The configuration of the East Rand Basin surface runoff model used for source apportionment studies

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Abstract

Numerous mines have been operating in the East Rand Basin (ERB) since the 1940s. Most of these mining activities have since ceased and the mines are busy flooding. If decant of acid mine drainage takes place, treatment options will have to be implemented. A source of major complexity is the fact that these mines have become interconnected over the years. Furthermore, these mines have changed ownership numerous times since mining started. The apportionment of responsibility for the decanting mines has become a major management concern as a legacy issue is created in terms of determining who is responsible for what portion of the environmental degradation.

An integrated modelling approach between mine water, groundwater and surface water is required to make predictions surrounding future water quality and quantity; and more importantly, who is responsible and what is the portion of that responsibility for each mine.

The focus of this study is only on the development and configuration of an appropriate surface water model of the ERB to be interfaced with existing mine flooding and groundwater models of the area. This includes examining the effect on the flow rate brought about by the wetlands found in the river system of the study area and the incorporation thereof into the surface water model.

Through a rigorous reviewing process, it was decided that the Storm Water Management Model (SWMM) would be used as the appropriate modelling platform. Although this model is generally used for urban storm water drainage modelling, it was successfully utilised in this study to model flows in a predominantly natural catchment.

Satisfactory model calibration was achieved, although the lack of data necessitated various assumptions in the model setup. The application of the calibrated model for source apportionment is illustrated through the use of an example scenario. With additional data, this model can be utilised to represent the real world situation of the ERB more accurately, thereby providing even better outputs and resulting in the better management of the ERB.

Key words: Mining, source apportionment, surface water model, SWMM, wetlands

Table of Contents

List of Figures

List of Tables

List of Abbreviations

AMD	Acid Mine Drainage
CN	Curve Number
DEM	Digital Elevation Model
ECL	Environmental Critical Level
EPA	Environmental Protection Agency
ERB	East Rand Basin
GIS	Geographical Information System
GUI	Graphical User Interface
HRU	Hydrological Response Unit
MAE	Mean Annual Evaporation
MAP	Mean Annual Precipitation
MAR	Mean Annual Runoff
NASA	National Aeronautics and Space Administration
SANS	South African National Standard
SAWS	South African Weather Services
SCS	Soil Conservation Service
SRTM	Shuttle Radar Topographic Mission
SWM	Stanford Watershed Model
SWMM	Storm Water Management Model
TDS	Total Dissolved Solids
USGS	United States Geological Survey
WWTWs	Waste Water Treatment Works

1 INTRODUCTION

1.1 PREAMBLE

"Water is mining's most common casualty" – James Lyon (interview, n.d.)

The mining industry is one of South Africa's key economic drivers and although it has played a major role in developing the country to the industrialised nation it is today, it has come at a substantial cost (Malherbe, 2000). This is especially true in terms of environmental degradation, more specifically looking at natural water resources.

Gold was discovered on the Witwatersrand in 1886, with mining development and production in the East Rand peaking in the 1940s. At that time, 24 mines and 90 shafts were in operation (Figure 1) (Van Wyk & Munnik, 1998). As is the case with most underground mining operations, a constant battle with the water table, even further exacerbated by ingress of surface water into the mines, saw elaborate pumping schemes being implemented in order to keep operations going. This, however escalated operating costs to such an extent that it was no longer economically viable to continue mining and many of the mines were obligated to close (Van Wyk & Munnik, 1998).

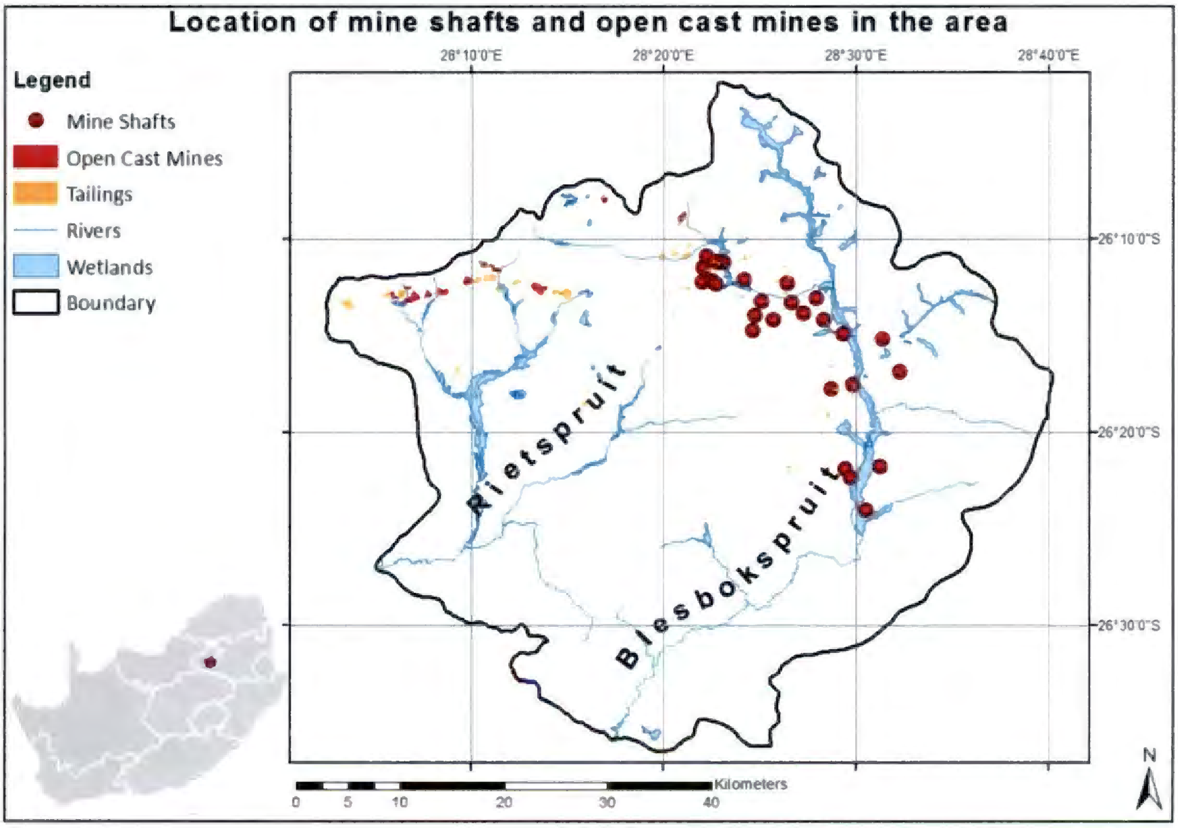


Figure 1: Location of mine shafts and open cast mines in the area

Water within a mine can be particularly troublesome. From a mining perspective, it has an economic and social impact in that production is hampered and safety issues are created. It is the environmental impact however, that is of greatest concern as water can potentially become highly contaminated when it comes into contact with the harmful chemicals used to extract the minerals (Lyon et al., 1993; Straskraba & Effner, 1998). During operation, flooding within mines are prevented by means of pumping. However, when a mine's closure is finalised, pumping is stopped and flooding occurs. This can result in mine water decant (Johnson & Hallberg, 2005).

Today, most mining activities have ceased in the East Rand Basin (ERB), with the exception of the reworking of a few tailing storage facilities. These mines are busy flooding and if decant takes place, acid mine drainage (AMD) will be introduced to the surface water. Both decant and groundwater seepage confluence at the surface streams and this is where treatment options will have to be implemented to address poor water quality.

Of particular importance here, is the fact that the Blesbokspruit, which under the Ramsar Convention, was declared to have a wetland of international importance in 1986, runs through the heart of the East Rand (Van Wyk & Munnik, 1998). It is of socio-economic and ecological importance and if drastic measures are not taken to protect this wetland, the Ramsar status could be lost.

There is still much debate on whether or not natural water resources have the ability to absorb the contamination caused by mine water without being damaged detrimentally (Pulles et al. 2005). The effectiveness of wetlands in this regard makes out a major part of this debate. It is widely accepted that wetlands act as natural filters by intercepting pollution and thereby improving water quality (Kotze, 2000). On the other hand, the capacity of these natural filters are still relatively unknown. Studies in this field are on the rise, however, because few results have been well documented, worst case scenario has to be assumed to ensure the protection of natural water resources.

For this reason, mines in the ERB have to determine who is responsible for what part of the pollution by means of a source apportionment study. For this to be achieved, an integrated model needs to be developed which includes mine water, groundwater as well as surface water modelling. Combining these models into one integrated model allows for the factoring in of a whole range of influences from various sources. Once the integrated model is set up successfully, predictions can be made which will provide much needed answers for the mines in terms of responsibility.

1.2 Problem statement

A major complexity is the fact that these mines have changed ownership numerous times since mining started (Salgado, 2011). If one approaches this situation on the basis of the "polluter pays" principle, a legacy issue is created in terms of determining who is responsible for what portion of the environmental degradation.

A problem that makes this situation even worse, is the fact that these mines have become interconnected over the years. The reason being twofold (Scott, 1995):

- On the one hand, it was implemented as a matter of safety, as the interconnectedness created numerous exits in the event of an emergency.
- The other reason was of financial importance in that the barriers that separated the mines initially, also contained gold reserves and was eventually mined out.

In light of these interconnections, the allocation of responsibility for the decanting mines has become a major management issue.

1.3 Aims and objectives

An integrated modelling approach between mine water, groundwater and surface water is required to make predictions surrounding future water quality and quantity; and more importantly, who is responsible and what is the portion of that responsibility for each mine.

Mine flooding and groundwater models have already been developed for the ERB. The research done in this study only involves one part of the integrated modelling solution, namely the surface water model.

The focus is on the development and configuration of an appropriate surface water model of the ERB to be interfaced with the existing models. As part of the study, an appropriate flow attenuation strategy will be applied and incorporated into the surface water model to account for the effects of wetlands on the flow rate of the river system. The model will be calibrated against historical flow data.

Finally, source apportionment will be illustrated through the use of the surface water model, by means of an example.

1.4 Assumptions and Limitations

Rainfall data is a very important aspect in the development of an accurate surface water model. It is a known fact that there are a limited amount of rainfall stations and rainfall data are not readily available. Rainfall station locations in relation to the study area are a major limitation. Ideally, a rainfall station should be located as close as possible to the area being studied in order to be representative of the rainfall inside the particular catchment. The model results will not represent the observed streamflow, if the rainfall is not representative of the real precipitation over the study area.

Cross-section data were obtained from a previous study (Dennis, 2014) conducted in the study area. Only 10 cross-sections were done for the entire study area. The existing 90 meters SRTM DEM proved insufficient to generate representative cross-sections, as a large proportion of the streams in the river system are less than 90m wide.

Waste water treatment works (WWTWs) are important contributors to stream flow and it is therefore important to incorporate the correct discharge volumes into the surface water model. For this study it is assumed that WWTWs are discharging at full design capacity. This is based on a statement made by one of the WWTWs management staff.

Another important contributor to stream flow is the shallow groundwater system. Discharge from the shallow groundwater system to the stream was determined by means of field measurements. For this study it is assumed that discharge from this source will be the same on both sides of the river.

Parts of the study area is characterised by karst regions which may include sinkholes. As a result of data availability, sinkholes were not specifically investigated in the study and therefore not included in the model.

1.5 OUTLINE OF THE STUDY

- The literature review related to this study, is discussed in Chapter 2.
- A description of the study area follows in Chapter 3. Included in this chapter is a discussion regarding the physical characteristics of the study area, as well as anthropogenic factors, such as land use and pollution sources.
- Chapter 4 covers the acquisition of both historic and field data, and the analysis and preparation thereof for input into the model.
- Chapter 5 provides an account of the methodology followed to set up and calibrate the model. A sensitivity analysis is done to determine which parameters, used in the model, are most sensitive to change. The model is also validated and it is illustrated how the model can be applied for source apportionment.
- In chapter 6 the study is concluded with recommendations.

2 LITERATURE REVIEW

2.1 INTRODUCTION

Hydrological modelling has become a very important science aiding in understanding the complexities of the earth's water systems and further helps to solve problems related to these water systems. One such problem for instance, which is of constant concern, especially in the urban environment, is the amount of direct surface runoff generated within a catchment from excess rainfall (Bedient & Huber, 2002).

Today, where the sustainable use of diminishing water resources has become a major priority, planning and management is key (Wheater et al., 2007). Equations of computational hydraulics within hydrological models are applied to real, natural and engineered or modified environments, which allows for better management and planning of real world systems (James, 2005). However, these models will always remain a simplified version of reality, which by implication, means that there will always be some margin of uncertainty involved. The uncertainty is related to both the quality of data used, as well as the applicability of the governing equations within the model, as they relate to assumptions and boundary conditions.

Beven (2003) goes so far as to state that "rainfall-runoff modelling is an impossible problem!" This statement is probably based on the fact that there are so many unknowns and factors that needs to be taken into account within a complex hydrological system. It is indeed nearly impossible to develop a model that exactly simulates the real world scenario. Fortunately, depending on the objectives and outputs needed from a model, all these unknowns are not always required.

Planning and management becomes a difficult task when there is only a limited amount of long-term hydrological data available (Brooks et al., 2013).This is especially true in the South African context due to flow-gauging stations and rainfall stations that are rapidly closing down (Figure 2).

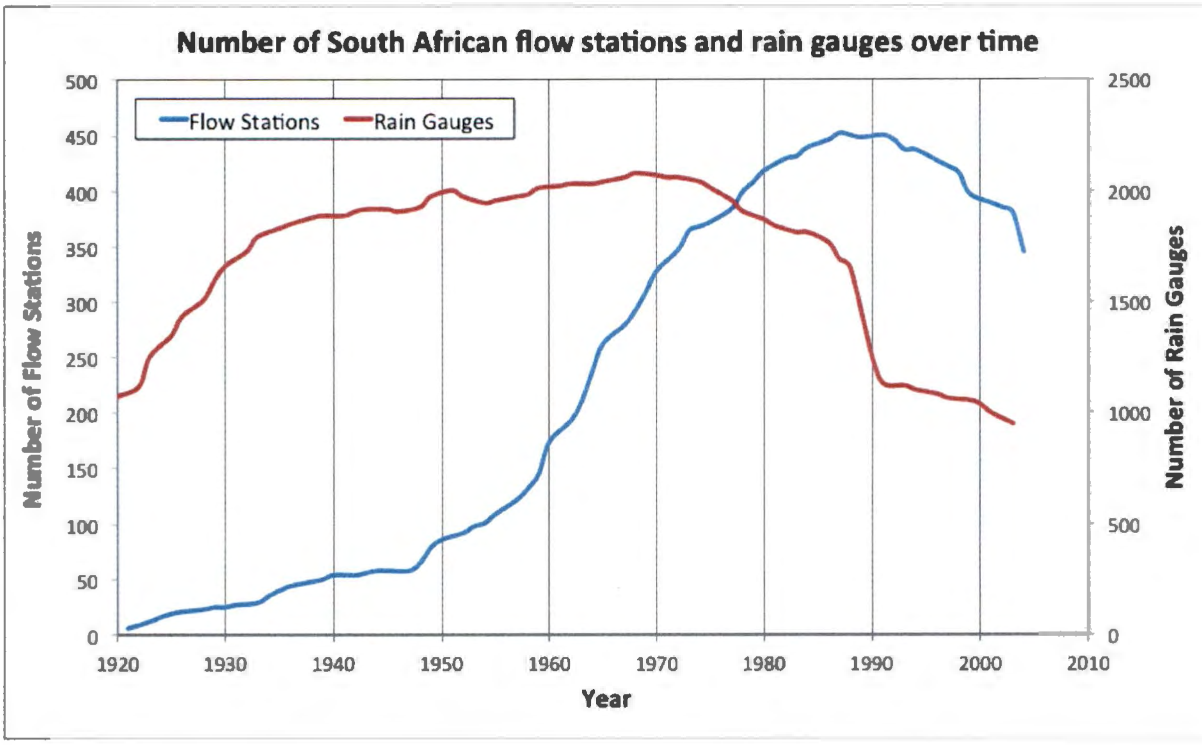


Figure 2: Flow-gauging stations and rainfall stations over time (Pitman, 2011)

Hydrologists are therefore obligated to rely on approximations. Simplified models assist with these approximations by extrapolating the little data that are available (Chow et al, 1988). A simplified model might not be considered as very accurate, however, the development of a model can in a sense be seen as a never ending process, limited only in terms of time and money.

If these two factors are ignored and a good understanding exist of how the system responds, a model can be modified and altered until there is very good correlation between the model output and the real world situation. Once this is achieved, fairly accurate predictions can indeed be made, even with a limited amount of data (Loucks & Van Beek, 2005).

2.2 TECHNOLOGICAL ADVANCEMENTS

Over the last few decades, hydrological science has become very much reliant on technology to further its cause. Technological advancement has seen a plethora of software programmes, tools and models being developed to assist the modern day hydrologist in solving their everyday problems. The introduction of Geographical Information Systems (GIS), DEMs and software capable of doing complex calculations, have revolutionised the hydrological field of study (Bedient & Huber, 2002). With this advancement, complex calculations have to a large extent become automated, enabling the hydrologist to work with large datasets in a time efficient and accurate manner.

For hydrological applications, topography is a very important factor that needs to be taken into account, as it directly controls the flow of water through a landscape. According to Peralvo (2004), the most widely used data structure employed to store and analyse information about topography in a GIS environment is a raster DEM. It can therefore be said that an accurate DEM is of crucial importance when the outcome that is required should be accurate and reliable.

High resolution DEMs for a specific area are not always readily available and are normally very expensive. There are instances where data are freely available, such as the National Aeronautics and Space Administration (NASA) Shuttle Radar Topographic Mission (SRTM) which comes as 3 arc-second DEMs and relates to a grid spacing of 90 meters. NASA has recently also released 1 arc-second data which relates to a resolution of 30 meters (Boggs, 2015). The 90 meters SRTM is available worldwide, whereas the 30 meters STRM data are only available for selected areas. The 90 meters SRTM data is widely used in South Africa (Dennis et al., 2012).

In instances where accurate hydrological calculations needs to be done for a specific area, an accurate DEM is required. This is important, as it has an influence on the reliability of the calculations. Logic dictates that a more accurate DEM should result in more accurate calculations. Accurate hydrological calculations were required for this study. In this instance, the 30 meters SRTM data would greatly assist in accuracy. Unfortunately, the 30 meters SRTM data were not available for the study area and therefore the 90 meters SRTM data were used.

2.3 HYDROLOGICAL MODELS

The Stanford Watershed Model (SWM) was the very first computer based hydrological model to be developed in the 1960s. This model evolved from the need to improve hydrological calculations (Crawford & Burges, 2004). Five decades onwards, the need is still ongoing with new models being constantly introduced, modified and enhanced as technology advances.

The multitude of different hydrological models have required a classification system of sorts. Many hydrologists have made an attempt, albeit in terms of their own interpretations. The result is that models have been classified in various ways (Xu, 2002). A comprehensive study by Jajarmizadeh et al. (2012) have found that literature on the classification of hydrological models are few and far between, yet knowledge thereof is crucial in understanding the capabilities of all the models that are available.

The reason for this is that many of the models have the same characteristics and some overlapping features, however, not all models can be utilised for the same purpose and therefore a process needs to be followed in order to determine which model will be best suited for any given project.

Figure 3 shows a summary of the process followed to determine which model to use, which is modified after Beven (2003).

- Define the objectives and the specific outputs needed from the model.
- Secondly, data availability needs to be explored. Some complex models require a great deal of information, which would obviously not be suitable in the instance where very little data are available.
- Only once the objectives are clearly defined and the circumstances surrounding data availability are known, can a suitable model be selected. Once selected, the available data will still have to be cross-referenced with the chosen model's parameters to ensure suitability.
- The fourth step is to calibrate. Calibration is achieved by finding the best correlation between data measured in the field and simulated data generated by the model.
- Validation follows and can be done in one of two ways:
  - Dependently - by relying solely on the calibrated model, or
  - Independently – by using the same data in another model and compare the results.

If validation is found to be challenging, parameter values of the model will have to be adjusted and the model recalibrated. Where validation is found to be impossible, it might necessitate the need to use a different model (Beven, 2003).

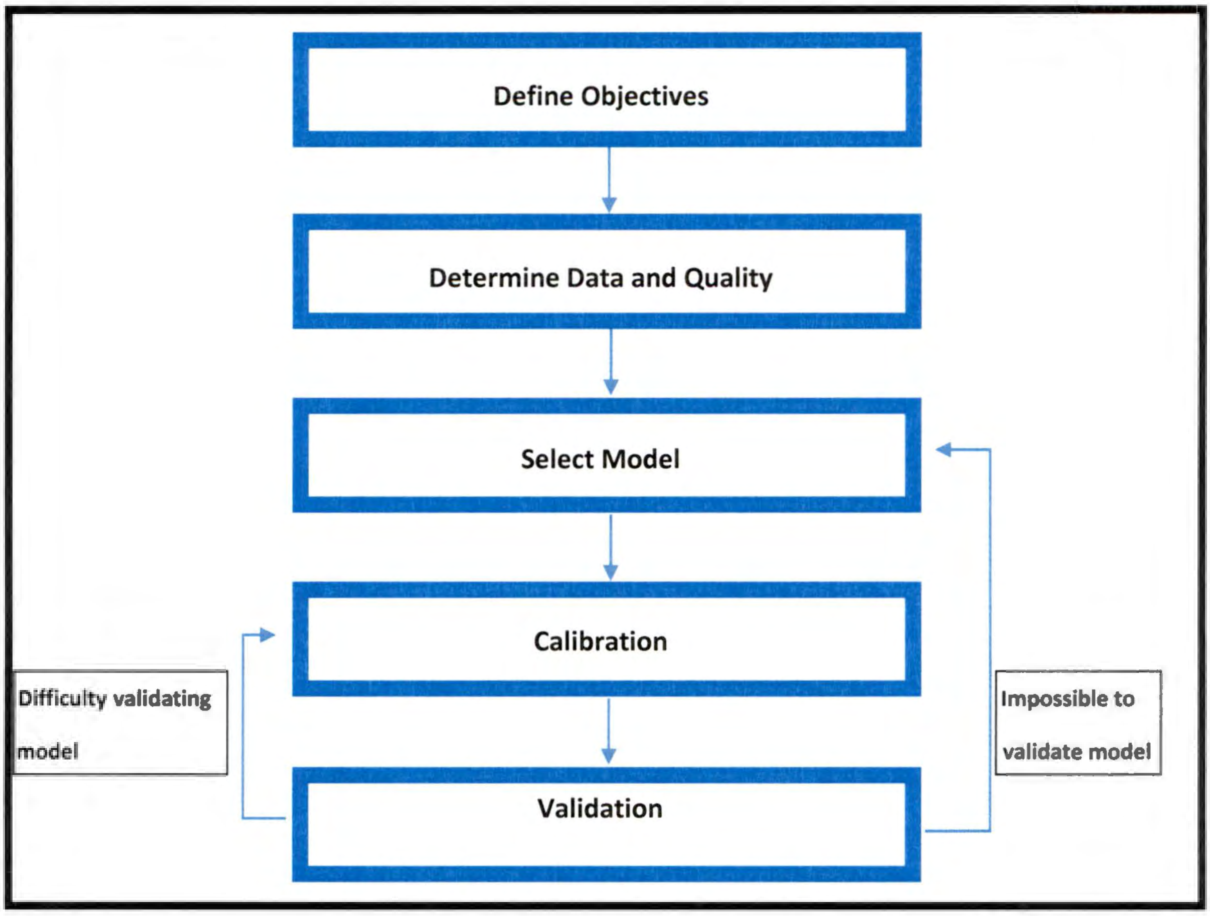


Figure 3 Summary of process to determine which model to use

The plethora of models available for hydrologic modelling necessitates the need for a review of these models in order to find the best suitable model for a study. By reviewing these different models, emphasis is placed specifically on the models' capabilities and data requirements and based on this, a comparison can be drawn with the data availability and the output required for a given study.

There are several sources available that can be consulted to assist with model selection. In particular, a study by Elliott and Trowsdale (2006), who compared models based on:

- Intended use
- Resolution and scale
- Catchment and drainage network representation
- Runoff generation and flow routing (Figure 4)
- Contaminant generation, treatment and transport
- User interface and integration with other software

Table 1 shows the models that were included in the study as well as their intended use (Elliott & Trowsdale, 2006).

