# Chapter 3: Hazards and vulnerability in the Tlokwe Local Municipality’s water catchment area

## 3.1 Introduction

In this chapter, the second research objective is addressed, namely identifying and conceptualising the generic hazards, and the hazards that are related to a water catchment area including the related groundwater compartments and those specific to the catchment area that can affect the Tlokwe Local Municipality’s surface catchment areas. To address this objective as outlined in Figure:5, the water catchment area and system as a part of the hydrological cycle is discussed with the aim of conceptualizing the hydrological cycle within the water catchment area and identifying the factors that must be considered in the catchment. The hydrological cycle and the catchment hydrological cycle are discussed.

This is followed by a concise discussion of Disaster Risk and its three determinants and risk identification, with the aim of conceptualising a model that can be used in the disaster risk process. A generic classification and a discussion of potential natural and anthropogenic hazards and specific water catchment related natural and anthropogenic hazards are then provided.

A concise description of the Mooi River catchment area and system, with the aim of providing a spatial model of the Mooi River Catchment area is provided. This is followed by a more detailed discussion of quaternary Catchment Area C23D that is used to demonstrate a methodology to acquire the information necessary for an effective conceptual model. This includes identifying and describing entities in the catchment area and system, a concise description of the catchment area and system and the possible risk factors affecting the catchment area and system.

A concise description of the groundwater systems associated with the Mooi River catchment area, including dolomite compartments and mining voids, follows. The aim is to provide a diagrammatic representation of the groundwater associated with the Mooi River catchment. The summary lists factors within the catchment, the catchment hydrological systems as well as potential hazards and their sources that must be taken into consideration when conceptualising a spatial information system.

Figure 5, gives an outline of sections discussed in chapter 3, with the expected output of each/.

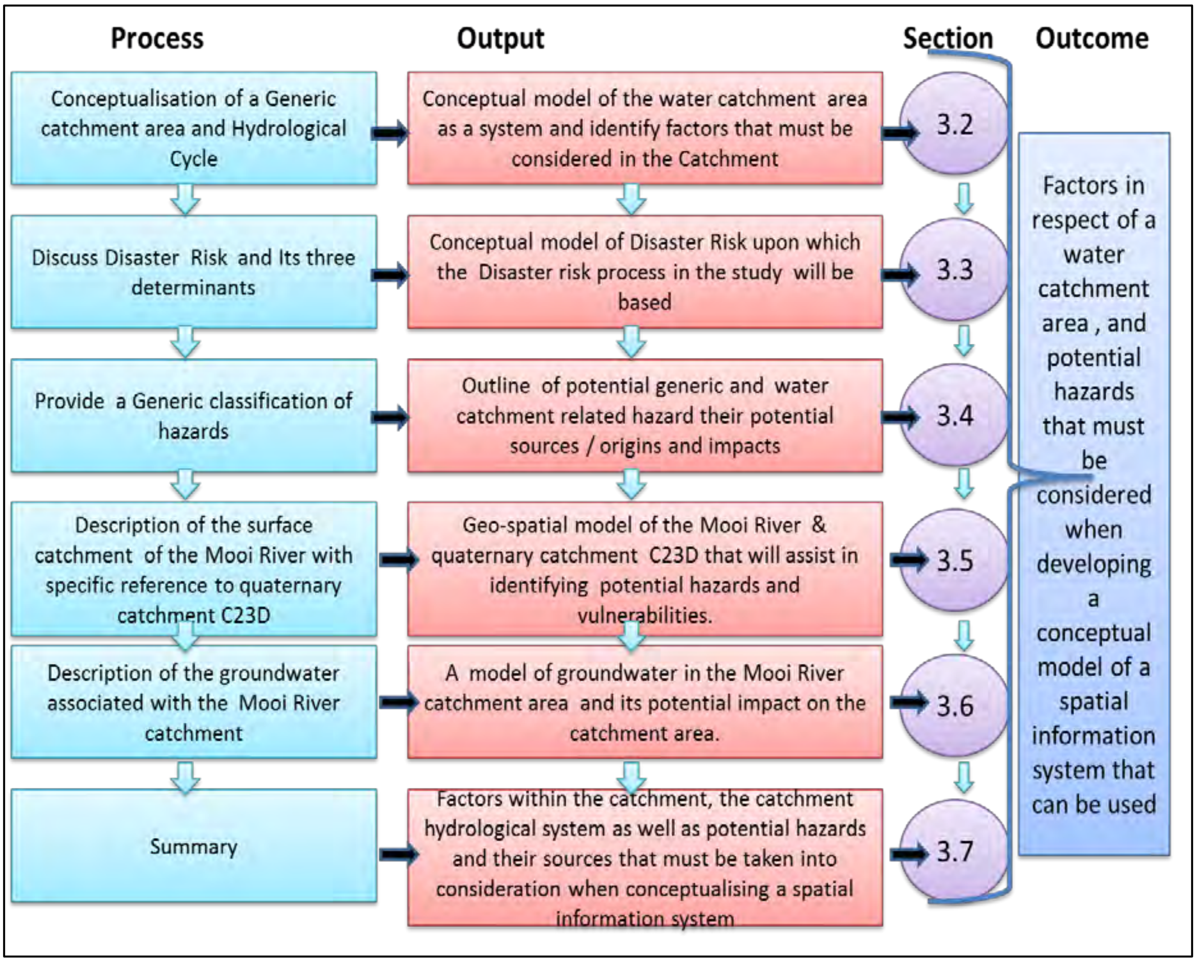


**Figure 5 : Outline of Chapter 3**

According to O'Keeffe *et al*., (1994:277) "The conditions, water quality and biota of any body of freshwater are the product, and reflections of events and conditions in the water catchment area". Therefore, both natural and anthropogenic activities together with the net flow of water in the catchment are arguably the potential source of hazards in the catchment area. In the next section the water catchment area in relationship to the hydrological cycle is discussed.

## 3.2 Conceptualisation of the generic catchment area and hydrological cycle

### 3.2.1 *Water Catchment Area*

The water catchment area as indicated in Figure 6 is the basic hydrological unit that can be described as the total geographical area, that is the land area and groundwater area from which all water that precipitates on that surface contributes to the discharge reaching a particular converging point known as the catchment outlet, within the river network (Environment Agency, 2011:1; Redowicz, 2011:Online; Fourie *et al*., 2010:Online; Davis, 2008:5; Thompson, 1996:4).

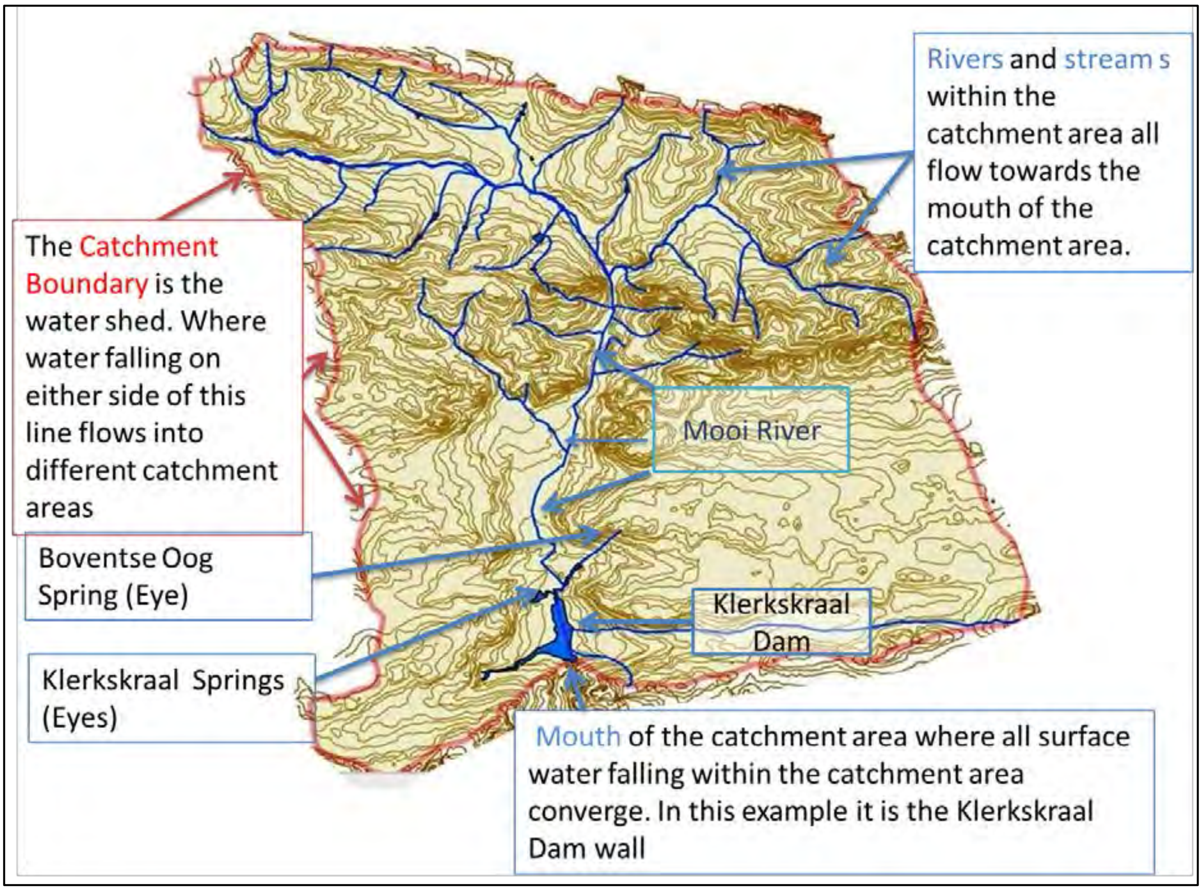


**Figure 6: Quaternary Catchment C23F as an example of a surface water**

The catchment can therefore be conceptualised as a basin where the river mouth is represented by the plug through which all the water in the basin (catchment) will flow (Fourie, *et al*., 2010:Online; Davis, 2008:5).

The surface catchment area as defined above is based on the assumption that all water that precipitates in the area will ultimately flow through the convergence point, in the case of this study, where the Mooi River, flows into the Vaal River.

However, it is possible that a portion of the precipitated water that infiltrates the ground can become part of the groundwater with its solvents, that ingress into the surface water of another catchment area. Therefore, groundwater that ingresses in the surface water of one catchment area can have its origin with its associated hazards in another catchment area (Know Your Watershed, 2011:6). It is also possible that anthropogenic interventions can result in the transfer of water between catchment areas influencing the net flow (quantity), the quality for example solvents and solids, and ecology of water of the catchments involved (Seetal, 2013:6; WWF GLOBAL, 2013:Online; WWF GERMANY, 2009:Online; Cyrus, 2001:Online).

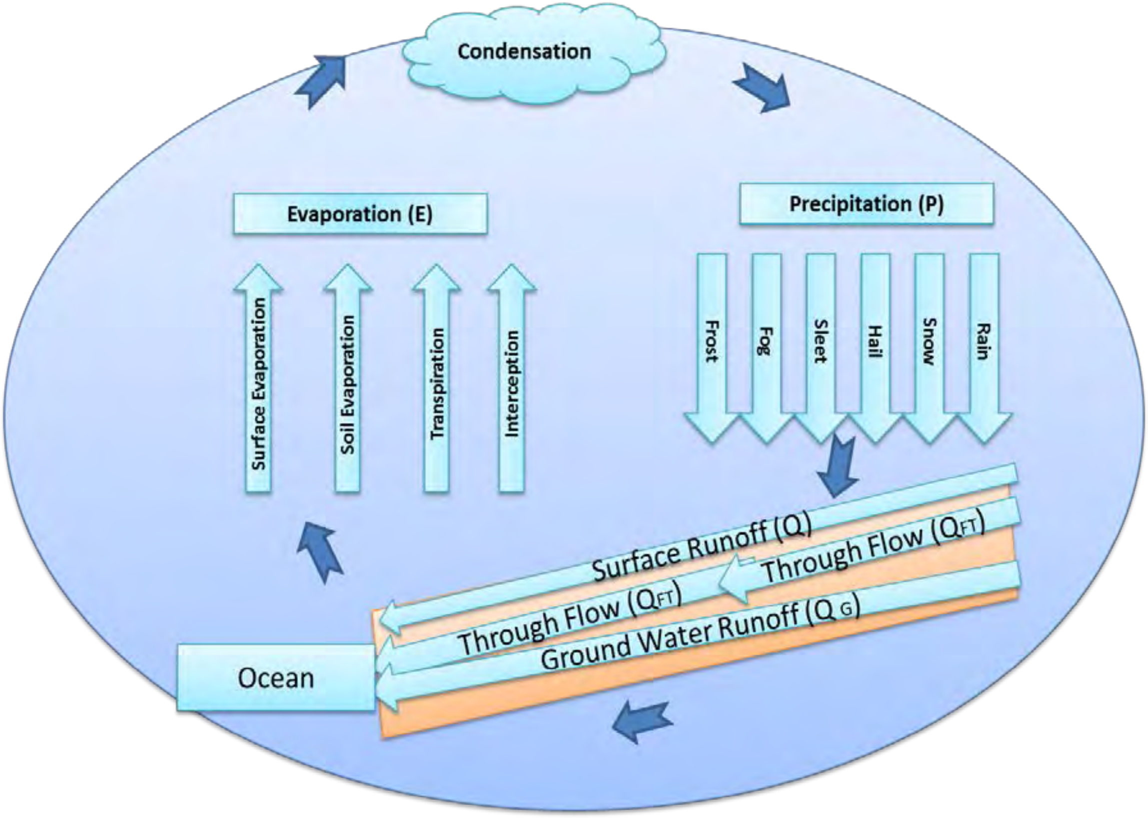
For the purpose of this study, water quality and water quantity include the potential hazards related with water quality and quantity. For example, water quantity, which implies a volume of water, where for example, a sudden increase of river flow has the potential to result in a flash flood. For water quality, for example, radioactive contaminants are hazardous pollutants, where both the former and latter have the potential to effect a disaster (UASA, 2011:Online; Van Der Merwe - Botha, 2009:Online; Jooste & Rossouw, 2002:Online).

