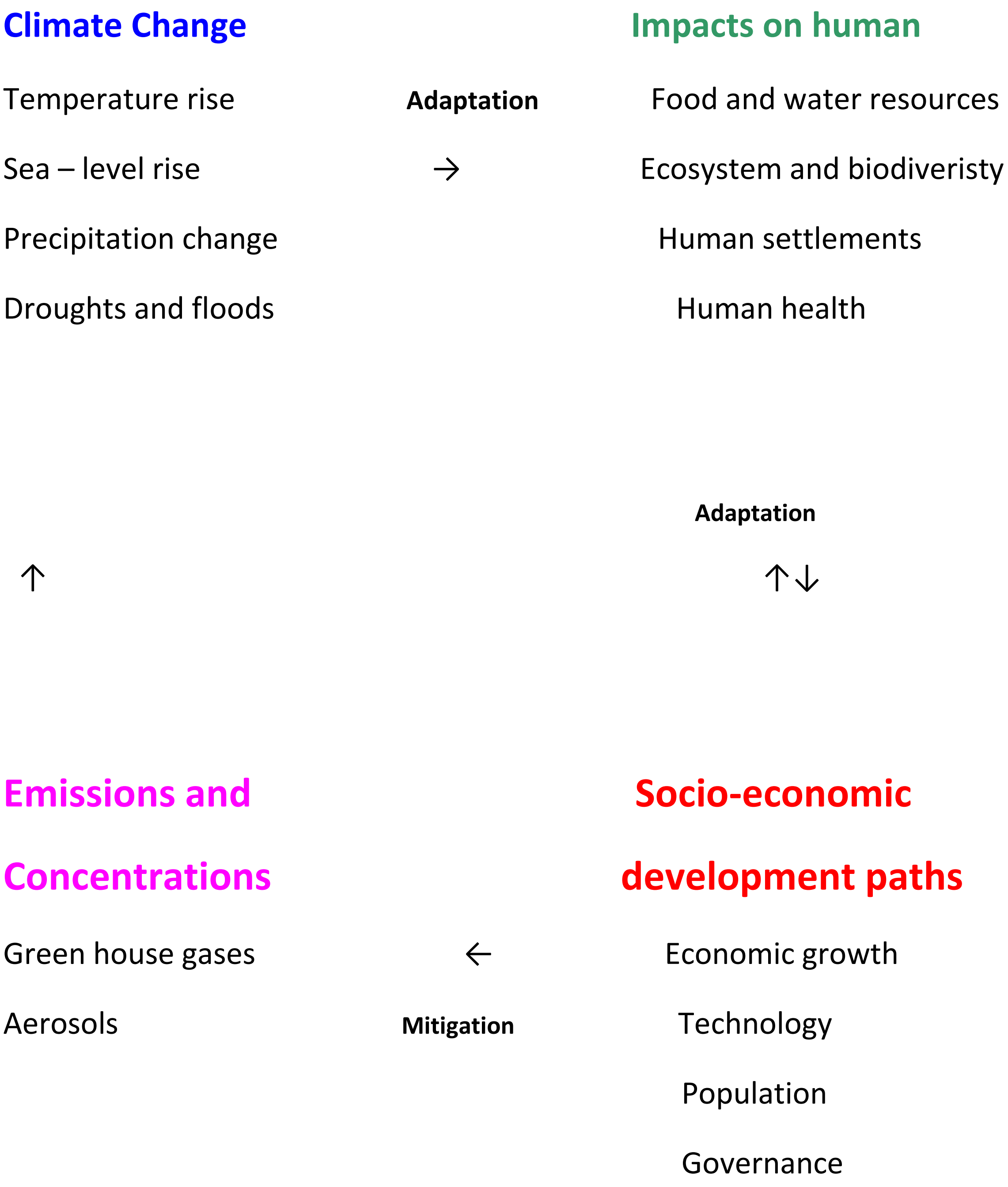


Figure 5.2: Climate Change – an Integrated Framework (IPCC, 2001).

5.3 PROJECTED CHANGES AND THEIR CONSEQUENCES

5.3.1 General understanding

All emission scenarios show increased levels of carbon dioxide concentrations (75 to 350% above the pre-industrial levels). Globally averaged water vapour, evaporation and averaged annual precipitation are projected to increase. All the Special Report on Emission Scenarios (SRES) indicate a rise of between 0.09 and 0.088 m during the next century. There are, however, substantial differences in projected values regionally.

Although the averaged annual precipitation is projected to increase in some regions, notably Southern Africa, a decrease in winter rainfall is predicted. Confidence in the regional predictions of sea-level rise is similarly low owing to variable data. The extent of snow cover, permafrost and sea-ice is projected to decrease further in the Northern Hemisphere, while the Antarctic ice sheet is likely to gain mass owing to increased precipitation.

5.3.2 Annual changes in physical, biological and social systems

The impacts of climate change need not be only adverse, but may also result in beneficial environmental and socio-economic effects. It is, however, likely that the adverse effects will dominate with greater changes and rates of change. Greater accumulative emissions of greenhouse gases will therefore result in more severe impacts.

Threats to human health are projected to increase overall, particularly in the lower-income populations in tropical and sub-tropical countries. This can be either be caused directly through, for example, reduced cold spells with a resulting increase in heat stress, loss of life in floods and storms, or indirectly through changes in the ranges of disease vectors, water borne pathogens, water and air quality, food availability, population displacement and economic disruptions. The predominant effect is projected to be adverse, but some impacts such as decreased cold stress and disease transmission, may be beneficially affected (IPCC, 2001).

Biodiversity in ecosystems is projected to be affected, with an increased risk of extinction of some vulnerable species. The stresses caused by climate change threaten not only damage, but complete loss of unique ecosystems and the extinction of endangered species.

Examples of these stresses include: drought, fire, pest infestation, invasion of detrimental exotic species, storms and coral bleaching, aggravating existing stresses such as land degradation. The effects of climate change on the productivity of ecosystems vary, since net primary productivity would be increased by increasing carbon dioxide concentrations. This may either be augmented or reduced by climate change, depending on, *inter alia*, the vegetation type. Climate change may also interfere with the net uptake of carbon dioxide by the terrestrial ecosystems that currently act as a carbon sink.

The effects of climate change on agriculture vary regionally. In the mid-latitudes, positive responses of yield on minimal increases in the temperature and carbon dioxide are expected. When there are larger increases, a reduction in yield is projected. A decrease in yield under even minimal changes in temperature is, however, predicted for tropical areas. The effects would be even more adverse when they coincide with a large decrease in rainfall in subtropical and tropical dry land systems. The effect of carbon dioxide fertilisation is taken into account in the predictions above, but not the impacts of pests, diseases, degradation of soil and water resources or climate extremes. Climate change may also alleviate water shortages in some regions, but are projected to adversely affect water supplies in already water-scarce areas, as it is projected to reduce stream flow and groundwater recharge in many parts of the world (IPCC, 2001).

5.3.3 Addressing climate change

From the discussion in the previous section it is clear that adaptation is a necessity. The cost of adaptation can be reduced by anticipation, analysis and planning. Adaptation, both anticipatory and reactive, varying according to location and sector can potentially reduce the impacts of climate change, enhance beneficial impacts and produce many immediate ancillary benefits. All damages, however, will not be prevented. The potential for adaptation is more limited for developing countries, which are projected to be more adversely affected. Adaptation can be reduced significantly when policies and measures also contribute to other goals of sustainable development. A number of formal strategic frameworks and interventions have been established at international level, including the United Nations Framework Convention on Climate Change, the United Nations Convention to Combat Desertification in Countries Experiencing Serious Drought, the Ramsar Convention and the Montreal Protocol.

Mitigation seems primarily to benefit economies through avoiding costs. Comprehensive, quantitative estimates of global primary benefits of mitigation do not exist and costs and benefits vary widely across sectors. In some sectors, such as coal, oils, gas and some energy-intensive industries based on energy produced from fossil fuels, may be adversely affected. Substantial technological and other opportunities exist for lowering mitigation costs.

Technological options include the reduction of global emissions of 1.9 to 2.6 Gt C_{eq} yr^{-1} by 2010 and 3.6 to 5.0 Gt C_{eq} yr^{-1} by 2050. Half of these reductions may be achieved with one component of their economic cost (net capital, operating and maintenance cost) with direct benefits (IPCC, 2001), whereas Barrow (1997) produced some future climate scenarios for the UK by combining the average regional results of five equilibrium GCMs with a simple global time-dependent model and the IPCC BaU scenario for future greenhouse gas emissions.

Models show that mitigation cost can also be reduced by emissions trading, based on Kyoto targets by the Annex B group of countries. The Kyoto Protocol was adapted at the third session of the Conference of Parties to the UNFCCC (United Nations Framework Convention on Climate Change) in 1997 in Kyoto, Japan. It contains additional legally binding documents in which countries in Annex B of the Protocol agreed to reduce their anthropogenic greenhouse gas emissions (CO_2, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride) by at least 5% below 1990 levels in the commitment period 2008 to 2012.

Since the IPCC Third Assessment report (IPCC, 2001), the number of studies of observed trends in the physical and biological environment and their relationship to regional climate change has greatly improved, as has the quality of the data sets (IPCC, 2007). Although evidence to provide policy makers with solutions to climate change have improved since the 2001 report, many research challenges still remain.

5.4 CLIMATE CHANGE IN SOUTH AFRICA

The generation of climate scenarios is imperative to any subsequent step in regional impact assessment. This is particularly important when assessing climate change on a regional scale (temporal and spatial) if any decision-making process is to follow, based on the outcome. As discussed in previous sections, the core tool for projecting future climate is the General Circulation Model (GCM) that, although effective on a global scale, is not appropriate on a regional scale.

The African continent straddles the equator and its convection is a significant source of atmospheric heat. It has an extended plateau, two large deserts and borders two tropical oceans which have markedly different characteristics.

Energy released over equatorial Africa is exported through tropical, as well as extra-tropical interactions, causing feedback with the global circulation and regional monsoons. The annual cycle of African rainfall is particularly strong and is expected to follow the pattern of the meridianal flow, which is built up by the Hadley cell and its association with land-surface characteristics and the surrounding oceans (Jury & Mpeta, 2005).

According to Jury and Mpeta (2005:2), the annual cycle of climate in the African region is studied using evenly gridded, model-interpolated fields based on ship- and land-based data sets. The rainfall and temperature over sub-Saharan African is specifically explored, as well as the temperature and circulation over the adjacent Atlantic and Indian Oceans. The data is composed of 31 years’ continuous monthly data.

5.4.1 Regional climate scenarios

Downscaling is the term used to define the development of regional scale projections of change based on the global projections (models used to simulate the global response of the climatic system). The tools available for downscaling are either Regional Circulation Models (RCM) or empirical downscaling. Although the research community is able to generate detailed scenarios, the uncertainties and probabilities associated with these scenarios remain undermined.

The downscaling methods are still limited in the magnitude of projected change, but it is a great deal more confident in the qualitative aspects (Midgley, *et al.*, 2005). Also, Midgley, *et al*. (2005) list downscaling as one of the four areas of uncertainty that currently limits the detail of regional projections in Southern Africa. The other three are:

Future emission

The global response to mitigation strategies on the emission of greenhouse gases can result in projected global mean temperatures varying by up to 4 ºCelsius.

Uncertainty in science

Current understanding of the climatic system in Africa is limited. This is especially of great concern as Africa is said to be more vulnerable to change; change in any form inherently impacts on society.

Natural variability

The relative short historical climate record for Southern Africa (and Africa) makes it difficult to define natural variability in time and space. Historical climate trends are nevertheless used as a foundation for assessing future change.

5.4.1.1 Atmospheric circulation

Midgley, *et al*. (2005) analysed circulation patterns over the Western Cape from 1958 to 2001. The frequency of strong low-pressure systems increased significantly during March to May and decreased during June to August, resulting in spatial changes in rainfall. Fewer intense low pressure systems during winter increased conditions favourable to brown haze and smog days in Cape Town. An increase in hot, dry berg winds occurred in September to February owing to an increase in the frequency of strong high-pressure systems.

5.4.1.2 Air temperature

An analysis conducted by New, *et al*. (2006) showed trends in daily extreme climate over Southern and Western Africa for 1961-2000 and found temperature extremes showing patterns of consistent warming. Hot extremes generally showed trends of greater magnitude than the cold, suggesting a faster change in warmer temperatures than cold. Midgley, *et al*. (2005) confirm these results. A temperature trend analysis of data over 30 to 40 years for 12 meteorological stations were obtained from the Institute for Soil, Climate and Water.

This analysis showed significant warming trends for minimum temperatures during December to March and July to September and for maximum temperature during January, May and August. Therefore, very warm days have become warmer or have recurred more regularly during the last decade (Midgley*, et al*., 2005).

5.4.1.3 Rainfall

Owing to high inter-annual variability, rainfall trends are more difficult to analyse than those of temperature. Midgley, *et al*. (2005) expands on preliminary work by Hewitson and Crane (2005a, 2005b). In general, mountainous areas show little change or positive trends, whereas low-lying areas have negative trends (decreased rainfall). Seasonal trends are more complex. Lower rainfall during winter seems likely and is linked to the trends in circulation patterns. The causes of the increased rainfall over the mountains are yet unknown.

Since the IPCC report (2001) climate model projections have become more sophisticated. The Climate Systems Analysis Group (CSAG) at the University of Cape Town has done extensive work on regional scenarios using empirical and regional downscaling models (Hewitson, 1997, 1999, 2001). The topic of climate change, its causes and effects, forms an integral part of any system which studies and models weather patterns, climate and water-related issues.

The important issue from a hydrological and water resource estimation perspective is that many uncertainties associated with estimates of future patterns of rainfall and evaporation exist. There is an ongoing need to reduce these uncertainties so that predictions of future climate patterns can be confidently used by hydrological scientists to make more reliable predictions of water availability that can in turn be used by water resource managers (Hughes, 2007).

5.5 CLIMATE VARIABILITY

5.5.1 Background and Introduction

Climate variability and change profoundly influence social and natural environments throughout the world, with significant impacts on natural resources and industry that can be great and far-reaching. For example, seasonal to interannual climate fluctuations strongly affect the success of agriculture, the abundance of water resources and the demand for energy, while long-term climate change may alter agricultural productivity, land and marine ecosystems and the resources that these ecosystems supply.

Recent advances in climate science are beginning to provide information for decision makers and resource managers to better anticipate and plan for potential impacts of climate variability and change.

Climate research has indicated that it is globally very likely that the 1990s were the warmest decade in the instrumental record, which extends back to the 1860s (Figure 5.1). Large climate changes occur within decades or less, yet last for centuries or longer and the increase in Northern Hemisphere surface temperatures during the 20th century likely exceeds the natural variability of the past 1 000 years (IPCC, 2001). Observational evidence together with model simulations incorporating a comprehensive suite of natural and anthropogenic forcings indicate that the changes that were observed over the last several decades are likely mostly due to human activities, but we cannot rule out that some significant part of these changes is also a reflection of natural variability (Figure 5.3).

All climate models used in the most recent Intergovernmental Panel on Climate Change (IPCC) assessment project predict that global mean temperatures will continue to increase in the 21st century and will be accompanied by other important environmental changes, such as sea-level rise, although the magnitudes of the projected changes vary significantly because of different scenarios and models (IPCC, 2001).