Table 1: Selected models and intended use

Model	Intended Use
MOUSE (Model for Urban Sewers)	Detail simulation of urban drainage
MUSIC (Model for Urban Stormwater Improvement Conceptualisation)	Conceptual design of drainage systems
P8 Urban Catchment Model	Estimation of urban storm water pollutant load
PURRS (Probabilistic Urban Rainwater and Wastewater Reuse Simulator)	Single site water use model
RUNQUAL (Runoff Quality)	Preliminary planning or education
SLAMM (Source Loading and Management Model)	Planning tool for load of contaminants
StormTac	Management of lake catchments
SWMM (Storm Water Management Model)	Detail model for planning & preliminary design
UVQ (Urban Volume and Quality)	Integrated water cycle, water re-use
WBM (Water Balance Model)	Planning level assessment of water quantity

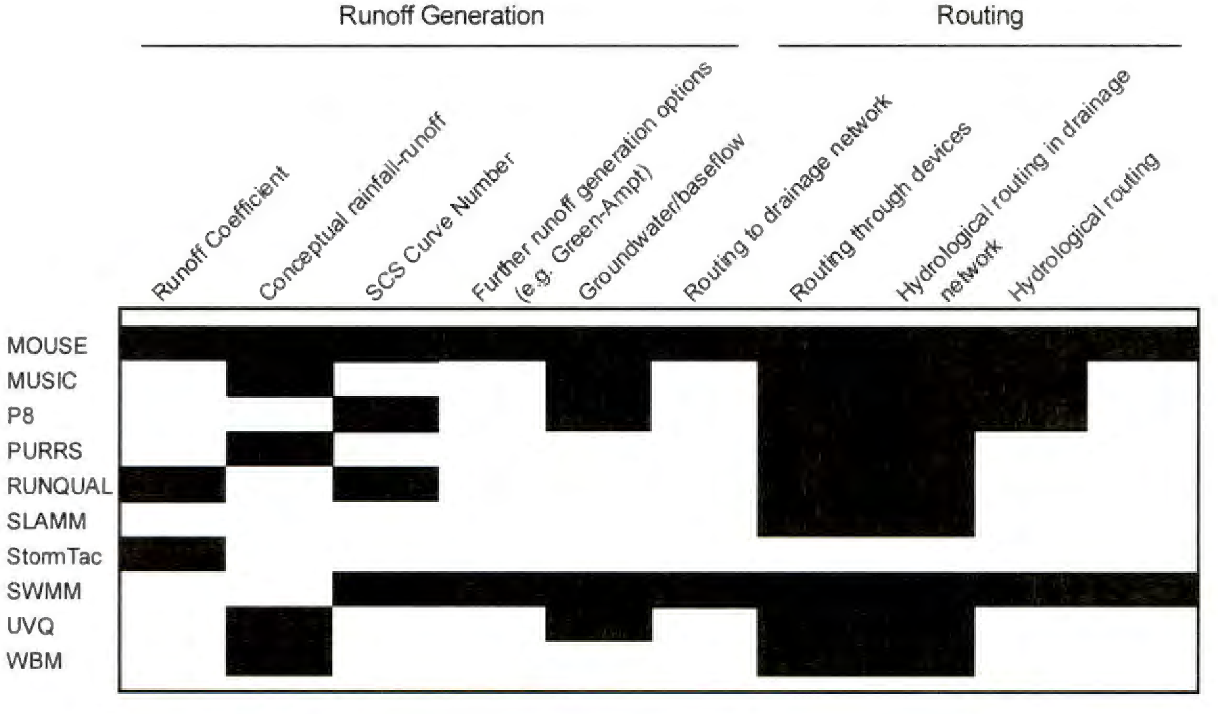


Figure 4: Runoff generation and routing methods (Elliott & Trowsdale, 2006)

Of the ten models that were reviewed, MOUSE and SWMM are the most diversified. The only difference is that MOUSE is a commercial model and SWMM is in the public domain.

2.4 Wetlands

Apart from a wetland's buffering capability in terms of water quality, it also has an influence on the flow rate of a river system. Coincidently, a major part of the ERB's river system consists of wetlands (Figure 1). The main aim of this study is to successfully set up a surface water runoff model for the ERB and therefore the impacts of the wetlands are of particular importance for this study.

In general, this matter has not received much attention in previous studies. The reason for this could be that these studies are very site specific. Channel characteristics and vegetation types for instance, plays a major role.

As previously mentioned, the study area is characterised by wetlands. It comprises a large proportion of the drainage system and a fundamental understanding is required regarding how these wetlands should be modelled in order to successfully set up the surface water model.

Wetlands, and more importantly the vegetation found within wetlands, play a major role in altering the dynamics of water flow, as well as the quality of water within a river system. Sim (2003) divides the role of wetland plants into 6 categories as outlined in Table 2.

Table 2: Roles of wetland plants

Role of Wetland plants	**Description**
1. Physical	• Reduces flow • Improves infiltration • Creates large surface area
2. Soils hydraulic conductivity	• Macrospores on roots improves contact between plants and pollution.
3. Organic compound release	• Provides food for denitrifying microbes
4. Microbial growth	• Provides a large surface area for microbial organisms
5. Creation of aerobic soils	• Transports oxygen into the substrate
6. Aesthetic values	• Provides habitat for wildlife

For the purpose of this study, attention was given only to the physical influence that wetlands have on a river system. According to Ollis et al. (2013), wetlands can be classified into six categories, namely:

- Floodplain wetlands;
- Channelled valley-bottom wetlands;
- Un-channelled valley-bottom wetlands;
- Depression;
- Seep; and
- Wetland flats.

The wetlands in the study area are classified as floodplain wetlands. By nature, these wetlands are topographically flat, which creates a large surface area where water comes into contact with the dense vegetation present in the wetland. This results in a reduced flow rate and subsequently improves infiltration. With the reduced flow, suspended solids and other constituents within the water are captured and together with microbial intervention, water quality may be enhanced (Kotze, 2000).

One of the major challenges for this study was finding a way to integrate the reduction of flow, brought about by the wetland vegetation, into the surface water model that was being developed. Galema (2009) mentions three formulas that are used to determine vegetation resistance, namely Chézy, Darcy-Weisbach and Manning. Chow (1959) states that Manning's formula is unsophisticated in nature and offers acceptable results when applied in open-channel calculations.

2.5 MANNING'S ROUGHNESS COEFFICIENT

Manning's roughness coefficient, named after its founder Robert Manning, was presented for the first time in 1889. It quickly gained popularity as an empirical equation that expresses resistance with a single value which is based on physical channel characteristics that contribute to the reduction of flow (Hall & Freeman, 1994; Arcement & Schneider, 1984; Hodges, 1997). Manning's equation is presented in the following equation:

$$Q = VA = \left(\frac{1.00}{n}\right) AR^{2/3}\sqrt{S} \quad (1)$$

Where:

Q = Flow rate (m^3/s)

V = Average velocity (m/s)

A = Flow area (m^2)

n = Manning's roughness coefficient ($s/m^{1/3}$)

R = Hydraulic radius (m)

S = Channel slope (m/m)

A study conducted by Hall & Freeman (1994) attempted to determine *n* for a wetland. A test facility was built with bulrushes as the predominant vegetation. Roughness was measured with bulrushes in low density and also in high density. The results indicated that there is a direct relationship between *n* and vegetation density. The roughness coefficient increases significantly as density of vegetation increases. An interesting fact to note is that it was also found that the *n* values measured in the study were between 2 to 5.4 times higher than the values recommended in the USGS guideline for vegetated channel roughness. This only holds true on condition that the ratio of the mean depth of flow to bed-material size is greater than 5 and less than 276, after which the *n* value will not vary.

One of the major focus points in a study by Hodges (1997) was to measure changes in velocity, based on *n*, resulting from variations in density and spacing of vegetation. The study also investigated height and form roughness of vegetation. As with the study mentioned above, the same results were obtained in that a correlation exists between *n* and density.

Some studies also showed that different vegetation types can have a dissimilar influence on n-values. This mostly refers to skin friction which describes the roughness on the skin of vegetation (Hodges, 1997). Kadlec & Wallace (2009) tabulated values of *n* from various studies done on wetland roughness. These measured values were based on different vegetation types found within free water surface (FWS) wetlands. Table 3 shows some of the values obtained.

Table 3: Values of Manning's n measured for FWS wetlands

Vegetation	Velocity (m/d)	Manning's n	Source
Cattails	400	13.8	Unpublished data
Cattails + Submerged Aquatic Vegetation	30-867	0.43-2.5	Unpublished data
Submerged Aquatic Vegetation	277-1562	0.42-1.33	Unpublished data
Dense Bulrush	50-60	5.9-6.7	Dombeck et al. (1998)
Dense Bulrush	40-75	2.1-7.6	Dombeck et al. (1998)
Dense bulrush	2075-13400	0.16-0.93	Freeman et al. (1998)

From Table 3 can be seen that depending on which reference is used, there are different values of roughness available for the same type of wetlands. It is clear that there is still much work to be done to understand the dynamics of wetlands and how it can influence a river system.

Data obtained from research suggest that roughness cannot be deemed constant. The only constant is that roughness will constantly change. The reason for this is that a river system is an active system with many factors that play a role in changing its dynamics, which needs to be accounted for. These factors include vegetation density, vegetation type, skin friction, depth of water, seasonal effects and even the alignment of vegetation in relation to flow direction (Hodges, 1997; Arcement & Schneider, 1984). This is however very difficult to translate into a surface water model and therefore, the best representative roughness coefficient needs to be selected that provides the best calibration. Rossman (2010) offers base values of *n* for numerous channel types and channel characteristics.

Cowen (1956) uses an approach in which the base value for *n* can be adjusted based on a number of given correction factors that may affect the roughness of a channel. These factors include the following:

- Degree of irregularity (smooth to severe);
- Variation in channel cross section (gradual to alternating frequently);
- Effect of obstructions (negligible to severe);
- Amount of vegetation (small to very large); and
- Degree of meandering (minor to severe)

Each of these factors have a range of adjustment values to choose from. Each adjustment value is accompanied by a description of the physical condition the channel needs to be in for that value to be chosen. The subsequent formula for computing the final Manning's n, is given by Cowen (1956) as:

$$n = (n_b + n_1 + n_2 + n_3 + n_4)m \tag{2}$$

where:

n_b = a base value of *n*

n_1 = Surface irregularities

n_2 = Channel variation

n_3 = Obstructions effects

n_4 = Vegetation density

m = Degree of meandering

n = Manning's n

2.6 GROUNDWATER CONTRIBUTION TO SURFACE FLOW

According to Xu (2002) "groundwater flow represents the main long-term component of total runoff". If groundwater contribution is not accounted for in the surface water model, the simulated flow data could potentially show significant differences when compared to the observed flow data.

A river can be characterised as either a losing or a gaining stream. This is determined by the direction in which the water flows, also termed as the water gradient. A losing stream is where the groundwater system receives water from the stream and a gaining stream is where the stream receives water from the groundwater system (Gordon et al., 2004). The type of stream is dependent on the level of the water table.

To determine how much the groundwater system is contributing to the river system, hydraulic conductivity has to be determined first. Hydraulic conductivity is "the measure of a soil's ability to transmit water" (Davie, 2008). For calibration purposes, it was necessary to determine in what way the groundwater system of the study area is contributing to the river system.

2.7 CONCLUSION

Rainfall runoff modelling is a complex process in which there are many unknowns and factors that needs to be taken into account to successfully simulate a hydrological system. The reason for this complexity is the fact that a hydrological system is an active and dynamic system that is constantly changed by these factors.

Wetlands for instance, which covers a large part of the study area, can influence a river system significantly in terms of flow rate. Finding a way to determine the effect thereof on the system can be challenging. Technological advancement however, sees the introduction of various software programmes, tools and models, which greatly assist in solving these intricacies. More detail of these aspects and how it is applied in the study will be provided in the chapters following. A description of the study area will follow in the next chapter.

3 DESCRIPTION OF THE STUDY AREA

3.1 INTRODUCTION

The ERB is situated in the Gauteng Province of South Africa and covers an area of approximately 768 km² with the towns of Kempton Park to the north, Springs to the east, Heidelberg to the south and Alberton to the west of the study area (Scott, 1995).

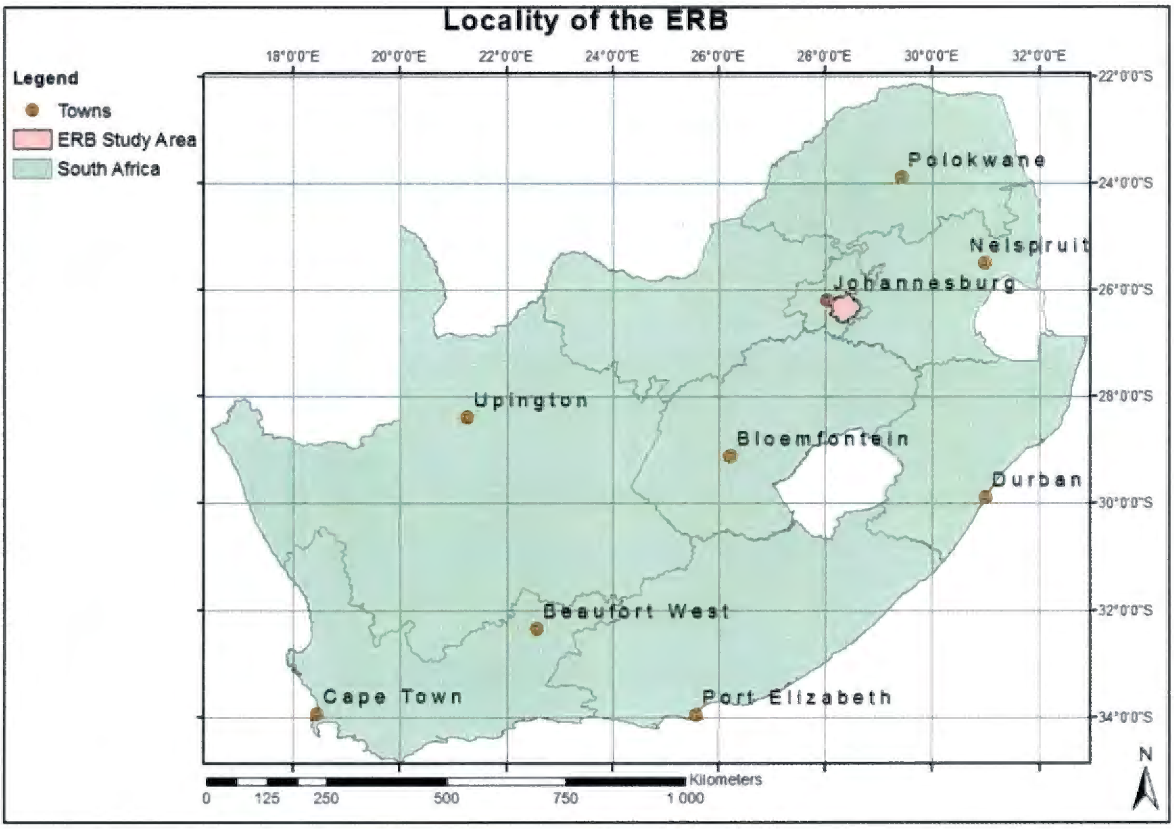


Figure 5: Locality map of the ERB

A number of photos were taken to showcase the topography and vegetation surrounding the Blesbokspruit within the study area. Starting at Heidelberg in the south and ending at Daveyton in the north. Figure 6 shows the respective locations where these photos were taken.

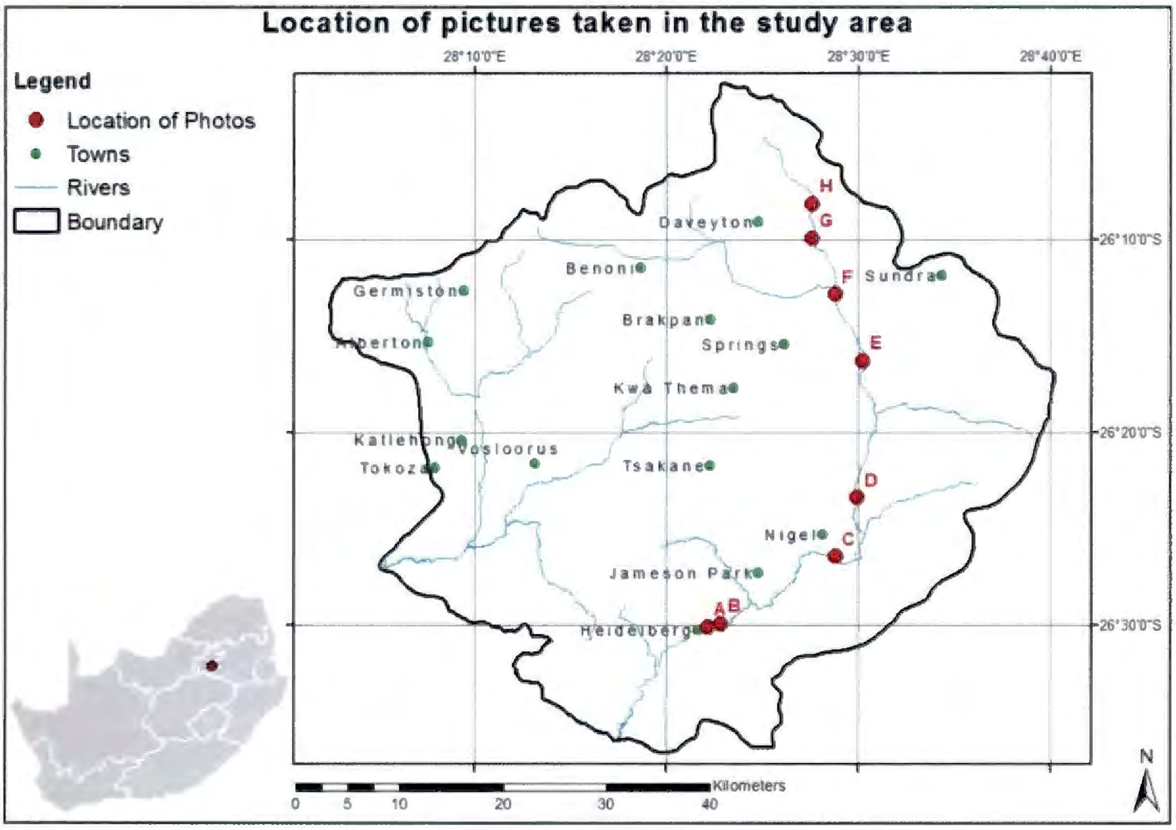


Figure 6: Location of pictures

Table 4 shows the pictorial of the Blesbokspruit. From the pictures it can be seen that the Blesbokspruit is channelised in its southern part in comparison with the extensive wetlands that can be seen when moving to the north.

Table 4: Pictorial of the Blesbokspruit

A – Groenfontein Road 	**B – N3** 
C – Leeds Road 	**D – Nigel Delmas Road** 
E – N17 	**F – Welgedacht Road** 
G – N12 	**H – Laris Road** 

3.2 PHYSICAL CHARACTERISTICS

3.2.1 Climate

The area is known for extreme temperatures varying from minimums as low as -10˚C in winter to maximums as high as 35˚C in summer. The average monthly temperatures for the study area are shown in Figure 7.

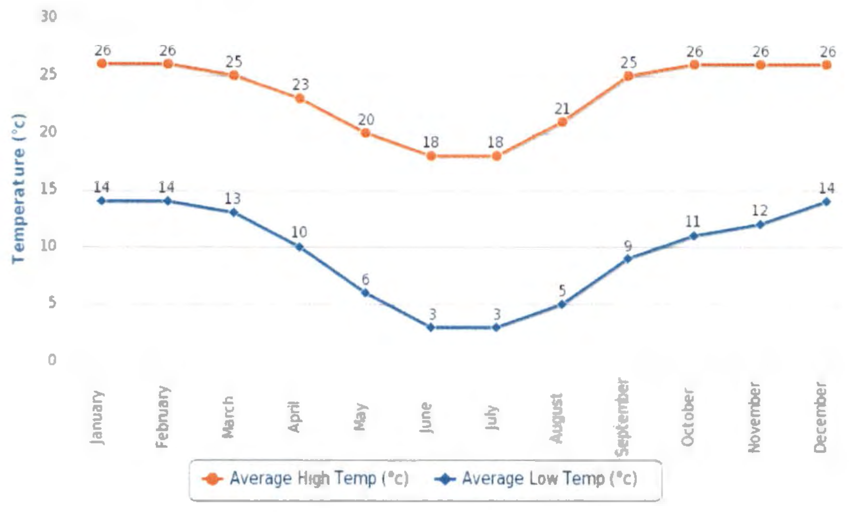


Figure 7: Average monthly temperatures (Dennis et al., 2012)

Convection rainfall occurs primarily in the summer months and average rainfall ranges around 720 mm per annum (Department of Water Affairs, 2012). Hailstorms also frequently occur during this time. Frost normally occurs from the month of April up until October. Figure 8 shows the average monthly rainfall for the study area.

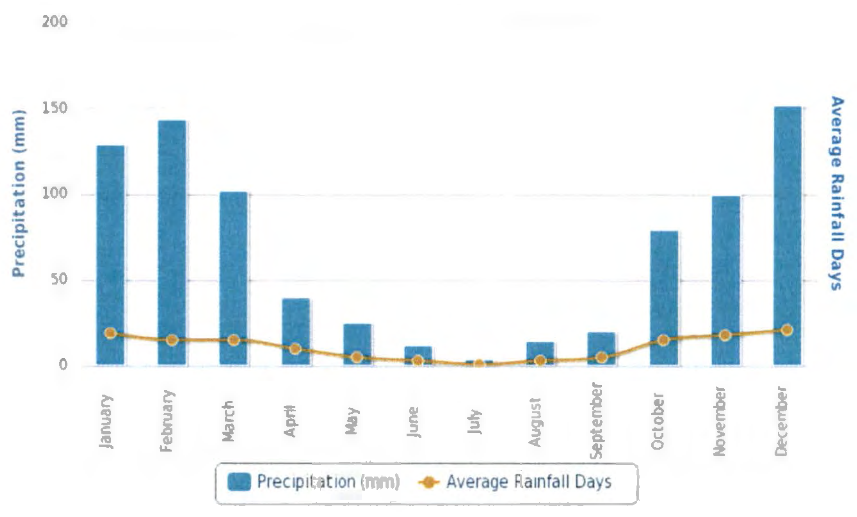


Figure 8: Average monthly rainfall for the study area (Dennis et al., 2012)

Table 5 shows the average monthly evaporation for the study area.

Table 5: Average monthly evaporation (Dennis et al., 2012)

Month	Evaporation (mm/month)
Jan	187
Feb	155
Mar	145
Apr	109
May	89
Jun	72
Jul	78
Aug	113
Sep	151
Oct	179
Nov	180
Dec	193
Total	1651

3.2.2 Vegetation

In terms of vegetation the study area consists predominantly of grassland as it falls within the grassland biome. These grasslands are mainly characterised by Cymbopogon-Themeda veld. The western and southern parts of the study area also consists of Bankenveld (Figure 9).

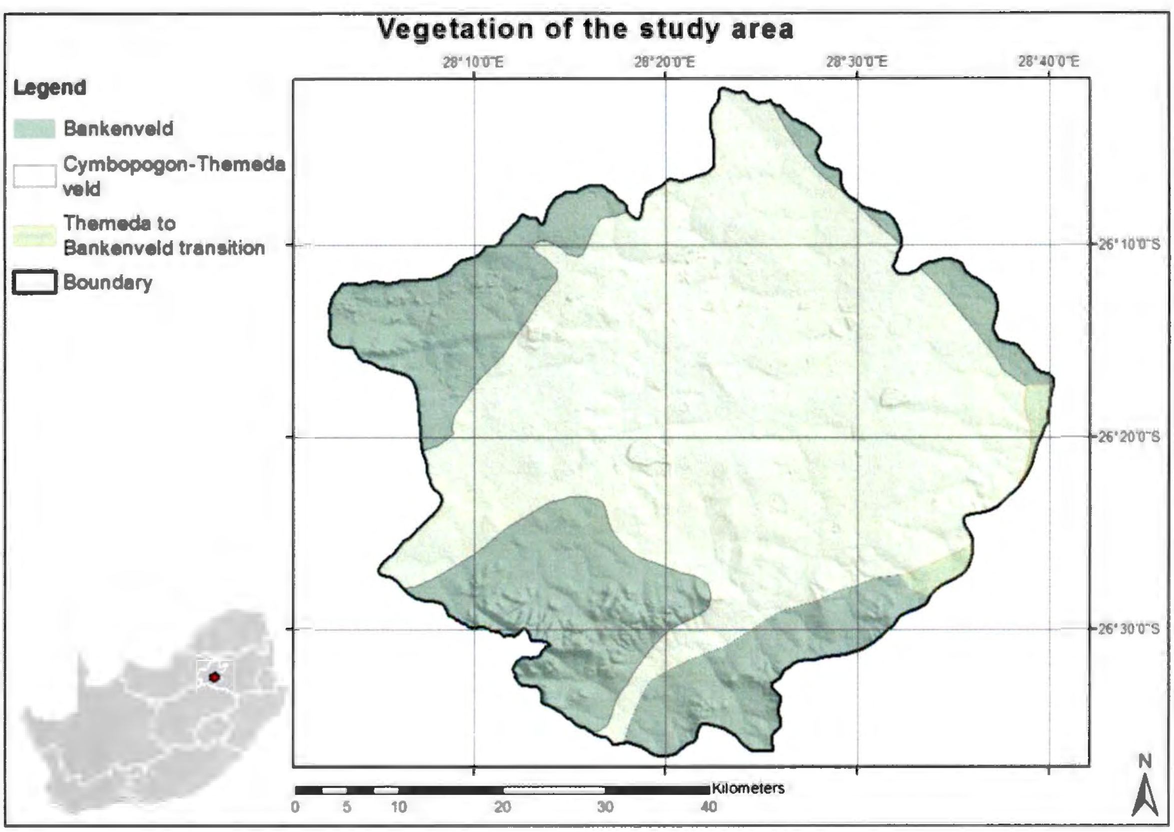


Figure 9: Vegetation of the study area

As mentioned in Chapter 2, the area is also characterised by wetlands. These wetlands consist mainly of dense reed vegetation, more specifically *Phragmites sp.* and *Typha sp.* (Figure 10)

More commonly known as Common Reed Grass, *Phragmites* is an extremely invasive perennial plant that can spread throughout the year. *Typha*, better known as Cattail, is also described as a perennial plant. Both these plants are known to be found in abandoned mining areas (Sim, 2003).

Figure 10: Phragmites.sp. & Thypha sp.

3.2.3 Soils

Figure 11 shows the different soil groups present in the study area as defined by Schulze and Horan (2006). The study area only includes B, B/C, C, and C/D soils, with C type soils being most predominant over the area. No A and A/B soils are present in the study area. Table 6 provides an explanation for the various soil groups found within the South African context.