Based on the above, knowledge of the water catchment area and system is significant in the management of the potential risks of disasters, in that it provides information concerning the spatial location of potential hazards, for example, an explosives factory and vulnerabilities, for example indigents, squatting on the banks of a river in relation to the water catchment area and hydrological system and water resource.

In the next section the cycle of the the net global movement of water namely the hydrological cycle is dicussed.

### 3.2.2 Hydrological Cycle

The hydrological cycle as illustrated in Figure 7 is a conceptual model of how water moves around between the earth and atmosphere in a solid, liquid or gaseous state (Know Your Watershed, 2011:Online; Davis, 2008:5). Figure 7, is the authors conceptualisation of the global hydrological cycle based on the literature reviewed.



Based on the work of Know Your Watershed (2011:Online) and Davis (2008:5)

**Figure 7: Schematic representation of the global water cycle.**

The hydrological cycle (natural water cycle) comprises: of the ecosystems that includes rivers, wetlands, surface water, groundwater, lakes, dams, natural and unnatural water channels, water obstruction, flood plains; processes that includes evapotranspiration / infiltration, run-off and precipitation and; continuous movement of water on and in the earth (ground- and surface water) and between the earth and the atmosphere (Know Your Watershed, 2011:4; Thompson, 1996:3,4 & O'Keeffe *et al*., 1994:277). Theoretically, the total amount within the global water cycle remains constant as outlined in the water balance equation below (Davis, 2008:10). The water balance equation for the global hydrological cycle is a mathematical model providing a description of the hydrological cycle operating within a given time and is represented as a closed system where there is no mass (water) or energy created or lost within it (University of Arkansas, 2013:Online; NCAR, 2013:Online; Redowicz,2011:22-24; Davis, 2008:10-12). The movement of water and energy within the cycle has the potential to give rise to meteorological and hydrological hazards; this potential is illustrated when considering the different phases of the cycle as represented in the water balance below.

The water balance equation is represented as:

$P \pm E \pm \Delta S \pm Q = 0$

Where **P** is precipitation. Precipitation is all of the water that is released from the atmosphere that reaches the earth's surface. It includes rain, drizzle, sleet, snow, fog and hail, and is the main input of surface water within the cycle. Precipitation is the result of the condensation of atmospheric water vapour that precipitates by atmospheric cooling. As the atmosphere cools, its ability to hold water decreases, causing the water vapour to condense as water or ice around minute particles called condensation nuclei, and then to precipitate (USGS, 2013a:Online; NCAR, 2013:Online; Redowicz, 2011:25-26; NWS Jetstream, 2010:Online; Davis, 2008:14-16; Ward, 2003:Online).

The importance of the precipitation phase of the cycle in Disaster Risk Management includes the intensity (storms with flash floods) and duration (torrential rain) of precipitation that can cause floods (City of Cape Town, 2013; Hoo, 2011:Online; Mail & Guardian:Staff Report, 2009:Online; Davis, 2008:30); the type of precipitation (hail and snowstorms) that can cause sudden drop in temperature, structural damage and damage to crops, and the role that precipitation plays in the quality and quantity of water. The amount of precipitation influences not only the quantity of water but the quality as well. As water has a dilution effect, the more water, the greater the potential of the water body to dilute and reduce the effect of the contaminants entering the water. Precipitation also has the potential to dissolve air borne particles, particles on buildings, trees and particles on the surface. An example of the above is acid rain, which can be caused by the burning of fossil fuels that release carbon dioxide, nitrogen oxides and sulphur oxides into the atmosphere*.* The carbon dioxide dissolves in the precipitation to form carbonic acid, nitrogen oxide combines with the precipitation to form weak nitric acid and sulphur oxide combines with the precipitate to form a weak sulphuric acid. All these weak acids can then lower the pH of rainwater, which is normally between 5 to 6 (Briney, 2013:Online; Rose-Innes, 2012; Scorgie & Kornelius, 2009:3; Davis, 2008:34 -35).

Where **E** is evaporation. Evaporation is the transformation of liquid water into a gaseous state in the presence of sufficient energy to effect the transformation. The diffusion of the gaseous water into the atmosphere is dependent on sufficient water being available to effect the evaporation, and the receiving atmosphere being below saturation point. Evaporation includes open water evaporation, interception (evaporation from a plants surface), and transpiration from plants (USGS, 2013b:Online; Oblack, 2013:Online; Science Daily, 2013:Online; Clulow *et al.*, 2012:Online; Davis, 2008:10,36,38). The importance of evaporation in respect of Disaster Risk Management is its effect on water quality and quantity. The effect on surface and groundwater quantity is that increased evaporation decreases the amount of water reaching surface streams and the amount of water infiltrating the ground; this can lead to droughts (SAPA, 2013:Online; Makana, 2013:Online; Wren, 1992:Online). The impact on the quality of water is that evaporation can lead to the concentrating of remaining impurities (including pollutants), as well as the concentrating of salt in the soil (Matercherea, 2011:3745 - 3748; Davis, 2008:54; Slaughter, 2005:3)

Where **ΔS** is change in water storage. Storage water includes water stored as soil water (moisture), deep groundwater, water in lakes, dams and other reservoirs, glaciers, seasonal snow cover, etc., with the largest portion of water stored as snow or ice caps (polar ice caps) and groundwater. Water in storage is influenced by inflow and inflow rate, as well as outflow and outflow rate, of the water in and out of the water storage component. Water stored is therefore in continuous flux, and will not remain constant and is therefore, indicated in the cycle as a change of water storage (USGS, 2013c:Online; USGS, 2013d:Online; USGS, 2013e:Online; Davis, 2008:11,56).

The importance of water storage in respect of Disaster Risk Management is its influence on water quality, quantity and geophysical activities (sink holes, seismic movements, etc.). As water infiltrates through the vadose zone into the groundwater, it can dissolve mineral salts, sewage, chemical, pollutants for example organic toxins (fertilizers) and sulphate's from tailing dams, biological pollutants such as E Col, affecting the quality of the water, in some instances making it unfit for domestic consumption (Zeelie & Hodgson, 2013:Online; Lawrence *et al.*, 2001:19 -21). Rise in groundwater level can result in an increase of the amount of water entering the surface water and likewise a decrease in groundwater can result in a decline of the base flow of surface water.

Where **Q** is Runoff. Runoff is the term that refers to the movement of water on or below the surface to a channelized stream after it has reached the surface as precipitation. The process of the movement of water in a channelized form is known as either river or stream flow (USGS, 2013f:Online; Oblack, 2012:Online; Annville Pennsylvania, 2013:Online; Barron *et al.*, 2009:6721-6723; Davis, 2008:78; Smakhtin, 1997:125.). The stream flow can be measured as the discharged volume (in $m^3$ /s (*cumecs*)), and recorded on a hydrograph (Ponce, 2013:Online; Ashton, 2011:5-14; Lim *et al.*, 2005:408). The hydrograph can be used as an effective Early Warning tool and modelling tool in disaster management. It can indicate base flow, and flows resulting after significant rain in the catchment namely, peak flow, storm flow or quick flow at the point where it is placed (Davis, 2008:78). The characteristics of the hydrograph and the shape of the storm flow recorded, is influenced by the upstream catchment characteristics. These include catchment size, angles of the slope, shape of catchment, soil type, urbanisation, the antecedent water moisture, vegetation type and the percentage coverage of the vegetation (S-cool, 2013:Online; EPA, 2012:Online; Davis, 2008:79; ASCE, 1996:349).

Where $\mathbf{Q}. = (\mathbf{Q}_{O} + \mathbf{Q}_{T} + \mathbf{Q}_{\mathbf{G}})$.

- Where $\mathbf{Q}_{\mathbf{O}}$ is the, overland flow, and refers to the water that runs across the surface of the land before reaching the stream (Eslick, 2013:Online; Williams, 2013:Online; Katopodes & Bradford, 1999:1-27).

- Where $\mathbf{Q_T}$ is the sub surface flow through or lateral flow, of subsurface water normally in the unsaturated zone. Once water infiltrates through the soil surface it continues to move either through the soil matrix or along preferential flow paths (Bachmair & Weiler, 2012:Online; Davis, 2008:62; Freeze, 2010:Online; Anderson *et al*., 1997: 2637-2639).
- Where $\mathbf{Q_G}$ is the ground flow of water in the deeper saturated zone. It is the major contributor to the base flow of channelized or river flow, with through flow been a lesser contributor. The water will normally infiltrate from the surface into the unsaturated zone, from there it will flow into the saturated zone, and down slopes often into a stream. The slow seepage of groundwater (saturated) zone is the major contributor to base flow of a river (EPA, 2012:B107-B112; Goulburn-Murray, 2010:1-5; NERC, 2009:1-5; Davis, 2008:86). The significance in the Mooi River catchment is the major rivers; the Mooi River, Wonderfontein Spruit and Loop Spruit are perennial even in the dry seasons as both the upper catchment of Mooi River and the Wonderfontein Spruit base flow is contributed to by major groundwater aquifers.

As the study focuses on a specific catchment area, the dynamics of the hydrological cycle for a catchment are discussed below.

### *3.2.3 The catchment hydrological cycle*

The catchment hydrological cycle is a more detailed conceptual model depicting the movement of water between the earth and the atmosphere within a specific catchment area. The cycle consists of the total amount of water that can be in the form of precipitation **(P)** (rain, snow, sleet, mist, etc.), total run off (**Q**) both ground- and surface water, both liquid and solid, (**E**) water vapour as the result of evaporation and transpiration, condensates and (**S**) water storage, within the specific catchment area (Redowicz, 2011:18-22; Barron *et al*., 2009:6728; Muller, 2009:4-7; Davis 2008:10; Slabbert, 2007:1,14-19; Snaddon *et al*., 1998:Online). Unlike the global hydrological cycle, the water balance in the cycle may change, as water precipitates and water flows outs of or into the system. For example a tropical front, where moist in the atmosphere originates hundreds of kilometres from the specific catchment area can contribute to a sudden net increase of the total amount of water in the catchment's hydrological cycle. While evaporated water arising in the catchment may condensate and precipitate outside the catchment area, resulting in a net loss of water in the catchment area. Ground- and surface water can be exported and imported from beyond the boundaries of the catchment, thereby impacting on the net gain or loss of water in the catchment cycle (D.I.G, 2013:Online; Canadian Geographic, 2013:Online; Davis, 2008:10-11; Perry, 2005:Online). Despite the catchment hydrological cycle being limited to a specific catchment, the phases of the cycle and generic factors contributing to the possible risk of disaster in the global hydrological cycle are similar. To establish an effective spatial information system that will reduce the potential risk of disaster in the catchment, it is important to identify the route of water-flow from precipitation to the river streams, sources of possible pollution including point sources of pollutants, and approximate location of diffuse pollution (Davis, 2008:129), water extraction points, factors influencing the speed and quantity of water-flow and other structures that could impact on the quality and quantity of water (Davis, 2008:92-95).

Figure 8, below, is a conceptualisation of the water catchment area and the hydrological cycle as an integrated system, indicating potential sources of hazards, including pollutants, and the activities that can influence the flow of water through the hydrological cycle. In Figure 8, the hydrological cycle includes the components of the water balance equation discussed above, but differs from the global water cycle as illustrated in figure 7, as the net inflows or outflows of water into the catchment will and can affect the water balance in the catchment system.

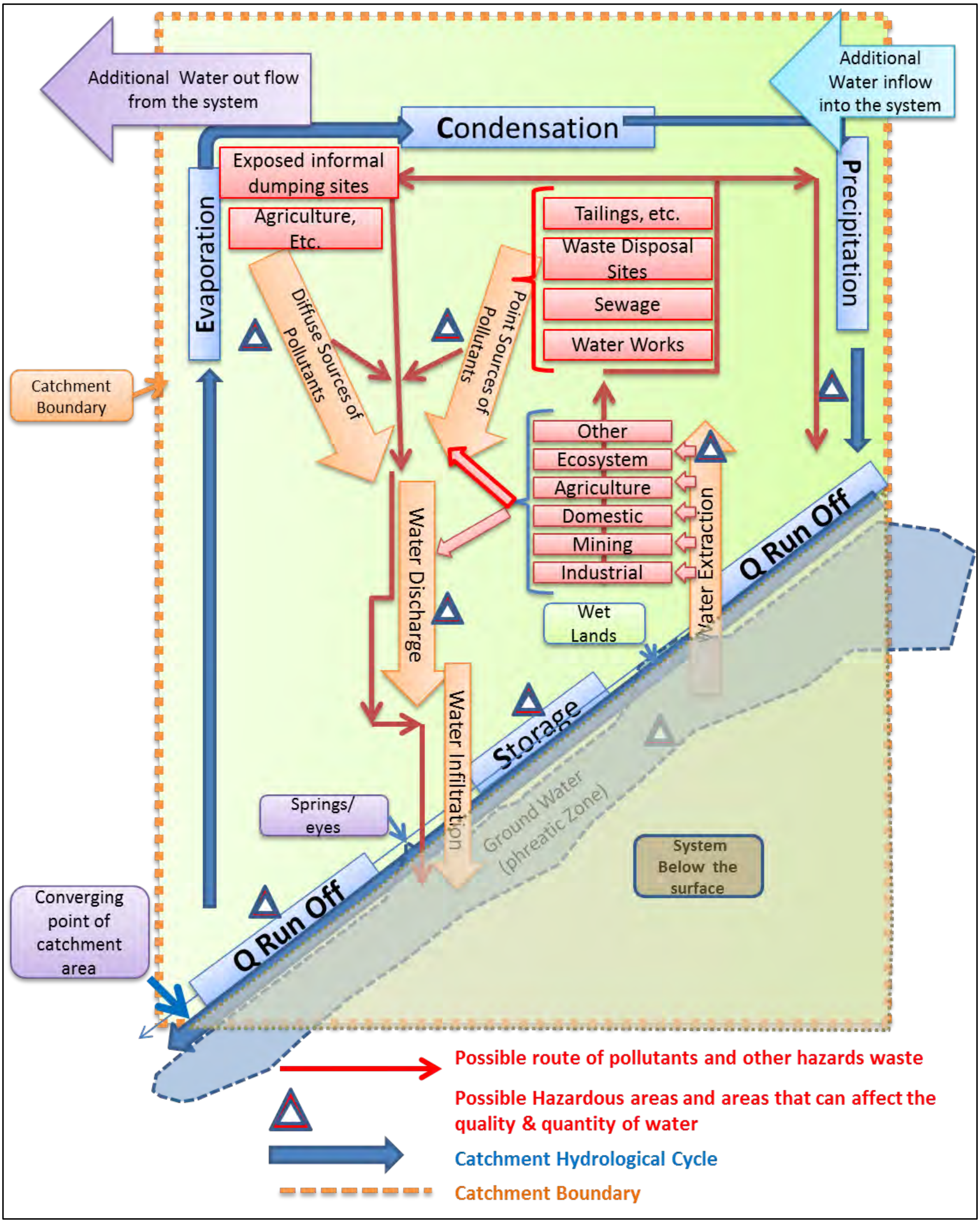


Figure 8: Conceptualisation of the water catchment and hydrological cycle as an integrated system.