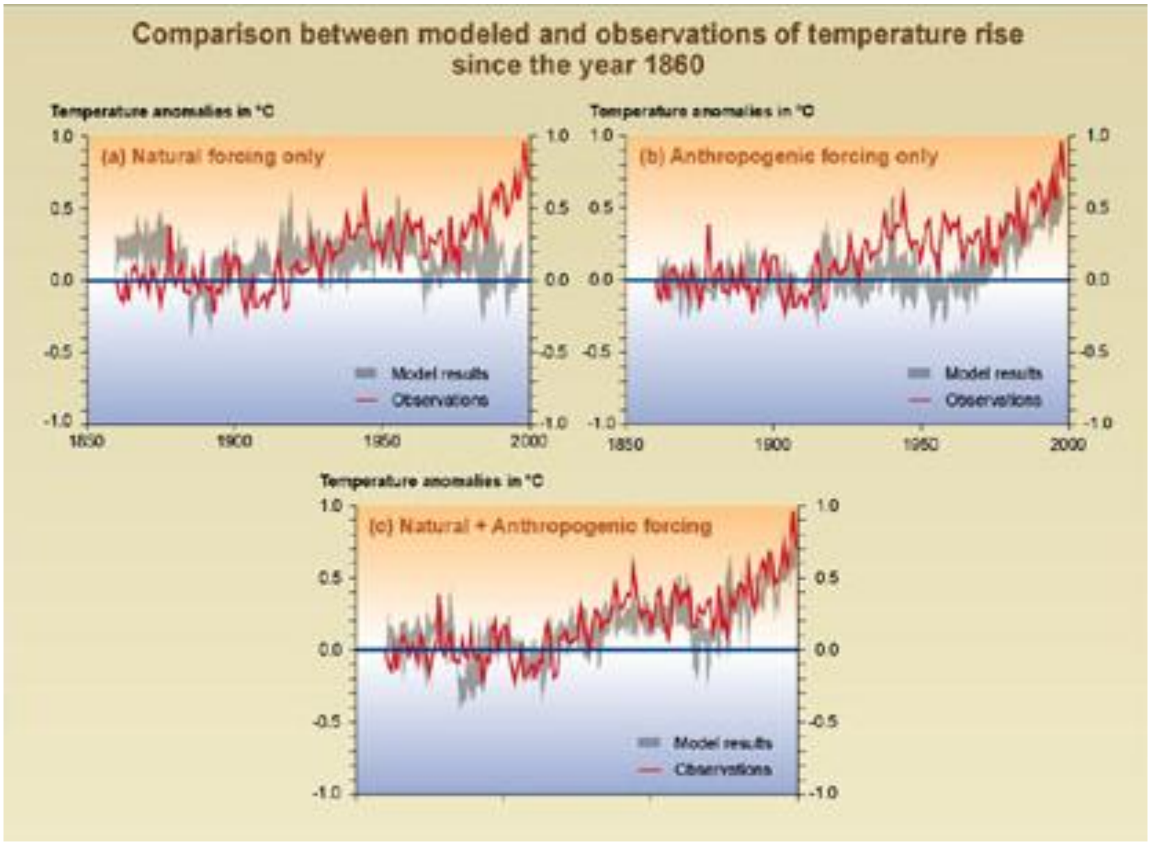


Figure 5.3: Changes in the Earth's surface temperature over the period of direct temperature measurement (a) natural forcing due to solar variations and volcanic activity; (b) anthropogenic forcing from greenhouse gases and an estimate of sulphate aerosols; and (c) including both natural and anthropogenic forcing (IPCC, 2001).

Climate research has also significantly advanced our understanding of the temporal and spatial patterns of climate variability. Substantial improvements in our ability to monitor the upper tropical Pacific Ocean now provide the world with an 'early warning' system that shows the development and evolution of El Niño-Southern Oscillation (ENSO) events as they occur.

This improved observational system, together with a greater understanding of the mechanisms that produce ENSO, has led to useful climate forecasts at lead times of up to several months. This developing capability has given the world an unprecedented opportunity to prepare for and reduce vulnerabilities to the impacts of ENSO and thereby provide direct social and economic benefits as returns on climate science investments.

Research that has been supported by the US Global Change Research Program (USGCRP) has played a significant role in the scientific advances, which have consequently provided new climate information to help society better prepare for potential effects of climate variability and change. While the progress in this area has been impressive, there unfortunately still remains many unresolved questions about key aspects of the climate system, including some that have vast societal and environmental implications. Several major recurrent natural patterns of climate variability other than ENSO have also been identified, but it is yet unknown to what extent they are predictable. The predictive capabilities at local and regional scale show promise in some regions and for some phenomena, but in many cases are still relatively poor. Moreover, confident estimates of the likelihood of abrupt climate transitions, although such events have occurred in the past, has yet to be obtained (IPCC, 2001).

5.5.2 El Niño-Southern Oscillation (ENSO)

El Niño-Southern Oscillation is a periodic change in the atmosphere and ocean of the tropical Pacific region. It is defined in the atmosphere by the sign of the pressure difference between Tahiti and Darwin in Australia; likewise in the ocean by warming or cooling of surface waters of the tropical central and eastern Pacific Ocean. El Niño is known as the warm phase of the oscillation and La Niña as the cold phase. The oscillation does not have a specific period, but occurs every three to eight years. Mechanisms that cause the oscillation remain a matter of research. The El Niño-Southern Oscillation is often abbreviated as ENSO and in popular usage is commonly called simply El Niño; its effects on weather vary with each event. ENSO is associated with floods, droughts and other weather disturbances in many regions of the world. In the Atlantic Ocean, effects lag behind those in the Pacific by 12 to 18 months. Developing countries dependent upon agriculture and fishing, particularly bordering the Pacific Ocean, are particularly affected.

By now most people have heard of El Niño, if only to know the name refers to some kind of abnormal weather. The term ‘abnormal’ varies widely in geography. For people who live in Indonesia, Australia or south-eastern Africa, El Niño can mean severe droughts and deadly forest fires. Ecuadorians, Peruvians or Californians, on the other hand, associate it with lashing rainstorms that can trigger devastating floods and mudslides.

Severe El Niño events have resulted in a few thousand deaths worldwide, have left thousands of people homeless and have caused billions of dollars in damage. Yet residents on the north-eastern seaboard of the United States can credit El Niño with milder-than-normal winters and relatively benign hurricane seasons. The name El Niño (Spanish for *the Christ child*) was coined in the late 1800s by fishermen along the coast of Peru to refer to a seasonal invasion of warm southward ocean current that displaced the north-flowing cold current in which they normally fished; typically this would happen around Christmas. Today, the term no longer refers to the local seasonal current shift but to part of a phenomenon known as El Niño-Southern Oscillation (ENSO), a continual but irregular cycle of shifts in ocean and atmospheric conditions that affect the globe. El Niño has come to refer to the more pronounced weather effects associated with anomalously warm sea surface temperatures in the eastern and central Pacific Ocean interacting with the air above. Its counterpart effects associated with colder than usual sea surface temperatures in the region, was labelled La Niña (*little girl*) as recently as 1985 (Conlan & Service, 2000).

Weather has always been a significant concern to humankind, and, over time, our inability to control it has made us try to measure it, compare it to previous years and predict it. Prediction, however, requires much information on conditions in different locations as well as a way to convey that information between distant places. In the latter half of the nineteenth century, the telegraph made it possible for meteorological data from stations scattered over a huge area to be collected rapidly, leading to the creation of several national weather services.

The global observational network grew in sophistication during the twentieth century, especially after the launch of the first satellite in 1957. Today, satellites, commercial airlines and ships at sea take measurements. Information also comes from balloons that are released twice a day into the upper atmosphere by meteorological stations around the globe, as well as by fixed buoys that record temperature several hundred meters deep in the ocean.

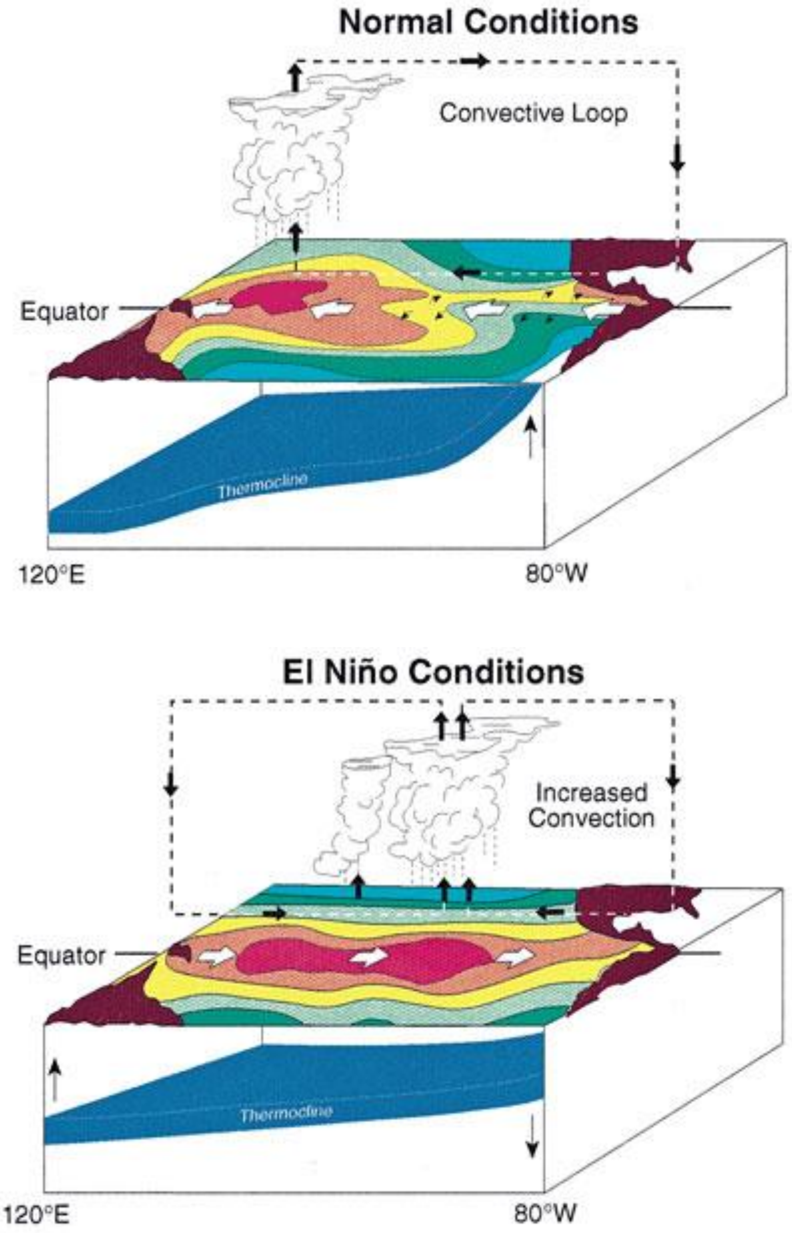
Even with all this high-tech help, including sophisticated computer models, we can predict the weather with reasonable accuracy only a few days ahead. However, has it become possible for climatologists to anticipate the onset of the El Niño phase of ENSO several months ahead. The answer has to do with how interactions between the ocean and the atmosphere play out over time. Fundamentally, many argue that the engine that drives long-term ‘climate’ is the heating and cooling of the tropical Pacific Ocean. The sea breeze is a familiar example.

On a sunny afternoon the land heats up faster than the ocean. As the air over the land warms and rises, the air over the cooler surface of the ocean flows toward the shore to take its place. Above, the warm air returns to the sea, then subsides over the ocean to complete the circuit. The same principles apply to the planet as a whole. Over the course of a year, the sun's rays strike more vertically in the tropical zones than at mid-latitudes or at the poles, resulting in the tropical oceans absorbing a great deal more heat than do waters elsewhere. As air near the ocean surface is warmed by the equatorial waters, it expands, rises (carrying heat with it) and drifts toward the poles. Cooler, denser air from the subtropics and the poles moves toward the equator to take its place.

In other words, the atmosphere and ocean together act like a global heat engine. This continual redistribution of heat, modified by the planet's west-to-east rotation, gives rise to the high jet streams and the prevailing westward-blowing trade winds. The winds, in turn, along with the earth's rotation, drive large ocean currents such as the Gulf Stream in the North Atlantic, the Humboldt Current in the South Pacific and the North and South Equatorial Currents. In the tropical ocean, westward-blowing trade winds harvest water vapour over the ocean, carrying it away from one part of the world and depositing it somewhere else. The result of this ocean-atmosphere dynamic is that the Pacific coast of South America, for example, is generally dry, while on the opposite side of that ocean basin, Indonesia and New Guinea contain lush jungles.

The trade winds also push the warm water in the upper layer of the tropical ocean westward. As warm water piles up in the western Pacific, the cool water in the lower layers of the eastern Pacific rises to the surface. Figure 5.4 illustrates the scenarios between normal condition and El Niño conditions. Under normal conditions, the steady equatorial trade winds move air westward, where warm air rises and condenses, and rains heavily in the western Pacific. Figure 5.4 illustrates the difference between El Niño and La Niña weather conditions.

In El Niño conditions, lower air pressure in the east weakens the trade winds, thus causing abnormal rainfall along the west coasts of North and South America. Temperature gradient is represented by red, orange, and yellow (warm) and aqua, green and blue (cool). The thermocline is a kind of interface between the warm surface waters and the much colder deep ocean floor (Conlan & Service, 2000).



NOAA/PMEL/TAO

Figure 5.4: Difference between Normal Conditions and El Niño Conditions

Source (NOAA/Environmental Research Labs, Pacific Marine Environmental Laboratory, **In** Conlan and Service, 2000)

Owing to all the movements of complex interplay of waves, currents and undercurrents that appear and disappear in response to the changes in the winds, it became very difficult for oceanographers to determine and make predictions using computers and models. Continuous measurements were therefore required for the models and predictions to be successful. In the early 1980s David Halpern of the National Oceanic and Atmospheric Administration (NOAA) in Seattle, pieced together findings from various programmes to set up lines of moored buoys located near the equator at longitude 110 °W and 140 °W.

Today, measurements with improved instruments continue at these and many other locations. Even with these moored buoys, events in 1982 and 1983 which caused severe drought and vast tropical storms, called for more extensive monitoring and warning systems. Researchers realised that a deeper understanding of El Niño and any hope of timely prediction would require a much more systematic and comprehensive set of observations than were available through the programmes then in operation. This realisation generated a groundswell of support for a major international research effort (Conlan & Service, 2000).

In 1985 the Tropical Ocean-Global Atmosphere (TOGA) programme thus began looking not only at the ocean or atmosphere, but also at the interactions between them, all across the Pacific. Sponsored by the United Nations World Climate Research Programme, TOGA, marked a major attempt at acquiring reliable observational data that would support experimental forecasts. It also spurred development of a new generation of observational equipment, such as moored and satellite-tracked drifting buoys capable of taking readings and relaying them via satellites to climate researchers in real time. NOAA scientists in Seattle and collaborators at numerous institutions began monitoring the equatorial Pacific with these buoys, satellites, ships and tide and temperature gauges. The result was an array of data on ocean currents, sea-level and water temperatures from the surface to 500 metres underwater, as well as air temperatures, humidity, and wind direction and speed.

Today, an impressive 10-year TOGA programme is a system of 70 buoys known as the Tropical Atmosphere-Ocean (TAO) array, which continues to collect and transmit vital information on the current state of the equatorial Pacific Ocean and atmosphere. During these 10 years, countries around the world collaborated by contributing to the Array.

Why was this done? Because El Niño effects weather worldwide; the more scientists can learn about El Niño, the better prepared all human beings can be. Figure 5.5 illustrates the seven strongest El Niño events since 1950; this was made possible by the TOGA system and the advances in technology.

With all of the data that is recorded daily, some of the buoys recording every hour, a vast amount of data is available for researchers and scientists to calculate events and weather conditions, as well as to keep record of past El Niño and La Niña events. Figure 5.6 represents a Southern Oscillation Index graph with monthly recorded data from 1950 to 1999. The blue represents the La Niña events and the red (- values) represents El Niño events. An array of graphs could be found and represented, but this specific graph was chosen because of its relevance to this study for comparison with a South African ENSO graph in Figure 5.5, as well as with a graph of the data used in the study area, illustrated in Figure 5.7.

The transformation of knowledge gained from climate research into information that is useful for societal decisions presents many challenges, as well as significant new opportunities. The process of understanding climate impacts and using climate information requires a detailed understanding of the interactions of climate, natural systems and human institutions. To obtain the maximum benefits from advances in knowledge of climate variability and change, it will therefore be necessary to create new relationships between the climate research community, social scientists, and the public and private sectors.

For this new information to be gathered and processed, co-ordinated research management will be required to ensure a broad-based and collaborative research programme, consisting of academic institutions, government and private laboratories, as well as public and private expertise. When developing a research strategy, it is vital to recognise that the problems of climate variability and change are closely connected. For example, regional impacts of climate change will depend directly on the variability of the global climate system. Also, future climate variability will depend in part on changes in mean climate. Problems of climate variability and change can therefore not be completely separated and the success of understanding each individually will require improved understanding of both (Conlan & Service, 2000).

To achieve this, four main objectives need to be addressed:

- Carefully designed, implemented and managed observing system elements that will directly improve the knowledge of the climate system and will drive improvements in climate models.
- Systematic, ongoing programmes of climate data collection, integration and analysis; process studies to elucidate critical processes that govern the climate system, but which in many cases are poorly understood and modelled.
- Building a research infrastructure, such as the Earth System Modelling Framework, that supports collaborations among climate scientists and climate modelling centres.
- Improving capabilities to assess climate information needs and to provide the necessary information to decision makers at local, regional and national levels.

Advances will require improvements in paleoclimatic data, as well as modern observational data systems, because the latter have generally been present for too short a time to extract robust features of climate variability on decadal or longer time scales. Climate variability and change research will play a central integrating role in the Climate Change Science Program (CCSP). The Climate Variability and Change research element will provide an array of advanced climate prediction and projection products that the other CCSP elements will verify (IPCC, 2001).

This can only be achieved through the continual development of core climate system models that integrate the observational, analytical and specialized modelling capabilities planned within the other CCSP elements to provide improved information necessary to respond to the scientific and decision making needs of the overall programme.