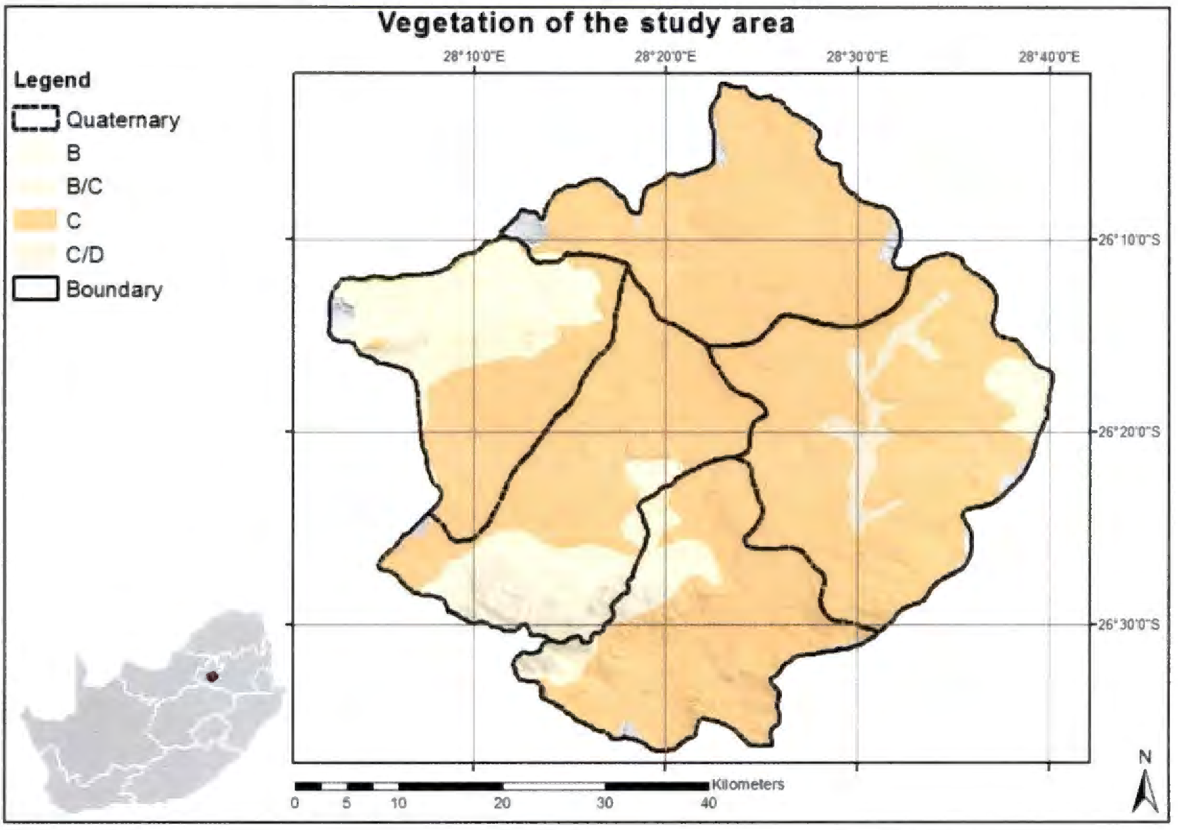


Figure 11: SCS Soils for the study area

Table 6: Definition of Soil Groups (Schulze, 2012)

Soil Group A *Low storm flow potential.* Infiltration is high and permeability is rapid in this group. Overall drainage is excessive to well-drained (Final infiltration rate ~ 25mm/h. Permeability rate > 7.6 mm/h).	
Soil Group B *Moderately low storm flow potential.* The soils of this group are characterised by moderate infiltration rates, effective depth and drainage. Permeability is slightly restricted (Final infiltration rate ~ 13mm/h. Permeability rate 3.8 to 7.6 mm/h).	
Soil Group C *Moderately high storm flow potential.* The rate of infiltration is slow or deteriorates rapidly in this group. Permeability is restricted. Soil depth tends to be shallow (Final infiltration rate ~ 6mm/h. Permeability rate 1.3 to 3.8 mm/h).	
Soil Group D *High storm flow potential.* Soils in this group are characterised by very low infiltration rates and severely restricted permeability. Very shallow soils and those of high shrink-swell potential are included in this group (Final infiltration rate ~ 3.3mm/h. Permeability rate < 1.3 mm/h).	
Notes: The typical final infiltration and permeability rates given above both refer to a saturated soil; Final infiltration rates to soils with a short grass cover; Infiltration rate is controlled by surface conditions whereas permeability rates are controlled by properties of the soil profile.	

3.2.4 Hydrology

Figure 12 shows that the study area falls within five quaternary catchments and is characterised by two drainage regions, namely the Blesbokspruit and the Rietspruit (Scott, 1995). The Blesbokspruit, which is the main focus of this study, is situated on the eastern side of the study area. It is a hydrological important river as it covers over 60km^2, thereby draining a large area of Gauteng to the south where it eventually meets the Vaal River (WISA, 2006). The Rietspruit drains the western side of the study area. Both these rivers are perennial.

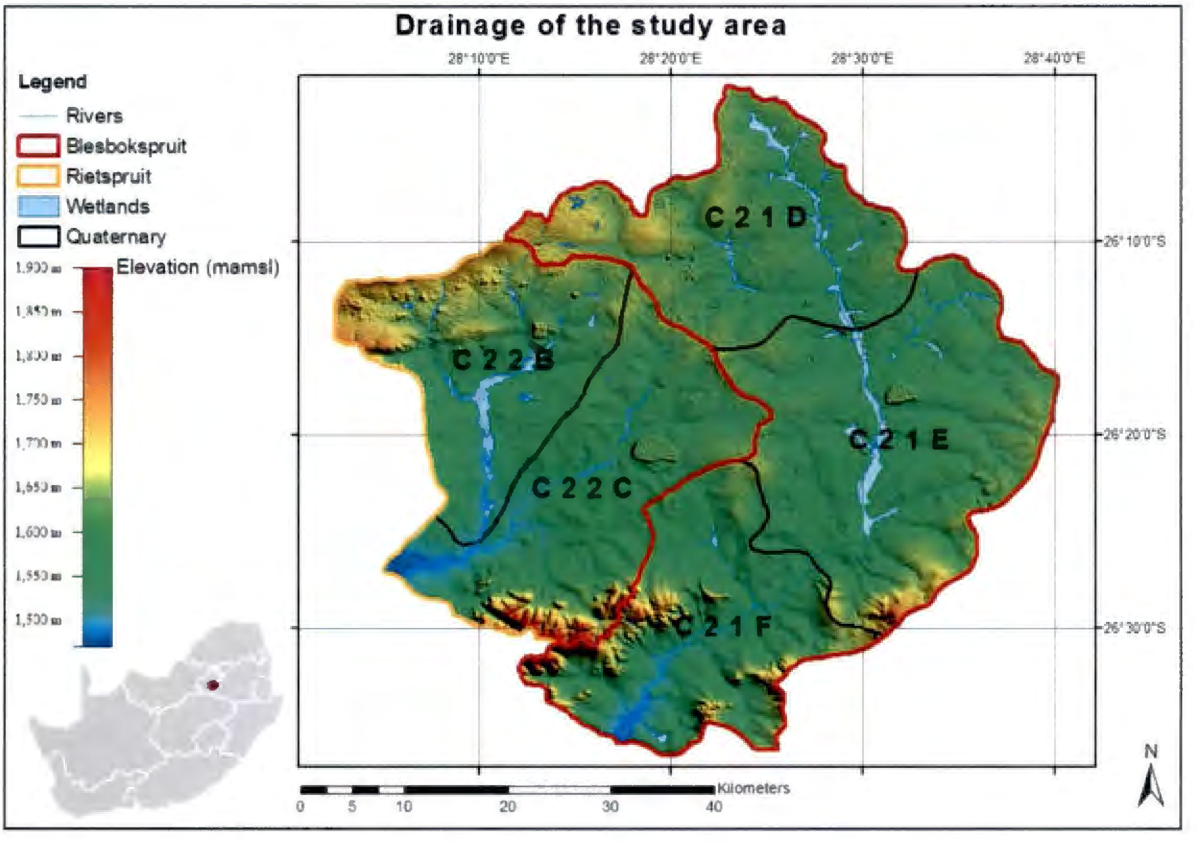


Figure 12: Drainage of the study area

Middleton and Baily (2005) summarises the average hydrological values for each of the quaternary catchments in Table 7. Included in this table is mean annual precipitation (MAP), mean annual rainfall (MAR) and mean annual evaporation (MAE).

Table 7 Hydrological values for the quaternary catchments of the study area

Quaternary	River	Catchment Area (km²)	MAP (mm/a)	MAR (mm/a)	MAE (mm/a)	Baseflow (mm/y)
C21D	Blesbokspruit	446	698	36	1625	7
C21E	Blesbokspruit	628	691	35	1625	6
C21F	Blesbokspruit	426	704	38	1625	7
C22B	Natalspruit	392	692	32	1630	7
C22C	Rietspruit	465	684	31	1625	8

3.2.5 Geology

Geologically, the area is fairly simple. Over the history of this area, the entire sequence of rock has been intruded by mainly dolerite (WISA, 2006). The basin is relatively shallow with gentle, northwest-striking folds and two protruding anticlinal structures (Figure 14) (Johnson et al., 2006).

The Ventersdorp lava overlies the Witwatersrand rocks in the central part of the basin, but is limited in extent. The overlying Transvaal rocks consist of the Black Reef Formation (Pulles et al., 2005). As these younger sedimentary rocks are covering the older formations, only a small portion of the Witwatersrand is exposed (Johnson et al., 2006). However, the younger rock has been eroded along the course of the Blesbokspruit and the older rocks can thus be seen adjacent to the spruit (WISA, 2006). Figure 13 is a stratigraphic representation of the layers found in the study area.

Supergroup/ Sequence	Group	Subgroup	Formation	Member/Bed/Reef	Approximate Thickness (m)
Karoo Sequence	Ecca Group				60
			Dwyka		0 - 10
Transvaal Sequence	Chuniespoort Group	Malmani	Monte Christo Oaktree		370
				Black Reef	30
Ventersdorp Supergroup	Klipriversberg Group		Alberton		450
Witwatersrand Supergroup	Central Rand Group	Turfontein Subgroup	Mondeor		210
			Elsburg		420
			Kimberley	Kimberley Reef	150 - 250
			Doornkop		0 - 200
			Booysens		100 - 140
		Johannesburg Subgroup	Randfontein Main Conglomerate	Main Reef	90 60 180 180 0 - 90
	West Rand Group	Jeppestown Subgroup	Roodepoort		183 350 230

Figure 13: Stratigraphic representation of layers (Dennis et al., 2012)

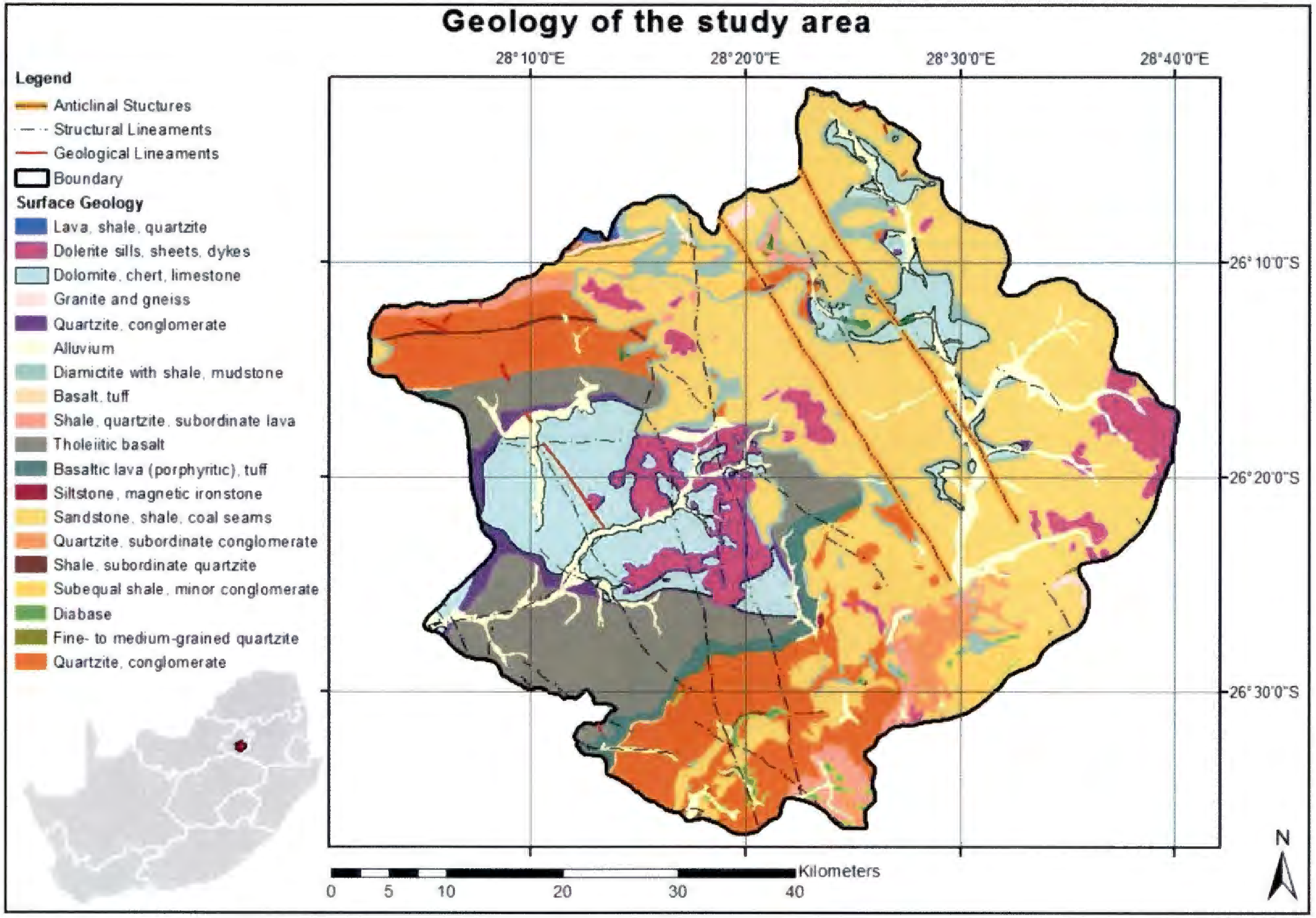


Figure 14: Geology of the study area

Figure 15 and Figure 16 shows a cross section of the reefs through the area.

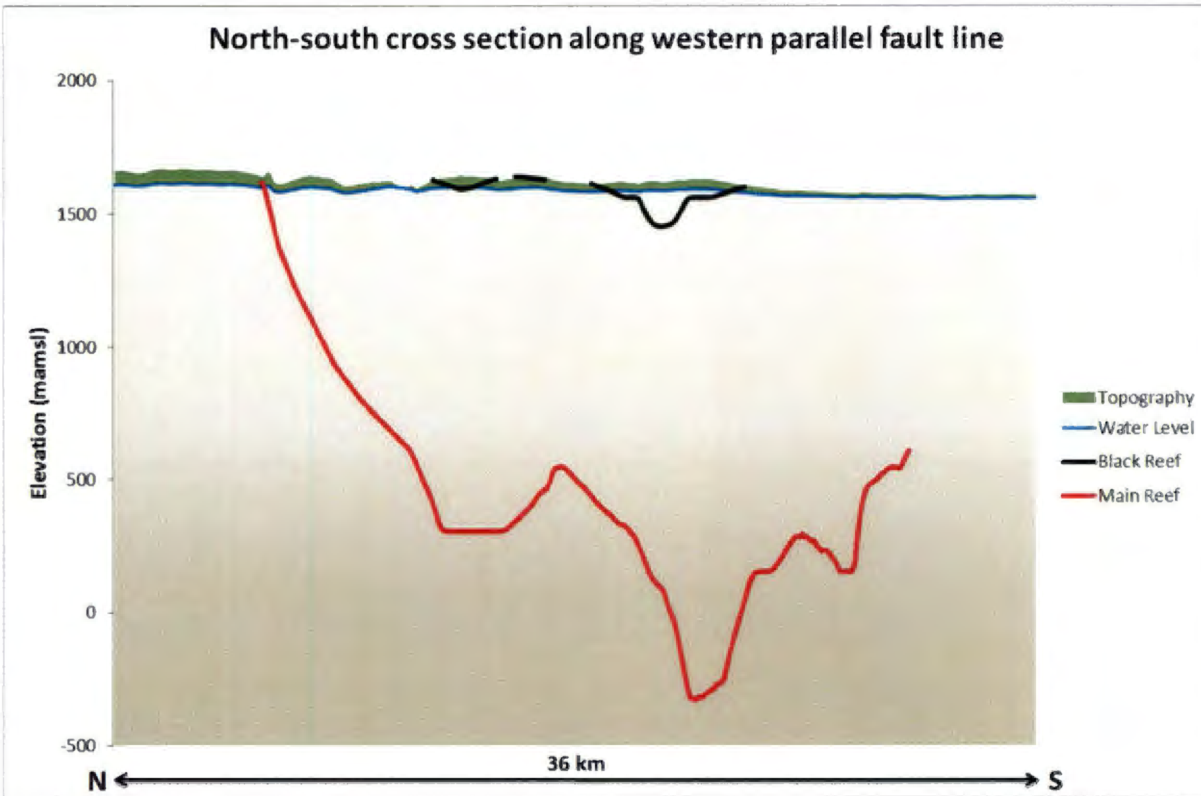


Figure 15: Cross section of reefs along western fault line (Dennis et al., 2012)

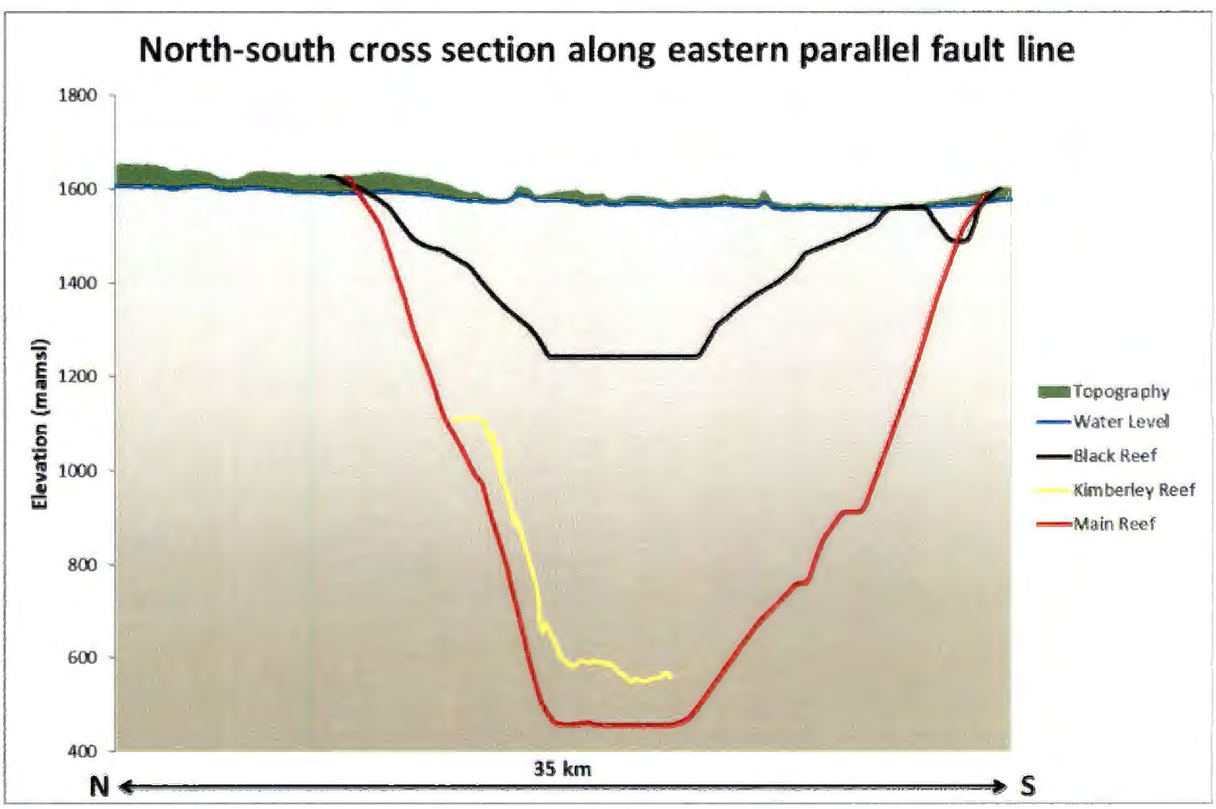


Figure 16: Cross section of reefs along the eastern fault line (Dennis et al., 2012)

3.2.6 Hydrogeology

The ERB is hydrogeologically different from the rest of the Witwatersrand area (Scott, 1995). This is because the ERB is positioned over arenaceous rocks rather than calcareous rocks. The study area is underlain by dolomitic aquifers (Figure 17). These are high yielding aquifers, capable of delivering more than 5 litre/s and according to the aquifer classification scheme of Parsons (1995) can be classified as major aquifers.

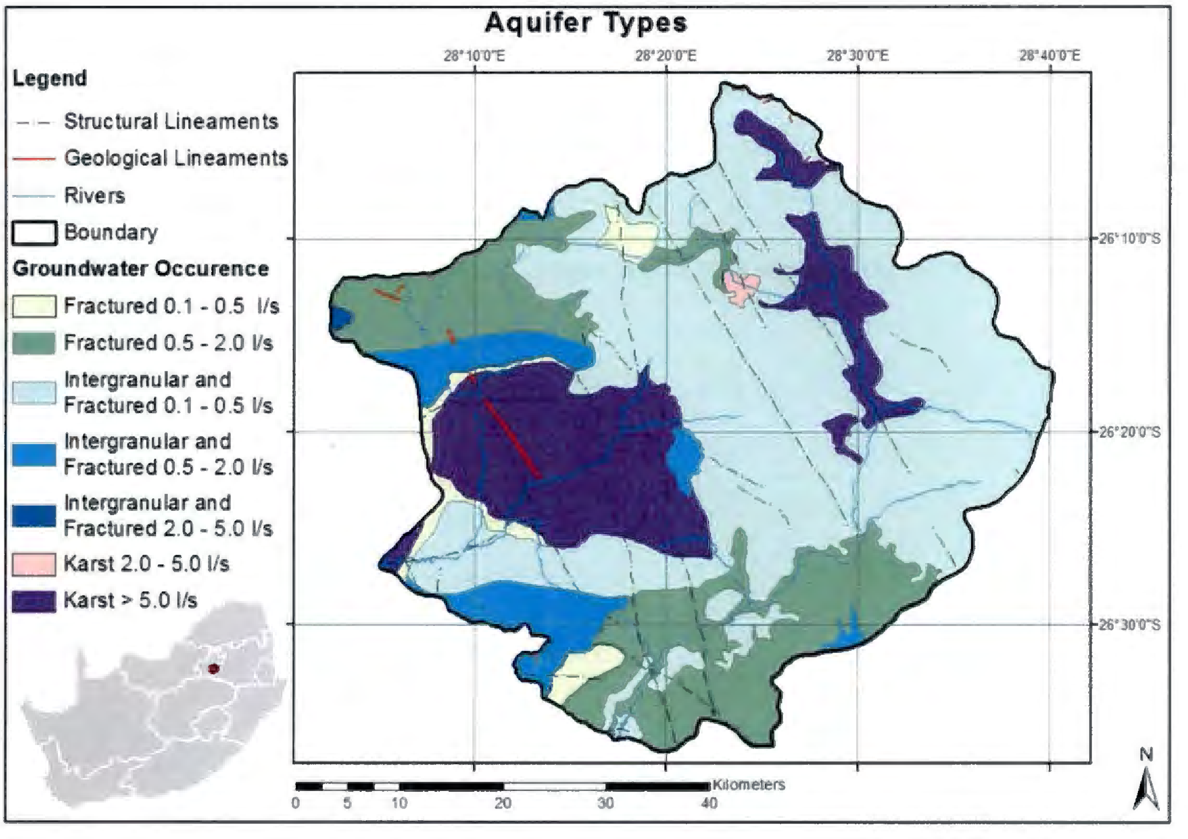


Figure 17: Aquifer Types

The aquifer situated in the north eastern part of the study area is mostly responsible for inflow to the gold mines through fractures. It is believed that the structural lineaments that cut across the Blesbokspruit also plays a big role in terms of ingress as it links the surface water with groundwater (Pulles et al., 2005).

3.3 ANTHROPOGENIC FACTORS

3.3.1 Land use

According to WISA (2006) more than 50% of the ERB consist of agricultural, mining and industrial land-use activities. The remaining land is urbanised as shown in Figure 18.

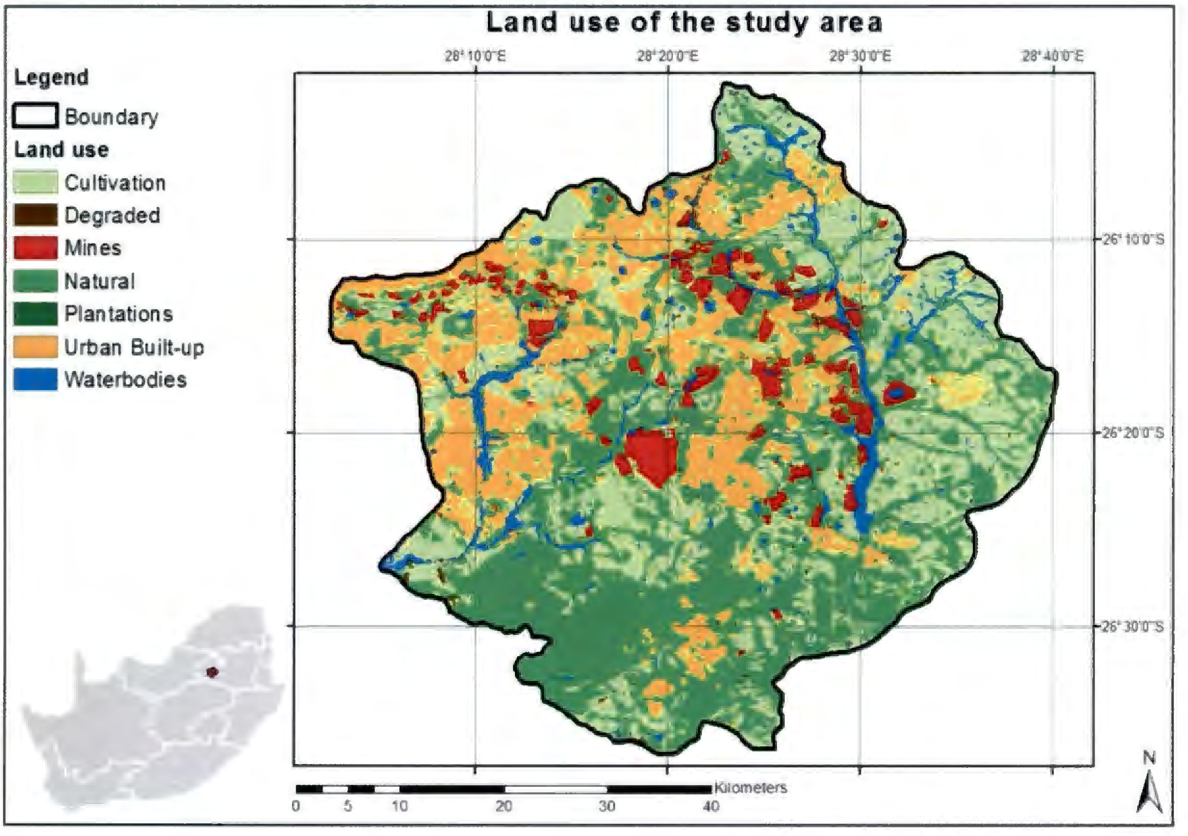


Figure 18: Land cover of the study area

3.3.2 Pollution

Water quality in the study area is a major concern as there are numerous factors and possible pollution sources that are impacting on the quality of water. These can be divided into non-point and point source pollution.