The above provides a concise discussion, of the water cycle and surface water catchment. As the focus of the study is on potential risk of disaster within the water catchment area, the following section introduces disaster risk and its determinants.

## 3.3 Disaster Risk and its three determinants

### *3.3.1 Introduction*

In this section, the term Disaster Risk, with its three determinants, namely hazards, vulnerability and resilience, is analysed. The data and information used in the discussion and the conceptual modelling are based on a document study and literature research of both primary and secondary data and information sources (De Vos, *et al*., 2008 :314-325 & Mouton, 2008:179-180). The aim is to formulate a conceptual model upon which the Disaster Risk Assessment process will be based that can be used when determining the information required for an effective spatial information system that will identify, avoid, mitigate and manage potential risk.

### *3.3.2 Concise discussion of Disaster Risk and its three determinants*

Disaster Risk is a function of ((hazards x vulnerability)/(resilience)). Therefore, the risk of disaster has three components, viz. hazards, vulnerability and resilience, and it is directly proportional to the hazards risks and vulnerability, while inversely proportionate to the resilience (coping capacity) against the potential risk. This implies that the greater the potential risk of hazards or vulnerability, the greater the potential risk of a disaster (Van Niekerk, *et al*., 2002:12).

Risk has two defining components. Firstly, the probability component (chance, likelihood, frequency, etc.) and secondly, the impact component (consequence, impact, seriousness, etc.) of the negative outcome that may arise (Steyn, *et al.*, 2008:335; Visser & Erasmus, 2007:196; Twigg, 2004:43; Guild *&* Marais*,* 2001:75).

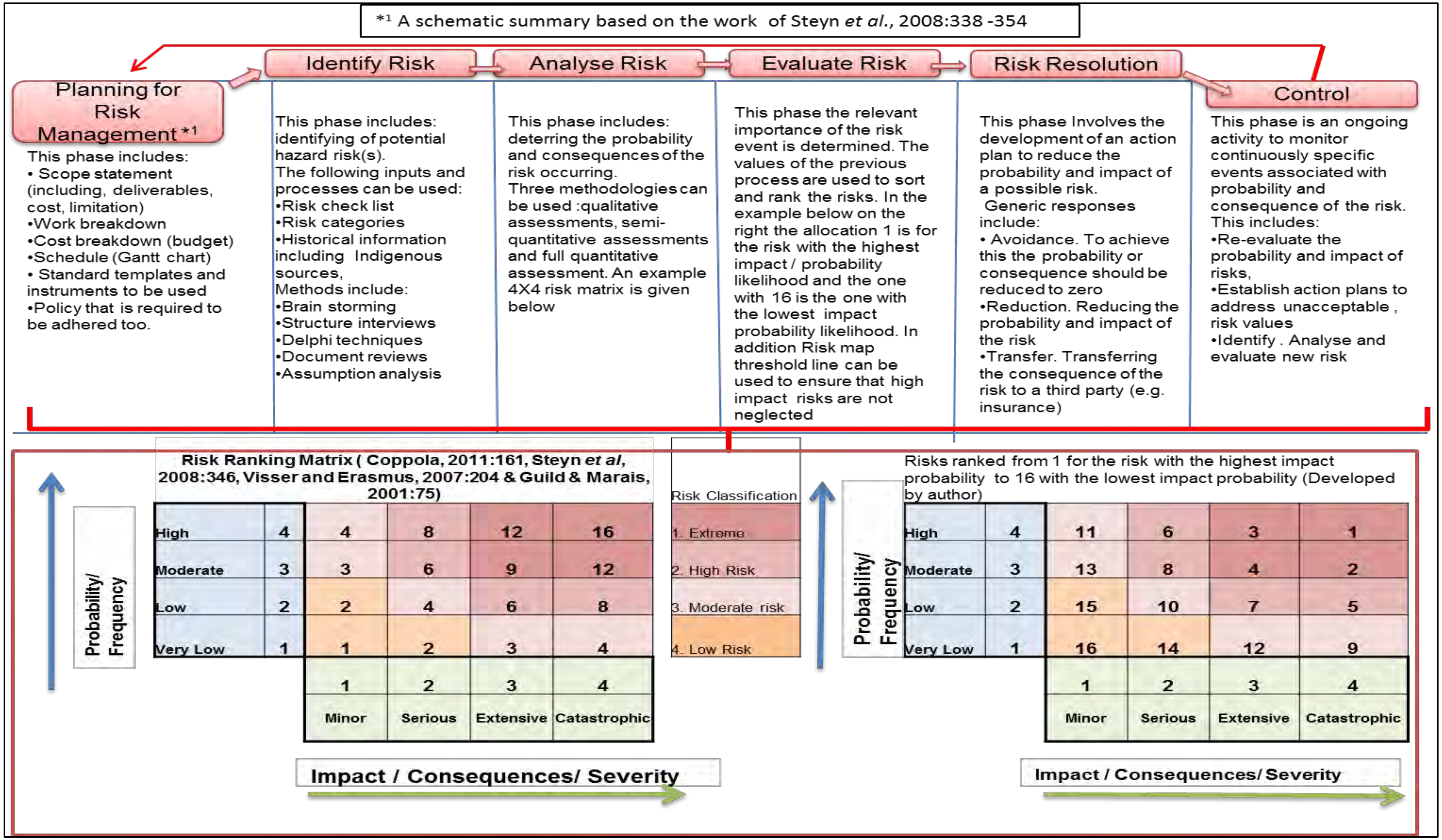
### *3.3.3 Risk and vulnerability analyses*

The importance of risk in disaster risk management, is the probability that a specific hazard or hazards may exploit particular vulnerability in a specific community or communities, resulting in social (including life and injury), economic and environmental loss, destruction, etc. (Van Niekerk, *et al*., 2002:18). Therefore, to avoid, mitigate, reduce the impact of a potential disasters, the risk of hazards and vulnerability (potential exposure to hazards) must be reduced while resilience (the ability to cope with the potential risk of hazards) must be increased.

This will require that in any effective disaster management system, the potential hazards and vulnerabilities be identified as early as possible, this includes the identifying of the potential source, likelihood of occurrence and potential ability of a hazard to trigger a disasters.

Figure 9, provides a concise outline of a risk management process that can be used to: obtain hazard data; analyse the risk of hazards; evaluate the risk of hazards; and avoid, reduce and manage the potential impact of the hazards.

Figure 10 provides a holistic process that can be used to address vulnerabilities with the aim of decreasing vulnerabilities while increasing resilience.



*1 A schematic summary based on the work of Steyn *et al.*, 2008:338 -354

**Planning for Risk Management** *1

This phase includes:
- Scope statement (including, deliverables, cost, limitation)
- Work breakdown
- Cost breakdown (budget)
- Schedule (Gantt chart)
- Standard templates and instruments to be used
- Policy that is required to be adhered too.

**Identify Risk**

This phase includes: identifying of potential hazard risk(s).
The following inputs and processes can be used:
- Risk check list
- Risk categories
- Historical information including Indigenous sources,

Methods include:
- Brain storming
- Structure interviews
- Delphi techniques
- Document reviews
- Assumption analysis

**Analyse Risk**

This phase includes: deterring the probability and consequences of the risk occurring.
Three methodologies can be used :qualitative assessments, semi-quantitative assessments and full quantitative assessment. An example 4X4 risk matrix is given below

**Evaluate Risk**

This phase the relevant importance of the risk event is determined. The values of the previous process are used to sort and rank the risks. In the example below on the right the allocation 1 is for the risk with the highest impact / probability likelihood and the one with 16 is the one with the lowest impact probability likelihood. In addition Risk map threshold line can be used to ensure that high impact risks are not neglected

**Risk Resolution**

This phase Involves the development of an action plan to reduce the probability and impact of a possible risk.
Generic responses include:
- Avoidance. To achieve this the probability or consequence should be reduced to zero
- Reduction. Reducing the probability and impact of the risk
- Transfer. Transferring the consequence of the risk to a third party (e.g. insurance)

**Control**

This phase is an ongoing activity to monitor continuously specific events associated with probability and consequence of the risk.
This includes:
- Re-evaluate the probability and impact of risks,
- Establish action plans to address unacceptable , risk values
- Identify . Analyse and evaluate new risk

**Risk Ranking Matrix ( Coppola, 2011:161, Steyn *et al*, 2008:346, Visser and Erasmus, 2007:204 & Guild & Marais, 2001:75)**

Probability/ Frequency

| | | | | | |
|---|---|---|---|---|---|
| High | 4 | 4 | 8 | 12 | 16 |
| Moderate | 3 | 3 | 6 | 9 | 12 |
| Low | 2 | 2 | 4 | 6 | 8 |
| Very Low | 1 | 1 | 2 | 3 | 4 |
| | | 1 | 2 | 3 | 4 |
| | | Minor | Serious | Extensive | Catastrophic |

Impact / Consequences/ Severity

| Risk Classification |
|---|
| 1. Extreme |
| 2. High Risk |
| 3. Moderate risk |
| 4. Low Risk |

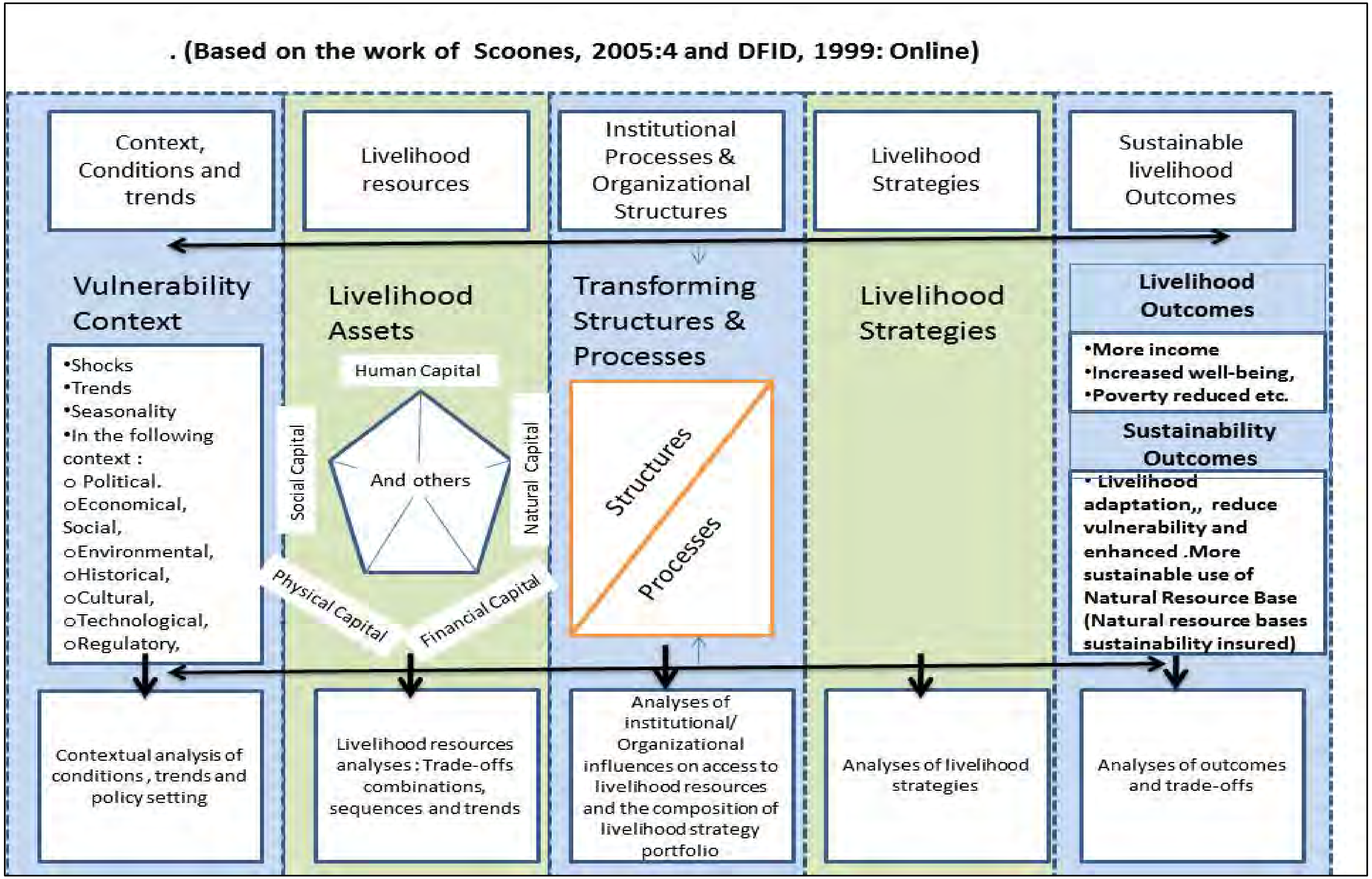
Risks ranked from 1 for the risk with the highest impact probability to 16 with the lowest impact probability (Developed by author)

Probability/ Frequency

| | | | | | |
|---|---|---|---|---|---|
| High | 4 | 11 | 6 | 3 | 1 |
| Moderate | 3 | 13 | 8 | 4 | 2 |
| Low | 2 | 15 | 10 | 7 | 5 |
| Very Low | 1 | 16 | 14 | 12 | 9 |
| | | 1 | 2 | 3 | 4 |
| | | Minor | Serious | Extensive | Catastrophic |

Impact / Consequences/ Severity

Figure 9: A Risk Management Process that can be used in risk management.