One of the recurring questions in climate variability studies is, *How can predictions of climate variability and projections of climate change be improved and what are the limits of their predictability?* One of the major advances in climate science over the past decade has been the recognition that most of the climate variability is associated with a relatively small number of recurrent spatial patterns or climate models. These include ENSO, the North Atlantic Oscillation (NAO), the Northern and Southern Hemisphere Annular Modes (NAM, SAM), Pacific Decadal Variability (PDV), Tropical Atlantic Variability (TAV), the Tropical Intra-Seasonal Oscillation (TISO) and monsoon systems.

To date there is limited understanding of the physical mechanisms that produce and maintain natural climate modes, the extent to which these modes interact, and how they may be modified by human induced climate changes in future. These limitations in knowledge introduce major uncertainties in climate predictions, climate change projections and estimates of the limits of climate predictability, especially for regional climate (Conlan & Service, 2000).

The essential research needs include the development and support for long term, sustained climate modelling and observing capabilities. These include remote sensing data sets, global and regional re-analyses and retrospective data, including new high-resolution paleoclimate data sets. Field observations and process studies are necessary for improving understanding and modelling the physical mechanisms responsible for climate feedbacks; evaluating the extent to which climate models successfully replicate these mechanisms responsible for climate feedbacks; evaluating the extent to which climate models successfully replicate these mechanisms; and determining observational requirements for critical processes. Additional research is required to develop improved methodologies to determine from global model projections changes in regional climate and seasonal to interannual variability (IPCC, 2001).

The benefits of these research needs will be an improved ability to separate the contributions of natural versus human-induced climate forcing to climate variations and change, resulting in more credible, lucid answers. There will also be an increased understanding of changes in natural variability and potential impacts on predictability that may result from anthropogenic forcing. Moreover, the research will provide more reliable and useful climate prediction products and other essential support to US and international decision makers and resource managers. It will also assist climate assessment efforts by increasing understanding of critical processes required to evaluate and improve major climate models.

Another question that relates to the study is, *How are extreme events, such as droughts, floods, wildfires, heat waves and hurricanes, related to climate variability and change?* One of the highest priorities for decision makers is to determine how climate variations, whether natural or human-induced, alter the frequencies; intensities and locations of extreme events. There is now compelling evidence that some natural climate variations, such as ENSO, PDV and the NAO/NAM, can significantly alter the behaviour of extreme events, including floods, droughts, hurricanes and cold waves (IPCC, 2001).

Studies of long-term trends in extreme events show that in many regions where average rainfall has been increasing, these trends are evident in extreme precipitation events. For other high-impact phenomena, such as tropical storms or hurricanes, no compelling evidence yet exists for significant trends in frequency of occurrence (IPCC, 2001).

Considering the research needs, progress in this area will require two keys steps. First, it will be necessary to improve the scientific understanding and quantitative estimates of how natural climate variations such as ENSO, NAO/NAM, SAM or PDV alter the probabilities of extreme events. Also, it will be essential to improve understanding of how human-induced climate change may alter natural variations of the atmosphere, ocean, land surface and cryosphere, and hence, the behaviour of extreme events in different regions. Key data requirements include the development of improved climate quality data and reference data sets and higher resolution model re-analyses to support analyses of extreme event variability and trends. Improving hydrological extreme event risk estimates will require improved hydrological data sets and advances in coupled climate-land surface-hydrology models.

Empirical and diagnostic research will be required to ascertain relationships between natural climate modes, boundary forcing mechanisms and extreme events to clarify the physical bases for these relationships and to evaluate the veracity of model simulations and projections. Further development of regional climate modelling and improved downscaling techniques will be necessary to provide information at the scales needed by resource managers and decision makers.

The continuing development of ensemble-based approaches and the capabilities to produce large ensembles from climate models will be examined, because they will be essential to improve probability estimates of extreme events for either short-term climate predictions or longer term climate projections. Because extreme events can have societal and environmental impacts, it will be essential to identify key climate information needed to better anticipate and plan for such events. Considering the profits or gains of these research criteria and what they will achieve includes improved anticipation of and response to extreme climate events; an increased understanding of and capabilities to project the regional manifestations of extreme climate events; and to provide a sounder scientific basis for policymakers to develop strategies for minimising potential vulnerabilities.

5.6 CLIMATE VARIABILITY IN SOUTH AFRICA

South Africa is situated in the sub-tropics and is therefore affected by the tropical and temperate latitude circulation systems and dominated by semi-permanent high-pressure systems. There has been great variability in rainfall over southern Africa since the commencement of the meteorological record in the 1800s. A number of weak oscillations were identified, such as the 18-year oscillation and the 10-12-year oscillation (Tyson 1996). The former oscillation accounts for 30% of the variance at best and largely in the north-east of the country while the latter has predominantly affected the southern Cape (Mukheibir & Sparks, 2005).

There is also the 2-3 year quasi-biennial oscillation (QBO) associated with the reversal of equatorial westerly winds at the 50hPa stratospheric level and evident mostly in the central interior, as well as the El Niño-Southern Oscillation Phenomenon (Tyson, 1986). Steyn (1984) argues that there are a host of other influences on the climate variability of the region, such as changes in macro pressure over the interior and adjacent oceans that impact on the weather and climate and result in wet and dry spells, and the location of troughs of standing westerly waves.

Rainfall variability is particularly pronounced over the dry western parts of South Africa, where a dry year can have significant repercussions. Furthermore, extreme dry years tend to be more frequent in the driest regions of the country. Links between ENSO and the African monsoons have also been examined by scholars such as Jury, *et al.* (2002).

According to Reason, *et al*. (2000), significant advances have been made in climate variability studies over southern Africa. Work done at the University of the Witwatersrand, which was restricted to station data over southern Africa and neighbouring countries, discussed some of the important atmospheric circulation occurrences associated with El Niño-Southern Oscillation (ENSO) effects over the region and the existence of interannual to interdecadal signals in summer rainfall.

The ENSO influence over the South Atlantic region occurs via Rossby wave propagation in the so-called Pacific South America pattern. The interaction of this propagation over South Africa with that emanating from the Indian Ocean is yet to be clarified. Recent modelling work suggests that the way that the Angola low and neighbouring SST is modulated during ENSO events helps determine the rainfall impact of a particular event over southern Africa (Cook, 2000).

Many challenges need to be addressed if South African research efforts in atmospheric science and physical oceanography are to be maintained or even improved. One of these challenges is the availability of research funds, which remains a poor comparison with some of the other countries who also conduct research in this field.

Tyson and Preston-Whyte (2000:322) declare that, “During the twentieth century the climate of subtropical southern Africa has been characterised by a high degree of both temporal and spatial variation”, although this variation appears to be random. On the other hand, non-random variables and components are also present. The most influential are those variables with an average period of about 18 years, which most affect the summer rainfall patterns of north-eastern South Africa. Figure 5.7 illustrates the averaged rainfall series for this affected region from 1910 to 1990. The years where the wet spell occurred, where the rainfall was above the normal rainfall, are predominant, but do not occur excessively. On the other hand, in the dry spell, the years below the normal rainfall are more predominant.

In all the records the most persistent wet spells were from 1971 to 1972 and 1980 to 1981, where six consecutive years received above normal rainfall. According to Tyson and Preston-Whyte (2000:323), the dry spells were drier than the wet spells were wet. Therefore, the dry spells occurred more frequently and affected a greater spatial area than the wet spells did.

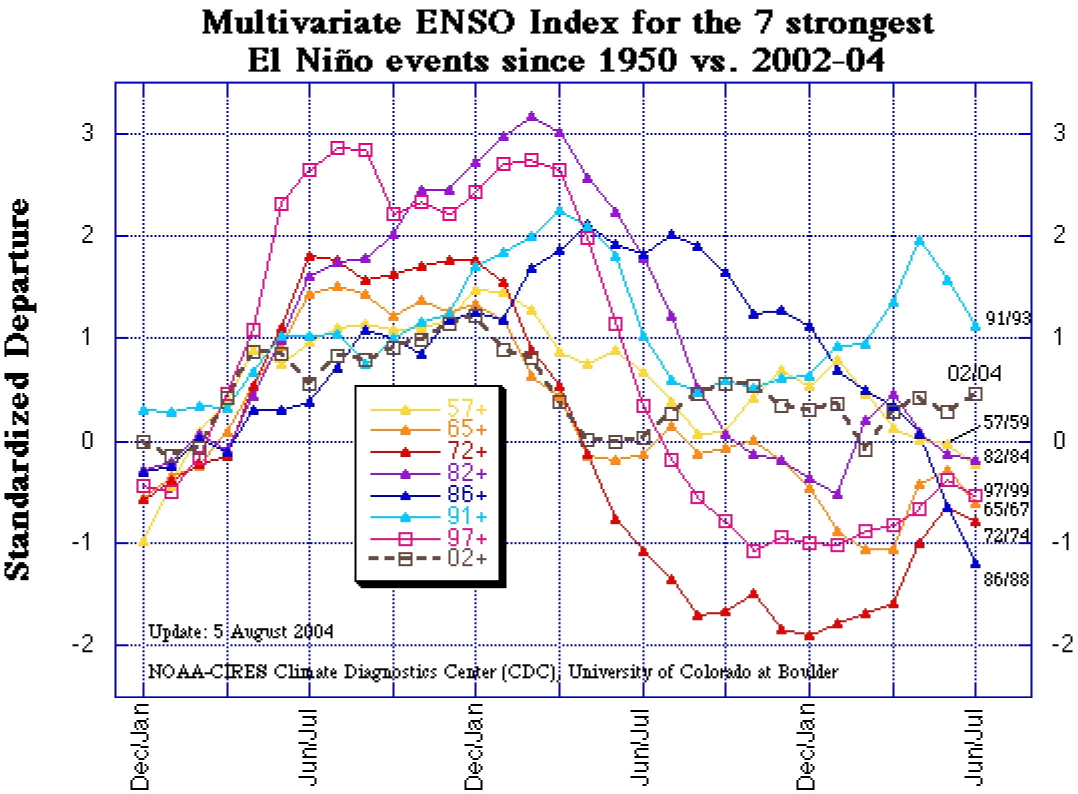


Figure 5.5: The 7 strongest El Niño events between the period of 1950 and 2004 (NOAA, 2009)

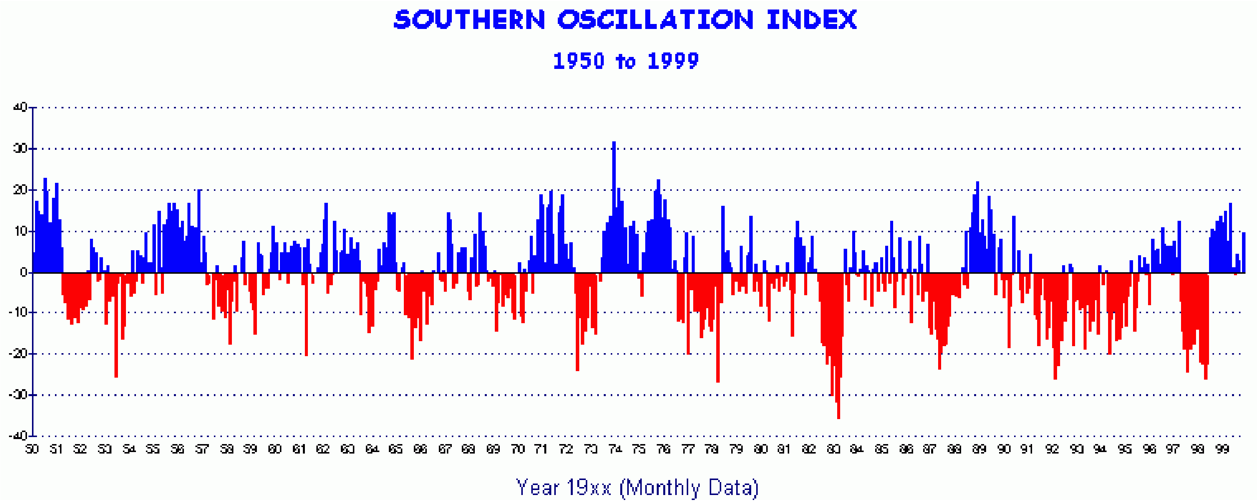


Figure 5.6: Monthly Southern Oscillation Index from 1950 to 1990 (Daly, 2008)

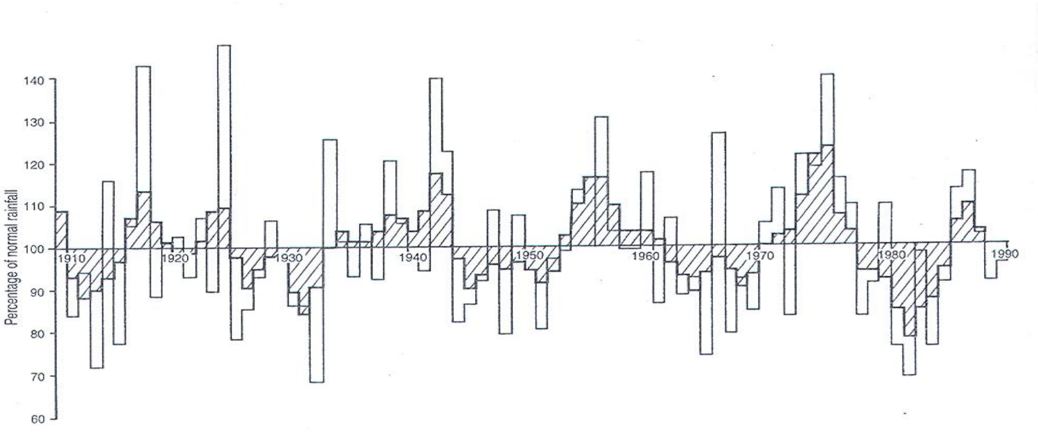


Figure 5.7: Averaged rainfall series for the summer rainfall region of South Africa (Tyson and Preston-Whyte, 2000:322)

CHAPTER 6

DATA ANALYSIS

6.1 BACKGROUND

In the previous chapters, climate variability and climate change were discussed as some of the most significant factors that lead to changing weather patterns in South Africa and around the world. These changes cause many natural disasters to occur, such as floods, droughts and cyclones to name a few. The main objective of this study is to determine the influence of climate variability on flood risk in the //Khara Hais Municipality in the Northern Cape. When considering the Northern Cape, it does not seem possible that there would be a likelihood of floods occurring, as the area's rainfall is neither that excessive nor continuous for this event to be likely.

6.2 DATA CAPTURE

As discussed in Chapter 3, various methods and equations are used for flood prediction. Some may only apply to a specific region or are preferred to be used according to the available data and variables. For this study, no specific flood model was used, as the location and study area did not lend itself appropriately to any of the variables needed for a model to be conducted, except for rainfall and runoff. An equation was developed which would identify which quaternary catchments in the Vaal River and Orange River would be good indicators of flow (Schall, 2009; Pers Comm). This would help in predicting and identifying when a possible flood event may occur in the area. Figure 6.1 illustrates the runoff in the two catchment areas, while Figure 6.2 represents the rainfall over the entire catchment area. The data which comprised 50 years' monthly rainfall and runoff of the two catchment areas were obtained from the Department of Water Affairs in Pretoria. Originally the data consisted of the daily amounts of rainfall per quaternary catchment, which was then summarised to monthly totals and this data were used in the statistical and spatial analysis. Only the rainfall data of the quaternary catchment areas of the Vaal River (C) and the Orange River (D) were used, because they formed part of the study area.