Non-point sources may include, but are not limited to:

- Open cast mines;
- Mine dumps; and
- Slimes dams.

Point sources consist mainly of WWTWs. Numerous WWTWs are situated in close proximity to the banks of the Blesbokspruit as shown in Figure 19.

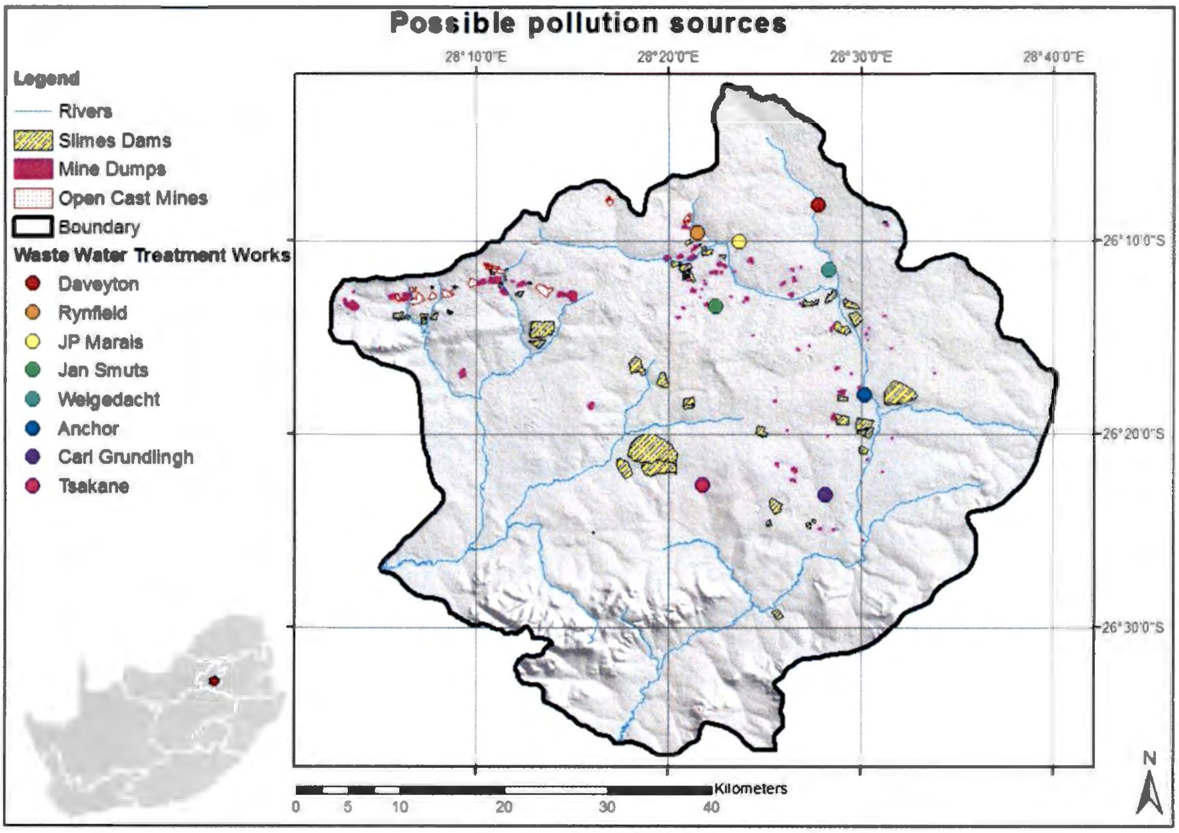


Figure 19: Possible pollution sources

Having areas that are highly industrialised, the rivers in the study area have also been altered by inputs such as eutrophic water. This is the result of WWTWs that cannot keep up with industrialisation and are running over design capacity (Figure 20).

Figure 20: Evidence of raw sewage being discharged into the river

Furthermore, mines have historically been discharging untreated water into the streams which have deteriorated the water quality in such a way that ecological diversity have been lost to some extent (WISA, 2006).

The geology in the study area also plays a role in the quality of water. According to Van Wyk and Munnik (1998) the geology of the reefs where gold is mined, is of such a composition that underground mine water may consist of any of the following constituents:

- Low pH;
- High TDS;
- High sulphates; and/or
- High levels of heavy metals.

For this reason, the Environmental critical level (ECL) for the ERB has been set to 1280 mamsl (Figure 21). ECL is defined as "the highest water level within the mine void where no water flows out of the mine workings into the surrounding groundwater or surface water systems" (Seath & Van Niekerk, 2011). The ECL has been implemented to protect the underground dolomitic aquifers as well as the surrounding environment, which is already under strain from further contamination. Further degradation of the water resource could be detrimental, should decant take place.

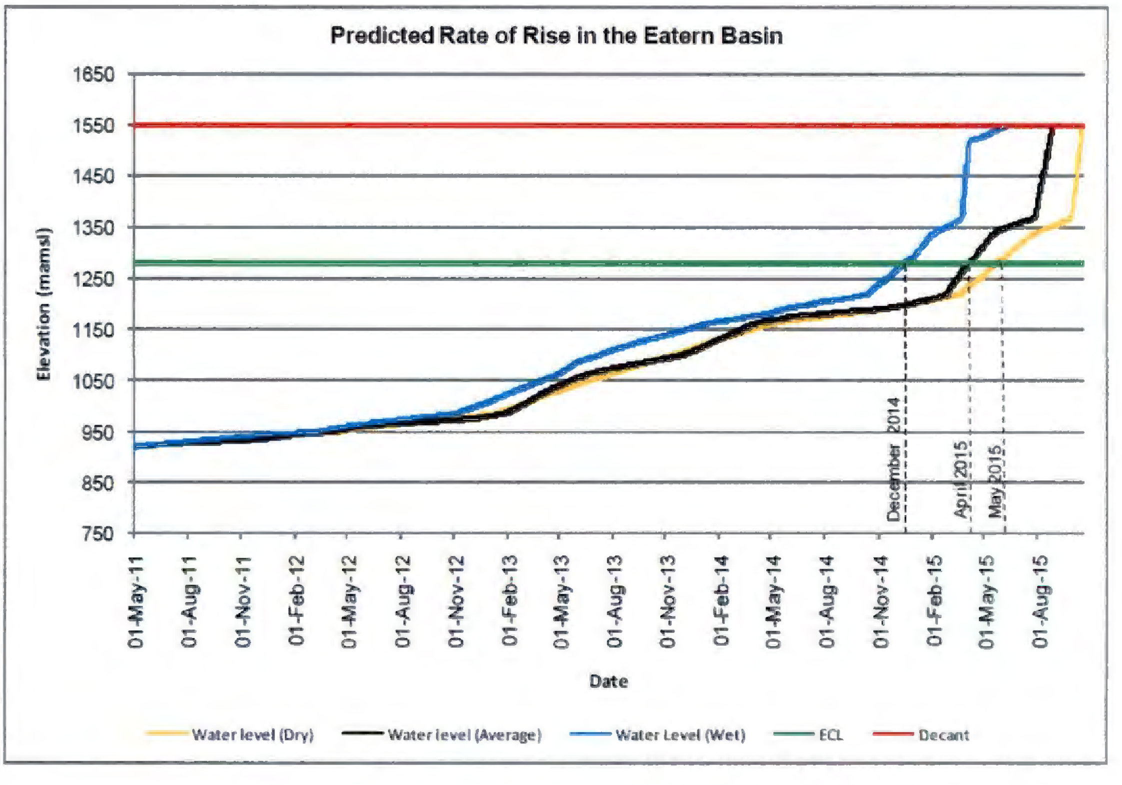


Figure 21: Predicted water levels of the ERB (TCTA, 2011)

There are many ways in which to rectify point-source pollution. Non-point source pollution is of greater concern as it is very difficult to track where it is coming from and to determine the impact thereof.

3.4 CONCLUSION

The ERB is situated on the South Eastern part of the Gauteng Province. The area is known for extreme minimum and maximum temperatures and rainfall occurs during the summer months. Located within the grassland biome, the study area consists predominantly of grassland. The study area is further characterised by wetlands, occurring primarily in the northern parts. There are two drainage regions of which the Blesbokspruit is the main focus for this study.

In a geological sense, the area is fairly simple and mainly intruded by dolerite. High yielding dolomitic aquifers underlies the study area and is mostly responsible for inflow into the gold mines. Should decant from the mines take place, water quality will be impacted significantly, which is already under tremendous strain from various other pollution sources found within the study area.

The study area is very dynamic in nature and has a multitude of influential factors that need to be taken into account when setting up a surface water model. In order to set up a reliable and accurate model, various datasets are required.

4 DATA ANALYSIS

4.1 INTRODUCTION

According to the American Society for Testing and Materials (ASTM) (2002), the gathering of data that are needed to solve a problem, involves locating, collecting, and organising data from available published and unpublished sources into a manageable database. Such a database could include, but are not limited to: geomorphology, geology, geophysics, climate, vegetation, soils, hydrology, hydrochemistry/geochemistry, and anthropogenic aspects.

To set up a surface runoff model, a number of the factors listed above are required as input parameters. Both historical data, as well as field data are required. Historical data were sourced from existing databases.

4.2 METEOROLOGICAL DATA

Rainfall data can be seen as the most important input into a surface water model, as it is the main driving mechanism for runoff calculations. For the model to provide accurate outputs, complete rainfall data sequences, without gaps, are required.

Most of the rainfall data were sourced from the online public database of the Department of Water and Sanitation (2015). Rainfall stations in and around the study area were analysed based on the continuity of the record length. Very few of the rainfall stations that were found in the area had useful data available, as most of the records are incomplete, with many gaps in the data. These gaps extend over several months and in some cases even years, making the possibility for the infilling of gaps impossible. As a result of this poor data quality, rainfall data were also extracted from the South African Weather Services (SAWS) stations.

A total of 63 rainfall stations within the ERB were analysed (Figure 24). Only 2 rainfall stations, namely 0476399W and 0476762W had adequate data. Both these rainfall stations are situated within quaternary catchment C21D as shown in Figure 25. The data are represented in a daily time interval and measured in millimeters (mm). The longest continuous data stretched over a period of 9 years, from 2004 to 2012, as shown in Figure 22.

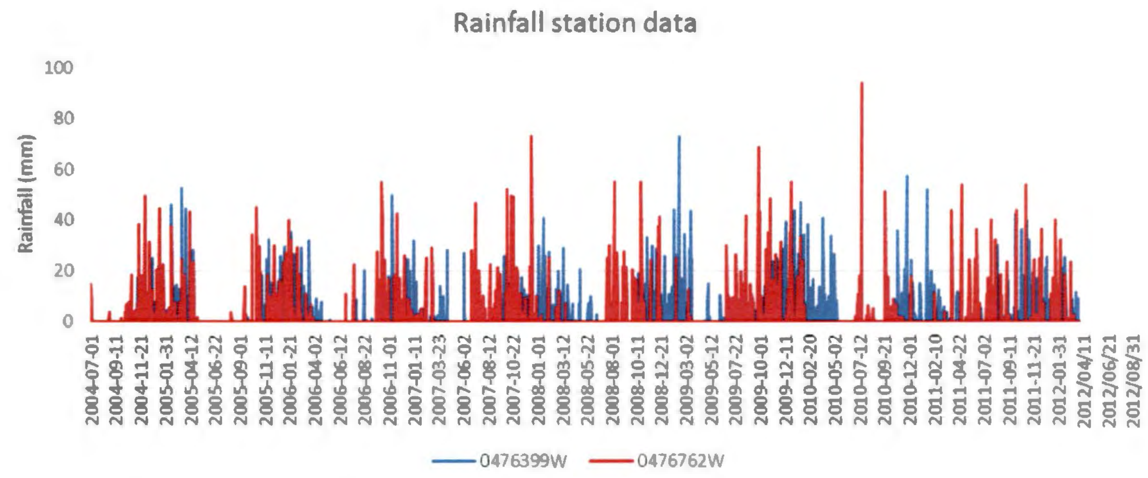


Figure 22: Rainfall station data

4.3 HYDROLOGICAL DATA

Flow data had to be sourced that stretched over the same time period as the rainfall data. As with the rainfall data, a similar situation was found in terms of historical flow data. From the number of available flow-gauging stations analysed in the area, only two, namely C2H133 and C2H136, could be utilised. These flow-gauging stations are situated in quaternary catchments C21F and C22C respectively (Figure 25).

Flow data for C2H133 stretched over a period of five years from 2004 to 2009, although gaps are present in the data. Flow data for C2H136 stretched over a period of only one year from 2011 to 2012 as shown in Figure 23. Flow data obtained is also in a daily time interval and measured in cubic meters per second (m^3/s).

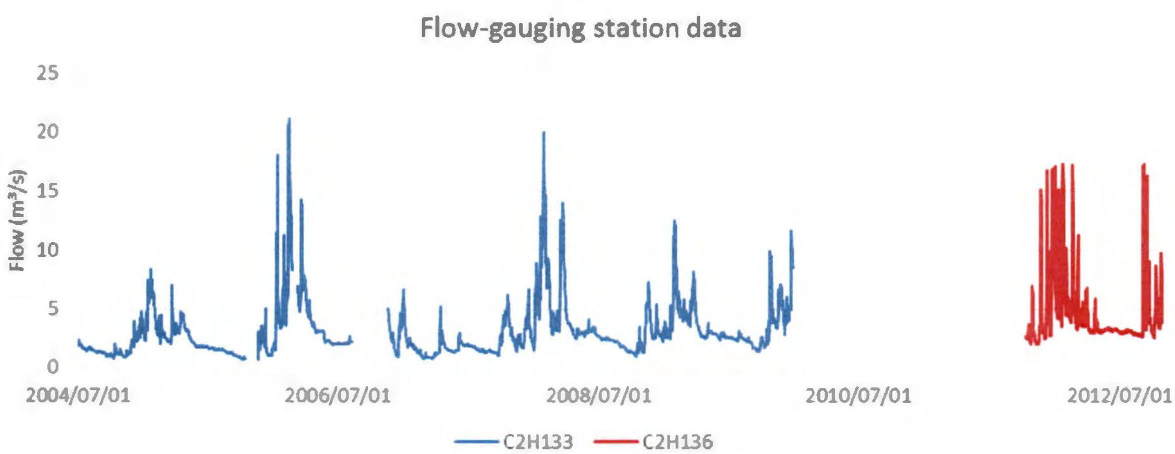


Figure 23: Flow-gauging station data

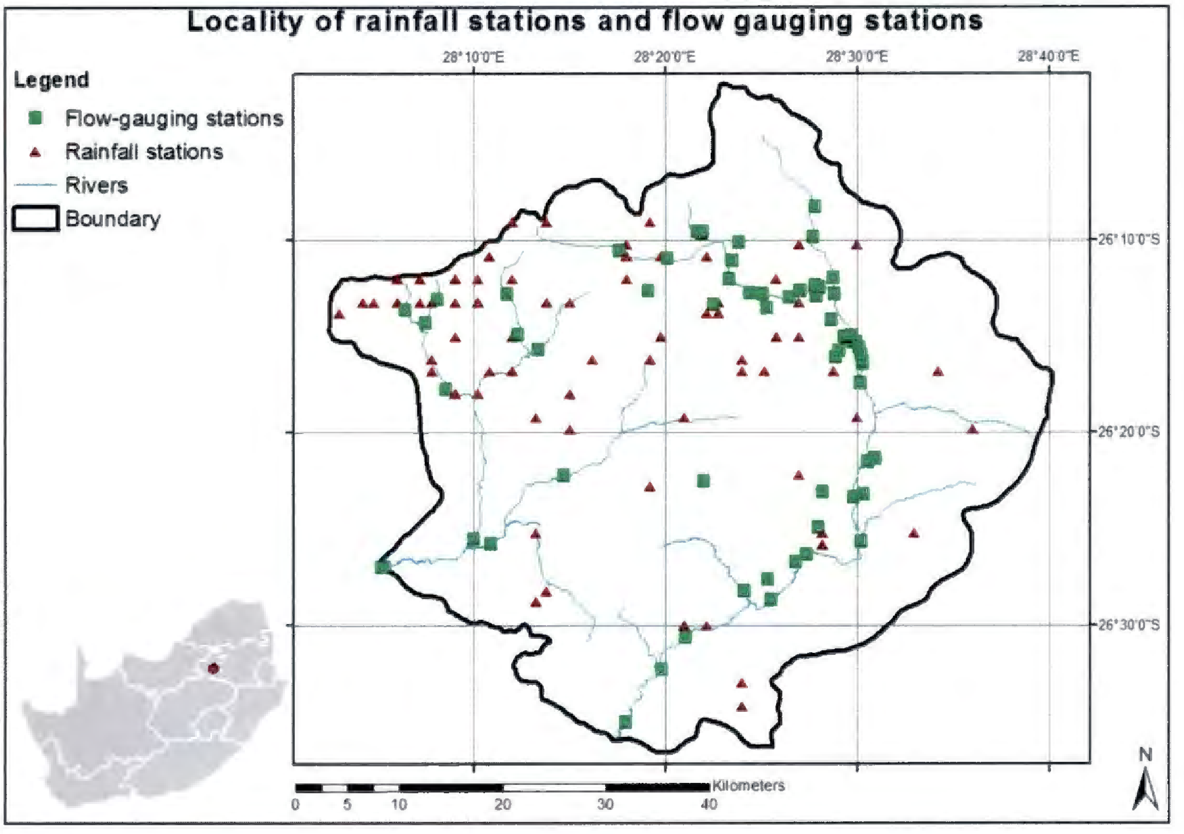


Figure 24: Locality of rainfall stations and flow-gauging stations

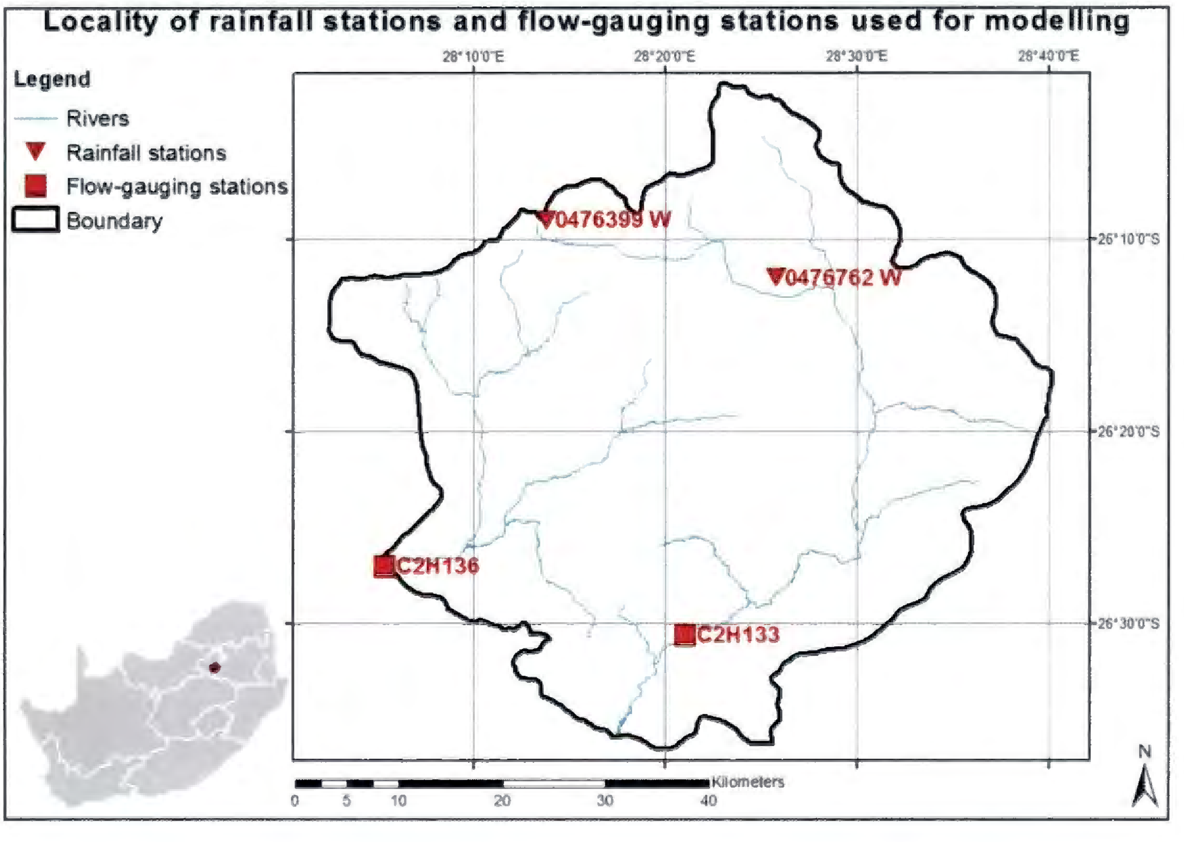


Figure 25: Locality of rainfall stations and flow-gauging stations used for modelling

4.4 RELIABILITY OF HISTORICAL DATA

Data sourced from existing sources are supplemented by quality codes which provide the user with information regarding the quality of data. Table 8 shows the quality of the specific historic flow data used for this study.

Table 8: Quality of flow-gauging station data

Flow-gauging station: C2H133				Flow-gauging station: C2H136			
Quality Code	Description	Count	Percentage	Quality Code	Description	Count	Percentage
1	Good continuous data	605	22.1	7	Good edited unaudited	365	94.6
2	Good edited data	673	24.6	60	Above rating	21	5.4
7	Good edited unaudited	827	30.2				
60	Above rating	5	0.2				
64	Audited estimate	474	17.3				
170	Permanent gap	152	5.6				
Total entries		2736		**Total entries**		386	

Figure 26 and Figure 27 shows the recorded runoff as a result of the rainfall, while the response reflects the time lapse between the two.

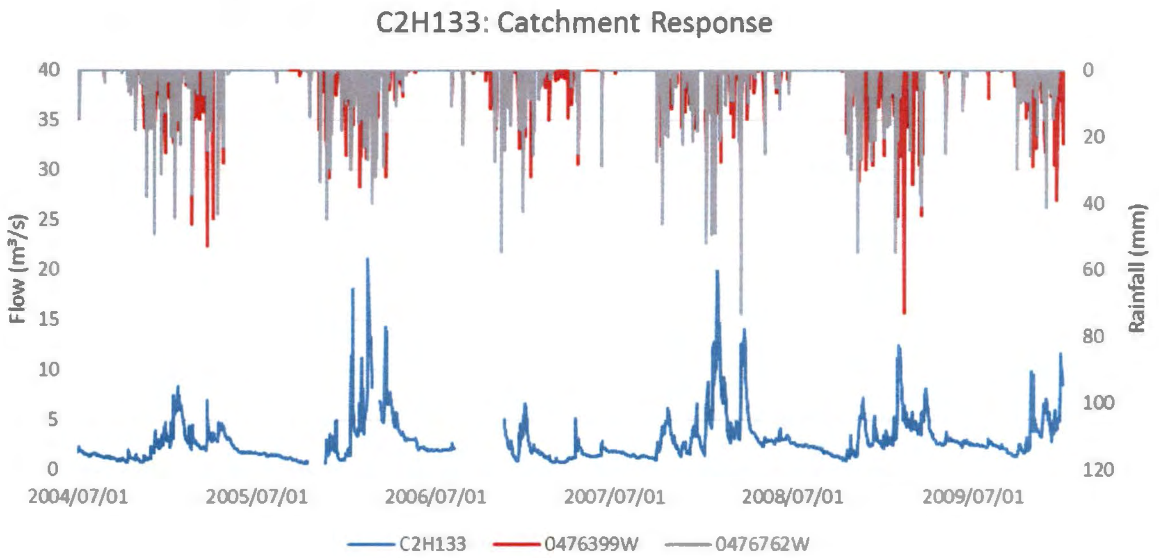


Figure 26: Catchment response in terms of flow-gauging station C2H133

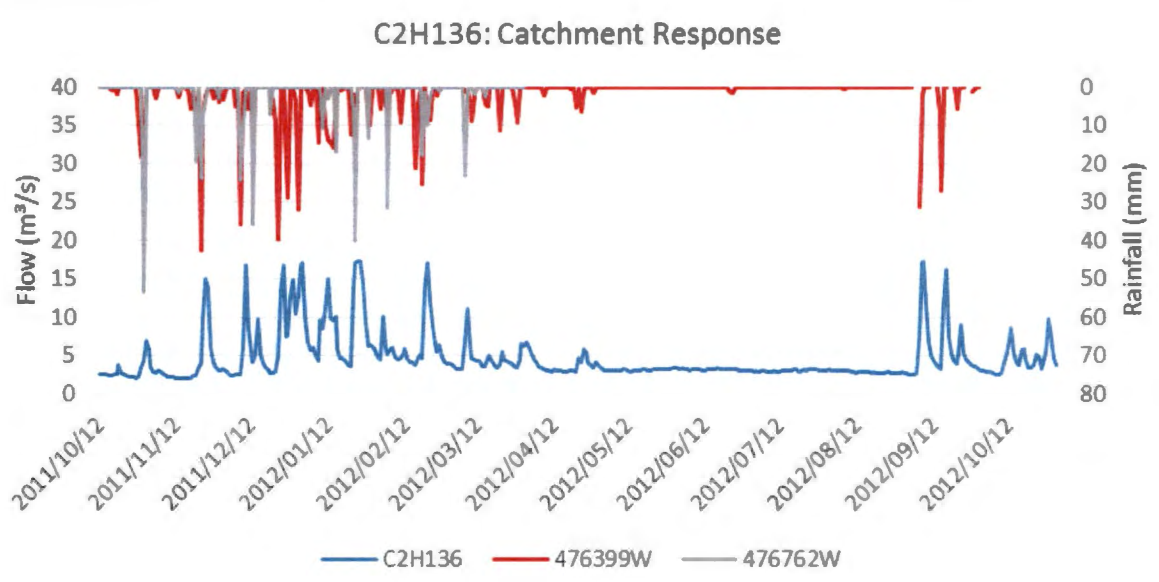


Figure 27: Catchment response in terms of flow-gauging station C2H136

4.5 Field Measurements

4.5.1 Surface sampling

To determine the current status of the hydrological system, in terms of water quantity and quality, field measurements were obtained. Physical data measurements in the field took place over three different time periods. This was done to ensure that measurements were taken over a full hydrological year, thereby ensuring that at least one dry season and one wet season were included over the entire measurement period (Table 9).