. (Based on the work of Scoones, 2005:4 and DFID, 1999: Online)

Figure 10: Sustainable Livelihood framework adapted for vulnerability analysis and reduction.

In this section, a summary of the determinants of disaster risk is provided. The following section provides a concise classification of one of the determinants of disaster risks, namely hazards.

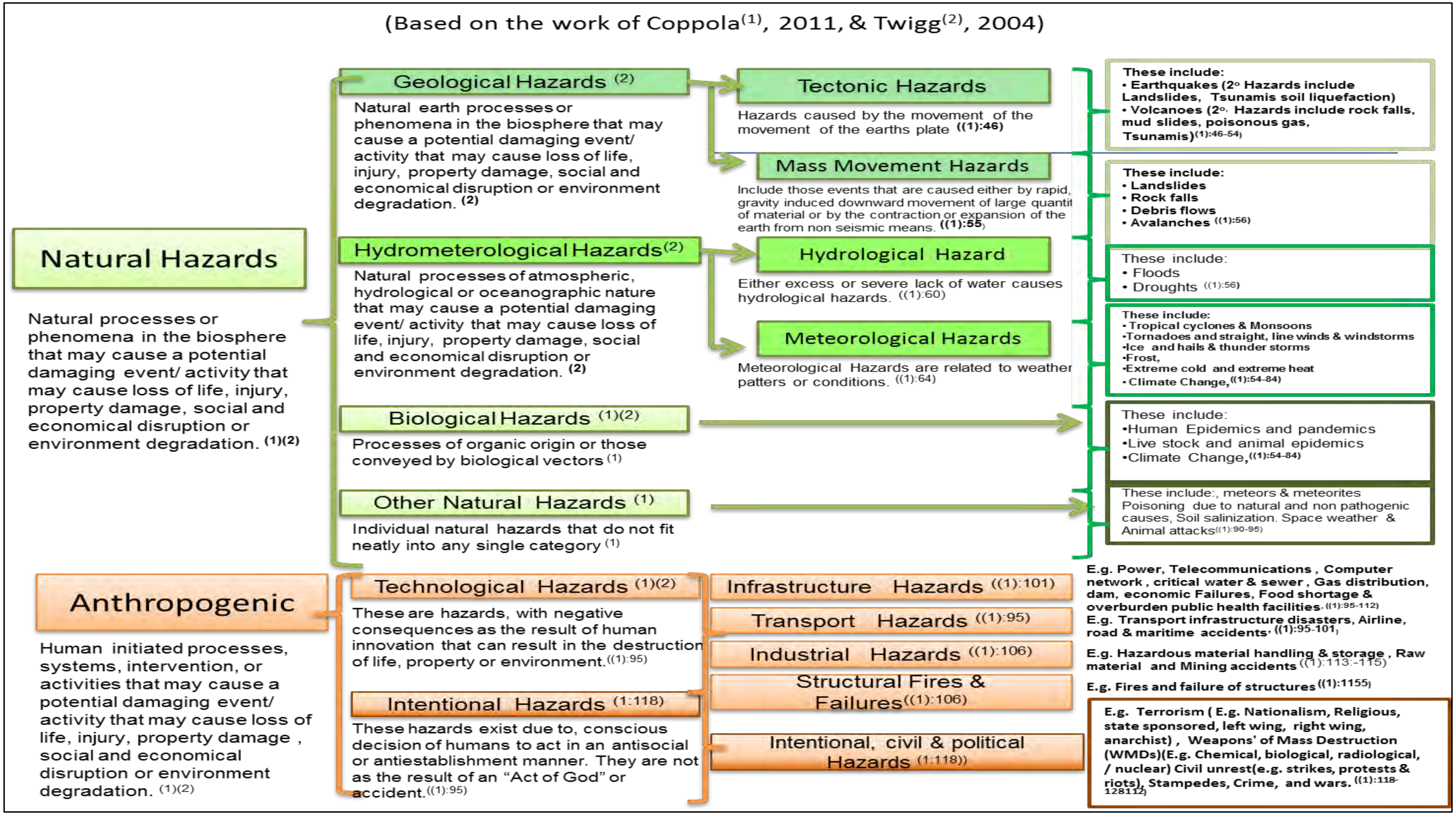
## 3.4 Classification of hazards

### *3.4.1 Classification of generic hazards*

To assist with hazard identification and assessments, hazards are categorised into several groups and sub groups. Although numerous category systems exist, according to Coppola (2011:15), the following should be considered when categorising hazards:

- The categories chosen must accommodate the full range of hazards and none should be overlooked.
- It is possible that a hazard in one category can cause a secondary hazard in another category. An example of the latter is Vajont (Vaiont), Italy, where in 1963, a landslide (primary hazard) occurred in the 261 m high dam. Because of the filling of the dam, the resulting wave was a 200-metre tsunami (secondary hazard) that flooded dwellings and villages (Longarone, Castellavazzo, Erto and Casso) below the wall, killing between 1800 - 2000 people (French Ministry Of Sustainable Development, 1963: 1-5; Semenza & Ghirotti. 2000:87-96). In this example the primary hazard and secondary hazard, are in different categories.
- It is possible to place a hazard in more than one category, and this may lead to confusion. Despite the confusion, all the hazards must be accommodated in the category system used.

The classification of hazards is a tool that assists in identifying potential hazards that may arise in an area being studied. Figure 11 provides a summary of different hazards, based on the above guidelines and the work of Coppola (2011) and Twigg (2004).



(Based on the work of Coppola(1), 2011, & Twigg(2), 2004)

**Natural Hazards**

Natural processes or phenomena in the biosphere that may cause a potential damaging event/ activity that may cause loss of life, injury, property damage, social and economical disruption or environment degradation. (1)(2)

**Geological Hazards** (2)

Natural earth processes or phenomena in the biosphere that may cause a potential damaging event/ activity that may cause loss of life, injury, property damage, social and economical disruption or environment degradation. (2)

**Tectonic Hazards**

Hazards caused by the movement of the movement of the earths plate ((1):46)

These include:
- Earthquakes (2° Hazards include Landslides, Tsunamis soil liquefaction)
- Volcanoes (2°, Hazards include rock falls, mud slides, poisonous gas, Tsunamis)(1):46-54)

**Mass Movement Hazards**

Include those events that are caused either by rapid, gravity induced downward movement of large quantit of material or by the contraction or expansion of the earth from non seismic means. ((1):55)

These include:
- Landslides
- Rock falls
- Debris flows
- Avalanches ((1):56)

**Hydrometerological Hazards**(2)

Natural processes of atmospheric, hydrological or oceanographic nature that may cause a potential damaging event/ activity that may cause loss of life, injury, property damage, social and economical disruption or environment degradation. (2)

**Hydrological Hazard**

Either excess or severe lack of water causes hydrological hazards. ((1):60)

These include:
- Floods
- Droughts ((1):56)

**Meteorological Hazards**

Meteorological Hazards are related to weather patters or conditions. ((1):64)

These include:
- Tropical cyclones & Monsoons
- Tornadoes and straight, line winds & windstorms
- Ice and hails & thunder storms
- Frost,
- Extreme cold and extreme heat
- Climate Change,((1):54-84)

**Biological Hazards** (1)(2)

Processes of organic origin or those conveyed by biological vectors (1)

These include:
- Human Epidemics and pandemics
- Live stock and animal epidemics
- Climate Change,((1):54-84)

**Other Natural Hazards** (1)

Individual natural hazards that do not fit neatly into any single category (1)

These include:, meteors & meteorites Poisoning due to natural and non pathogenic causes, Soil salinization. Space weather & Animal attacks((1):90-95)

**Anthropogenic**

Human initiated processes, systems, intervention, or activities that may cause a potential damaging event/ activity that may cause loss of life, injury, property damage , social and economical disruption or environment degradation. (1)(2)

**Technological Hazards** (1)(2)

These are hazards, with negative consequences as the result of human innovation that can result in the destruction of life, property or environment.((1):95)

**Infrastructure Hazards** ((1):101)

E.g. Power, Telecommunications , Computer network , critical water & sewer , Gas distribution, dam, economic Failures, Food shortage & overburden public health facilities. ((1):95-112)

**Transport Hazards** ((1):95)

E.g. Transport infrastructure disasters, Airline, road & maritime accidents, ((1):95-101)

**Industrial Hazards** ((1):106)

E.g. Hazardous material handling & storage , Raw material and Mining accidents ((1):113:-115)

**Structural Fires & Failures**((1):106)

E.g. Fires and failure of structures ((1):1155)

**Intentional Hazards** (1:118)

These hazards exist due to, conscious decision of humans to act in an antisocial or antiestablishment manner. They are not as the result of an "Act of God" or accident.((1):95)

**Intentional, civil & political Hazards** (1:118))

E.g. Terrorism ( E.g. Nationalism, Religious, state sponsored, left wing, right wing, anarchist) , Weapons' of Mass Destruction (WMDs)(E.g. Chemical, biological, radiological, / nuclear) Civil unrest(e.g. strikes, protests & riots), Stampedes, Crime, and wars. ((1):118-128112)

**Figure 11: Classification of hazards.**

It should be noted that the list is not exhaustive, as with technology development and urbanisation new hazards will arise. For example, an automated flow control system at a major dam can, as a result of a power failure, result in an error, for example, not opening enough flood gates, causing the dam to overflow or its wall to give way to the pressure, resulting in a downstream flooding.

As this study focuses mainly on potential hazards related to the water resource and the catchment area only, an introduction to the groups and subgroups of generic hazards according to Coppola (2011:38) and Twigg (2004:15) is given. Potential hazards associated with the water resource and associated catchments are then provided in more detail.

Coppola (2011:38) and Twigg, (2004:15) group the hazards as follows (See Figure 11):

**Natural Hazards.** These natural processes have the potential to exploit vulnerability and cause a disaster. Natural hazards can then be divided into sub groups including the following:

- Geological hazards are natural earth processes or phenomena, which include geological, neotectonic, geophysical and geomorphologic, hazards.
- Hydrometerological hazards are hazards of atmospheric, hydrological and oceanographic nature.
- Biological hazards are organic in origin or those conveyed by biological vectors, and include exposure to parasites, bacteria, fungus, virus bio-toxins and other bio-active substance,

**Technological hazard**. These are anthropogenic (man-induced) hazards, and include industrial, transport, chemical spills, pollution, urbanisation, mining, agricultural practices, dam failures, production of toxins, ozone depleting products, nuclear activities, and bioengineering.

**Environmental degradation**. These are hazardous activities (both natural and anthropogenic) that can irreversible damage the natural resource base and adversely alter the natural (eco) systems and processes.

**Intentional hazards** is another group that Coppolla (2011:35) includes. Intentional hazards are hazards arising from the conscious decision of man to act in anti-social or anti-establishment manner. These include wars, terrorism, sabotage, and modern chemical, biological and nuclear warfare.

When developing an effective disaster management system it is important to note that certain hazards give rise to disasters. These can occur when the hazard event occurs or at very short notice, known as rapid onset/impact disasters, these include earthquakes, flash floods, bush and veld fires, tsunamis, and tornados, of which many cannot be predicted in advance. While other hazardous events can take a longer period of time for example weeks, months, years and decades to manifest as a disaster, (known as a slow onset / impact disasters). These hazards include, droughts, environmental degradation, desertification, coral bleaching, urbanisation, water salinization and the slow accumulation of toxic matter, for example, heavy metals (Uranium and Mercury) and toxins (organophosphates) (DWF, 2013:Online; IRIN, 2012:Online; Femina & Werrell, 2011:Online; Blakemore, 2011:Online; & Provention, 2009:Online*)*. For example, in the Wonderfontein Spruit tributary of the Mooi River, deep-level mining has contributed to the dewatering of certain groundwater compartments, the depositing of uranium and other heavy metal in tailings, and is contributing to acid mine drainage which will increase as mines become less active. These pollutants are slowly migrating through both groundwater and surface water to the primary source of Tlokwe Local Municipality drinking water (North West Independent, 2013:1; Lang, 2011:Online; Masondo & Evans, 2011:Online; Lang, 2010:Online; Winde, 2010b:239; Winde & Stoch, 2010b:76).

The next section focuses in more detail on hazards related to water resources and water catchment areas.

### *3.4.2 Water resource and water catchment related hazards*

#### 3.4.2.1 Biological Hazards

These are potential hazards resulting from living organisms and include those as a result of toxins and/or disease produced by bacteria, viruses, algae, fungi and parasites. A detailed discussion on biological hazards is beyond the scope of this mini-dissertation. A detail discussion for interest is provided in Appendix C 1.

**Bacteria:** Some bacteria are highly contagious and can be spread through contaminated drinking water polluted by human and animal faeces and other waste, and in some instance can be found in groundwater. Good sanitation, individual hygiene and treatment of water by boiling and use of bactericide such as chlorine can prevent and stop the spread of these bacteria (DOH 2011a:Online; Geddes & Grosset, 1997). Concentrated populations with poor sanitation are more susceptible to epidemic outbreaks. The illnesses can result in the infected population becoming more vulnerable to other potential hazards. An example of typical bacteria epidemics is the regular cholera out-breaks in Southern and South Africa. The 2001 cholera out-break in Kwazulu Natal recorded 12000 infections and 50 deaths by 2 January (Barrow, 2001:Online); by 12 January 2001 it had spread to six provinces and the total deaths numbered 64, and the total infections 18000 (BBC, 2001:Online). The 2008 outbreak that started in Zimbabwe and later spread to South Africa had 98741 infections and 4, 293 deaths reported in Zimbabawe. By December 2008, Vhembe district of Limpopo was declared a disaster area (Doctors Without Borders, 2008:Online). In December 2008, it was found that the eastern part of the Limpopo River between Zimbabwe and South Africa tested positive for cholera (Gabara, 2008:Online). By January 2009, 15 deaths had been recorded in South Africa, and the number of cases were 2100 (AFP, 2009:Online). Regarding Disaster Risk Management, in Tlokwe Local Municipality which has a blue drop status for water and is faring well with green drop status, there are parts of the community that are occasionally exposed to leaking sewage, which increases the risk of deadly bacteria outbreaks (Boqo, 2012:5).