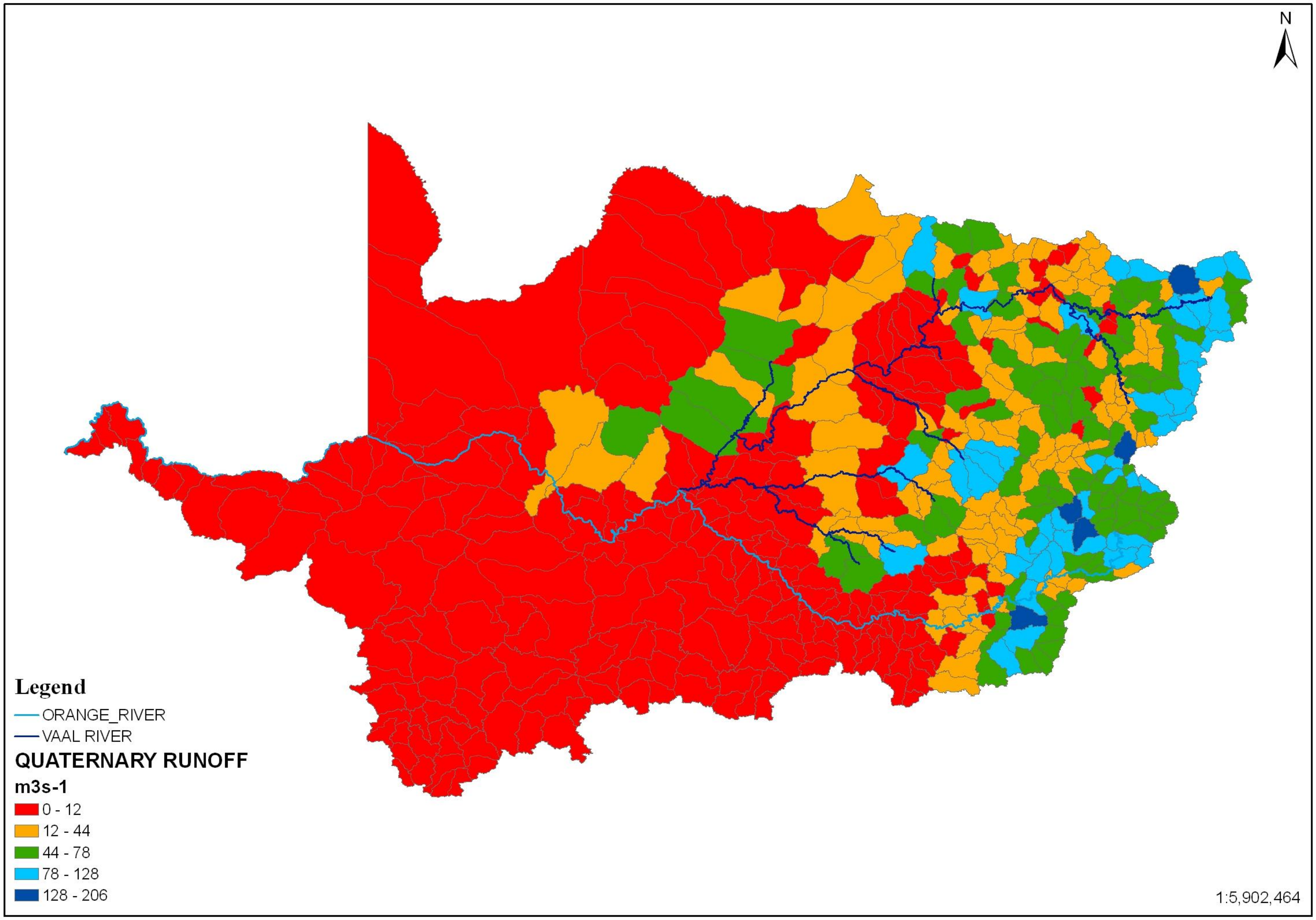


Figure 6.1: Runoff in the Quaternary Catchment areas of the Orange River and Vaal River

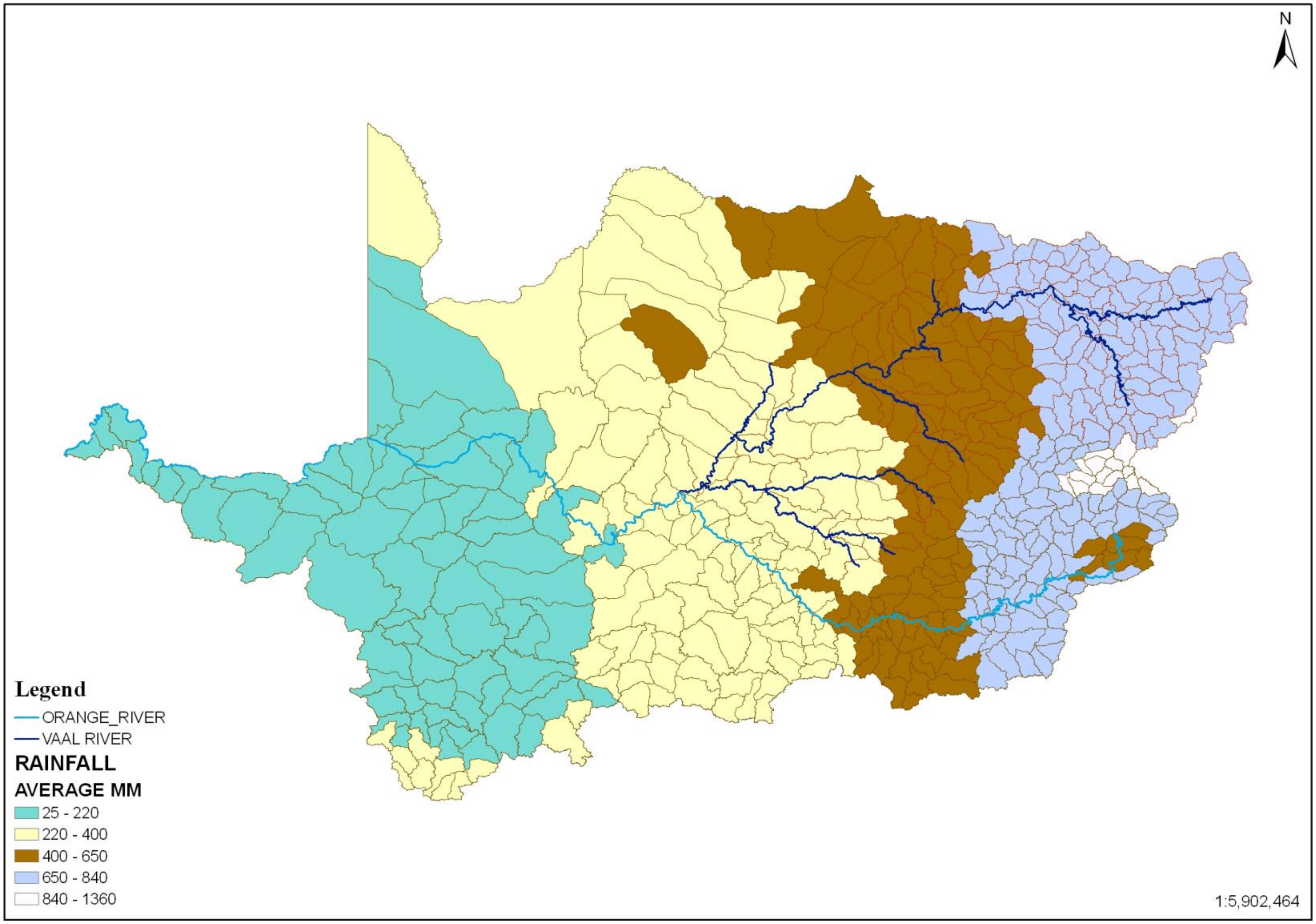


Figure 6.2: Rainfall over the Quaternary Catchments of the Orange River and Vaal River

6.2.1 Statistical Analysis

Average monthly flow data of the Orange and Vaal Rivers from October 1950 to December 1999 were made available. Corresponding detailed monthly total rainfall figures were given for both the Orange and Vaal catchment areas from January 1950 to December 1999. The objective of the statistical analysis was to develop a regression model for flow with rainfall in preceding months and rainfall of the two rivers in preceding months as predictors. Quaternary catchment areas were used, so that a more accurate prediction would be made available for using either tertiary or secondary catchment areas. The areas for these quaternary catchment areas were therefore provided, and the rainfall and the runoff data was given.

Average monthly rainfall for the catchment areas of the Orange and Vaal were calculated. Scatterplots of monthly flow (mm^3) versus rainfall (mm) in the same month and a scatterplot of the natural logarithm of monthly flow (logflow) versus rain were produced (Figures 6.3 and 6.4). The plot of logflow versus rain suggested a linear relation between those two variables, with reasonably constant variance across the range of rainfall values which is shown in Figure 6.4. All further analyses were thus conducted with logflow as the dependent variable. Further scatterplots were produced of logflow versus rainfall in the previous month (rainl1), versus rainfall two months previously (rainl2) and versus rainfall three months previously (rainl3) (see Figures 6.5–6.7). All the statistical analyses were carried out using SAS 9.1. The scatterplots are the simplest way of representing the explanatory data of flow against flow, as well as flow against rainfall. Therefore no equations were used to draw these scatterplots.

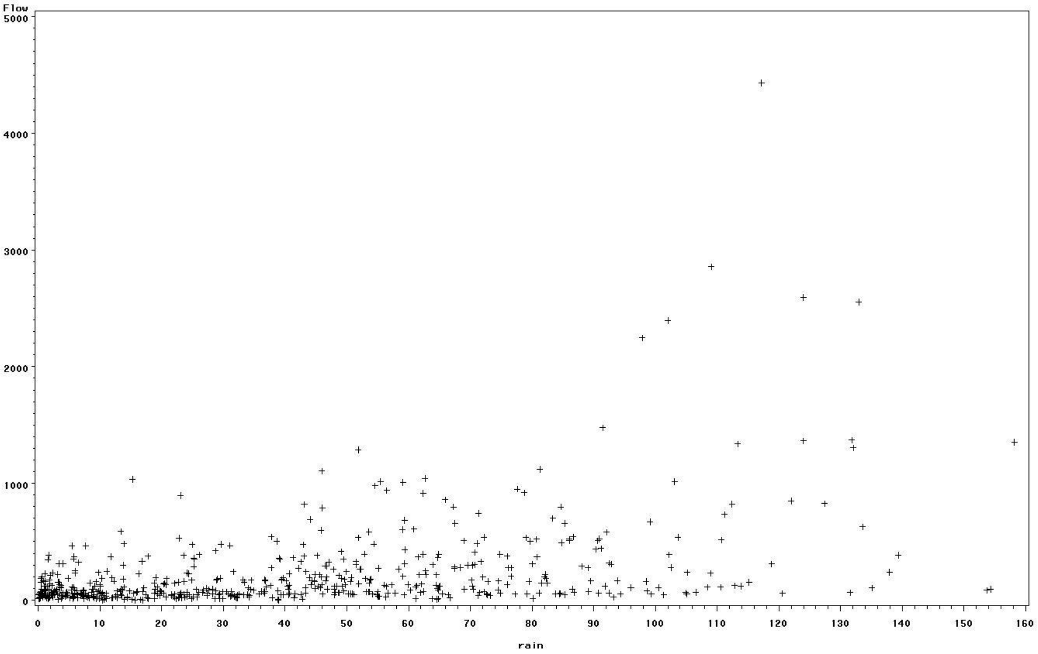


Figure 6.3: Monthly flow (y) versus monthly rainfall (x)

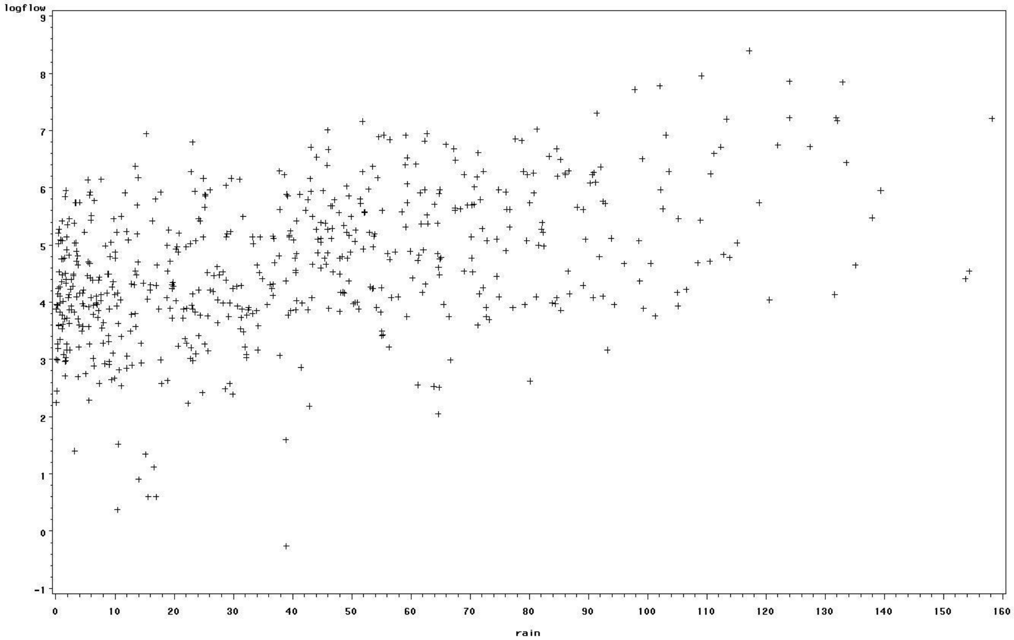


Figure 6.4: Natural logarithm of monthly flow (y) versus rain

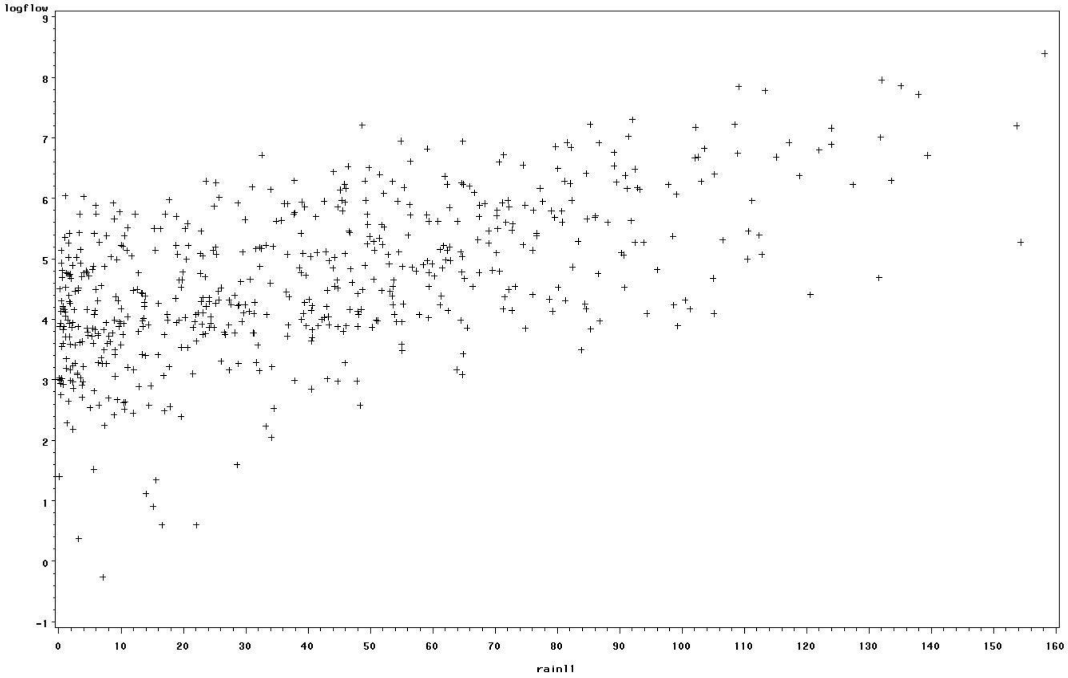


Figure 6.5: Scatterplot of logflow versus rainfall in the previous month (rainl1)

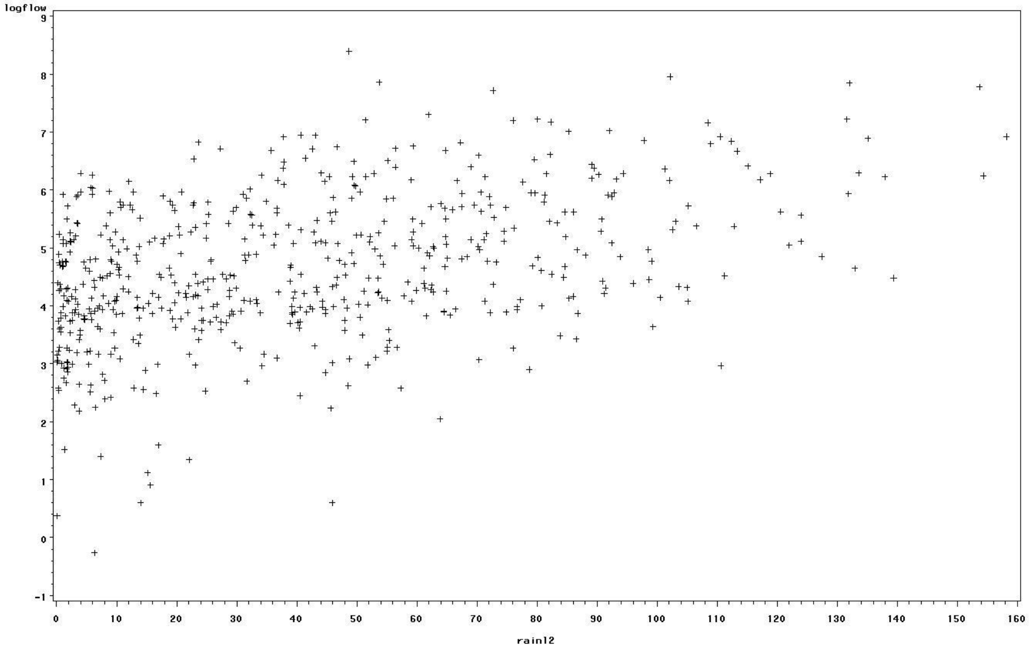


Figure 6.6: Scatterplot of flow versus rainfall two months previously (rainl2)

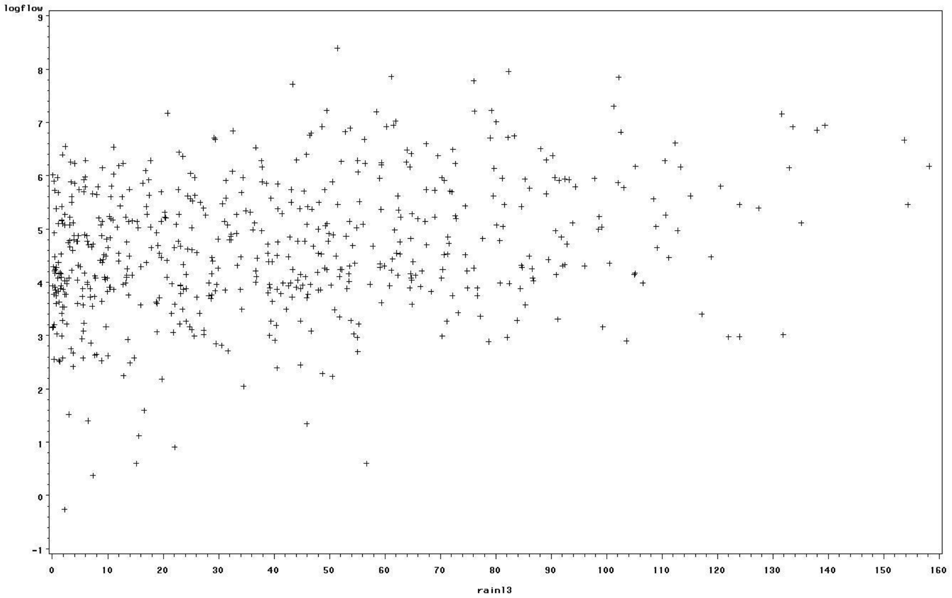


Figure 6.7: Scatterplot of flow versus rainfall three months previously (rainl3)

Similarly, scatterplots were produced of logflow versus logflow in the previous month (flowl1), versus logflow two months previously (flowl2) and versus logflow three months previously (flowl3), Figures 6.8-6.10 represent these results. All scatterplots suggest linear relationships between the variables plotted, although the strength of the relationship seemed to decrease with time for the plots of logflow versus logflow in previous months.