Table 9: Field sampling dates

Date	Classification
November/December 2013	Wet
March/April 2014	Average
June/July 2014	Dry

Several measurements were taken at ten different locations as shown in Figure 28.

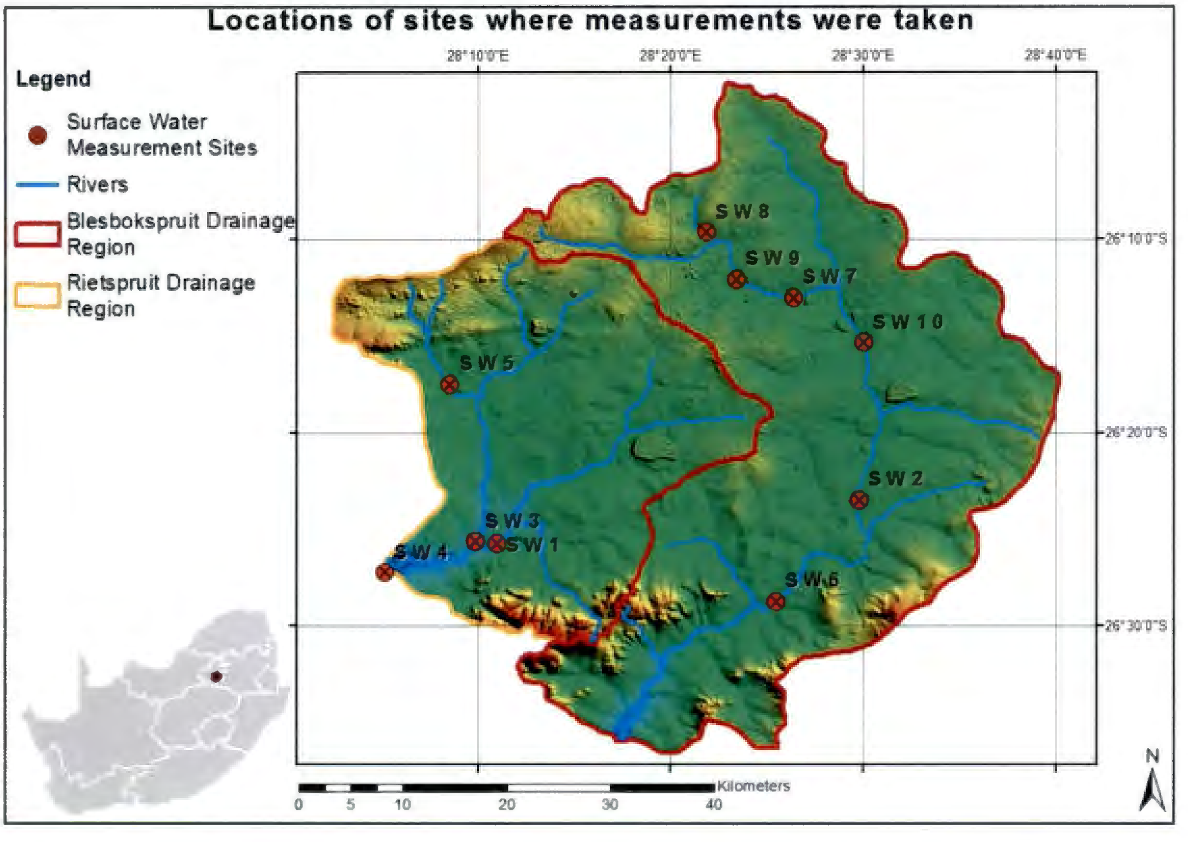


Figure 28: Locations of sites where measurements were taken

The locations where measurements took place were primarily governed by accessibility to these sites where cross sections and stage measurements could be taken. Table 10 provides a pictorial of the sites where measurements were taken.

Table 10: Pictorial of sites where measurements were taken

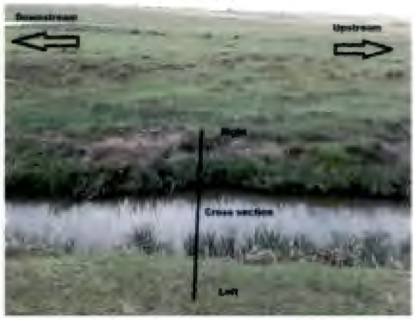
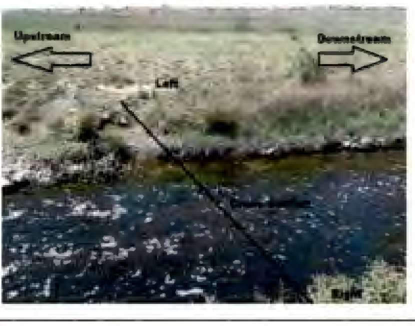
SW1	SW2
	
SW3	**SW4**
	
SW5	**SW6**
	
SW7	**SW8**
	
SW9	**SW10**
	

Figure 29 shows examples of sites that were unsuitable for taking measurements.

Figure 29: Examples of unsuitable measurement sites

Measurements that were taken at the 10 suitable sites included:

- Cross-section surveys
- Flow velocity measurements
- Wetted perimeter area calculations
- Water quality samples

The first round of data measurements were obtained from a consulting company which gathered baseline hydrological data in November 2013 for the same ERB study area. In order to remain consistent with the way in which data were gathered in the first round, the same methodologies used by the consulting company had to be employed in the second and third rounds that followed.

4.5.1.1 Cross-section surveys

Cross-sections were surveyed by means of using a rope or cable and measuring tape across the river or stream. The river was crossed either by guiding a boat across or, where possible, by walking through the river with a wader. A gauge plate was used to measure the ground profile of the cross-section. Seven points were surveyed across each section as shown in Figure 30:

- Points 1 and 7 were at the ends of the rope
- 2 and 6 where the water level starts
- 4 in the middle of the section
- 3 and 5 at equal distances between point 4.

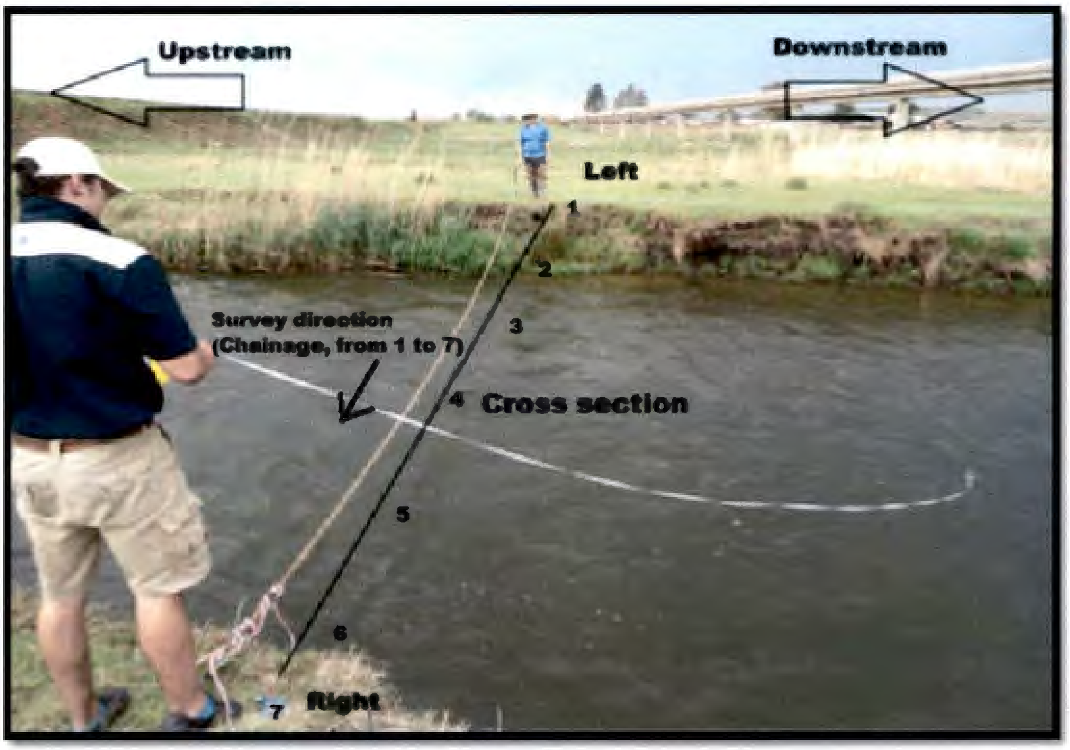


Figure 30: Cross section being surveyed at SW3

Appendix 8.1 provides a summary of the cross-sections that were measured.

4.5.1.2 Flow velocity measurements

Flow velocity measurements were taken by means of an electronic flow velocity meter with a 5m extendable handle of the impeller type. Velocity was measured at 3 points in each section. One in the middle and one on each side between the middle and the river bank. Measurements were recorded at 60% of the depth over a 40 second period.

Three measurements were taken at each point and the average was calculated. The average velocity for the entire section was consequently adopted by taking the average of the three averages at the three measurement points as depicted in Appendix 8.2. Table 11 summarises the final results.

Table 11: Summary of measured flows (m^3/s)

Blesbokspruit	Nov-13	Apr-14	Jul-14	Rietspruit	Nov-13	Apr-14	Jul-14
SW8	0.16	0.15	0.17	SW5	5.95	3.54	0.55
SW9	0.47	0.89	0.74	SW1	0.00	0.10	0.15
SW7	0.73	1.10	0.43	SW3	4.25	8.19	4.60
SW10	0.39	0.4	0.36	SW4	30.33	31.99	25.06
SW2	0.65	2.62	1.43				
SW6	0.00	5.44	3.16				

As already mentioned, it is believed that most of the WWTWs are operated beyond their specified design capacity. This is based on a statement made by one of the WWTWs management staff. Apart from the photographic evidence shown in Figure 20, no other data could be obtained as evidence to support this statement. The only data that could be obtained were the WWTWs design capacities. For the purpose of this study it was assumed that all these WWTWs are running at full design capacity. Table 12 shows the design capacities of WWTWs situated in the study area (Figure 19).

Table 12: Discharge rates of WWTWs as per design capacity (ERWAT, 2015)

Sample	Plant name	Latitude	Longitude	Discharge volume (Ml/d)
TW 1	Daveyton	-26.135	28.462	16
TW 2	Rynfield	-26.159	28.358	13
TW 3	JP Marias	-26.167	28.394	15
TW 4	Jan Smuts	-26223	28.374	10
TW 5	Welgedacht	-26.191	28.472	35
TW 7	Anchor	-26.299	28.503	32
TW 8	Carl Grundlingh	-26.395	28.469	2
TW 9	Tsakane	-26.377	28.363	10

4.5.1.3 Wetted perimeter area calculations

Wetted perimeter areas were calculated for each flow rate measured (three sampling runs over different periods). Areas were calculated for each individual section by dividing the area between the water level and the river bed on each cross-sectional diagram into areas of squares and triangles. The individual areas were accumulated to obtain the total area (Appendix 8.2).

4.5.1.4 Water quality samples

Water quality samples were also taken at each of the measurement sites. Results obtained were plotted against the SANS 241:2005 drinking water standards. Figure 31 and Figure 32 indicates that the macro indicators pH and TDS for both the Blesbokspruit and Rietspruit fall within the acceptable range for drinking water quality.

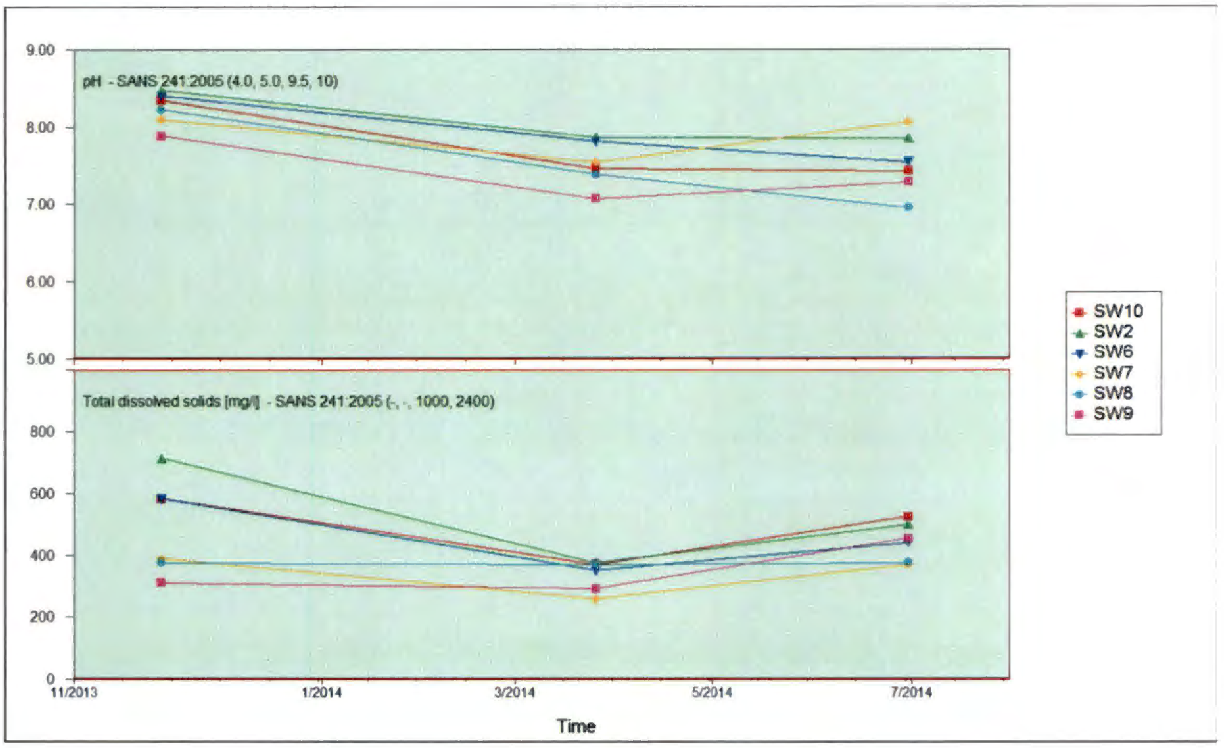


Figure 31: Macro indicators for Blesbokspruit

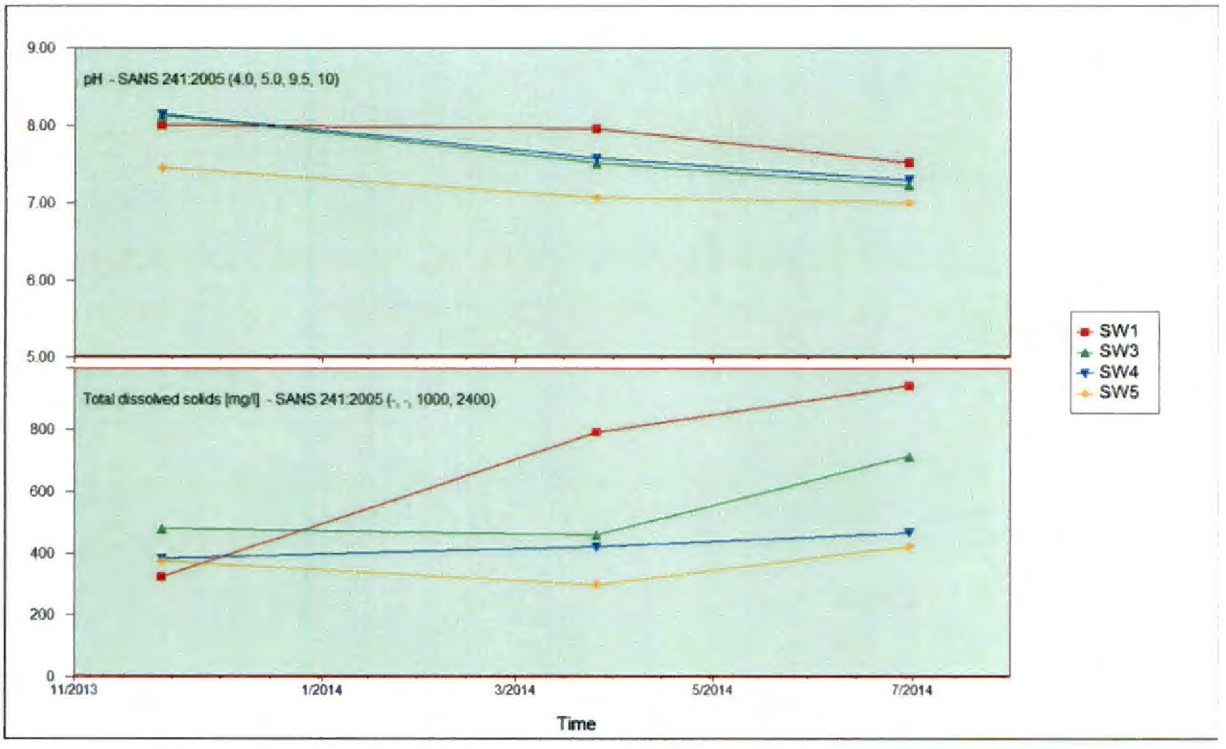


Figure 32: Macro indicators for Rietspruit

Major anions and cations for both the Blesbokspruit and Rietspruit are presented by Figure 33, Figure 34, Figure 35 and Figure 36.