**Protozoa (parasitic).** These include the enteric protozoa (of which one of the major symptoms is diarrhoea) that are water borne and found in infested drinking water and recreational water that is infested, often by faecal waste that contains the infective stage of the parasites' life cycle (DOH 2011:Online; CDC, 2011:Online). In its infective phase as oocytes or cysts, chlorine and iodine do not seem to have an impact on theses parasites. Boiling and use of filters that will prevent the parasite from entering drinking water sources are the most effective means to purify contaminated water. In respect of Disaster Risk, protozoa infection can manifest themselves as secondary hazards and all can cause diarrhoea (Marks & Anad, 2012:Online; CFIA, 2012:Online; DOH, 2011:23; CDC, 2010a:Online; CDC, 2010b:Online).

**Viral:** More than 100 species of viruses can be found in sewage. The diseases that can be caused include hepatitis, polio, meningitis and gastroenteritis. Viral matter of between $10^5$ and $10^{11}$ can be found in one faecal stool of an infected person (Bosch, 1998:191). The virus in faecal matter (in the case of faecal matter deposited on the ground), in disposed solid waste and in untreated sewage can reach both ground- and surface water by land run-off and other point sources, exposing humans to infected water that may be used for agriculture, drinking and recreational purposes (Bosch, 1998:193). Norwalk virus is an example of a virus that has been associated with swimming in lakes and pools (Hedberg & Osterholm, 1993:205). It should be noted that many waterborne viruses are resistant to boiling, changes in pH and disinfectants. Consequently, water that conforms to bacterial standards could remain contaminated by certain types of viruses (Taylor, 2011:209). Implying that water that has not specifically been treated for viral contamination can remain contaminated*.* In respect of disaster risks, lack of sanitation and raw sewage can assist in the spread of the disease. The importance of good water treatment, hygiene and good sanitation must be emphasized if a viral outbreak is to be prevented or reduced in respect of water borne viruses*.*

**Algae Blooms:** In South Africa many water impoundments are found that can be contaminated by poorly and untreated sewage effluent, phosphates and other fertilisers used for agricultural purposes, giving rise to eutrophication (Pindihama *et al.*, 2011:19884; Harding, 2006; Oberholser *et al.*, 2005:86; O'Keeffe *et al.,* 1994: 287). Eutrophication, the process of nutrient enrichment, for example, an increase of Phosphates (O'Keeffe *et al.,* 1994:286 -287), gives rise to an environment that is suitable for the accelerated growth of algae that can result in algae bloom. In South Africa, the species responsible for these blooms include cyanobacteria and the blue/green algae (DOH, 2003). The excess algae can deplete the oxygen carrying capacity of water, accelerate eutrophication, block water plant filters and produce toxins in general affecting sensitive ecosystems. The toxins produced include hepatoxin such as microcystins, nodularins & cylindrosermopsins that affect the liver; neurotoxins such as anatoxins and saxitoxins that depress the function of the nervous system, and dermatoxins such as lyngbyatoxin & aphlysiatoxia that influence the skin (Oberholster *et al*., 2005:57- 60). Although the organism can be destroyed, it is the toxins that can cause acute poisoning in humans and deaths in animals (Pindihama *et al.,* 2011:19885). It is difficult to remove the toxins from water through normal water treatment methods (Pindihama *et al*., 2011:19884; Harding, 2006:I; Oberholster *et al*., 2005:86). Although no human fatalities have been reported in South Africa, stock and game losses have been recorded (Pindihama *et al*., 2011: 1988; Harding, 2006:I; Oberholster *et al*., 2005). Algae blooms have the potential to produce enough toxins in water used by livestock to cause significant losses. The potential chronic effects of the toxins cannot be disregarded. This potential to cause livestock losses, and significantly impact on the livelihood of communities, requires that these toxins be considered as a potential hazard**.**

**Invasive flora and fauna** can destroy the environment, and impact on the indigenous fauna and flora (ISSG, 2012:Online; NECIS, 2012:Online). In the following dams of the catchment area, Boskop Dam, Potchefstroom Lakeside Resort and the Klipdrift Dam, carp (Cyprinus Carpio) can be found, and in Potchefstroom Lakeside Resort wide mouth black bass (Microsterus Salmoides, (Musil & Macdonald, 2007:175) are found, both of which are invasive species. An example of the impact of invasive species is the Cyprinus Carpio that is known for uprooting plants, reducing the quality of water, destroying water plants and concentrating nutrients thereby significantly impacting on the environmental integrity (Charles & Dukes, 2007:Online).

**Animal vectors** include rodents, for example, rats carry fleas (e.g. Xenophysylla Cheopis) that can carry the plague (Yersinia Pestis), which can infect humans. The pandemic in Europe that killed approximately 25 000 000 people in 1340, is an indication of the disastrous effect caused by the infection that can occur where sanitation is problematic (National Geographic, 2012:Online; Davis and Netlleman, 2012:Online). Insect vectors, for example mosquitoes (Anopheles) which breed in stagnant water and other water sources, have the potential to cause lethal and debilitating illnesses (Jupp, 2005:Online). An example is malaria, which can cause epidemics (In 2010 there were 7963 malaria infections with 81 deaths in South

Africa (DOH, 2011)) or result in increased vulnerability of the infected to other potential hazards including droughts, heat waves and famine. In respect of disaster risk management, animal vectors can be a result of other hazards (for example droughts and flooding) resulting in infestation of rodents and insects such as mosquitoes.

Hydrological hazards are discussed below.

#### 3.4.2.2 Hydrological Hazards

Hydrological hazards are extreme events associated with water occurrence, movement and distribution and are one of the more significant hazards (CGER, 1999:4). These include floods and droughts and they are often secondary hazards resulting from meteorological processes. These include prolonged rainfall for example, Hurricane Sandy in 2012 (Barron, 2012:Online; Kunkle *et al*., 2012:Online), Hurricane Katrina in 2005 (Shah, 2005:Online; NOAA, 2005:Online), and the 1981 Laingsburg flood, where 425 mm of rainfall in the catchment of the Buffalo river above Laingsburg over a period of two days resulted in a six meter high wall of water build up that flooded Laingsburg on 25 January 1981, killing 194 persons and destroying 184 houses (SAWDIS, 2009:Online) and sea surges as a result of onshore winds. Hydrological hazards themselves can give rise to secondary hazards, including landslides, mudslides and soil erosion (Coppola, 2011:69; CGER, 1994:4). Specific hydrological hazards are discussed below.

##### 3.4.2.2.1 Floods

Floods can be either slow rising over days or weeks, or can be fast rising, causing flash floods (Coppola, 2011:69). In the case of the Mooi River there are at least two large dams, a number of smaller dams, and a significant number of small farm dams and a number of hydrological points in the catchment area that could assist as early warning systems; the dams, if properly managed, could assist in delaying slow onset flooding. For the latter to be successful, it will require that the water monitoring point information be integrated into the Tlokwe Disaster management system. When considering a spatial information system that will address the possible hazards of floods, it is important to consider high-risk geographic land types. These include river flood plains, low lying and in some cases highly fertile areas, flanking rivers (Coppola, 2011:60). Unfortunately in South Africa we continuously see as the result of urbanisation the development of settlements on these flood plains, for example, Klipriver (Joburg, 2012:Online) in the Gauteng Province and the Cape Flats (Cape Times, 2012:Online; Stewart, 2009:Online) in the Cape Province. In Tlokwe small groups of families tend to settle for short periods of time in the flood plain of Mooi River below the golf course (Riekert, 2011). Secondly, it includes basins and valleys that are prone to flooding. These are areas exposed to abnormally high runoff during intense rainstorms (Coppola, 2011:60). Thirdly, it includes land lying below retention structures, for example dams, weirs and levees which, as a result of poor construction or maintenance, can give way, flooding the area below them (Coppola, 2011:61). Examples include the Levee break during the Hurricane Katrina (levee failure from lake Pontchartrian during Hurricane Katrina (NOAA, 2005:Online)), and of dam failures (Movri Dam Disaster (Dhar *et al*., 1981:71)). Fourthly, deforestation and overgrazing has the ability to cause floods, as soil that was anchored by vegetation is systematic eroded, thereby reducing the water retention capability resulting in a systematic increase in run-off with erosion (Coppola, 2011:62).

#### 3.4.2.2.2 Drought

A drought is an example of a slow onset hazard when dry weather persists long enough, reducing the available water to such an extent that crops are damaged and there is insufficient water for industrial, agriculture and domestic use.

According to Coppola (2011:62), droughts can be categorised as meteorological (seasonal rainfall is below average), agricultural (insufficient moisture to meet a specific crops need), hydrological (decline in surface and groundwater) and socioeconomic (famine). Although droughts are rare occurrences in the Tlokwe Local Municipality area, the potential effect of climate change, the cessation of mining upstream and anthropogenic interventions (sabotage, negligence, etc.) on the quantity and quality of water available for domestic and agriculture use are unknown. Droughts therefore must be considered by the Tlokwe Local Municipality in that it is directly dependent on the Mooi River for domestic, industrial, agricultural and commercial activities, and large areas of the Local Municipality are used for intensive and extensive agricultural activities. Where some areas are provided with water through surface man-made canals, others use boreholes and others are mainly dependent on rain. Rain and other weather related patterns are discussed in the next section.

#### 3.4.2.3 Meteorological Hazards

These weather events are related to atmospheric weather patterns or conditions (Coppola, 2011:64).They include tropical depressions, tropical storms, cyclones, hurricanes and typhoons that describe a large scale closed circulation system in the atmosphere that combines with low pressure and strong winds. Secondary hazards can arise from the impact of these types of storm systems such as lack of drinking water, spread of disease through sewage-contaminated water, and an increase in vermin such as rats (Coppola, 2011:54; IFRC, 2009:Online).

**Tornadoes**, although rare, have occurred in various regions in South Africa. These are funnel clouds extended downwards from a cumulonimbus cloud, mostly formed from a super cell that is rotating thunder storms, with the destructive winds generated having the ability to cause destruction, loss of life and injury effects when coming into contact with community dwellings and other infrastructure such as buildings (OBlack, 2014a:Online; Weather Wiz Kids, 2014a:Online; Coppola, 2011:67-68; The Weather Channel, 2009:Online).

**Strait line winds** are thunderstorm related wind movingly linearly at high speeds and can be severe when exceeding 92 km/h. These strait line winds include, downdrafts (column of air rapidly move towards the ground surface), downbursts (downdraft with a horizontal dimension of 4km), microburst (concentrated downburst with maximum speed of 268 km/h), gust forces (where the leading edge of the rain cooled wind meets warm air of the thunderstorm) (Coppola, 2011:68-69).

**Hailstorms** are events where there is a precipitation of large lumps of ice and compact snow. Hail are ice crystals forming within in a cloud suspended in strong updrafts while more layers of ice are added until the holding capacity of the cloud is exceeded (Oblack, 2014b:Online; Weather Wiz Kids, 2014b.:Online; Tsagalidis, 2012:Online; Coppola, 2011:6-71; The National Weather Service Forecast Office, 2010a:Online).

**Frost** occurs where crystals form from water vapour when it freezes upon contact with a surface below frost point (Weather Online, 2014:Online; Met Office, 2013:Online; Coppola, 2011:71)

**Extreme cold**, where the actual temperature can be further decreased by increase in wind, also called the chilling factors, can result in hypothermia and later death in individuals who are not protected from extreme cold (International federation of Red Cross and Red Crescent Societies, 2014:Online; Coppola, 2011:71-73; National Disaster Management, 2008:Online;).

**Extreme heat**, including heat waves, is caused by extremely high temperatures and can result in death, with the aged and young most susceptible (International federation of Red Cross and Red Crescent Societies, 2014:Online; Coppola, 2011:71).

**Windstorms** are periods of high winds not associated with convective events, considered severe if they exceed 64km/h; for example, gradient high winds caused by large-scale pressure system (Coppola, 2011:75).

**Wildfires** are secondary hazards that can result from metrological events, including lightning, hot and dry winds (Weather Wiz Kids, 2013c: Online; Coppola, 2011:77; Twisp, 2012: Online).

**Thunderstorms** are local storms produced mainly by cumulonimbus clouds. They can be accompanied by thunder, lightning, winds, heavy rain and in some cases, hail. Their damage is normally the result of the precipitation and the winds they generate (Coppola, 2011:78 -79; The National Weather Service Forecast Office, 2010b:Online ).

The above provides merely a summary of a few of the meteorological hazards associated with water catchment areas, and focuses mostly on those that can occur in South Africa.

#### 3.4.2.4 Mining induced seismic activity

Deep-level mining inducing seismic activity occurs in close proximity to the Tlokwe Local Municipality area. For example, Stilfontein gold mine is approximately 2.5 km from the Tlokwe Local Municipality boundary (Odendaal, 2011; Durrheim *et al*., 2010; Meyer, 2005; Kirsten, 1994:1). The investigation of Durrheim *et al*., (2006: 7-8) is important, since it found that deep mining caused rocks surrounding excavations to deform, straining the rock mass and causing failures either along pre-existing weaknesses or causing new raptures. Large seismic events invariably take place along pre-existing geological weaknesses, and sometimes may occur hundreds of metres away from the mining activity. Dewatering of the rock mass during mining may tend to stabilise faults that are close to failure. When the ground-water level in the mine rises (for example when a mine has stopped pumping), fault stability decreases and seismic events are likely to be triggered.

The above highlights the potential hazardous effect of deep-level mining, and the cessation of pumping of water from mines in respect of seismic events.

In the next paragraph, another consequence of the closing of mines and cessation of pumping namely Acid Mine Drainage (AMD) is discussed.