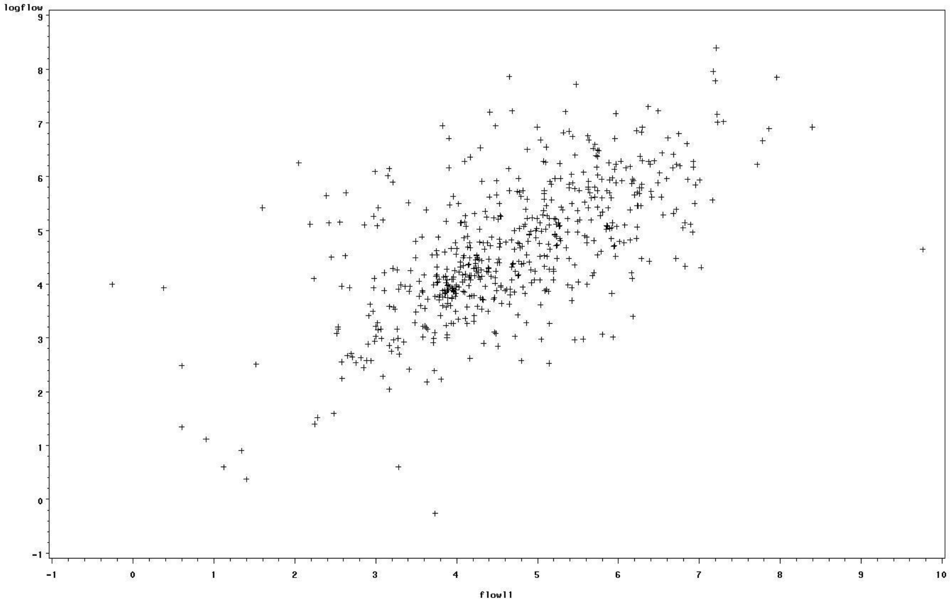


Figure 6.8: Scatterplot of flow versus logflow in the previous month (flowl1).

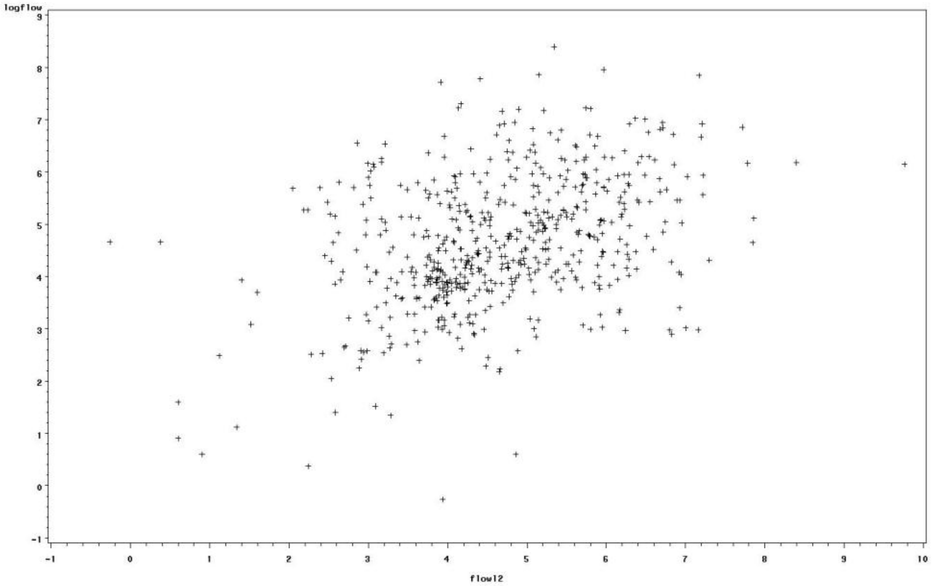


Figure 6.9: Scatterplot of flow versus logflow two months previously (flowl2).

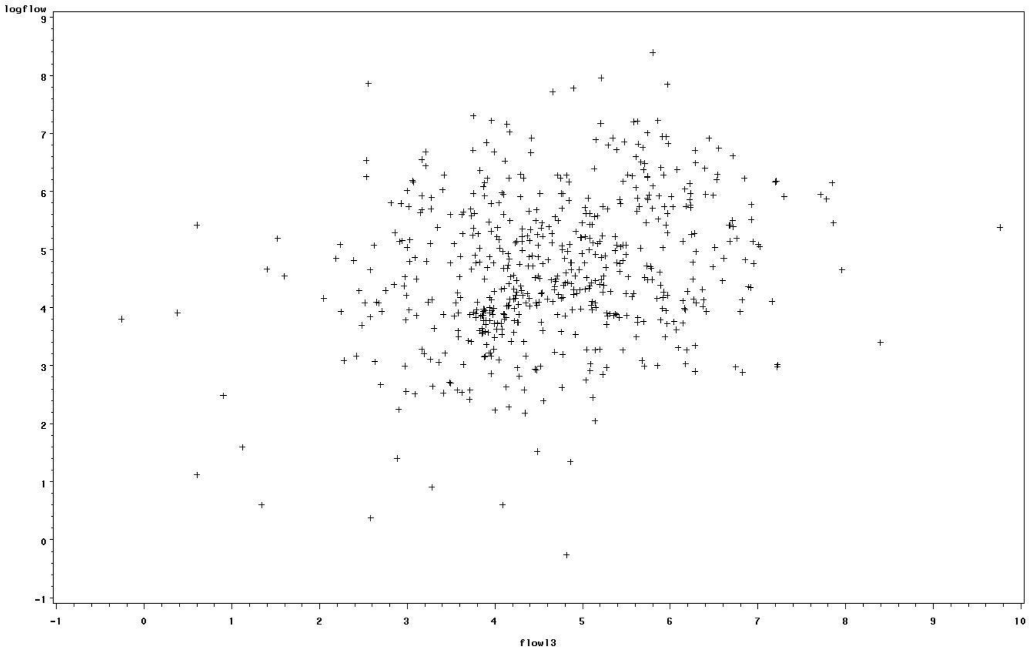


Figure 6.10: Scatterplot of flow versus logflow three months previously (flowl3).

After the previous analysis which suggested that a linear relationship exists between flow and both rainfall and flow in preceding months, these two linear regression models were fitted:

Model 1

This regression model is based on rainfall data alone. Here, flow was modelled as the dependent variable and rainfall in the preceding 18 months as the independent variables where the equation is:

$$y_i = \mu + r_{i-1} \cdot \beta_1 + \cdot \cdot \cdot + r_{i-18} \cdot \beta_{18} + e_i \qquad (1)$$

Where y_i is the flow and in month i and $r_i-1, \ldots, r_i-18$ are the average rainfall figures in the preceding 18 months.

Model 2

This regression model is based on both rainfall and flow data. In this model flow is the dependent variable and both logflow in the preceding 3 months and rainfall in preceding 18 months as independent variables, this is represented as:

$$y_i = \mu + y_{i-1} \cdot \gamma_1 + \cdot \cdot \cdot + y_{i-3} \cdot \gamma_3 + ri_{-1} \cdot \beta 1 + \cdot \cdot \cdot + r_{i-18} \cdot \beta_{18} + e_i \quad (2)$$

Development of Model 1

The linear regression fit of Model 1 showed that the regression coefficients β14 to β18 were not significant. Therefore, the variables r14 to r18 were dropped from the model, and the following reduced model fitted:

$$y_i = \mu + r_{i-1} \cdot \beta_1 + \cdot \cdot \cdot + r_{i-13} \cdot \beta_{13} + e_i \qquad (1.1)$$

In the equation model (1.1), all coefficients with the exception of β9 were significant, so that the equation model (1.1) was accepted as the final regression model based on rainfall data alone. Disaggregating the rainfall data, Model 1 was fitted separately to the respective average rainfall data for the Orange and Vaal catchment areas. Results for both catchment areas were very similar to the results for the total catchment area.

In particular, the regression coefficients β14 to β18 were not significant in either analysis, so that for both catchment areas the equation model (1.1) may be accepted as the final regression equation based on rainfall data alone. Estimates of regression coefficients of model (1.1) were similar across catchment areas.

Development of Model 2

Linear regression of Model 2 showed that the regression coefficients $\gamma 2$ and $\gamma 3$, and $\beta 14$ to $\beta 18$ were generally not significant. Therefore, the variables y_{i-2} and y_{i-3}, and $r14$ to $r18$ were dropped from the model, and the following reduced model fitted:

$$y_i = \mu + y_{i-1} \cdot \gamma_1 + r_{i-1} \cdot \beta 1 + e_i \qquad (2.1)$$

Equation model (2.1) is a parsimonious (only two predictor variables) and therefore pragmatic model for the prediction of flow based only on information on rainfall and flow in the previous month. Disaggregating the rainfall data, Model 2 was fitted respectively to the average rainfall data for the Orange and Vaal catchment areas. Results for both catchment areas were very similar to the results for the total catchment area. In particular, for both catchment areas model (2.1) may be accepted as a pragmatic model based on rainfall and flow data.

After these processes, more disaggregation of the rainfall data was conducted and this section with the equations and models applies to the Vaal catchment area. With model (2.1) as the basis, namely involving flow and rainfall of only the previous month in the regression model, the following model was fitted using disaggregated rainfall data of the Vaal catchment area:

$$y_i = \mu + y_{i-1} \cdot \gamma 1 + r_{i-1},1 \cdot \beta 1 + \cdot \cdot \cdot + r_{i-1,9} \cdot \beta 9 + e_i \qquad (3)$$

Where $r_{i-1},1, \dots , r_{i-1,9}$ are the average rainfall figures for the 9 sub-areas, which are C1 to C9 of the Vaal catchment area.

Most of the estimated regression coefficients of model (3) were zero, so that stepwise model selection was used to identify significant predictors. The model selected was the following:

$$y_i = \mu + y_{i-1} \cdot \gamma 1 + r_{i-1,5} \cdot \beta 5 + r_{i-1,8} \cdot \beta 8 + e_i \qquad (3.1)$$

Thus the rainfall figures of the 5th (C51 and C52) and 8th (C81, C82 and C83) sub-areas of the Vaal catchment area were the best predictors of flow.

Similarly, the same procedure was conducted with the Orange catchment area and the following model was fitted using disaggregated rainfall data:

$$y_i = \mu + y_{i-1} \cdot\gamma 1 + r_{i-1,1} \cdot\beta 1 + \cdot\cdot\cdot + r_{i-1,4} \cdot\beta 4 + r_{i-1,6} \cdot\beta 6 + \cdot\cdot\cdot + r_{i-1,8} \cdot\beta 9 + e_i \quad (4)$$

Where $r_{i-1,1}, \ldots, r_{i-1,4}, r_{i-1,6}, \ldots, r_{i-1,8}$ are the average rainfall figures for the 8 sub-areas of the Orange catchment area, which are D1 to D8.

Most of the estimated regression coefficients of model (4) were zero, so that stepwise model selection was used to identify significant predictors. The model selected was the following:

$$y_i = \mu + y_{i-1} \cdot \gamma 1 + r_{i-1,1} \cdot \beta 1 + e_i \qquad (4.1)$$

Thus the rainfall figures of the 1st sub-area of the Orange catchment area provide the best predictor of flow.

Finally, considering the total catchment area, a regression model was fitted combining the predictor variables of models (3) and (4), namely flow in the preceding month, the average rainfall figures for the 9 sub-areas of the Vaal catchment area, and the average rainfall figures for the 8 sub-areas of the Orange catchment area. Again, most of the 17 regression coefficients were zero, so that stepwise model selection was used to identify significant predictors.

The model selected was model (4.1), so that the rainfall figures of the 1st (D11-D18) sub-area of the Orange catchment area provide the best predictor of flow among all sub-areas of the Vaal and Orange. From the statistical analysis conducted above, a graph was drawn from a randomly selected quaternary catchment area C52E. The rainfall in this catchment area over the priod of 1950 to 1990 was drawn. Figure 6.11 illustrates the rainfall pattern.

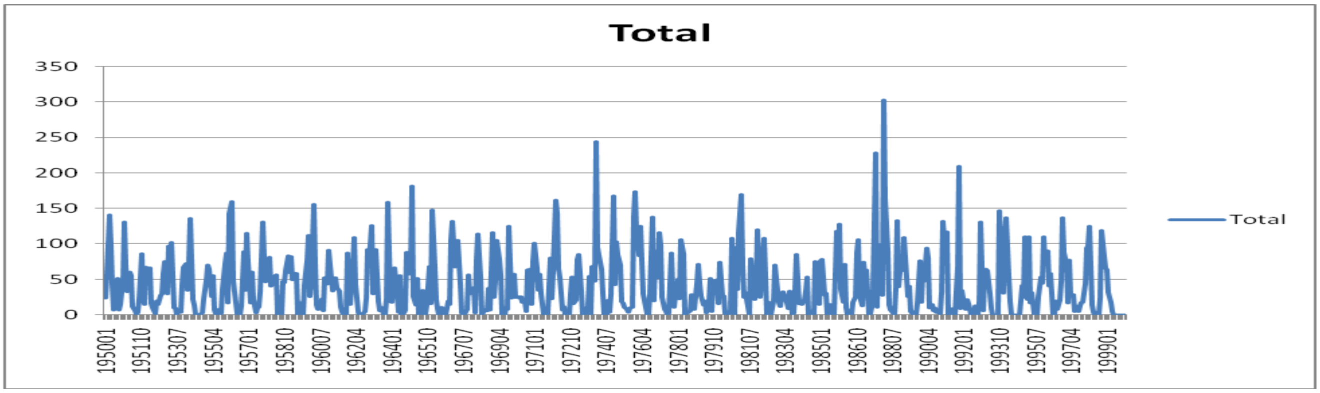


Figure 6.11: Rainfall in the C52E catchment area from 1950 to 1990.

To represent these suggested catchment areas that were determined in the statistical analysis, Figure 6.12 represents the C and D catchment areas that are good predictors of flow as discovered in the statistical analysis above. It is interesting to note that the areas are situated in the Eastern part of the study area.