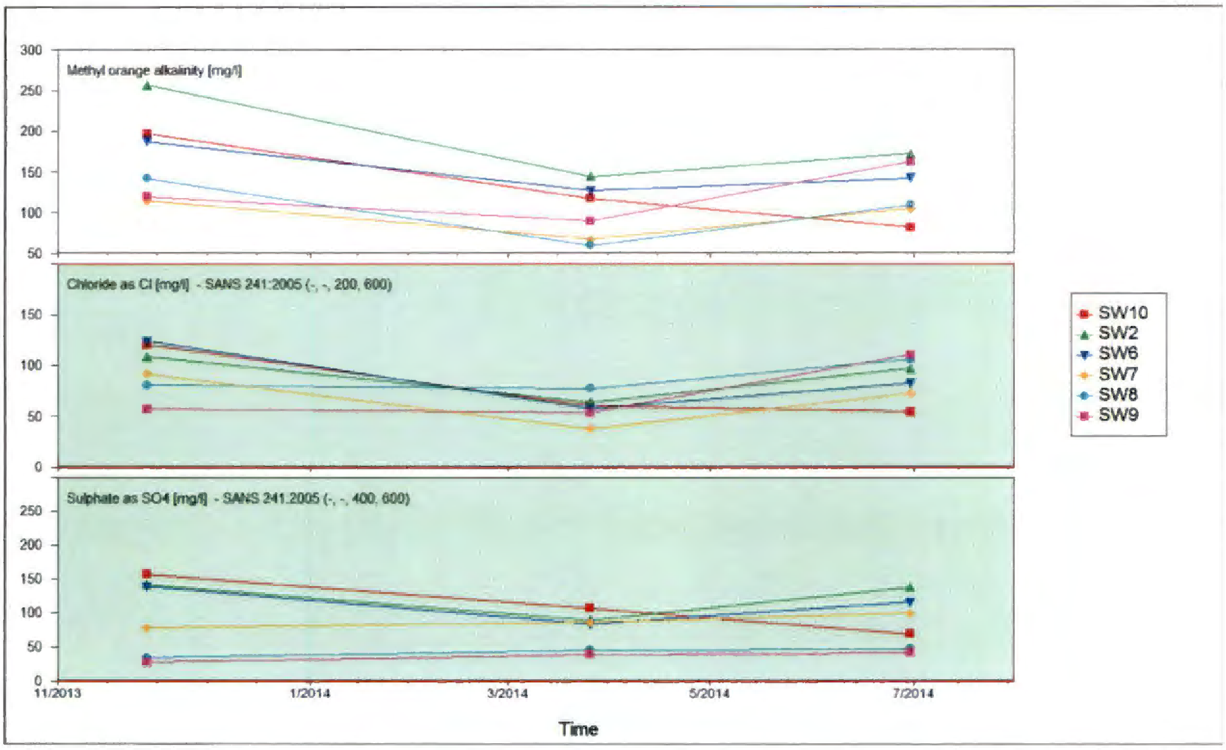


Figure 33: Major anions for Blesbokspruit

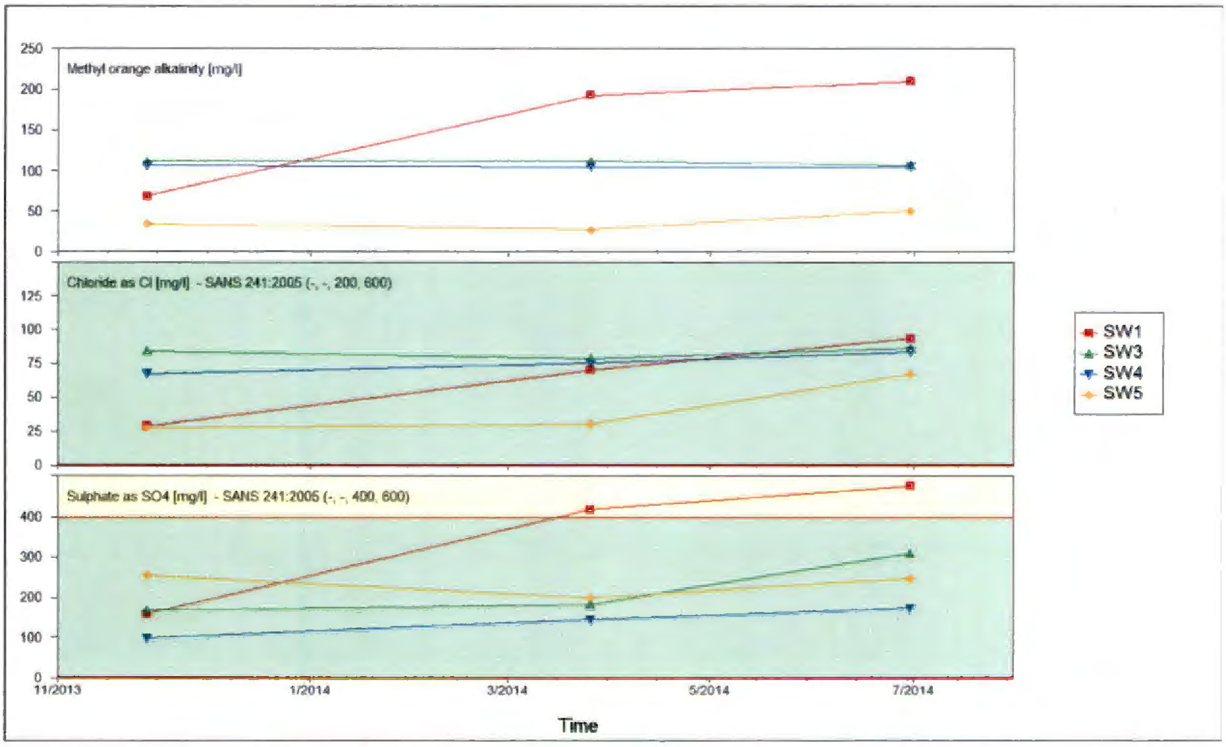


Figure 34: Major anions for Rietspruit

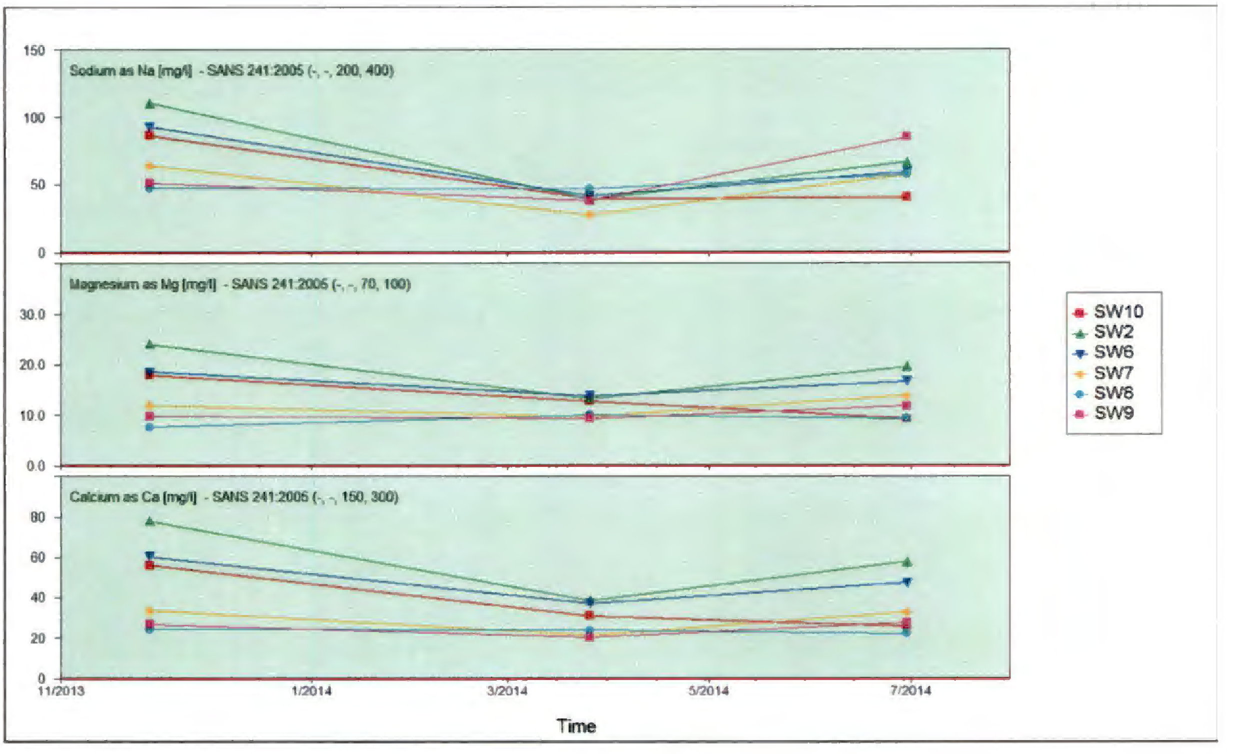


Figure 35: Major cations for Blesbokspruit

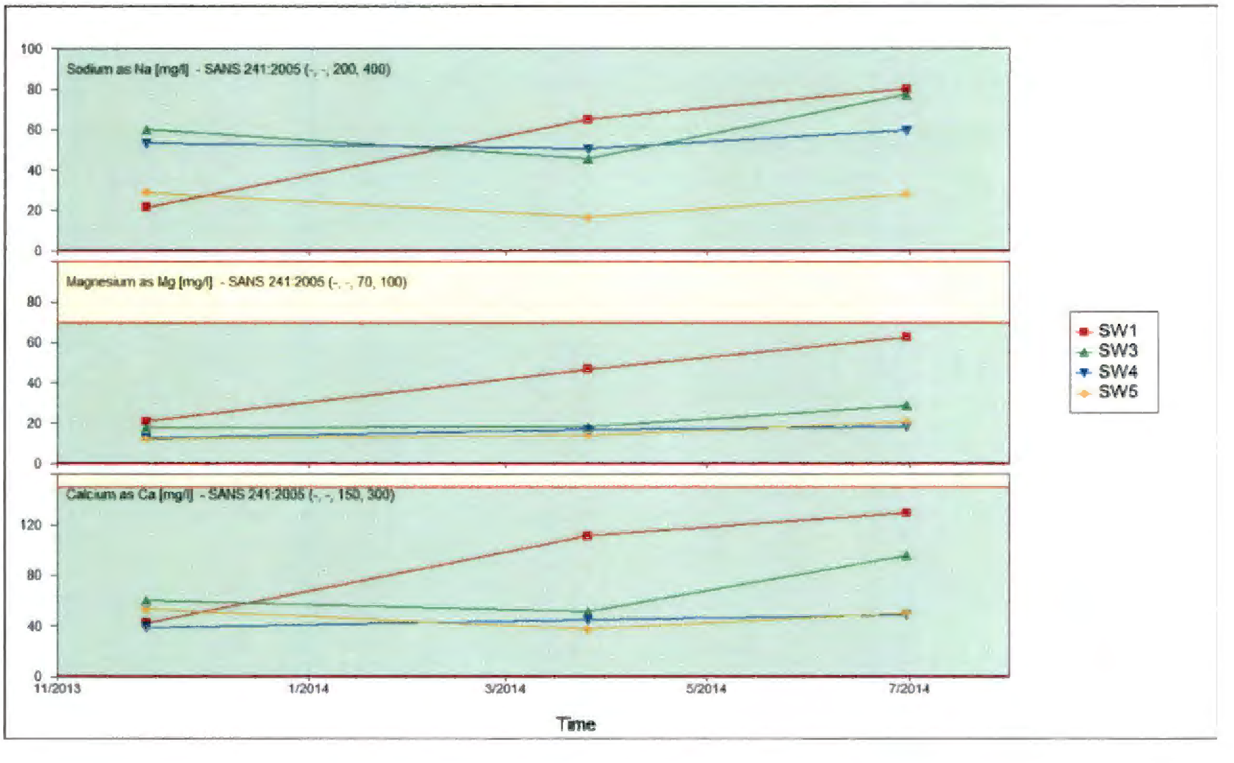


Figure 36: Major cations for Rietspruit

It is evident from the figures above that all the results for both anions and cations fall within acceptable limits, except for sulphate at SW1 situated in the Rietspruit.

Piper and expanded Durov diagrams are used to display hydrochemical data in a meaningful way where data can be grouped in terms of chemical composition and trends can be identified (Kovalevsky et al., 2004). The hydrochemical data collected for this study is presented in Figure 37 and Figure 38. These diagrams are not the focus of this study and therefore a detailed clarification of these diagrams is presented in Appendix 8.3

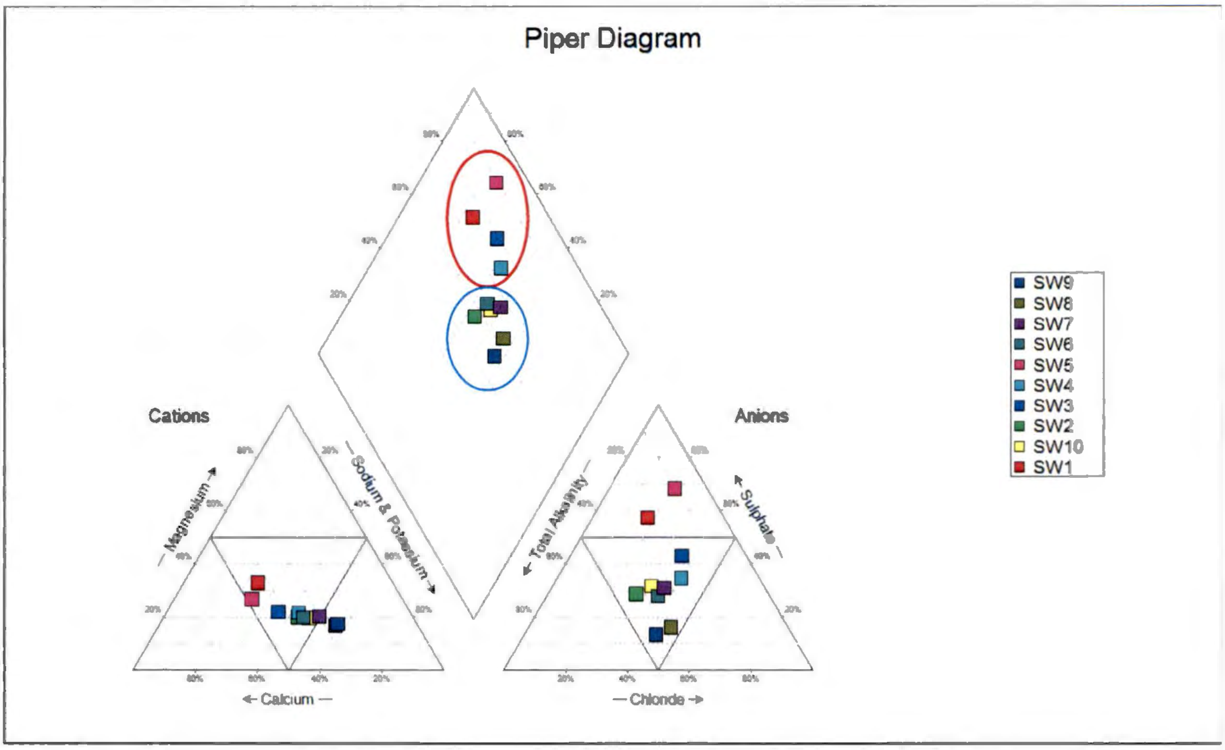


Figure 37: Piper diagram for the study area

In the piper diagram, the four samples from the Rietspruit (indicated by red circle) plot in the calcium-sulphate dominant part of the diamond diagram. This indicates that these points are impacted by mine drainage. The samples from the Blesbokspruit (indicated by blue circle) still show high calcium, but with higher chloride and bicarbonate and less sulphate compared to the other samples.

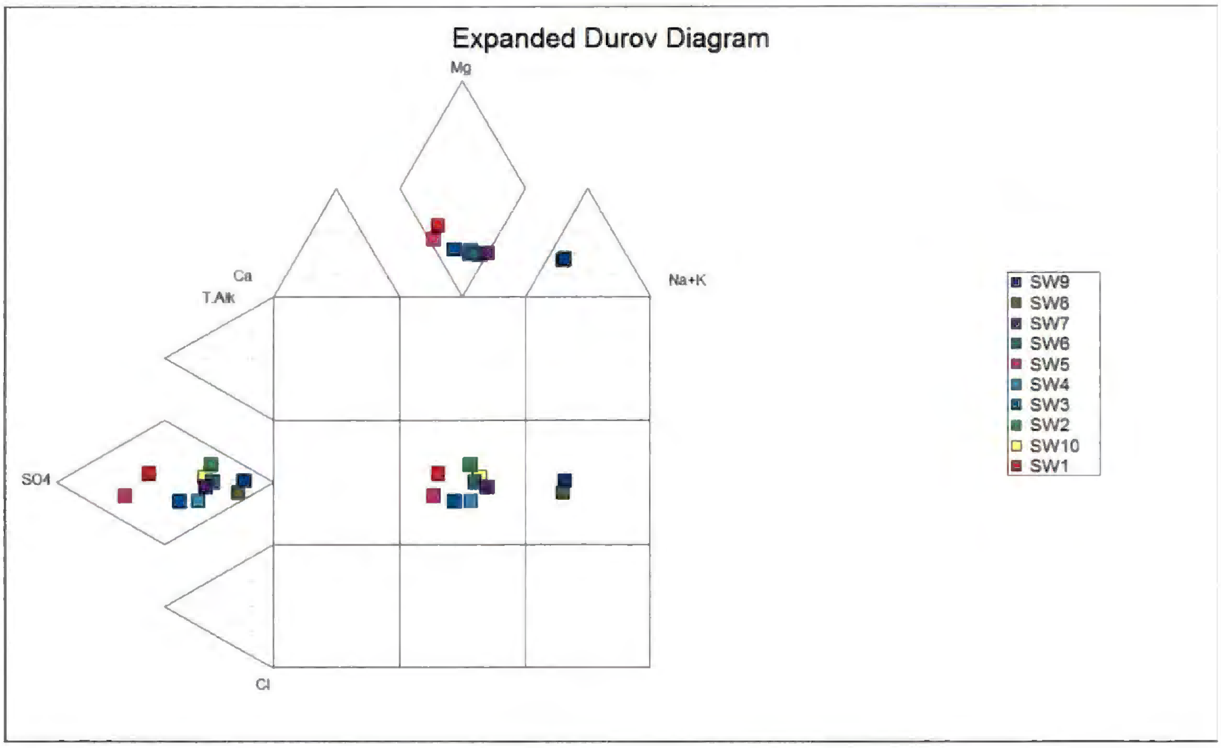


Figure 38: Expanded Durov diagram for the study area

Both the Blesbokspruit and Rietspruit indicates a water character associated with that of the coal and gold mining industry. A detailed water quality analysis is presented in Appendix 8.4

4.5.2 Determination of groundwater contribution

This study is only focused on the development of a surface water model. Groundwater contribution was therefore not specifically included in this model as it will be integrated with an existing comprehensive groundwater model that was developed separately.

To support calibration, it was necessary to determine whether the groundwater system of the study area was contributing to the river system or not. To get a good representation of the groundwater contribution over the whole river system of the study area, four sites were identified which stretched over the entire study area (Figure 39). More sites were identified initially, however, only these four sites were found to be suitable for the methodology that was followed.

At each site, three holes were drilled in close proximity to the river by means of a hand auger. Each hole was drilled to a depth of two meters and the level of the water table was measured. From these measurements the groundwater gradient could be determined which indicated whether the river was a loosing of gaining stream.

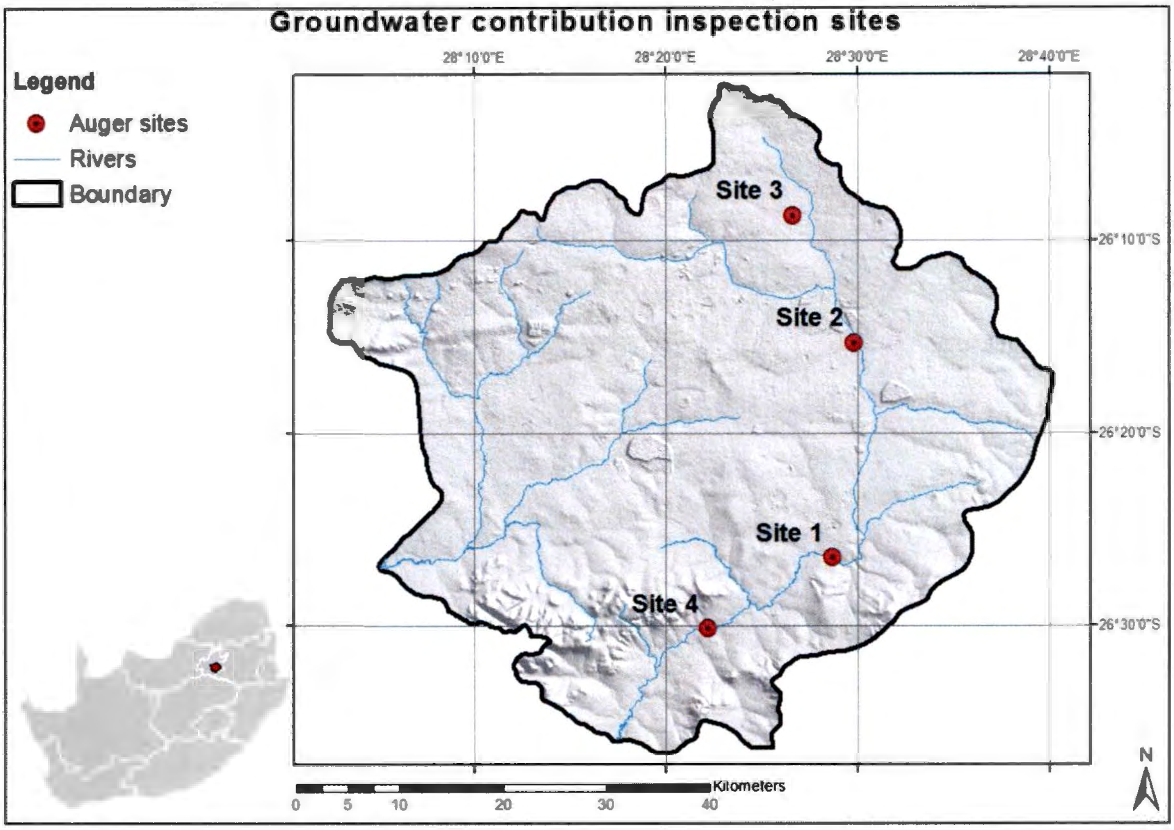
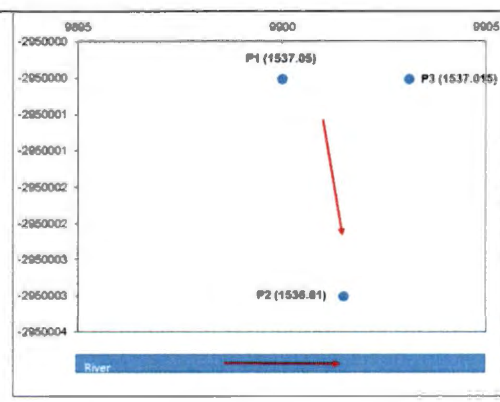
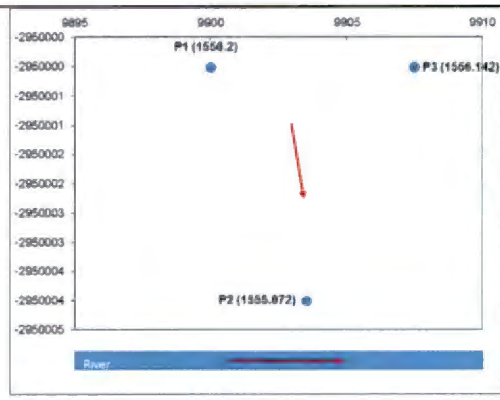
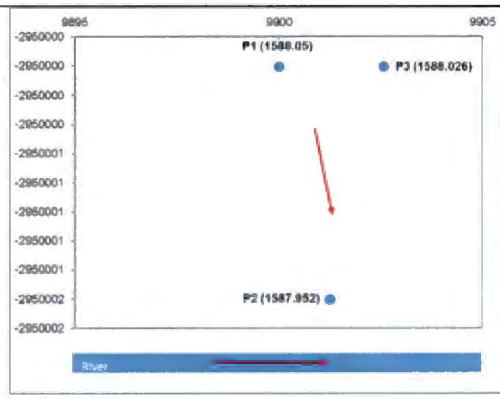
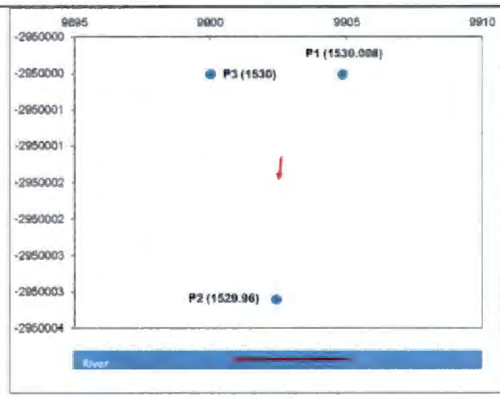


Figure 39 Groundwater contribution inspection sites

In all four cases it was found that the river was a gaining stream. A slug test was done at each site to determine the hydraulic conductivity. With the river being a gaining stream, hydraulic conductivity was subsequently used to determine the discharge from the shallow groundwater system to the river system (Table 13). These sites were homogenous in nature on both sides of the river in terms of slope, vegetation and ground type. It was therefore assumed for this study, that discharge would be the same on both sides of the river.

Table 13: Groundwater contribution

Site 1		
Hydraulic conductivity (m/d)	6.01	
Gradient	0.1	
Length (m)	1	
Discharge (m³/d)	1.17	

Site 2		
Hydraulic conductivity (m/d)	5.57	
Gradient	0.03	
Length (m)	1	
Discharge (m³/d)	0.34	
Site 3		
Hydraulic conductivity (m/d)	6.09	
Gradient	0.04	
Length (m)	1	
Discharge (m³/d)	0.48	
Site 4		
Hydraulic conductivity (m/d)	5.83	
Gradient	0.01	
Length (m)	1	
Discharge (m³/d)	0.14	

4.6 Conclusion

Successfully setting up a surface water model that would accurately simulate reality, required various data sources to be consulted. In areas where required data could not be obtained from existing sources, field measurements were taken. This included cross-sectional measurements as well as water quality sampling. All data collected were organised into a manageable database for analysis. On analysing the data, it was found that large portions of the data were incomplete, which rendered it useless. This was especially true for both rainfall- and flow gauging station data, where many gaps were present in the historic records. Although this presented a challenge, enough useful data were obtained and reworked in such a way to be introduced into SWMM for modelling purposes.

5 MODELLING

5.1 INTRODUCTION

As described in Chapter 2, a review of all available models was done, however the following key requirements also played a decisive role in finding an appropriate model to use for this study:

- Data requirements – In this study a limited amount of data were available and a model had to be chosen that could utilise as much of the available data as possible in order to achieve the most accurate outputs possible.
- Open source or public domain models – These were favoured due to budget constraints.
- Technical support – It was imperative to find a model with sufficient technical support or documentation in order to assist in the event that problems with the model and modelling process arise.

Following a systematic approach of reviewing all the available models from various sources and taking into account all the key features needed for this study, SWMM was selected as the preferred model to be used.

SWMM is a dynamic rainfall-runoff model which was developed in 1971 by the Environmental Protection Agency (EPA) as a more complex follow-up version of the SWM model (Cervantes, 2004; Rossman, 2010). It is mostly used to model single event or continuous runoff in terms of water quantity and quality in urban areas, although Nakamura and Villagra (2009) has shown that SWMM can be utilised successfully in non-urban areas (Rossman, 2010).

Since its development, SWMM has been constantly updated and improved, leading to it becoming one of the most widely used models. The reason for this is that the programme structure is developed to be simplistic while still being able to solve complex problems. This is achieved by allowing the user to modify the model in such a way to select only the necessary computing processes (Jones, 1997; Cervantes, 2004). SWMM was primarily chosen for its hydrological and water quality modelling capabilities.

SWMM has extensive data requirements, however, it also has the capability to provide reasonable outputs with limited data. Table 14 provides an overview of the SWMM data requirements (Jones, 1997).

Table 14: Overview of data requirements for SWMM

Data Type	**Data required**
Basic characteristics	Area, slope percentage impervious area, infiltration capacity, Manning's n
Inlet characteristics	Elevations, locations
Rainfall characteristics	Rainfall history in daily time step
Pollution sources	Constituents, concentrations, treatment devices

5.2 MODEL CONFIGURATION

5.2.1 Data processing

SWMM has four main hydrologic/hydraulic processes, namely: precipitation, rainfall losses, runoff transformation and flow routing (Li et al., 2014). An important parameter, that has an influence on all four of these processes, is the drainage area. As already mentioned, the study area is split into two main drainage regions with the Rietspruit on the western side of the study area and the Blesbokspruit on the eastern side (Figure 40). Both these rivers drain in a southerly direction towards the Vaal River. Based on the location of the two selected flow-gauging stations, it was decided that these would be assigned as the respective outlets for the two drainage systems in the surface water model.

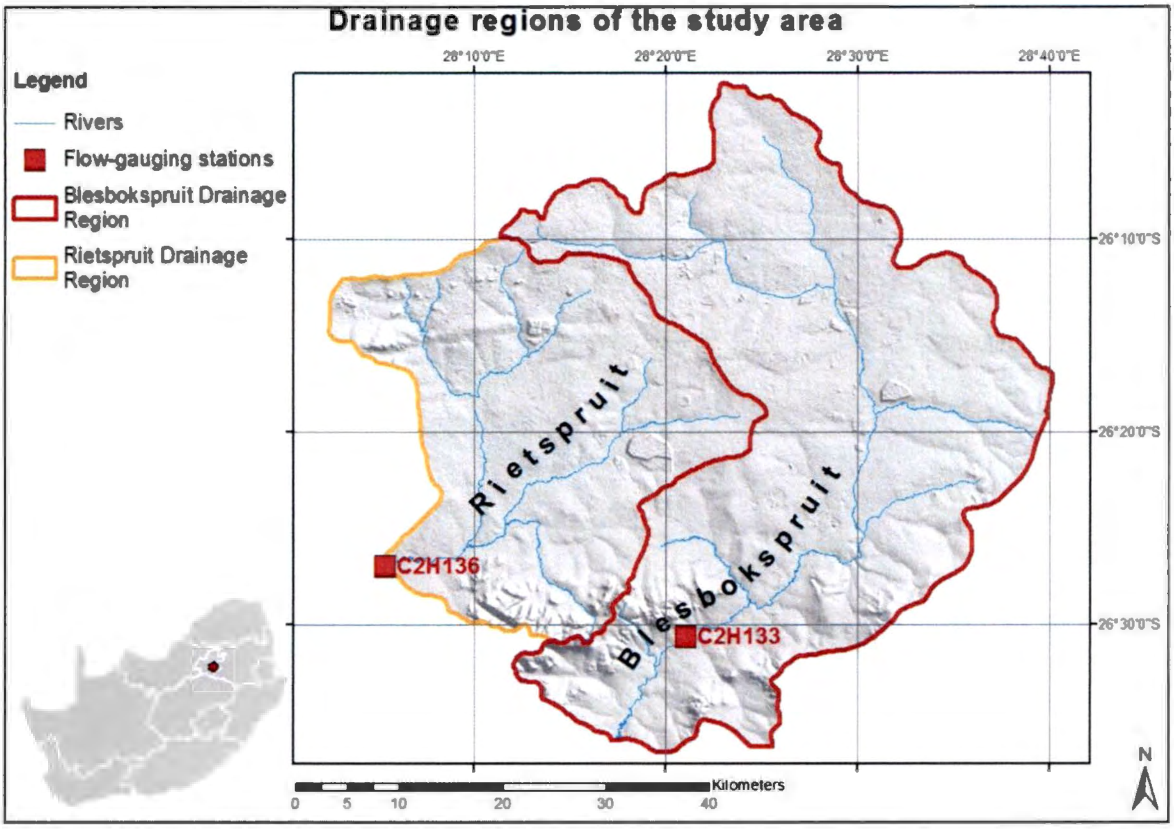


Figure 40: Drainage regions of the study area

A drainage area was determined by delineating the catchment of the study area. This surface water model will be integrated with other models and for compatibility purposes, the DEM and subsequent catchment delineation for this model had to be aligned with the existing catchment delineation of the other models.

According to Rossman (2010) "SWMM conceptualizes a drainage system as a series of water and material flows between several major environmental compartments". SWMM allows for the entire catchment that will be modelled to be sub-divided into smaller catchments. The reason for this is to provide areas that are more homogeneous in character which makes for less assumptions to be made and therefore leads to a more accurate model. For this study these smaller catchments will be referred to as Hydrological Response Units (HRUs).

Figure 41 indicates that the study area was sub-divided into 60 HRUs. The HRU areas ranged from 1.4km² to 122km². The two flow-gauging stations, situated in HRU 48 and HRU 56 respectively, are the only measureable outlets of the drainage system. HRU 57 to 60, situated downstream of the outlets, would therefore no longer form part of the study area.