#### 3.4.2.5 AMD (Acid Mine Draining)

According to Naidoo (2009), AMD is one of the single most important threats to the environment. AMD arises primarily when mineral pyrites (fool's gold or iron disulphide), comes into contact with oxygenated water, converting it into acidic water that has an increased solubility for heavy metals including Uranium, thereby further increasing the toxicity of the water (Pratt, 2011:Online; McCarthy, 2011:Online; McCarthy, 2010:Online). In 2002, approximately 7-13.5 million litres per day of AMD water started decanting from an abandoned mine near Krugersdorp (Pratt, 2011:Online; Hobbs & Cobbing, 2007:Online), having a significant impact on the environment. This resulted in a 16000 cubic metre void in the calcium carbonate rock near the Cradle of Humankind world heritage site (Pratt, 2011:Online). A detailed discussion of AMD is provided in Appendix C 3.

The significance of the above is that it demonstrates the possibility of decanting of AMD (or Acid Rock Drainage) on the surface and polluting surface water when mining and pumping of mining void water ceases. In the case of the Mooi River, one of its tributaries is in close proximity to a number of mines that have closed or that are reaching the end of their productive life span.

### 3.4.2.6 Sinkholes and subsidence's

Large dolomite aquifers underline significant portions of the Mooi River Catchments area to the North and North East of Boskop Dam, the Wonderfontein Spruit tributary of the Mooi River and areas within the Tlokwe Local Municipality area (Potgieter, 2014). Dolomite is composed of $CaMg(CO_3)2$, calcite ($Ca(H_2CO_3)$) and magnesite ($Mg(H_2CO_3)$), that can under the right conditions dissolve in the presence of $H_20$ (water) and $C0_2$ (carbon dioxide) to form a weak carbonic acid ($H_2CO_3$) (DOWA, 2009:6; Heath, 2008:5; DOPW, 2003:1). In nature and in the absence of any major events, this process is slow and can take millions of years before erosion, subsurface solution cavities and caves are formed (DOWA, 2009:4). The process of sinkhole forming begins when water percolates through faults, fissures etc. into the sub surface dolomite, causing erosion as the carbonic acid dissolves the dolomite, leaving large cavities below the ground surface with the potential of collapsing and forming sinkholes. The process of sinkhole formation can be triggered by surface water seepage (e.g. leaking water bearing services, including sewage and storm water systems) eroding the soil covering the dolomite rock and carrying material down into the underlying cave system, which breaks through "cave-ins" to the surface to cause a sinkhole (DOPW, 2003:2). Sinkholes can also form when the groundwater level is lowered (e.g. through borehole and mine dewatering). This lowers pore water pressure, which then lowers the ground bearing capacity (DOPW, 2003:2). The resulting sinkhole/s formed can be from 1 to 100m in diameter and between 1 to 150m deep (DOPW, 2003:2)

The above is significant from a disaster risk perspective, in that large portions of the upper Mooi River, Wonderfontein Spruit and part of the Potchefstroom city area lie on top of dolomite, and the impact of future mining activities (including closures) on the groundwater levels and dolomite is unknown. Sinkholes are discussed in more detail in appendix C4.

In the next paragraph, Uranium and radiation are discussed.

### 3.4.2.7 Uranium and radiation

Radioactivity is the spontaneous release of energy in the form of particles or waves from unstable atoms (Wymer, 2001:300). The particles that can be released are

Alpha and Beta particles and the wave is known as the Gama wave (Wymer, 2001:300; Urone, 2001:790).

The effect of radiation on the body is known as ionising radiation, and it can have either a deterministic effect or stochastic effect on the body. Deterministic effect is where the energy is imparted to the cell; if the energy exceeds a certain threshold (see Table 3), the cell stops functioning. If sufficient cells are damaged it can destroy the tissue and impair functioning and may even cause death.

Table 3 Effects of a dose of radiation (Kotze *et al.*, 2003:985; Urone, 2001:827)

| Dose | | Effect | Risk Ranking according to (Author) |
|---|---|---|---|
| rem | Sv | | |
| 0-25 | 0-0.25 | No observable effect | Low |
| 26-100 | 0.26-1 | Slight or moderate decrease in white blood cell count | Medium |
| 100-200 | 1-2 | Significant reduction in white blood cells, nausea, loss of hair, and is rarely fatal. | High |
| 200-500 | 2-5 | Lethal to 50% of those exposed in 30 days if untreated | High |
| >500 | >5 | Death | High |

| Definition of rem and Sv based on Urone (2001:825-826) | | |
|---|---|---|
| rem | Roentgen equivalent man | A dose unit of ionizing radiation closely related to its effect on biological tissue. rem = rad X Relative Biological Effectiveness |
| Sv | Sievert | Is defined as Gy (gray were I Gy = 1 J/kg = 1rad) x Relative Biological Effectiveness |

Stochastic effect occurs when the energy imparted to a cell is below the threshold, and the cells survive, but may become modified. For example, after a latency period that may develop into cancer cells (Wymer, 2001:300-301; Urone, 2001:825-827). Uranium doses far exceeding national and international limits have been found in the Wonderfontein Spruit tributary of the Mooi River (North West Independent, 2013:1; Lang, 2011:Online; Masondo & Evans, 2011:Online; Lang, 2010:Online; Winde, 2010a:239; ).

The above provided a concise discussion of generic and water related hazards. In the next section, a concise description is given of the methodology that is used to obtain information related to Mooi River surface and groundwater catchment area using quaternary catchment area C23D as an example of its application.

## 3.5 Description of the surface catchment of the Mooi River

### *3.5.1 The Quaternary catchment area of the Mooi River*

In the previous sections, a generic description of the catchment hydrological cycle, catchment area and hazards was provided. In this section, the Mooi River catchment area is discussed with specific reference to the quaternary catchment C23D. The limiting nature of the mini-dissertation allows for the in detail discussion of only one of the quaternary catchment areas are discussed in detail. The discussion includes the methodology used to describe the catchment system of the Mooi River and a more detailed application of the methodology on quaternary catchment C23D.

The first part of this section provides a schematic outlay of the quaternary catchments C23D, C23E, C23F, C23G, C23H, C23K, C23J, C23L, that form the Catchment Area of the Mooi River. This enables the reader to visualise the spatial relationship of the quaternary catchment areas. This is followed by an overview of the methodology used to provide a concise description of the quaternary catchment area C23D. Figure 12 provides a schematic outlay of all the quaternary catchments of the Mooi River, assisting with visualising the individual quaternary catchment's spatial location and its relationship to the other quaternary catchments within the catchment area of the Mooi River. In Figure 12, a schematic outlay of the quaternary catchments based on Google Earth© satellite images and Map 1, 2 and

3 is provided. It should be noted that the schematic outline is not drawn to scale, as its purpose is to indicate the relationship between the various catchment areas.

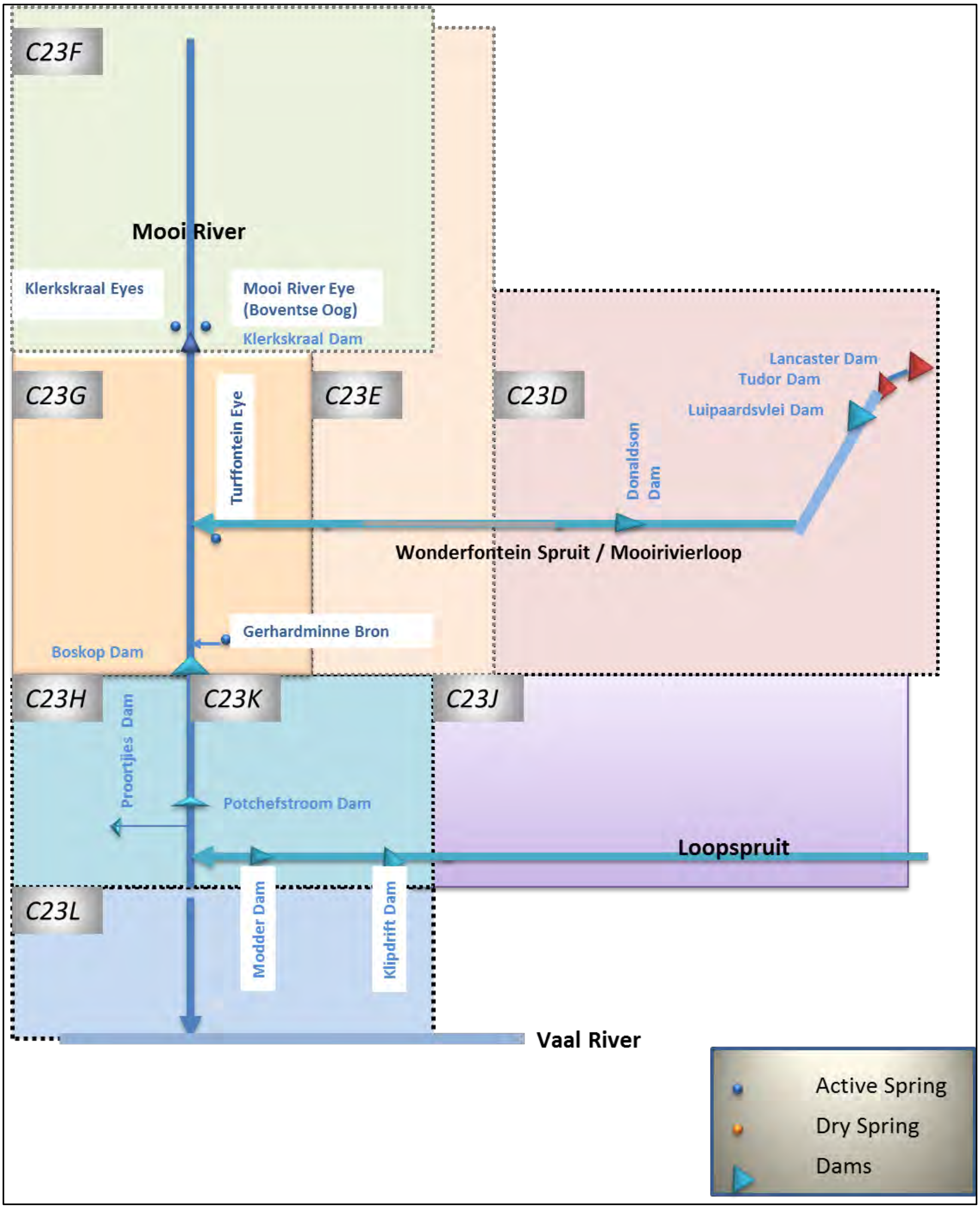


**Figure 12: Schematic representation of the Mooi River and its major tributaries in relation to the quaternary catchment areas.**

A concise discussion of the methodology used to describe the Mooi River catchment area and system follows.

### *3.5.2 The research design and methodology used to describe the Mooi River catchment area and system.*

In this section, a concise description of the methodology used to describe the catchment system is provided. It is used to identify and describe the catchment area, point sources of inflows, potential hazards, potentially vulnerable communities, ecosystems and other features that could influence the occurrence of potential disasters.

To a significant extent, the methodology involves the identifying of spatial information including artefacts that can be deduced from satellite images, such as mining activity or signs thereof, farming activity or signs thereof, human settlements or signs thereof, etc. that could also be identified from hard copy and digital maps, photographs, satellite images and diagrams of the study area. It includes the use of existing information in the form of studies (Commissioned by organs of state, universities, etc.) and official reports (Environmental Impact Assessment Studies, etc.) and therefore involves a document study, which is a qualitative methodology (De Vos, *et al*., 2008:272,315; Struwig & Stead, 2007:13). The statistical method used is mainly descriptive by nature, as graphs and summaries of analysed data are used, for example in determining the gradient of a river course (Utts & Heckard, 2007:15.17) (See Appendix E Part D). The methodology and processes to identify the surface water (that is the river with its tributaries) in the Mooi River catchment area are discussed below.

Existing digital vector and raster maps, original copies of topographic maps, Google Earth©, "World Wide Telescope: Microsoft Research©, and the review of recent literature are used to identify the flow of the Mooi River, its tributaries, catchment area, the point sources of inflows into the river, the points of discharge and features of interest. This is achieved by using existing digital maps from various sources, see Appendix D, topographic paper maps, and superimposing the maps on the satellite images from Google Earth© and World Wide Telescope: Microsoft Research© to identity features and to determine the accuracy of data by a process similar to triangulation. In that, all the available, digital and hard copies of maps together with personal observation and interpretation of satellite images are used to collaborate the accuracy of the data used (Huysamens, 1995:169).

In the case of this study, Arc GIS$^{©}$, a geographical information system was used to convert various types of digital maps obtained from various sources into shape files. It should be noted that many of the available maps are using the municipal demarcations prior to the recent local government elections, and it is therefore necessary to redraw these maps so as to include the new demarcations; for example Merafong City is now included in the Gauteng Province. It should be noted that although Potchefstroom is the official name of the area studied, the municipality is called the Tlokwe City Council. The shape files are then reprocessed to create demarcated shape files for the catchment area of the Mooi River and its tributaries. The reprocessing included dissolving (Ormsby *et al*., 2009:284-5,286-293), intersecting (Ormsby *et al*., 2009:315, 316), creating, and editing (Ormsby *et al*., 2009:386-97) of features. The major landmarks and the rivers identified on the shape files are then converted into kml (Keyhole Markup Language (Shankland, 2008:1)) format and are used (superimposed) together with Google Earth satellite images to trace and verify the flow of the rivers; point sources; identify mining activities and other artifacts that could impact on the ground- and surface water. Snap shots (satellite images) of important landmarks, features and point sources are then taken.

Where spatial information is only available on satellite images, the information was traced and converted into kml format, and where necessary converted into shape files. To verify dry river beds, or visual traces of old stream and river beds, contours were used, imposed on satellite image, and digitized. The elevation of the digitized paths was determined using the elevation profile tool application that is available on Google Earth$^{©}$ together with the contour shape file of the catchment area, to ensure that the traced possible river course has an elevation profile expected of a river course. That is, the river would indicate a drop in mean level above sea level as it flowed from its origin towards its catchment convergent point.

When using the data the following must be considered:

- Deviation in accuracy may arise as the magnification of the satellite images change.

- The projection of the earth which is spheroid, when represented in two dimensions, can cause distortions. These distortions can be observed where highly magnified satellite imagery sets join.
- The accuracy is dependent on the tools used to digitize. In this study the tool used for digitizing is a mouse.
- Despite the above possible accuracy problems, when determining perimeter and surface areas, using two different GIS (Arc GIS©, Planet GIS©), the deviation is less than 0.08 %.