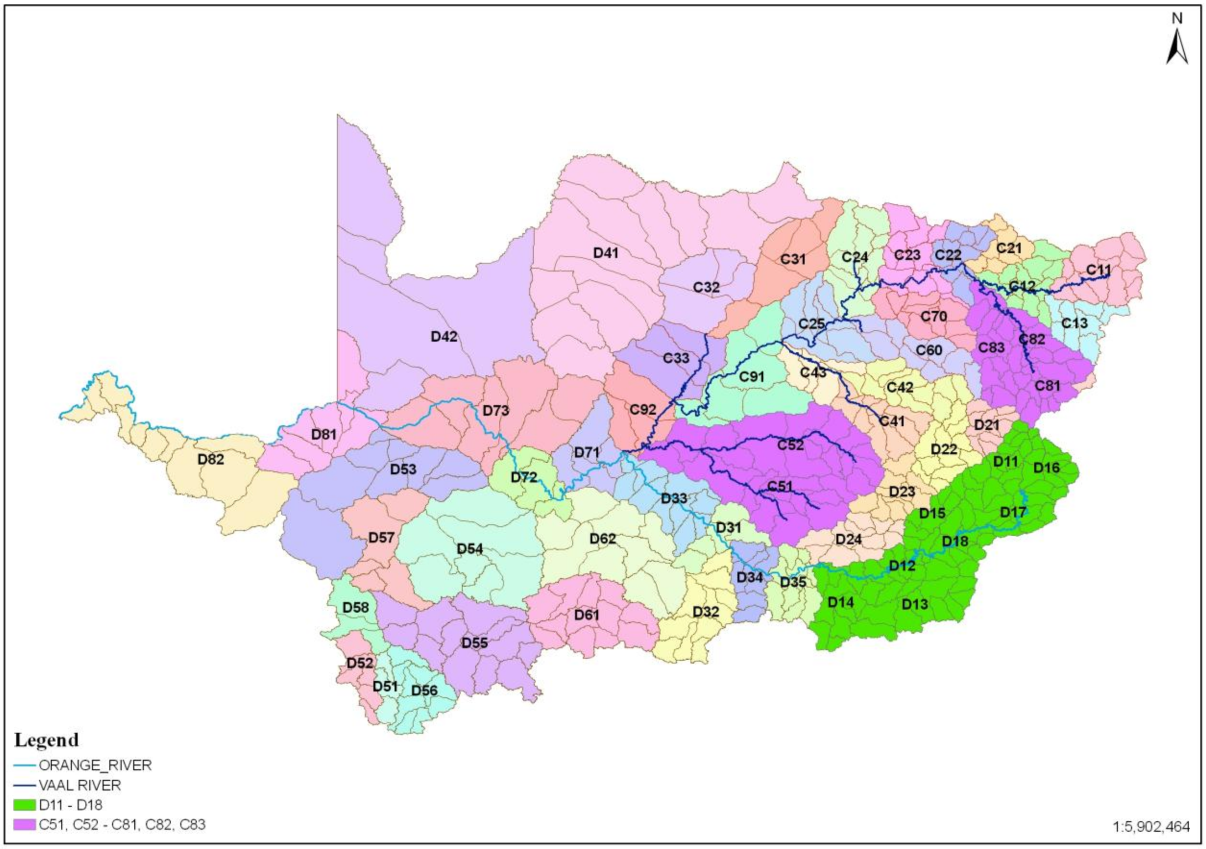


Figure 6.12: Vaal (C) and Orange (D) catchment areas which are good predictors of flow.

6.2.2 Spatial Analysis

The importance and advantages of a well functioning GIS for solving spatial problems is very useful and assists researchers to visualise the problem at hand and how it can be dealt with and solved. However, a GIS consists of more than just data; it also entails hardware, software, processes and users (Burrough & Mcdonnell, 1998).

Freely flowing interchange of data among organisations is one of the most important elements in the success of a GIS-based management operation and also with any spatial research where specific data is required. The available data were often in the incorrect formats for use in a GIS, so the spatial properties of data are also an important factor to be considered. Data manipulation therefore needs to be done so that the data can be used correctly and the correct results obtained. In this study, data were obtained from the Department of Water Affairs and Forestry (DWAF) in Pretoria. It consisted of 50 years' daily rainfall data, as well as monthly runoff (flow) data from the gauge D7H008 which is situated near the Orange River at the Boegoeberg Dam Reservoir (DWAF, 2009).

As mentioned in the previous section, the data were then sorted and joined into the relevant quaternary catchment areas to be compatible for use in the GIS. The rainfall in each of the quaternary catchment areas was added for each year and for each month in that year. After this the maximum flow which was $4432m^3s^{-1}$ and median was $94.18m^3s^{-1}$ were determined.

The average flow was determined to be $224.05m^3s^{-1}$. The data were then sorted and spatial analysis was conducted to show when the greatest amount of rain fell in the catchment areas. This date turned out to be in March 1988 and from the flood records in history there was a flood in that year during that month. Keeping the statistical analysis in mind, a two-month warning period was determined by using the fourth model where the rainfall figures of the 1st sub-area of the Orange catchment area provided the best predictor of flow among all sub-areas of the Vaal and Orange.

There are also six different types of spatial analysis according to Longley, *et al*. (2005:320):

1. Queries: the most basic of analysis operations where the GIS is used to answer questions posed by the user.
2. Measurements: simple numerical values that describe aspects of geographic data, including the measurement of length, area and/or shape.
3. Transformations: simple methods of spatial analysis that change datasets, combining them or comparing them to obtain new datasets and eventually new insights.
4. Descriptive summaries: attempts to capture the essence of a dataset in one or two numbers; the spatial equivalent of the descriptive statistics commonly used in statistical analysis that includes the mean and standard deviation.
5. Optimisation: techniques that are normative in nature and designed to select ideal locations for objects given certain well-defined criteria.
6. Hypothesis testing: focuses on the process of reasoning from the results of a limited sample to make generalisations about an entire population.

Spatial modelling accompanies spatial analysis. *Model* is one of the most overworked terms in the English language. A data model is a template for data; a framework into which information about the earth's surface can be fitted. There are two main requirements for a spatial model, namely that there is a variation across the space being manipulated by the model and the results of modelling change when the location of the objects change. Location is very important and it is also the key requirement for spatial analysis to take place.

A question frequently asked is, *Why use modelling?* The answer is that models are built for a number of reasons. Firstly, they might be built to support a design process in which the user wishes to find a solution to a spatial problem. Secondly, a model may be built to allow the user to experiment on a replica of the world, rather than the real thing. Finally, models allow the user to examine dynamic outcomes by viewing the modelled system as it evolves and responds to different inputs. The other advantage of using modelling techniques is that it gives the user an opportunity of experimenting with 'what-if' scenarios.

Modelling techniques are also very helpful and informative in prediction, planning purposes and noticing changes, as is the situation with this study of the Orange and Vaal River catchment areas and climate variability.

6.2.2.1 Map Production

The purpose of the study was to identify the influence of climate variability on flood risk, so as to show where the flood risk would occur and which areas would be affected and to produce map images. The highest rainfall record was in March 1988, so with using spatial statistics tools, the hot spot analysis was used to identify and show where the rainfall from the highest to lowest occurred in the two catchment areas in March of that year.

The same was done for January and February of the same year; these two months were used because of the statistical analysis results which determined that a two-month prediction period could be used to identify when large amounts of rainfall can be expected, also to prepare for the possibility of a flood occurring. This process was performed on ten such cases to determine which would visually best show the results of the highest, medium and lowest amounts of rainfall in the quaternary catchments of the Orange and Vaal Rivers.

Figure 6.13 represents the rainfall that was the highest recorded in the 50 years of data collected; the flow was $4432m^3s^{-1}$ in March 1988 which was when the flood was recorded. Figure 6.14 illustrates the rainfall a month prior to this event, February 1988. Finally, Figure 6.15 shows the rainfall two months prior to the March 1988 flood event, which is January 1988. The catchment areas in red indicate where the highest amount of rainfall occurred, while the blue represents where the lowest amounts were calculated. This colour scheme is used in all the images presented.