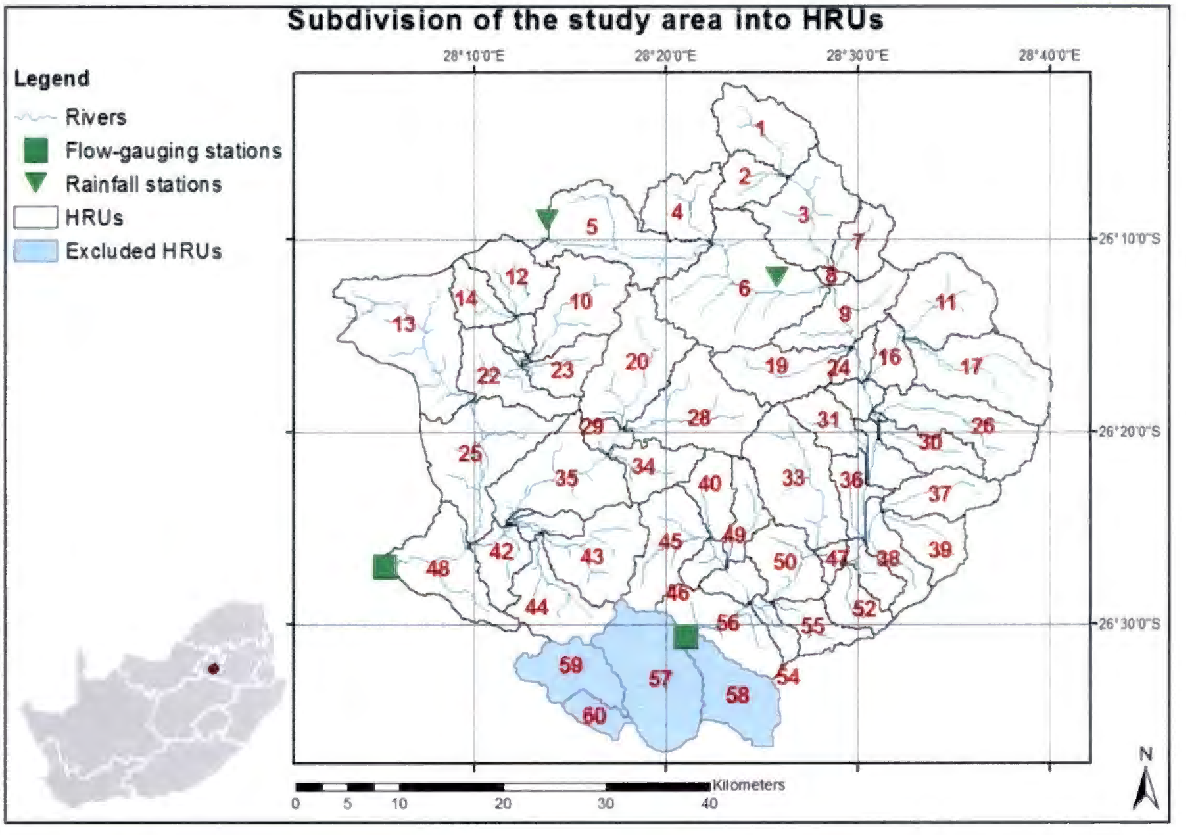


Figure 41: Subdivision of the study area into HRUs

Based on the subdivided catchments, data were extracted by means of GIS and apportioned to each HRU. Table 15 contains a summary of the data that were compiled for each HRU.

Table 15: Summary of data assigned to each HRU

HRU	Area (km^2)	Slope (%)	Imperviousness (%)	Flow Path Length (m)	SCS Soil	Curve Number
HRU1	48.1	0.68	4	6230	C	82
HRU2	24.2	0.81	1.3	2980	C	80
HRU3	63.1	0.64	1.5	10890	C	83
HRU4	36.1	0.95	2.1	4560	C	86
HRU5	76.2	0.92	23	12560	C	83
HRU6	122	0.88	8.8	13990	C	83
HRU7	26.5	0.79	0.3	4150	C	80
HRU8	3.7	0.69	0	1641	C	84
HRU9	47.9	0.9	6.7	6780	C	84
HRU10	57.7	1.08	21.5	8620	B	76
HRU11	58.1	0.68	0.1	4990	C	83
HRU12	35.3	1.31	12.8	3030	B	76
HRU13	100.5	1.64	27.7	11980	B	74
HRU14	22.5	1.25	40.4	3200	B	77

HRU	Area (km^2)	Slope (%)	Imperviousness (%)	Flow Path Length (m)	SCS Soil	Curve Number
HRU16	19.9	0.84	0.4	5470	C	81
HRU17	70	0.67	0.3	9070	C	79
HRU18	12.1	0.61	0.8	3500	C	85
HRU19	45.8	0.83	11.7	7130	C	84
HRU20	72.6	0.8	4.5	8400	C	81
HRU21	1.7	0.77	52.3	1266	B/C	81
HRU22	42.7	0.91	25.4	6380	C	84
HRU23	25.7	0.72	1.3	3440	C	83
HRU24	12.3	0.95	2.4	3180	C	86
HRU25	85.1	0.65	5.8	15100	C	85
HRU26	61.2	0.83	0	9050	C	80
HRU27	1.5	0.37	0	2840	C/D	89
HRU28	71.5	0.96	3	8010	C	83
HRU29	10.9	1.08	0	2900	C	81
HRU30	26.1	0.74	0	4390	C	79
HRU31	26.8	0.8	3	5960	C	83
HRU32	17.3	0.56	0	4570	C	84
HRU33	74.7	0.82	4.7	10450	C	81
HRU34	29.3	1.11	0	3600	B/C	82
HRU35	73.3	0.72	0.5	12270	C	81
HRU36	21.5	0.4	3	5610	C/D	88
HRU37	35.1	0.96	0	4370	C	78
HRU38	26.4	1.19	0.4	3480	C	79
HRU39	29.9	1.04	0	4290	C	78
HRU40	25.8	0.96	0.8	3750	C	82
HRU41	12.6	0.79	0.2	3690	C	82
HRU42	28.1	1.91	0.2	4500	C/D	82
HRU43	57.4	1.38	0	5540	B/C	74
HRU44	47.6	3.55	0	7420	C/D	79
HRU45	51.1	1.21	0.1	3390	B/C	73
HRU46	11.7	1.17	0	3300	B/C	72
HRU47	16.8	1.76	1	3010	C	78
HRU48	59.7	1.74	1.4	9270	C	80
HRU49	22.8	0.97	0.5	5490	C	81
HRU50	38.3	1.06	2.4	6430	C	79
HRU51	7.2	1.21	2.3	2990	C	79
HRU52	22.7	1.88	0	2730	C	77
HRU53	16	1.57	0	4200	C	77
HRU54	11.7	1.29	1.8	2300	C	77
HRU55	23.8	1.48	0	3760	C	78
HRU56	49.6	2.03	2.6	7180	C	78

5.2.1.1 Slope

The slope for each HRU was calculated by utilising the slope tool from the spatial analyst toolbox in ArcGIS. This tool measures the rate at which the z-value changes over the course of each catchment. The output is in percentage slope where 0% indicates a flat surface and 100% indicates a 45 degree slope. Slope values in Table 15 indicates that the study area is relatively flat.

5.2.1.2 Imperviousness

Imperviousness was derived from the urban built up class of the 2009 Land Cover data (SANBI, 2009) and expressed as a percentage of the area of each HRU. The land cover data were also cross-referenced by means of a visual inspection. Aerial images were used to digitise all the impervious regions of a particular HRU and the area was determined as a percentage of the total area. An assumption was made that 60% of these regions are totally impervious. Results obtained correlated almost 100% with the land cover data.

5.2.1.3 Flow path length

The flow path length for each HRU was determined by measuring the distance from the hydrological most distant point in the drainage network of a particular HRU to the outlet thereof.

5.2.1.4 SCS soils

SCS hydrological soils of the study area were extracted from existing data using GIS (Figure 11). For this study, it was decided that the most dominant hydrological soil group in each HRU would represent the entire HRU (Table 15).

5.2.1.5 Land Cover

Land cover data with seven classes were used for the study area (Figure 18). With the study area being sub-divided, land cover had to be determined for each HRU. Each land cover class was extracted by means of GIS and expressed as a percentage of the total area (Appendix 8.5).

5.2.1.6 Curve Number

Based on the hydrological soil group and land cover, a curve number (CN) was assigned to each land cover class in each HRU (Appendix 8.6). As each land cover class is represented as a percentage of the total area of a specific HRU, the CN value assigned would also only represent the percentage of that specific land cover class. The final CN value was therefore assigned to each HRU based on a weighted average (Appendix 8.5).

5.2.2 Setting up the model

SWMM provides a graphical user interface (GUI) where a hydrological network can be built as a representation of reality. It has a vast assortment of features that can be added to this network which are typically found in a storm water set up, such as weirs, pipes, pumps etc. However, runoff in the ERB is mostly diverted to streams, therefore the model for this study only consists of the following features:

- Rainfall stations
- Sub-catchments
- Junctions
- Conduits
- Outfalls

For ease of reference, a background map of the ERB was imported into SWMM before the hydrological network was built. The 56 HRUs, as determined by GIS, was drawn in the SWMM GUI. Note that SWMM refers to HRUs as sub-catchments (denoted by S). The two available rainfall stations as well as the two flow-gauging stations were also added. The flow-gauging stations were assigned as outfalls for the system. Each HRU reports to a junction node (denoted by J). Junction nodes in turn, are connected to each other by conduits (denoted by C) which in this case represents streams and are added to the network in hierarchal order from upstream to downstream, with the last junction being connected to the outfall node. Figure 42 shows a screenshot from the SWMM program of the fully set up hydrological network of the ERB.

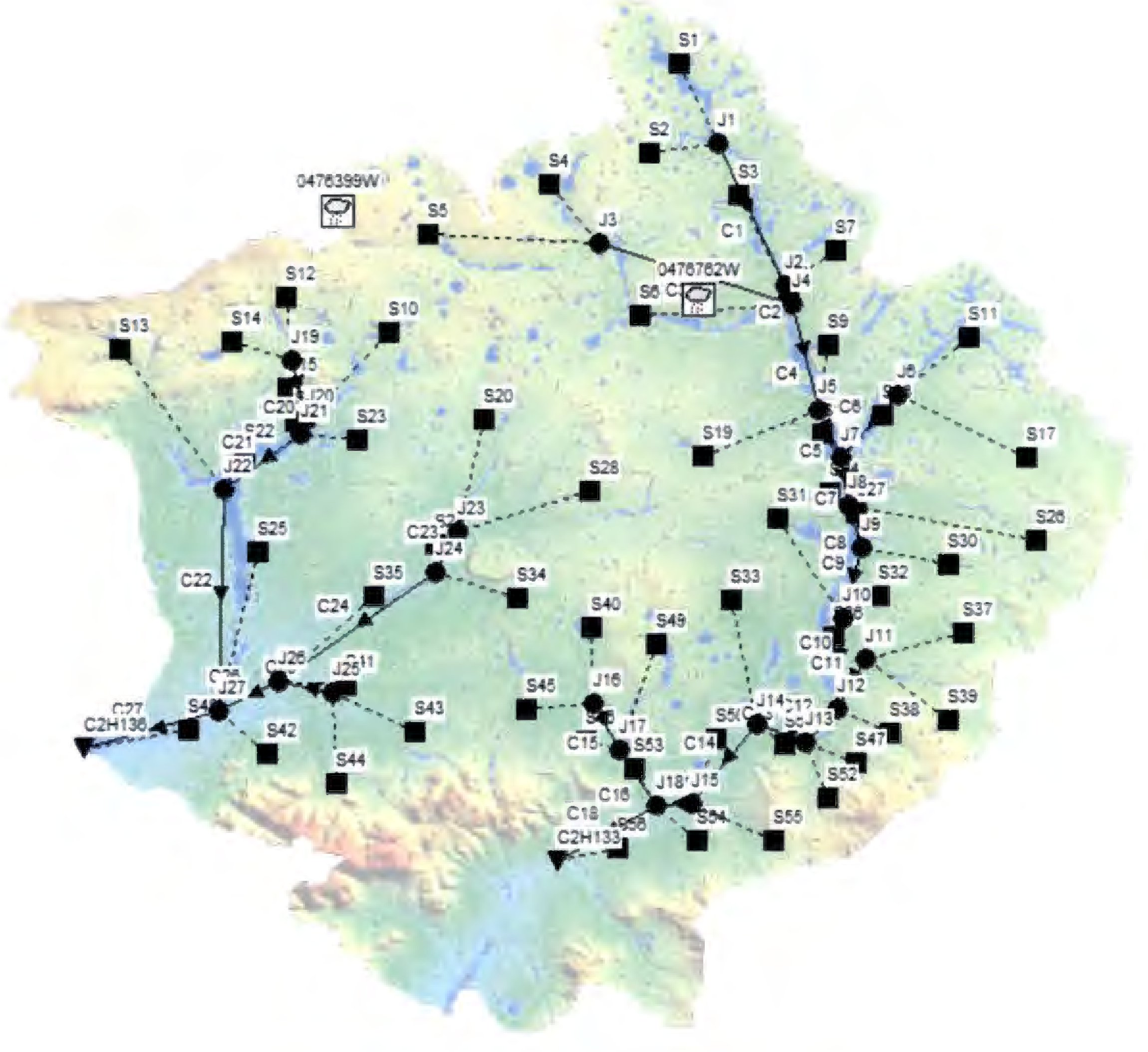


Figure 42: The SWMM ERB hydrological network

Once the hydrological network has been set up, data for each feature had to be entered into the system.

5.2.2.1 Rainfall stations

Data are added to each rainfall station by means of a pop-up window. Within this window, the rain format, time interval, rain units and coordinates are indicated (Table 16).

Table 16: Data required for each rainfall station

Data required	Description
Name	User-assigned name
X-coordinate	X coordinate of sub-catchment centroid
Y-coordinate	Y coordinate of sub-catchment centroid
Rain format	Type of rainfall data recorded
Rain units	Units of rainfall data
Time interval	Data recording time interval
Data source	Source of rainfall data

A file is also attached to each rainfall station which contains rainfall data for that specific station over a certain time period. The data is entered in a specific format (Table 17).

Table 17: Example of the SWMM format required for rainfall data

Name	Year	Month	Day	Rainfall (mm)
0476399W	2004	07	04	14.5

5.2.2.2 *Sub-catchments*

To define sub-catchment characteristics, each HRU receives various input data. Data are also added by means of a pop-up window in SWMM (Table 18).

Table 18: Data required for each sub-catchment

Data required	Description
Name	User-assigned name
X-coordinate	X coordinate of sub-catchment centroid
Y-coordinate	Y coordinate of sub-catchment centroid
Rainfall station	Assigned to sub-catchment
Outlet	Name of node that receives runoff
Area	Area of sub-catchment (ha)
Width	Width of overland flow path (m)
%-slope	Average surface slope (%)
%-impervious	Percent of impervious area (%)
N-impervious	Mannings n for impervious area
N-pervious	Mannings n for pervious area
Infiltration	Infiltration parameters

As shown in the previous chapters, most of the data used for input into the sub-catchments of the SWMM model were extracted from GIS. This includes the area of each HRU, % slope, % imperviousness and width, which is simply a ratio relating to the longest flow path and the area of the HRU. SWMM provides for infiltration to be determined by one of three methods:

- Horton equation
- SCS curve number or
- Green-Ampt method

The SCS curve number method was chosen for this project given the fact that land cover data and hydrological soil group data were readily available and the subsequent CN value, as derived from these data sets, could be apportioned to each HRU. Therefore the CN value was used as input parameter to SWMM in order to determine the infiltration rate for each HRU.

A rainfall station with its particular rainfall data were also assigned to each HRU. SWMM allows for the allocation of only one rainfall station per HRU. An important factor to take into account here is the spatial variability of the available rainfall data, as it can have a direct impact on catchment response, which will ultimately determine the accuracy of the model.

Various methods exist to ensure accurate spatial distribution of rainfall data. A study by Ly et al. (2012) found that the Thiessen polygon method was one of the most frequently used deterministic methods for rainfall distribution in hydrological modelling. Rainfall distribution for the ERB was subsequently defined by means of the Thiessen polygon method (Li & Heap, 2008).

By using this method the study area was split into two rainfall distribution regions based on the locality of the two rainfall stations (Figure 43). HRUs on the left side of the Thiessen polygon boundary were assigned to the 0476399W rainfall station and all the HRUs on the right side were assigned to the 0476762W rainfall station. These two rainfall distribution regions compares very well with the two drainage regions of the study area (Figure 40). By implication, one rainfall station is assigned to each drainage region, thereby ensuring that rainfall is distributed in the best possible way over the study area.

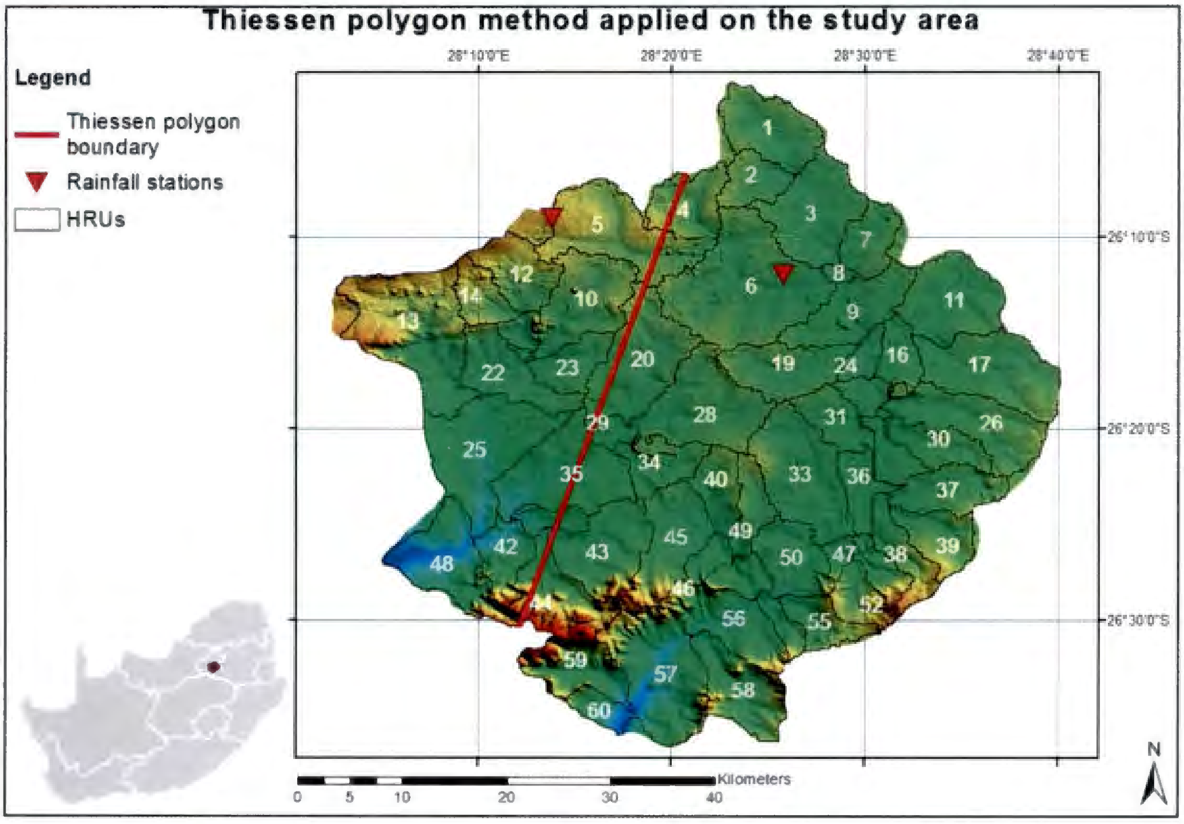


Figure 43: Illustration of the Thiessen polygon method applied on the study area

Other values required as inputs for the HRUs, such as Manning's n for overland flow and depression storage values, were sourced from the SWMM user manual appendices which provides guidelines in terms of values that can be used for generic areas (Rossman, 2010). As a result, smooth asphalt with a Manning's n value of 0.01 were chosen for impervious areas and for pervious areas light underbrush was chosen with a Manning's n value of 0.4. Typical values for Manning's n is available in Appendix 8.7.

5.2.2.3 Junctions

Junction nodes were only assigned with an elevation value at that specific node (Table 19). Elevations were derived from the DEM.

Table 19: Data required for each junction

Data Required	Description
Name	User-assigned name
X-coordinates	X coordinate of sub-catchment centroid
Y-coordinates	Y coordinate of sub-catchment centroid
Invert Elevation	Elevation of the junction's invert (m)

5.2.2.4 *Conduits*

Most of the conduit properties are derived from field measurements, such as cross-sections, and used as input data for that specific conduit within the hydrological network (Table 20).

Only 10 cross-sections were measured in the field over the entire study area for the three data measurement periods (Figure 28). The network that was set up in SWMM, however, has a total of 27 conduits. Thus, except for the length of each conduit, which could be derived from GIS, realistic channel characteristics could not be assigned to all the conduits.

The trapezoidal channel shape provided by SWMM, were assigned to those conduits without field measurements. This was based on the fact that the 10 cross-sections that were measured in the field, were all trapezoidal in shape.

Inlet and outlet nodes (in this case the junction nodes) were also defined for each conduit as this determines the direction of flow within the conduit based on the difference in elevation between the nodes.

Table 20: Data required for each conduit

Data required	**Description**
Name	User-assigned name
Inlet node	Node on the inlet end of conduit
Outlet node	Node on the outlet end of conduit
Shape	Conduit's cross section geometry
Max depth	Max depth of cross section (m)
Length	Conduit length (m)
Roughness	Manning's roughness coefficient

This surface water model accounts for channel roughness by means of Manning's n. The buffering of flow by wetlands in the study area was also accounted for by means of Manning's n. A lack of field data for the wetlands of the study area, in terms of velocity and hydraulic radius, made it difficult to determine the direct effects of these wetlands on the system. The procedure discussed in Chapter 2 was followed to determine the most appropriate value of Manning's n that would best translate the flow reduction induced by wetlands into the surface water model.

Base values of Manning's n for channels where wetlands were present were taken from Rossman (2010) and adjusted by using the correction procedure as prescribed by Cowen (1956). The final value of Manning's n, for the channels where wetlands are present, equated to a value of 4. This is a high value for Manning's n, but it is still within acceptable limits when compared to literature, where Manning's n ranges from 0.1 to 13.8 for the same vegetation type.

5.2.2.5 Outfalls

As with the junction nodes, the outfall nodes were also only assigned with an elevation value as derived from the DEM.

5.2.2.6 Climatological data

In terms of climatology, SWMM provides for five different factors to be added into the system:

- Temperature
- Evaporation
- Wind Speed
- Snow melt and
- Areal Depletion

The only climatological data that were available for this study was evaporation. The available data stretched over a 49 year period from 1935 to 1984. The data were converted to a monthly average in SWMM (Table 21).

Table 21: Evaporation data for the study area

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
3.4	3.1	2.6	2.1	2.0	1.7	1.9	2.6	3.6	3.8	3.6	3.6

5.2.2.7 Flow routing

SWMM provides three flow routing models to choose from by which flow is calculated, namely:

- Steady flow;
- Kinematic Wave; and
- Dynamic wave.

Steady flow is the most simplistic routing model, which operates on the assumption that flow is uniform and steady. The kinematic wave routing model on the other hand allows for variation of flow and area both in space and time. The Dynamic wave routing model is the most complex and accounts for effects like channel storage, backwater and flow reversal. (Rossman, 2011).

The initial setup of the surface water model is complete once all the required data have been analysed and added to SWMM for simulation runs. After simulations are run successfully, the model needs to be calibrated.

5.3 MODEL CALIBRATION

Based on the limited amount of data available in terms of hydrological factors, the dynamic wave routing model was not considered. Both the steady flow and kinematic wave routing models were initially used to determine the best suitable routing model and associated calibration results.

Flow-gauging station C2H133 is the outlet node of the Blesbokspruit and the historical data from this flow-gauging station is compared with the model output results for conduit 18 (C18), which is the very last conduit before the outlet node (Figure 42). In the same way, flow-gauging station C2H136 is the outlet node of the Rietspruit. Historical data from this flow-gauging station is therefore compared with the model output results for conduit 27 (C27), being the last conduit in the Rietspruit. The model was run from 01/07/2004 until 31/21/2009 and the resultant simulated flows were compared to the observed flow. Figure 44 and Figure 45 shows a comparison of the calibration data against simulated data for both routing models from the first simulation in daily time step interval without calibration having been performed.

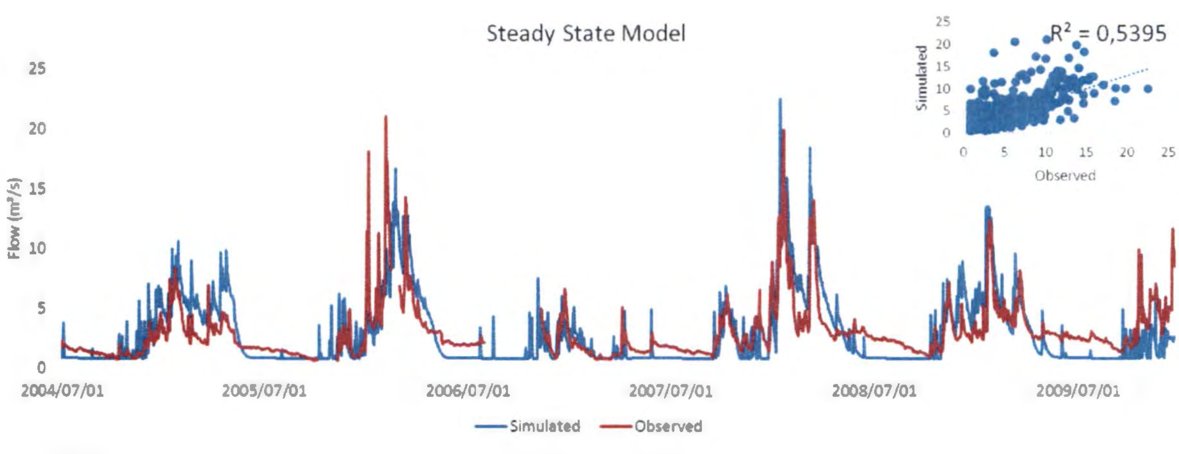


Figure 44: First simulation result of steady state routing model

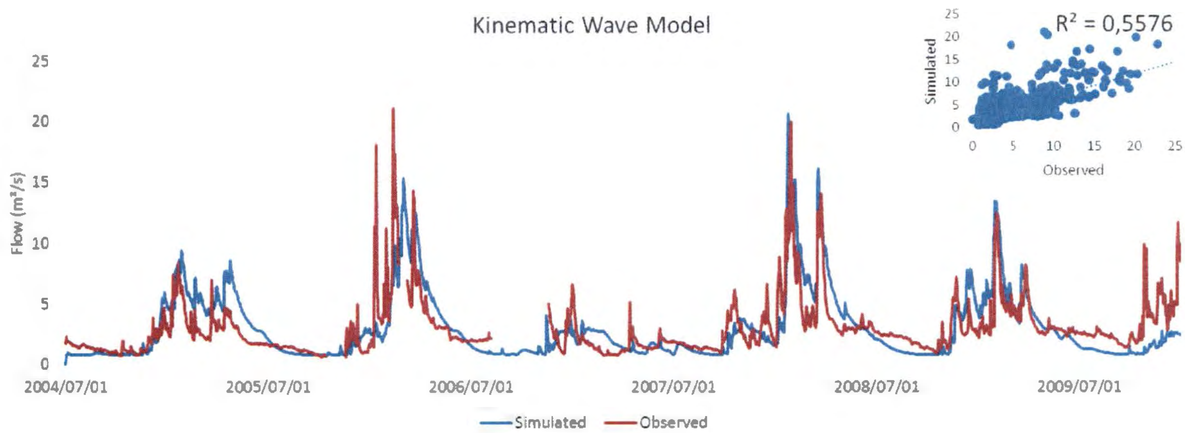


Figure 45: First simulation result of kinematic wave routing model

Statistical comparison of the simulated outputs of the two routing models does not show much variance in terms of correlation with observed values. The steady state model is only slightly sub-standard to that of the kinematic wave model, with R^2 values of 53% and 55% respectively.