The catchment data collected for the quaternary catchment area C23D, includes vector layers of the rivers, local government data, roads, areas of seismic activity and location of settlements and was superimposed on a satellite image of the catchment area. The farms associated with the Wonderfontein Spruit and major tributaries within quaternary catchment area C23D were then identified. The elevation profile of the river and major tributaries in quaternary catchment C23D were determined and converted to drop in metres over kilometres to give an indication of angle of the slope of the river course, as it can be assumed that the greater the angle of the slope of the river course, the greater the increase in the water runoff rate that can be expected. These tables and graphs are attached as Appendix E.4 & E. 5. Satellite images where photos are taken of important river inflows, outflows, settlements, dams and other infrastructure (including, road bridges, water canals, mine tailings and activities in the river bed that needed to be considered when assessing the potential of hazards and the needs for effective disaster risk management are attached as Appendix E 2 & E 3.

In this section, a map (Map 4 & Appendix A3) superimposed on a satellite image of the C23D quaternary catchment area is provided, and is followed by a discussion with the aim of providing more insight into the quaternary catchment area. The discussion is divided into three sections. In the first section a general description of the quaternary catchment is given; this includes farms, local government structure related to the catchment, settlements and other points of interest. The second section provides general dimensions, the perimeter, and the area of the catchment. The third section discusses the river flow characteristics, which includes the elevation profile. (Tables and graphs are attached as Appendix E). This is followed by a discussion of a few of the significant points observed. It should be noted that the above discussion is deduced from the observations of the satellite images and shape files. The presentation of the quaternary catchment is provided below

### 3.5.3 ***The use of the above methodology to discuss Quaternary Catchment C23D***

#### 3.5.3.1 Introduction

The C23D catchment was used as a example in this study as it is arguably one of the most vulnerable quaternary catchments in the Mooi River catchment, and it provides an example how potential hazards have being manifested through anthropological activities.

The Wonderfontein Spruit flows across a number of dolomitic compartments separated by dolorite and syenite dykes, of which a number have been dewatered to allow mining, (see Map 3) that do not only influence the quality and quantity of water, but as the result of anthropogenic intervention, for example mining, have potentially negatively impacted on water quality, quantity and environment.

The quaternary catchment C23D lies in the Gauteng Province. From its origin near the Tudor Dam it flows through the Lancaster Dam, over the Luipaardsvlei-, Kagiso-, Nelsghoogte-, Bekkersdal-, Gemspost- and Venterpost farms. At least nine large mine tailings were identified, and a number of town developments on either side of the Spruit (stream) can be observed. These include Kagiso, Azaadville, Rietvallei, Mohlakena, Bekkersdal and Westonaria (See Appendix C: Part A, B, C & D).

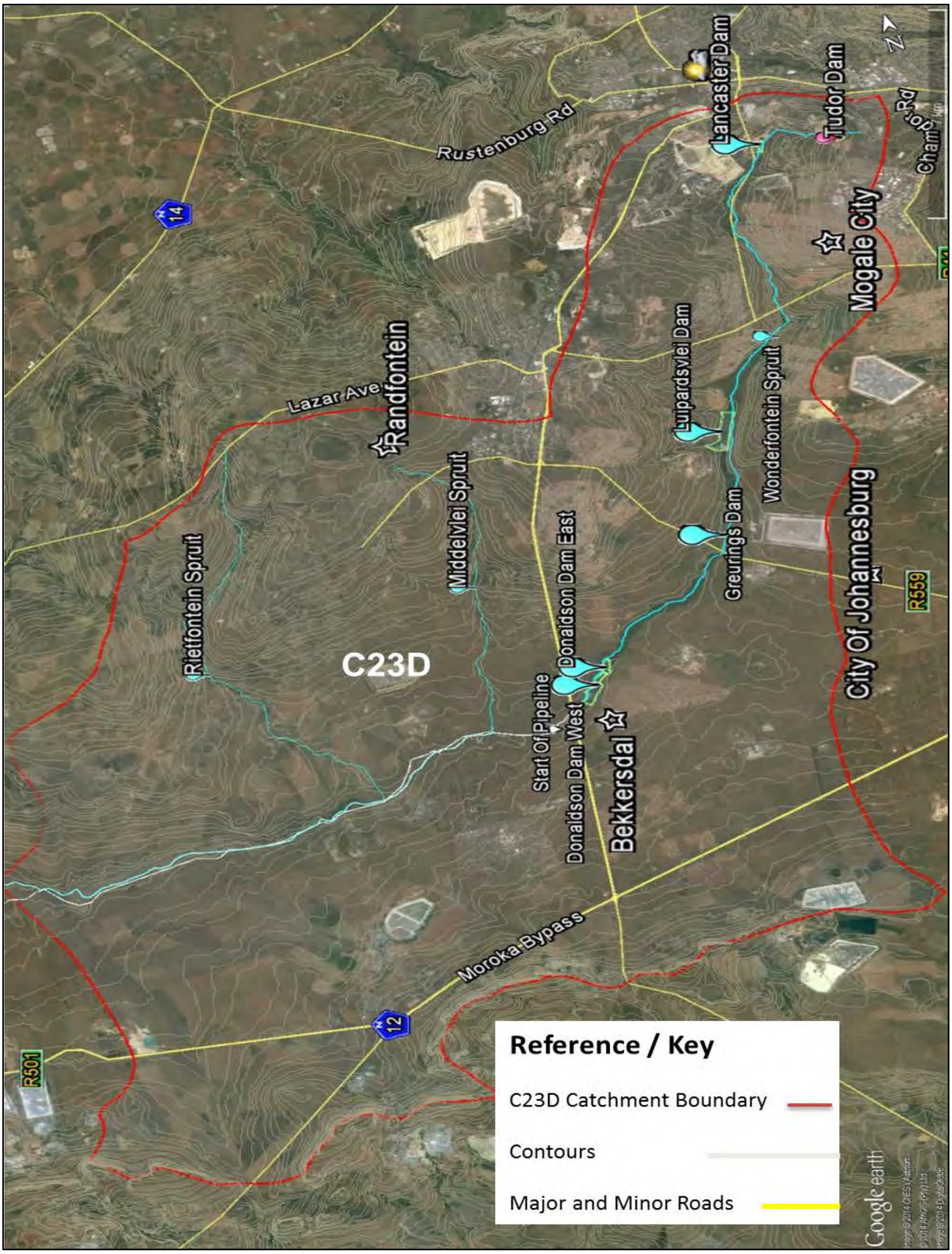
#### 3.5.3.2 Catchment dimensions and river flow characteristics

The perimeter is 115.42 km and the catchment area is 512.5 km$^{2.}$ The river course, flow and the drop in metres above mean sea level (mamsl) are outlined in Appendix C: Part D & E.

#### 3.5.3.3 Potential hazards in the quaternary catchment area C23D

The Wonderfontein Spruit has its origin at Tudor Dam (see Map 4), which is presently filled with sediment high in radioactive particles, and water-flowing from the point of the Tudor and Lancaster dams is highly acidic. From there the river flows through the wetland to the South of Kagiso. In this area the wetlands, assists in removing the sediments, and the pH of the water is increased as a result of the occasional, raw sewage flows into the sprurt from the poorly maintained sewer alongside the spruit near Kagiso and the Kagiso sewage pump. In this area the activated sewage that enters from the Flip Human sewage works also provides nutrients that helps sustain the wetland (Opperman, 2008:iii, 91, 96). It should be noted that at many sewage plants there is an occasional flow of raw sewage into African rivers (Kleynhans, 2011:2; Merafong Local Minicipality, 2011:24,43). The sewage inflows assist in maintaining the wetlands. It is further estimated that the mines in the West and Far West Rand discharge approximately 12 tons of uranium in the fluvial system annually (Coetzee *et al*, 2006:20).

This could explain the reasons for finding sediments in the Wonderfontein Spruit with uranium concentration up to 1000 times the natural background concentration, and uranium concentrations of 10000 and 40000 times the natural background concentration have been found in decanting groundwater from abandoned mines (Coetzee et al, 2009:166). The mining process also results in the unnatural leaching of heavy metals from the exposed reef. Therefore, water pumped from the mine can have abnormally high concentrations of heavy metals and is a contributor to the so-called Acid Mine Drainage (AMD). It is estimated that approximately 17 Ml/day (with a salt load of 12603 Kg /day) from the Wonderfontein Spruit, flows into the Mooi River (Van Dyk, 2005:34). The significance of the quaternary catchment is that it is heavily populated with a number of working and non-working deep-level mines, large industries and large townships. The water in this catchment is therefore exposed to hazardous pollutants and toxins. Secondly, the wetlands to a certain extent slow down the flow of the water, thereby allowing sedimentation of uranium and heavy metals through natural and biological processes. This also assists with the normalization of the pH. Thirdly, the fresh water from the Mooi River eyes and Gerhrad Minnebron Eye can have a diluting effect on the water-flowing in from the Wonderfontein Spruit. Fourthly, the water quality and quantity will via the surface and groundwater interaction have a significant influence on the water used by Tlokwe Local Municipality for domestic use



**Map 4: Quaternary Catchment C23D is superimposed on a Google Earth© satellite image**

## 3.6 Description of the groundwater associated with the Mooi River catchment.

### *3.6.1 Introduction*

Groundwater forms part of the water-flow and water storage phase of the catchment's hydrological cycle (Davis, 2008:10-12). Groundwater and groundwater voids have the potential to influence both the quantity of and quality of water available in a catchment area. For example, discharge of hazardous toxins, including radioactive nuclides, can result in geophysical hazards, including sinkholes and seismic movements as the result of changes in the storage dynamics (for example, significant increase or decrease of the groundwater level) of these voids (Stoch & Winde, 2010:84). Two major sources of groundwater in the Mooi River catchment area are namely dolomitic karst aquifers (dolomite compartments) and underground voids. The majority of anthropogenic underground voids have resulted from mining.

A concise discussion of the groundwater compartments (Dolomitic karst) in the Mooi River catchment is given below.

### *3.6.2 Groundwater compartments*

The compartments are composed of two chains of compartments each divided into smaller compartments by dolerite and syenite dykes (Winde & Erasmus, 2011:294). Portions of the one chain of compartments form part of the catchment area of the Mooi River in the North and the other forms part of the catchment area of the Wonderfontein Spruit (a tributary of the Mooi River) and the Mooi River catchment between Klerkskraal Dam and Boskop Dam. Figure 13 provides a schematic representation of the catchment area (it should be noted that it is not drawn to scale).

Figure 13 illustrates the spatial relationship between the two chains of dolomite compartments. The Northern compartments that form part of the Mooi River Catchment Area is the Mooi River, Holfontein and Steenkoppies compartments (Holland, 2009a:Online; Holland, 2009b:Online; Holland and Wiegmans, 2009:Online). As there is very little industrial, mining or community development or commercial activity in these areas, the quality and quantity of the water is mainly influenced by agricultural activities. The water is therefore of a reasonable quality and of sufficient reserves.

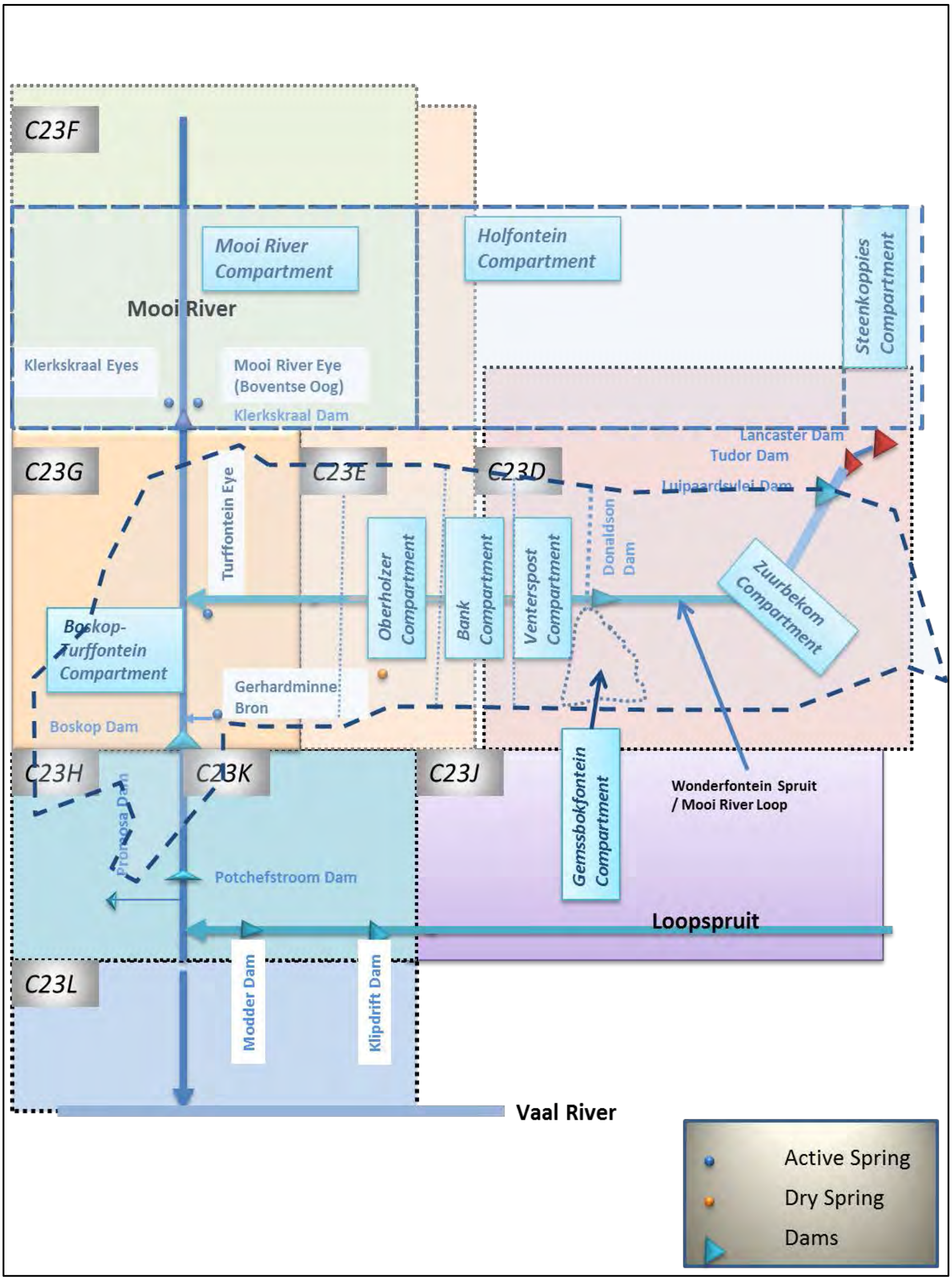


**Figure 13: Schematic representation of the Mooi River and major tributaries in relation to the quaternary catchment areas and Dolomitic**

The water compartment associated with the Wonderfontein Spruit water catchment area are Zuurbekom, Gemsbokfontein, Venterspost, Bank, Oberholzer and the Boskop-Turffontein dolomitic karst compartments (Winde & Erasmus, 2011:293-298;. Stoch & Winde, 2010:86-87; Holland, 2009a:Online; Holland 2009b:Online; Department of Water Affairs & Forestry, 2006:29; Cousens & Garrett, 1969a:422; Cousens & Garrett, 1969b:Online). Three of these compartments Venterspost, Bank and Oberholzer, have been dewatered to prevent the flooding of the mines in the area (Winde and Erasmus, 2011:293-298; Stoch & Winde, 2010:86-87; Department of Water Affairs & Forestry, 2006:29). To prevent recharge of these dewatered compartments, water is channelized away from the natural riverbed through a pipeline which has a diameter of one metre and is approximately 29 km in length and was built from Donaldson Dam to Carletonville. Secondly, water is continuously pumped from the functioning mine voids, and the water not used by the mine is released into the catchment. Thirdly, mine water released into the river is channelized via cement canals to prevent the water recharging the voids.