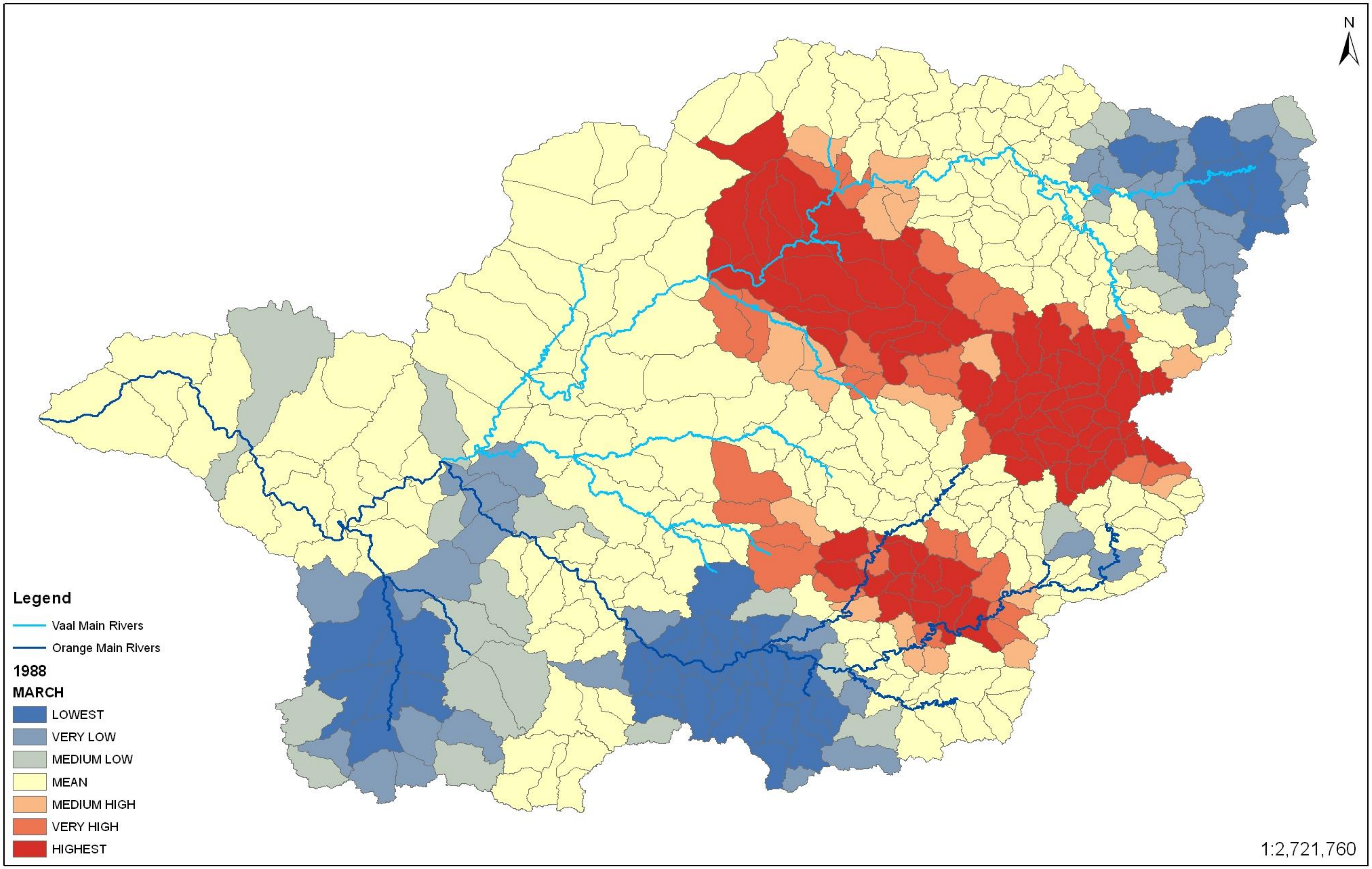


Figure 6.13: High and low rainfall areas in March 1988

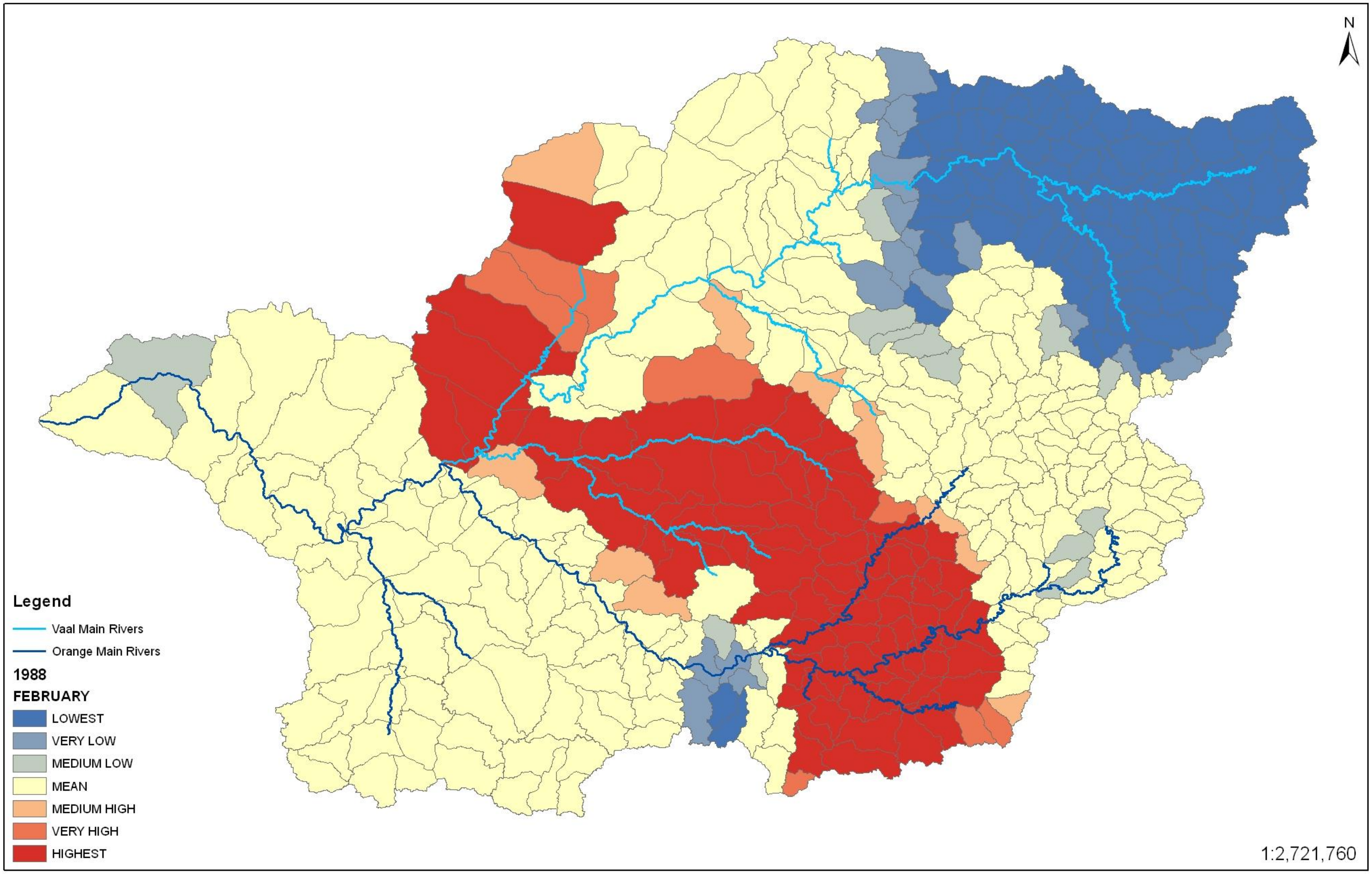


Figure 6.14: High and low rainfall areas in February 1988

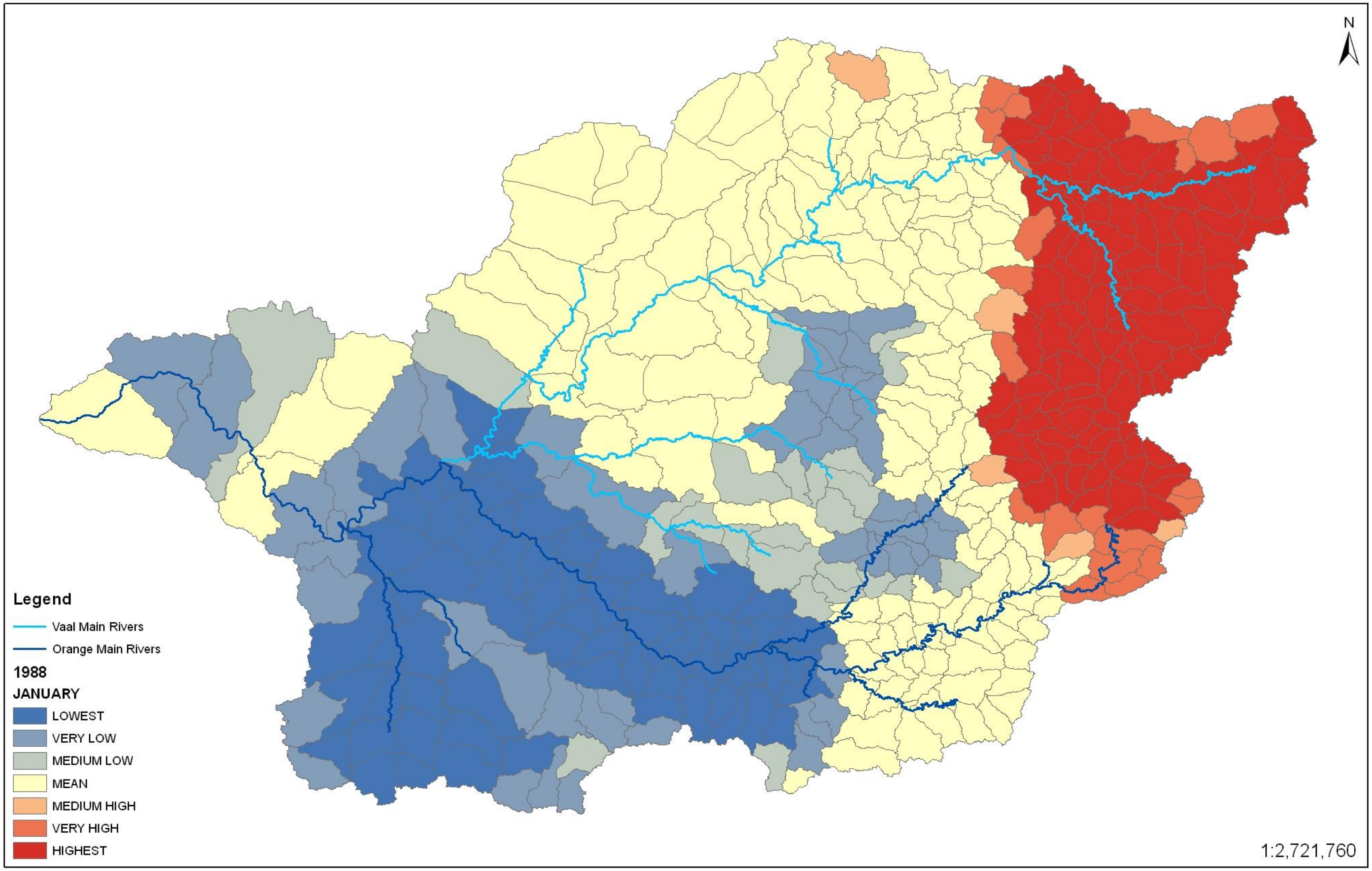


Figure 6.13: High and low rainfall areas in January 1988

A pattern emerges in Figures 6.13-6.15. In January (Figure 6.15) the highest amount of rainfall was in the eastern part of the catchment areas and the lowest accumulated in the southern and western parts. In February (Figure 6.14) the highest has moved more to the central part of the area and the lower amounts are now in the eastern part. In March (Figure 6.13) the higher amounts moved slightly back and a little to the south; the lowest moved back toward the south and the west. This high rainfall over the central part in February and then in March when it moved a little higher up in the Vaal catchment area resulted in heavy rains and a large amount of runoff in areas in the Free State, Natal and the Cape. The affected towns included Bloemfontein, Douglas, Jacobsdal, Ritchie, Ladysmith, Barkley West and Groblershoop. The Orange, Modder, Riet and Vaal Rivers contributed to this event. The Spitskop Dam burst on the Hartz River.

The example where the medium amount of flow was taken was in November 1977 where the measurement was 598.9m^3s^{-1} for that month. Figure 6.16 illustrates this event and the high amounts of rainfall are scattered across the catchment areas, mostly occurring in the north and patches in the east and west respectively. The lower amounts are centrally situated in the catchment areas. Refer to Figure 6.17 which illustrates the flow one month prior to this reading, which was in October 1977. The higher rainfall is in the eastern and some in the southern area, where a large amount of the lower rainfall is mostly in the Orange River catchment area. Figure 6.18 represents the rainfall two months before November, i.e. September 1977. The higher amounts were still in the east with some patches occurring farther north; a few lower rainfall amounts are also situated in this area, but still mostly occur in the western and southern parts as was the case in October 1977.

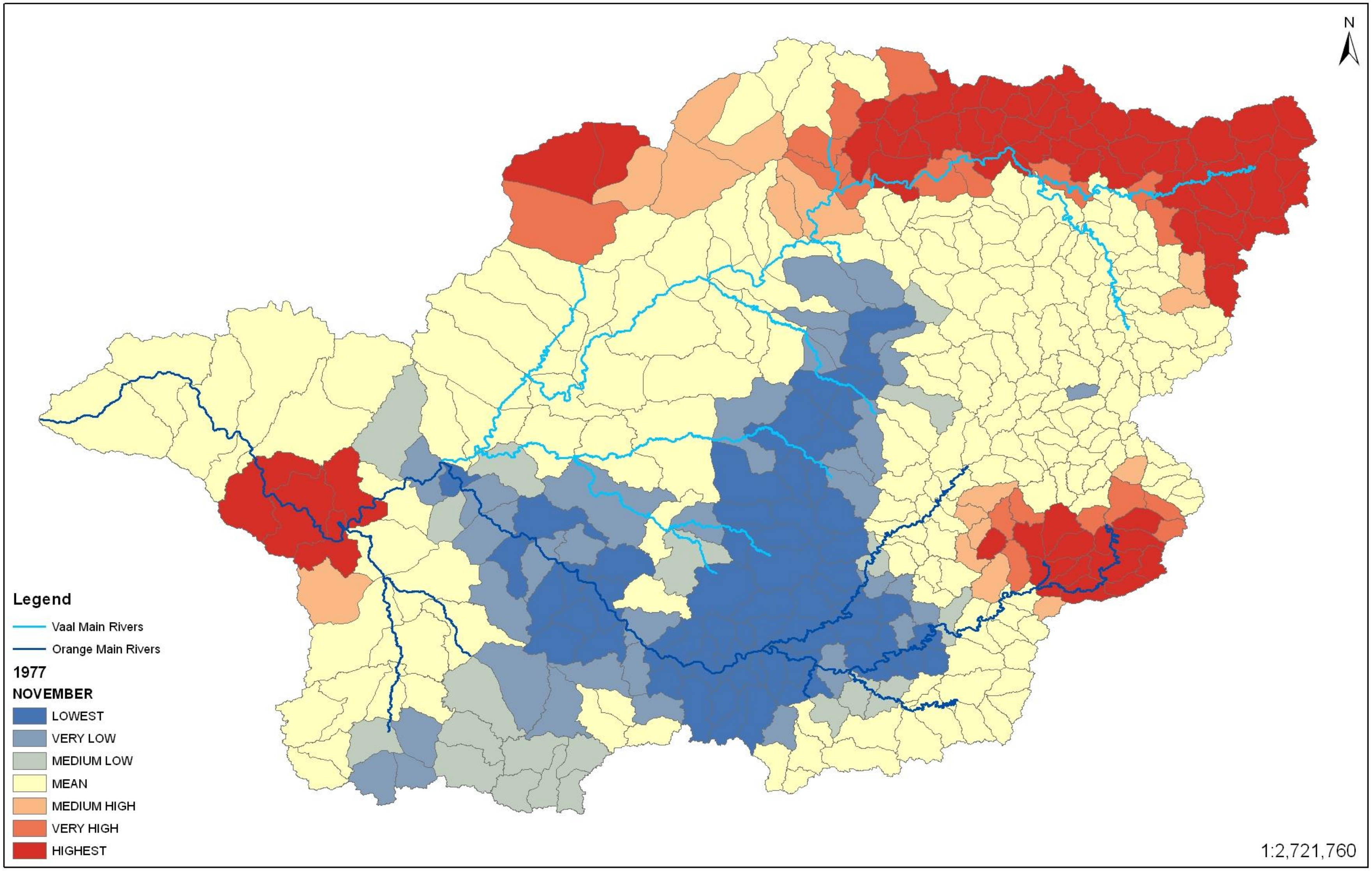


Figure 6.16: High and low rainfall areas in November 1977

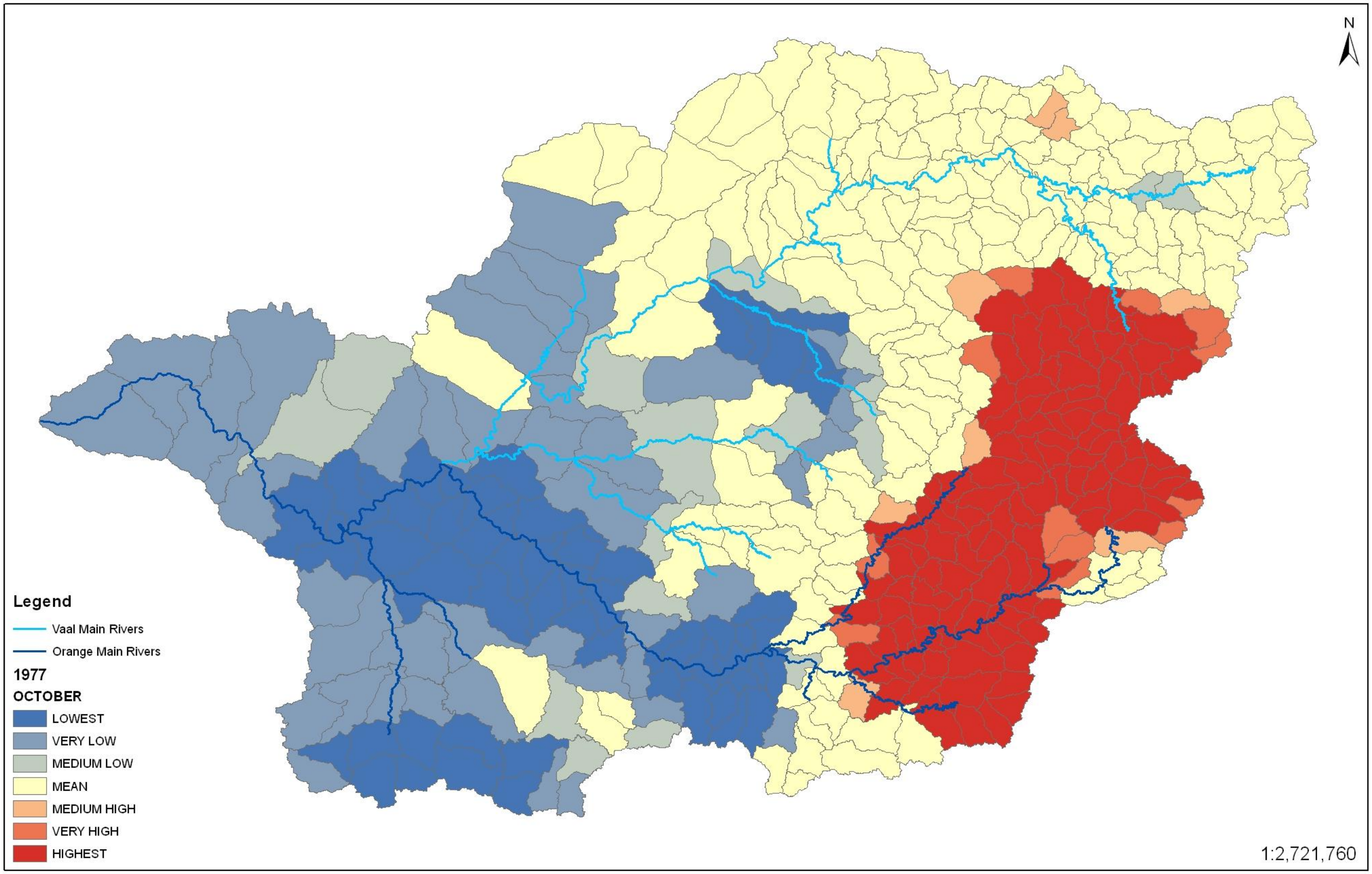


Figure 6.17: High and low rainfall areas in October 1977

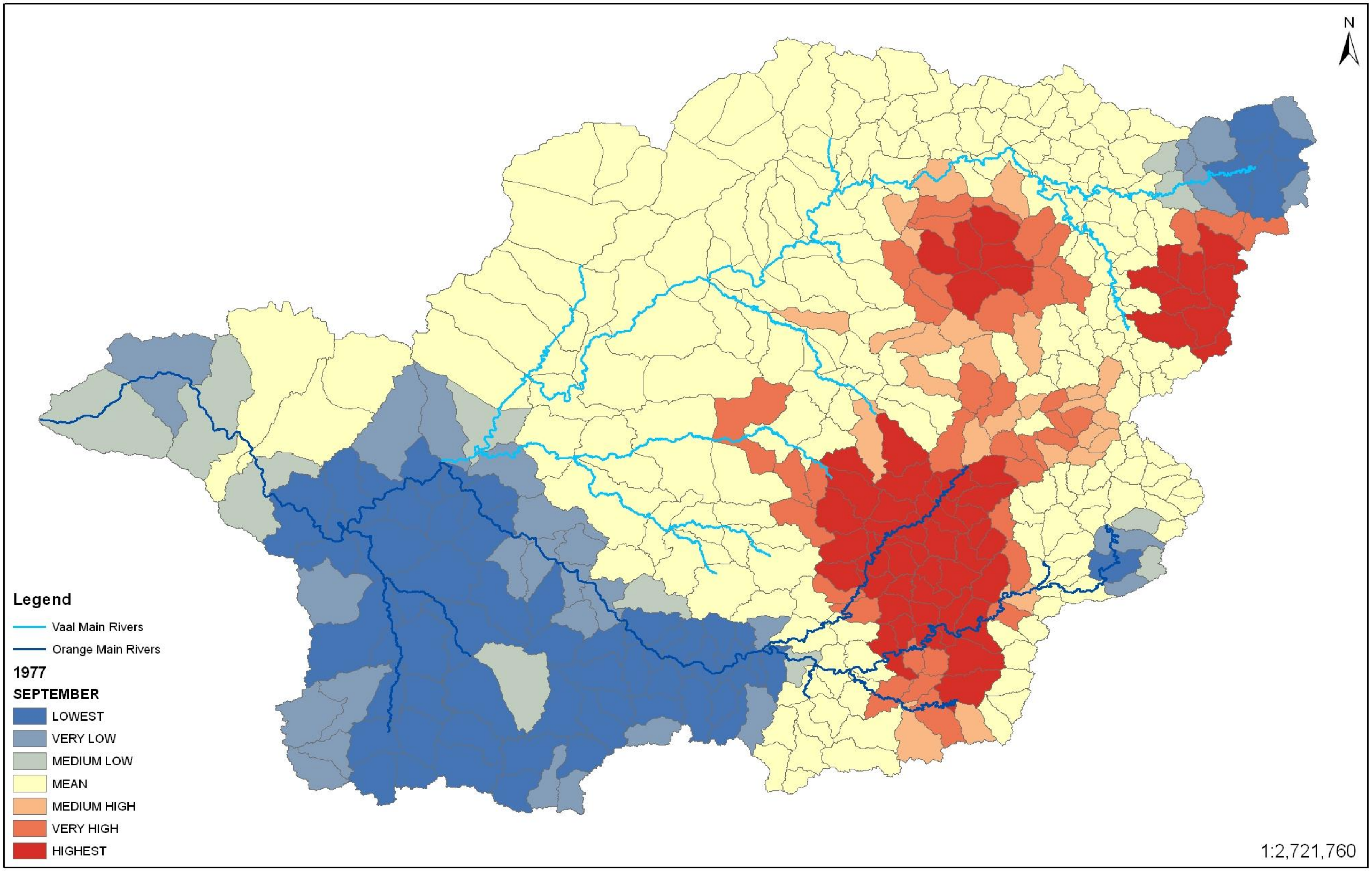


Figure 6.18: High and low rainfall areas in September 1977

Lastly, the results where the lowest average flow was selected, were in July 1997. The average that was calculated was $245.9m^3s^{-1}$. Figure 6.19 shows that the higher rainfall figures are concentrated in the east and a few places in the central parts of the catchment area. The lower figures occur in the north, west and south. Figure 6.20 represents the rainfall in June 1997, where a small cluster of the higher figures are in the east and small patches occur in the south and in the central area. The lower rainfall figures are in the north and only a small cluster is in the southern part of the catchment area. Figure 6.21 represents the rainfall in May 1977. Here the higher figures have moved to the northern parts of the catchment areas and the lower rainfall figures occur in the west and central parts of the area.