### *3.6.3 Mining Voids*

Gold mining in the catchment area is predominantly deep-level mining. To enable extraction of gold bearing ore from the gold bearing reef, shafts were sunk below the dolomite water compartments, then tunnels were excavated to reach the face of the gold bearing reef, and the gold bearing reef was then extracted. In this process, large cavities resulted, and in some instance the dolerite and syenitic dykes that separated the compartments were breached, possibly compromising the impermeable boundaries between the compartments. Water entering these cavities or voids was then pumped to the surface to prevent flooding. When mines ceased functioning, the pumping stops and these voids are exposed to potential flooding and filled with water polluted from the heavy metals on the exposed face of the voids and other pollutants in the void that are remnants of the mining activities (Cousens & Garrett, 1969:425 -428). Figure 14 provides a schematic outline of the mining basins in the East Rand, West Rand and Far West Rand, these basins are a result of mining voids, that have as a result of mining compromised the dykes separating the different compartments. In Figure 15, a schematic representation of the mining voids in relation to the dolomitic compartments is provided.

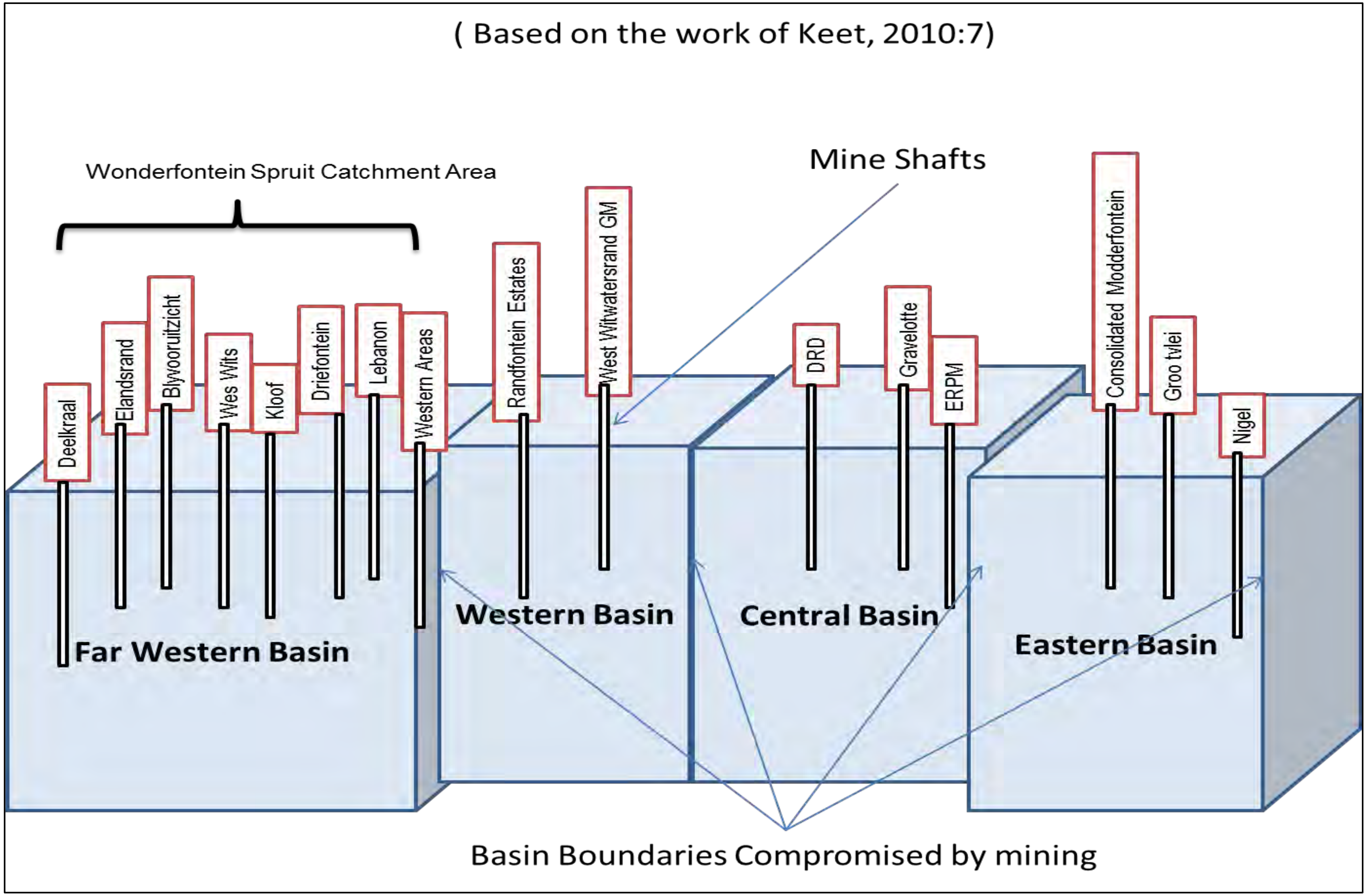


Figure 14: Significant Mining Basins associated with the Wonderfontein Spruit Catchment Area.

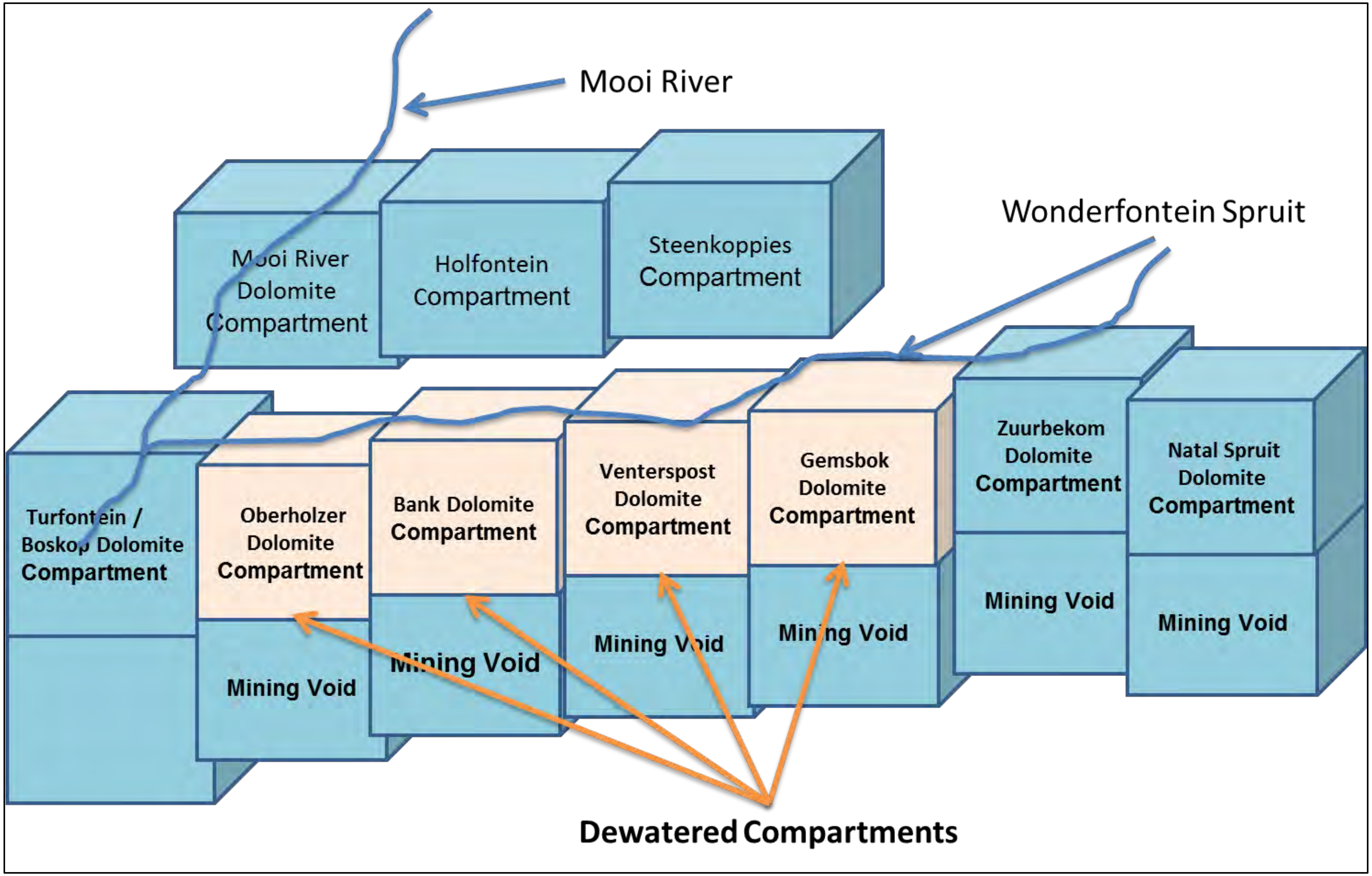


**Figure 15: Schematic representation of the dolomite compartment and mining voids associated with the Mooi River Catchment Area**

Figure 14 and 15, provides an insight into the breaching of existing dolomitic compartment’s, and the formation of new underground voids as the result of mining that have the potential to store additional groundwater, while the potential does exist, that mining initiated water pollutants such as AMD, heavy metals, radioactive nucleotides, can now migrate between previously sealed compartments. The significance from a disaster and water resource management perspective is their potential to influence the water resource quality and quantity in the Mooi River, therefore, processes, such as the cessation of mining and the consequential flooding of mines, far beyond its surface catchment boundaries, and these factors must be considered in long term disaster management planning.

A concise summary of this chapter is provided below.

## 3.7 Summary

In this chapter the two fundamental aspects of research objective 2, firstly, the water catchment and resource system are conceptualised and secondly, a concise description of generic and water related hazards is given. Both aspects are then applied in a concise discussion of the quaternary catchment area C23D. Based on the above, when developing a spatial information system to enhance effective disaster risk management and disaster management, the factors outlined below must be taken into consideration.

Firstly; It is important to identify the route of water-flow from precipitation to the river streams, sources of possible pollution including point sources, and approximate location of diffuse pollution (Davis, 2008:129). Water extraction points, factors influencing the speed and quantity of water-flow, town planning and development and other structures that could impact or be impacted upon potential hazards related to the water catchment area and water resource. Information on hydrological and geo-hydrological dynamics, including historical and current records on base, peak and maximum flows of the river and its tributaries; the historical and current records on the natural and anthropogenic reservoirs and aquifers levels and capacities; flow rates of natural ingresses (springs, etc.) in rivers from aquifers and; historical and current records of rain fall in the catchment area and elevation profiles, will assist in the establishment of an effective disaster risk and disaster management system.

To assist in addressing the possible hazards of floods, it is important to consider high-risk geographic land types. These firstly, include river flood plains, which include low-lying land that is in some instances highly fertile areas flanking rivers. Natural and anthropogenic activities within the catchment area are reflected in the receiving water ecosystem. This implies that information on the type of activity including spatial information is required of all activities within the catchment area that are potential hazards or potential hazard sources. The catchment area of the river flowing may extend beyond the borders of the local municipality in which the river flows. For example, the Mooi River catchment lies in two provinces, namely the North West Province and Gauteng Province; three district councils, and Tlokwe, Kgetleng River, Rustenburg, Ventersdorp, Merafong, Westonaria, Mogale City and Westonaria Local Municipalities. Each of these governance structures has its own priorities and needs. Therefore, the short and medium term needs for economic and social development of one local municipality, may have a negating impact on the economic development, social development and environmental integrity of a local municipality downstream in the catchment. This implies that information and spatial information on activities in the catchment areas within and outside the local municipality’s area of responsibility that may have a hazardous impact on the local municipality must be maintained and effectively utilized to avoid and mitigate potential disasters.

A risk has two factors, namely probability and impact, and provision must be made for these when determining the risk of a hazard and risk of a disaster. Hazard risk determination is a process that includes identification, analysing evaluation and resolving of the hazard risk. The relationship between the three determinants, hazard, vulnerability and resilience must be taken into consideration and provision must be made for all possible hazards that may occur. Finally, vulnerable social, economic and environmental systems must be spatially identified and the vulnerability determined, so that the risk of disaster can be reduced or mitigated.

The concise discussion on quaternary catchment area C23D provides a methodology for identifying, obtaining and presenting the information needed for an effective spatial information system.

In the next chapter, a spatial information system is conceptualised.