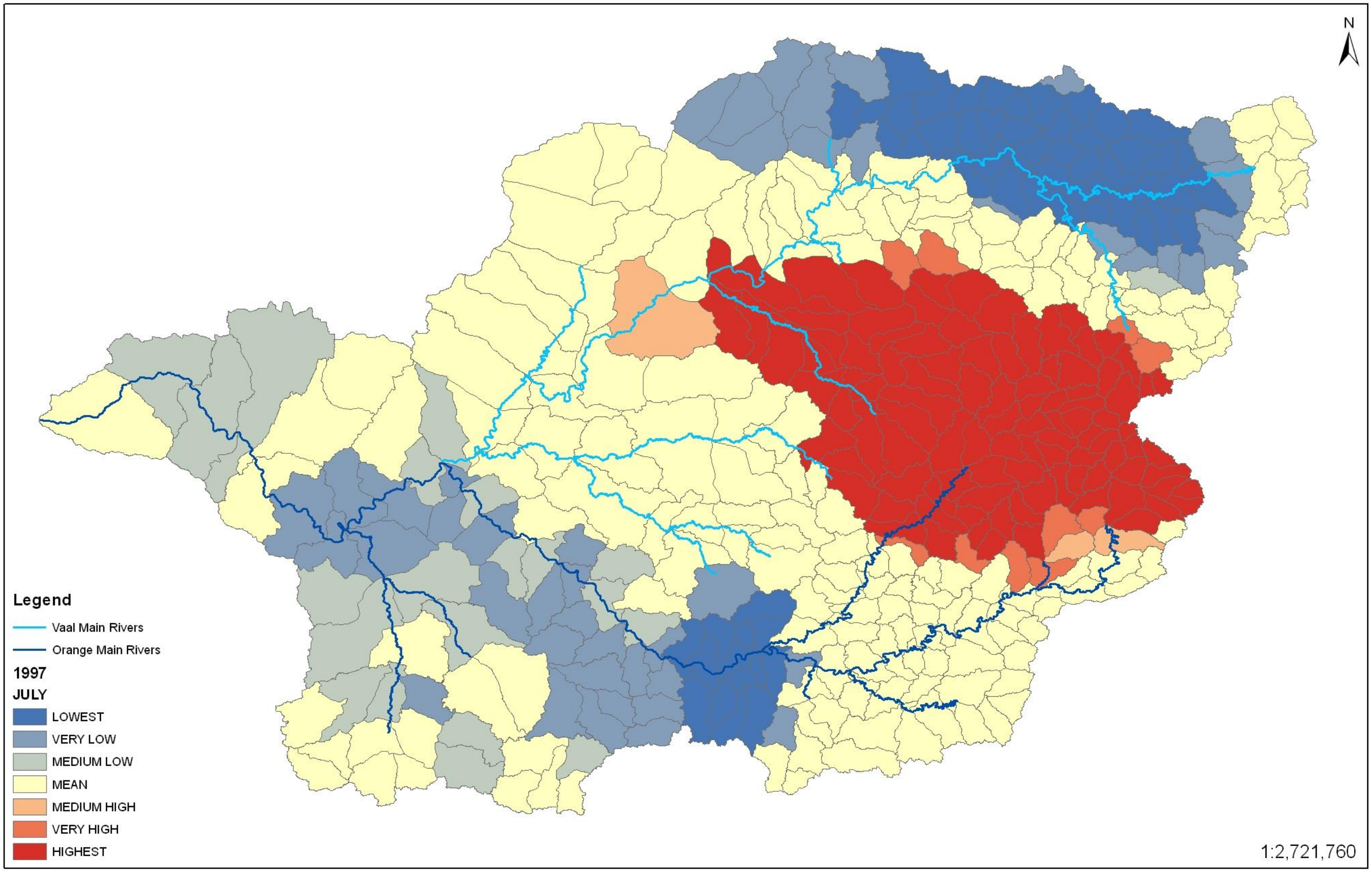


Figure 6.19: High and low rainfall areas in July 1997

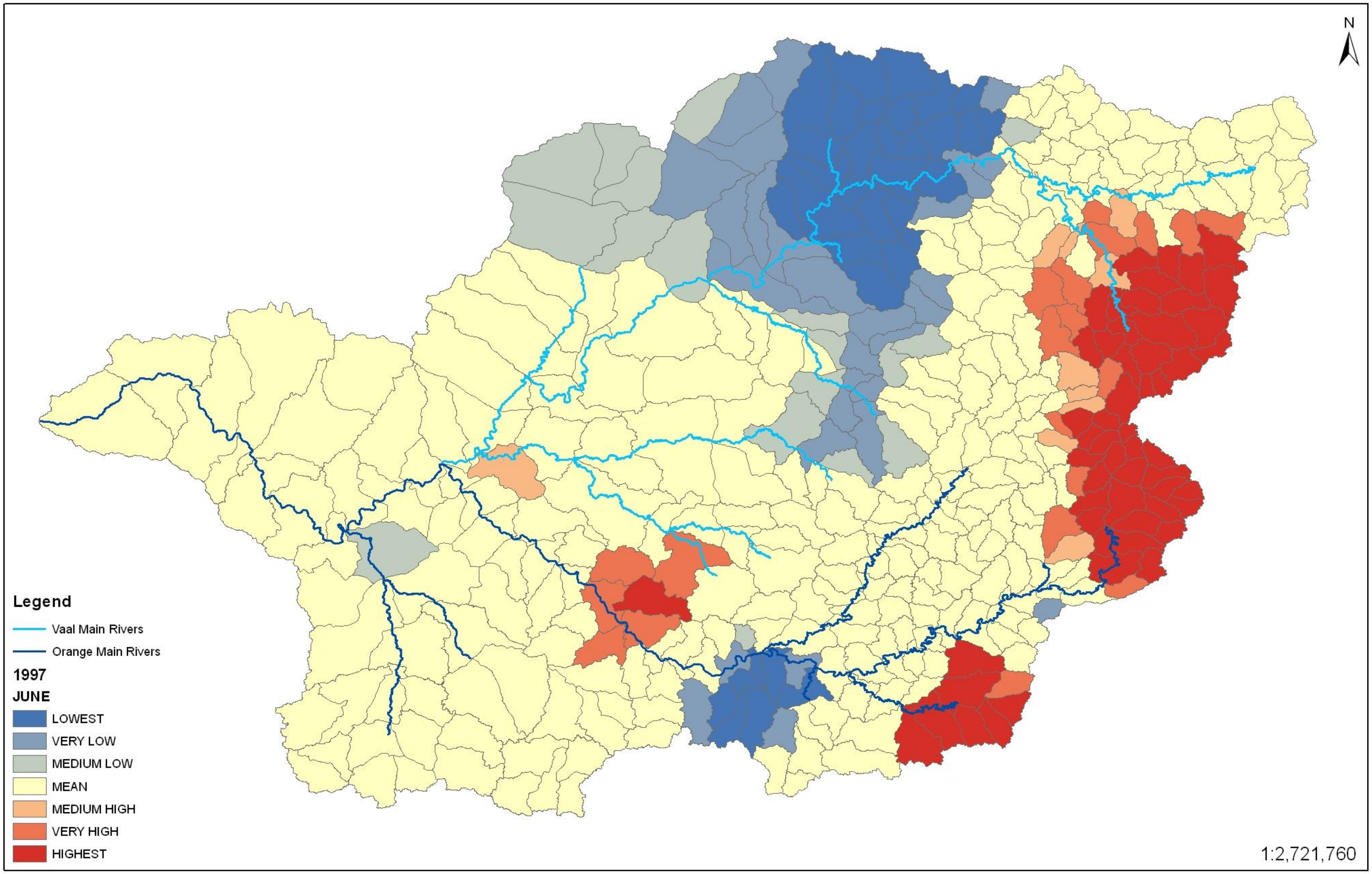


Figure 6.20: High and low rainfall areas in June 1997

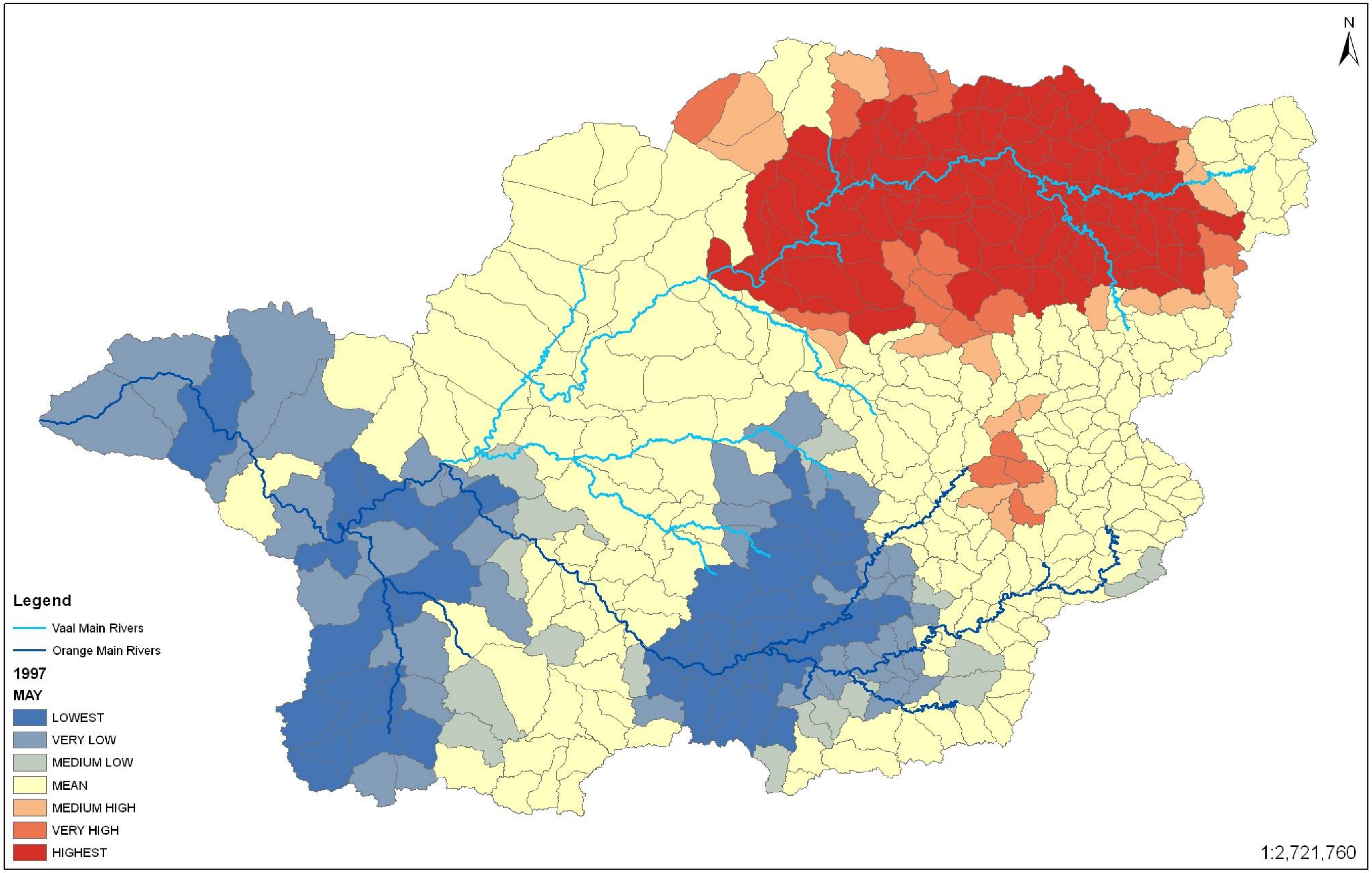


Figure 6.21: High and low rainfall areas in May 1997

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

The climate of the continent and the world is controlled by complex maritime and terrestrial interactions that produce a variety of climates across a range of regions and continents. Climate influences agriculture, the environment, water and even the economy of countries all over the world. The climate of the world varies from one decade to another and a changing climate is natural and expected. However, there is a well-founded concern that the unprecedented human industrial and development activities of the past two centuries have caused changes over and above natural variation. Climate change is the natural cycle through which the earth and its atmosphere accommodate the change in the amount of energy received from the sun. The climate goes through warm and cold periods, taking hundreds of years to complete one cycle. Changes in temperature also influence the rainfall, but the biosphere is also able to adapt to a changing climate if these changes take place over centuries. Unfortunately, human intervention is currently causing the climate to change too fast. Plants and animals may not be able to adapt fast enough to this rapid climate change as humans can; the whole ecosystem is therefore in danger.

The global climate system is driven by energy from the sun. Several gases in the atmosphere act to trap the energy from the sun, thus warming the earth. These gases are called greenhouse gases and the process is the greenhouse effect. Without this there would be no life on earth. Human activities over the last 200 years, particularly the burning of fossil fuels (oil, coal and natural gases) and the clearing of forests, have increased the concentration of greenhouse gases in the atmosphere. This is likely to lead to more solar radiation being trapped, which in turn leads to the enhanced greenhouse effect. The annual cycle of the earth's climate is forced by solar insolation and corresponding surface fluxes that vary from summer to winter (Jury and Mpeta, 2005).

Many questions arise about climate change and climate variability and how they affect South Africa. Higher temperatures influence rainfall, but it is still uncertain how the annual rainfall will change. It could increase in some parts of the country and decrease in others. The water resources will be affected, where South Africa's industrial, domestic and agricultural users are highly dependent on a reliable supply of water.

A reduction in rainfall amount or variability or even an increase in evaporation would further strain the already limited amount of water resources. An increase in rainfall or a reduction in plant water use would ease the problem slightly. Human and animal health will also be affected, because there are several insect-carried human and livestock diseases which are sensitive to the climate. A small increase in temperature would, for example, allow malaria to spread into areas which are currently malaria-free and would increase its severity in areas where it already occurs. The forestry industry could probably tolerate a small increase in temperature, but a decrease in rainfall would reduce the area that can support plantations and the growth rate of the trees. A positive point is that rising carbon dioxide could help reduce water use by plantations.

As was observed in the previous chapter, the maps that were provided indicate the scenarios that occurred when the flow amounts where at the highest, moderate and the lowest. No specific way was used in choosing the dates; it was done randomly with all the situations tested. In 1988 when the flood occurred in March, the flow and rainfall were their highest in the upper parts of the Vaal catchment area. This was not the only factor that led to the event; the rainfall and runoff in February and January contributed greatly to the flood event. In February the flow was the highest in the Orange and in some parts of the Vaal catchment areas and in January only in the Vaal catchment. Within a two-month period, the rivers' water levels can rise, dam walls may break and all of this may lead to flood events. The 1988 flood was due to the high levels of rainfall, as well as flow in the region over the three months.

With the aid of statistical analysis a model was used to determine which predictor would be most useful to the provinces and municipalities to aid them in preparing for another such event again. The two variables of rainfall and flow were used and a two-month prediction model was produced. *This could be used as an early warning system for farmers, as well as for inhabitants of the towns which the flood event would affect.*

In the study that was conducted by NETGroup with the Disaster Management Plan in 2002, the flood line in Upington in the //Khara Hais Municipality had already been determined to indicate where the flood waters would flow and which areas would be affected.

Reviewing the other flow maps where the high and low flow areas were indicated, it may be noted that there is a change in the rainfall patterns over the years. This supports the notion that climate variability does in fact occur from year to year and even from season to season. Climate variability would thus in fact influence the //Khara Municipality in term of flood risk. The only time that a flood event would occur again in this region would be 1) if the rainfall is excessive in the Orange and Vaal catchment areas, as was the case in 1988 over a period of two to three months; and 2) if the walls of the Vanderkloof and Gariep Dams were to break or overflow. Otherwise, the main influence of high water levels in the Orange and Vaal Rivers and their tributaries would come from the Vaal River, as this area has more rainfall overall throughout the year.

It may also be speculated when considering Figures 5.6, 5.7 and 6.12 that they represent a pattern. In Figure 5.6 it is the ENSO graph of the rainfall patterns around the world from 1950 to 1990 that also conveniently falls in the same years as the data used for the study. On the other hand, Figure 5.7 represents the summer rainfall across South Africa. When trying to represent the data and the results from the data in a graph, a randomly selected quaternary catchment area C52E was chosen. The reason for selecting the C catchment, which is the Vaal catchment area, was that because the rainfall and flow are more abundant in that area than in the Orange catchment area. The C52 was selected because of the statistical analysis conducted; the two best sub-areas in the Vaal catchment area were the 5th and the 8th catchment areas. When the graph for this area was drawn (Figure 6.12), there was a similarity in the pattern distribution of the three graphs.

This similarity is that in the El Niño (dry) years, the rainfall is considerably low and is in the negative half of the graph. By contrast, in the La Niña (wet) years, the rainfall is relatively higher and falls above the 0 mm mark and into the positive numbers. It may therefore be suggested that if in a La Niña year, for two months in succession, for instance, in October and November, there is a considerable amount of rainfall, the Disaster Management Team and municipality members should take precautions; there is a high probability that a flood event could occur in the area in December.

The future of climate change issues in South Africa is mainly the domain of the government, but all citizens can do their share and contribute to the aim of reducing carbon emissions. Although future climate change seems to be of importance to the government, it is clear that climate change, variability and associated increased disaster risks will seriously hamper future development.

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