A definite distinction between the two models can however be made where the steady state model hydrograph highlights that the simulated flow does not follow a natural progression. It displays a condition that can be described as "bottoming out", where the recession limbs are characterised by horizontal lines every time rainfall intensity subsides. This is especially true during dry periods, such as over the winter months. This can be ascribed to the fact that the steady state model does not allow flow in the conduits to fluctuate as rainfall intensity increases and decreases over time. The kinematic wave model on the other hand shows a more natural progression of flow, even during dry periods

Due to the better performance of the kinematic wave model, it was the only flow routing model that was studied further with the aim of establishing the best calibration for the model. Rainfall did not form part of the calibration process as it is the only parameter that introduces water into the system. Assuming the rainfall data are correct, the focus was only placed on calibration of discharge.

The model contains so many parameters and calculation functions that a rigorous calibration of the model is very difficult. According to Rauch et al. (2002), the "pragmatic solution" is that only a few key parameters which are labelled as being critical to the study need to be calibrated. To determine these key parameters, a sensitivity analysis was conducted.

5.4 SENSITIVITY ANALYSIS

A sensitivity analysis can be seen as one of the key steps to work through when setting up and calibrating a model, as it gives an indication of the model's performance by assessing the effect of input parameters on the model's outputs (Li et al., 2014). It entails a process whereby input parameter values are increased and decreased by a certain margin to see the response of the model in terms of the output generated. When a major response is seen, that specific parameter is sensitive to change and is therefore deemed to be a key parameter.

For this study, initial input parameters identified to be subjected to the sensitivity analysis, were based on the fact that there is a margin of subjectivity in the way that the parameter values were obtained. The parameters that were subjected to the sensitivity analysis, included:

- Evaporation (constant evaporation vs evaporation occurring only during dry periods);
- Manning's n for wetlands;
- Drying time of soils;
- CN value; and
- Width of HRU.

The values of these parameters were increased (High) and decreased (Low) by a margin of 10% and the results compared in terms of deviation from the average calculated flow. Results from the sensitivity analysis are shown in Figure 46. The CN values were found to be the most sensitive, with evaporation and Manning's n being less sensitive and HRU width and soil drying time even more so. Although the CN values are the most sensitive, its highest deviation from the average simulated flow is still only ~0.45 m^3/s. CN values were not adjusted to take the variation in the antecedent moisture condition of the catchment into consideration. This is allowed as a separate function in SWMM's simulation options.

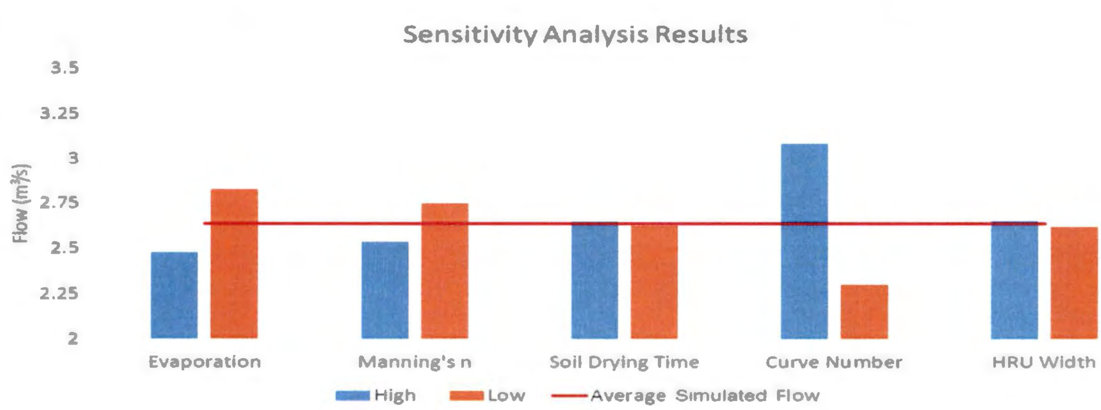


Figure 46: Sensitivity Analysis Results

5.5 MODEL RESULTS

5.5.1 Blesbokspruit

The final calibrated output for conduit 18 together with its correlation in terms of observed data are showcased in the following figures. The discrepancies seen in the calibration results between the observed flow and simulated flow can be the result of a number of different reasons, ranging from errors in field measurements to channel changes to instrument limitations.

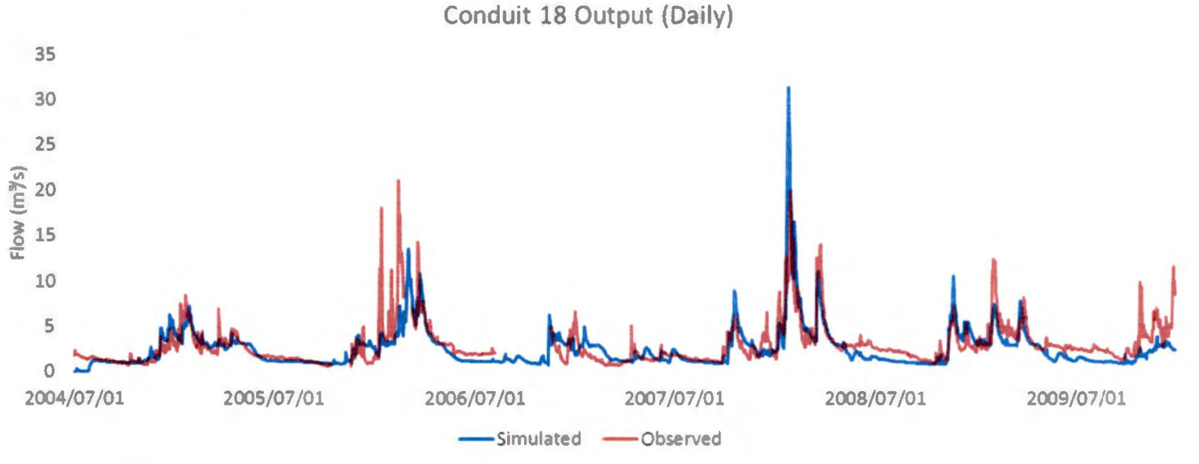


Figure 47: Output of conduit 18 expressed in daily time step

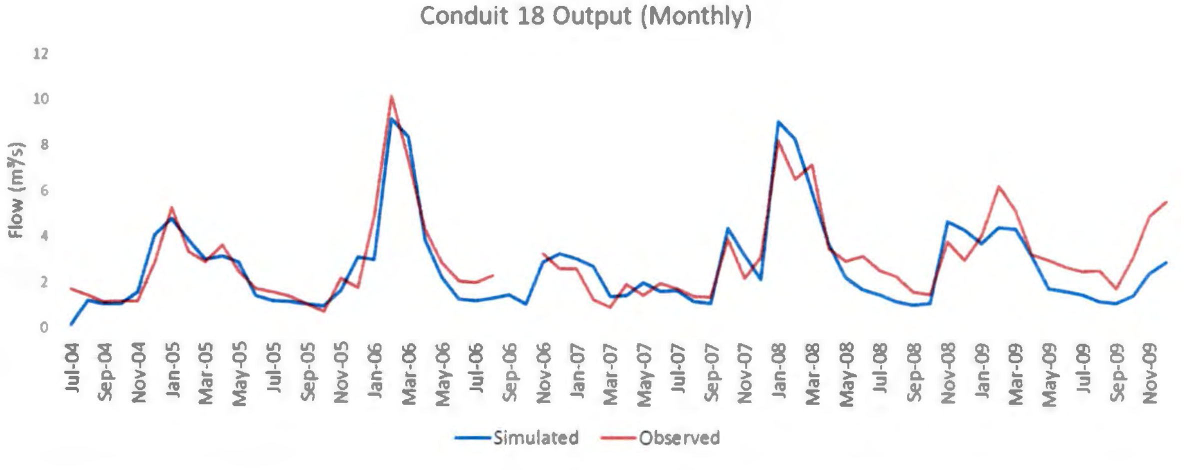


Figure 48: Output of conduit 18 expressed as average monthly flow

Goodness of fit statistics of average monthly flow (m³/s) for conduit 18 is displayed in Table 22 and the correlation between simulated and observed flows is shown in Figure 49.

Table 22: Goodness of fit statistics for conduit 18

	Simulated Flow (m^3/s)	Observed Flow (m^3/s)
Mean	2.69	3.04
Standard Deviation	1.96	1.89

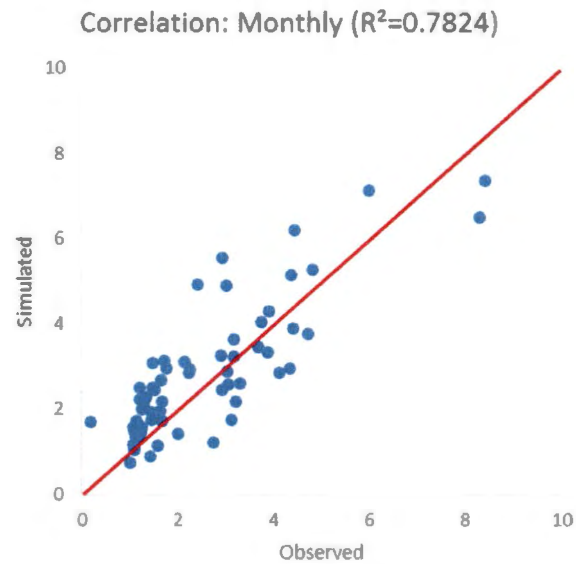


Figure 49: Correlation of average monthly flows for conduit 18

A good correlation of 78% was obtained. Figure 50 provides a good perspective in terms of comparing simulated flow with observed flow, in the form of a cumulative daily flow curve.

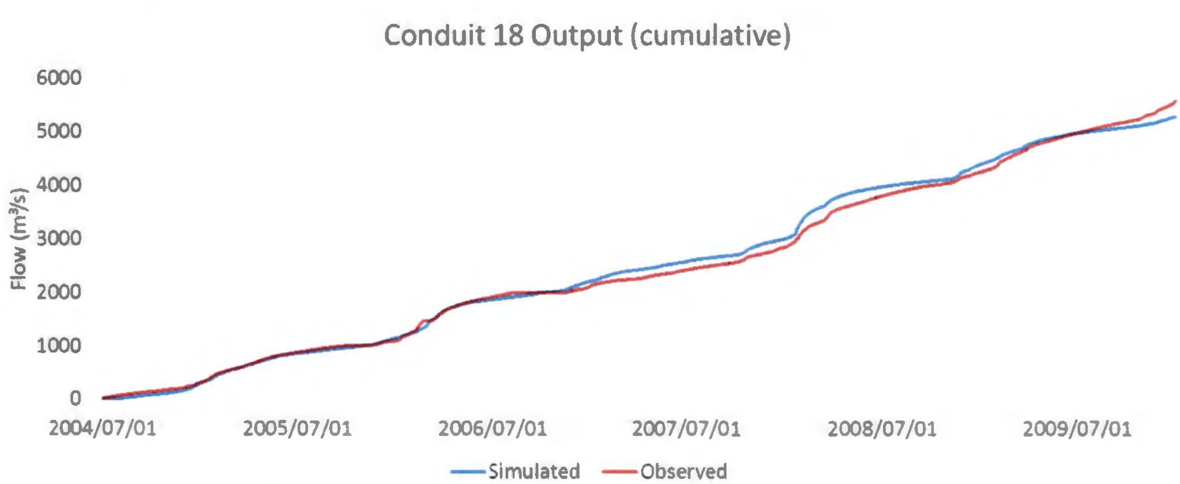


Figure 50: Output of conduit 18 expressed as cumulative daily flow

Figure 50 shows that the simulated output compares very well with the observed data.

A slight over prediction of the simulated data is seen from 2007 onwards. The deviation between the simulated and the observed output could be ascribed to a physical change (e.g. extractions from the river) that took place in the system for which data are not available and therefore not accounted for. In light of the limited amount of data, this is the best possible calibration that could be obtained.

5.5.2 Rietspruit

The final calibrated output for conduit 27 together with its correlation in terms of observed data are showcased in the following figures.

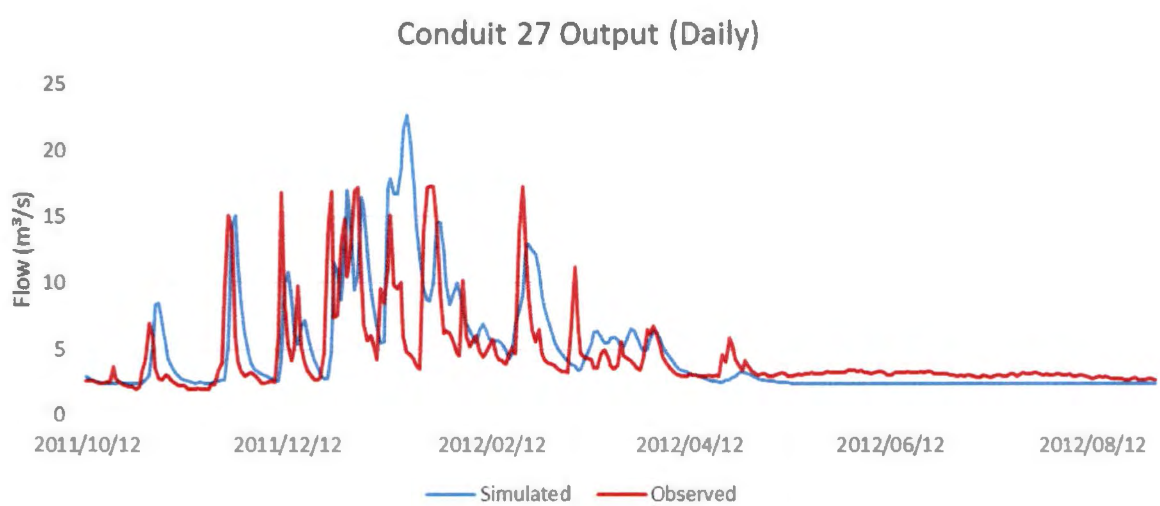


Figure 51: Output of conduit 27 expressed in daily time step

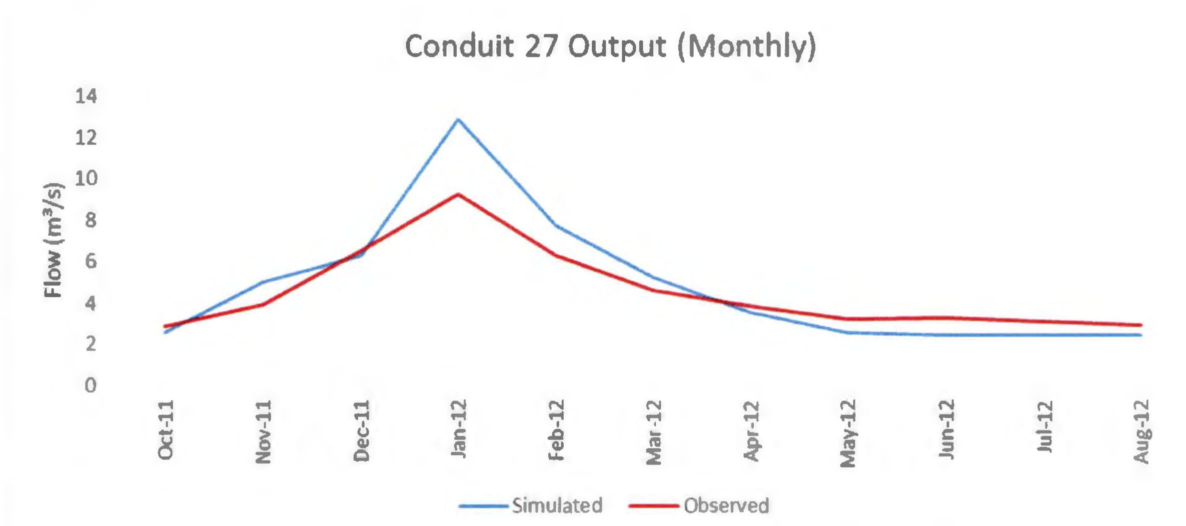


Figure 52: Output of conduit 27 expressed as average monthly flow

A discrepancy between simulated and observed flows can be seen in the peak flow of conduit 27. It is also evident from the resultant standard deviation values (Table 23). This can be attributed to a challenge that presented itself when calibrating conduit 27. The observed data readings are capped at 17.292m³/s as a result of the flow-gauging station being limited to maximum observed levels equal to 17.292m³/s. This means that any flows above this value were not recorded.

Table 23: Goodness of fit statistics for conduit 27

	Simulated Flow	Observed Flow
Mean	4.85	4.53
Standard Deviation	3.09	1.94

An attempt was made to extend the rating curve of the particular flow-gauging station (Figure 53) in order to adjust the observed flow data accordingly.

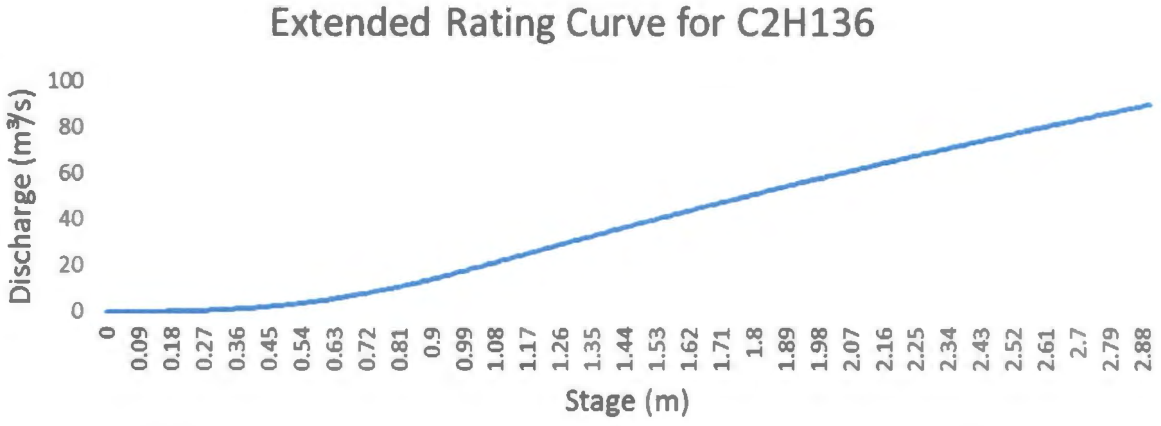


Figure 53: Extended rating curve for C2H136

A comparison was made between the stage and correspondent discharge from the extended rating curve, and the stage and discharge that was gathered from field measurements (Table 24). The results could not be correlated satisfactorily. The attempt to extend the rating curve was therefore not successful as it did not provide accurate readings when extended. The reason for this can be ascribed to a change in the cross-sectional profile or the flow rate may be altered as a result of overbank flow, which may also change roughness coefficients. None of this information was available.

Table 24: Discharge comparison between field measurements and rating curve

Stage (m)	Discharge obtained from field measurements (m^3/s)	Discharge obtained from extended rating curve (m^3/s)
1.44	25.1	36.8
1.65	31.9	44.8
1.83	30.3	52.3

In light of this situation, calibration was only focussed on low flows where simulated values could be referenced against the observed data. In spite of the peak flows, a very good correlation of 95% was still obtained in this way (Figure 54).

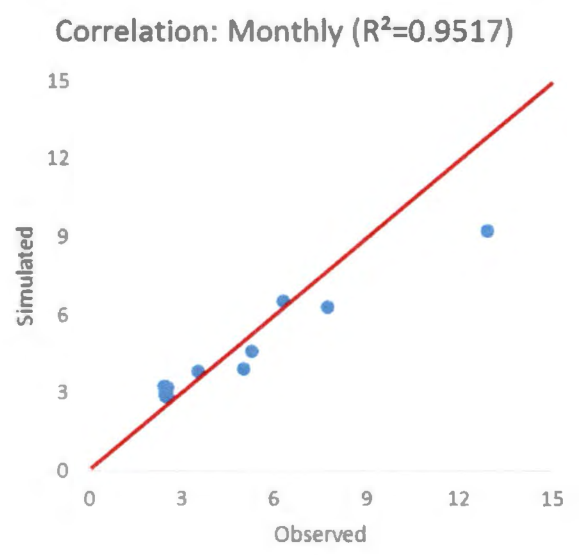


Figure 54: Correlation of average monthly flows for conduit 27

Figure 55 indicates the cumulative flow curve and its associated correlation for the Rietspruit. The same response is seen as was found with the cumulative flow in the Blesbokspruit. This can again be ascribed to a lack of data availability with regard to the status of the system.

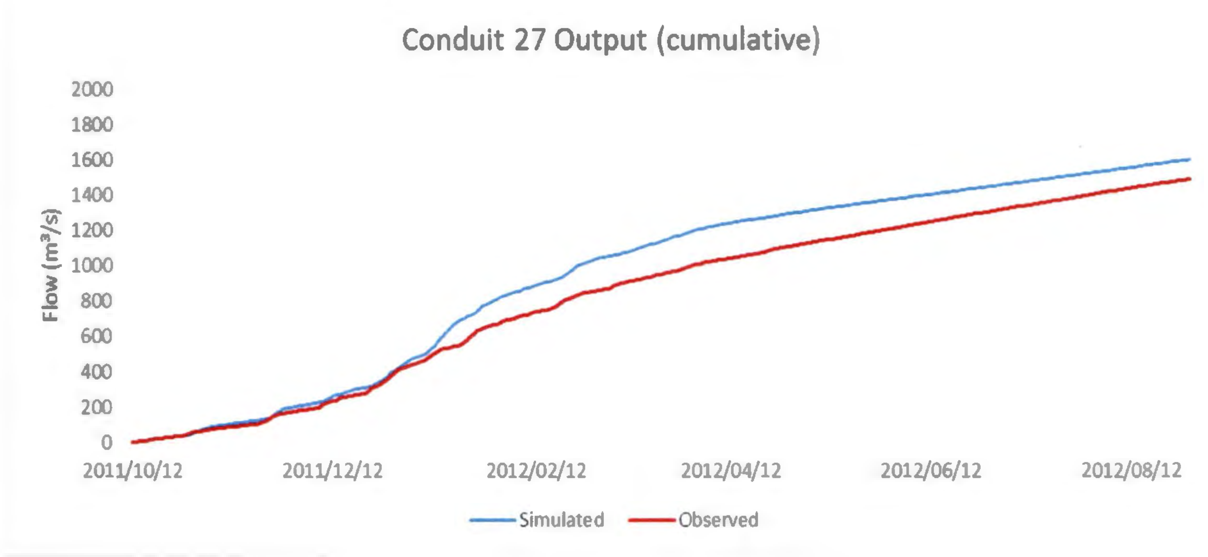


Figure 55: Output of conduit 27 expressed as cumulative daily flow

Final model parameters are available in Appendix 8.8.

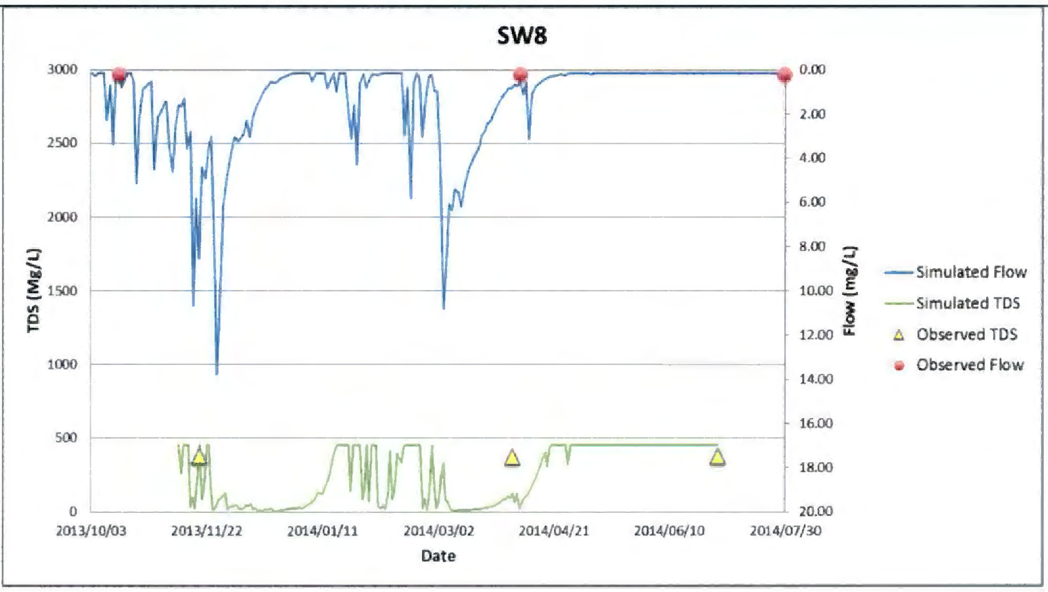
5.6 Model Validation

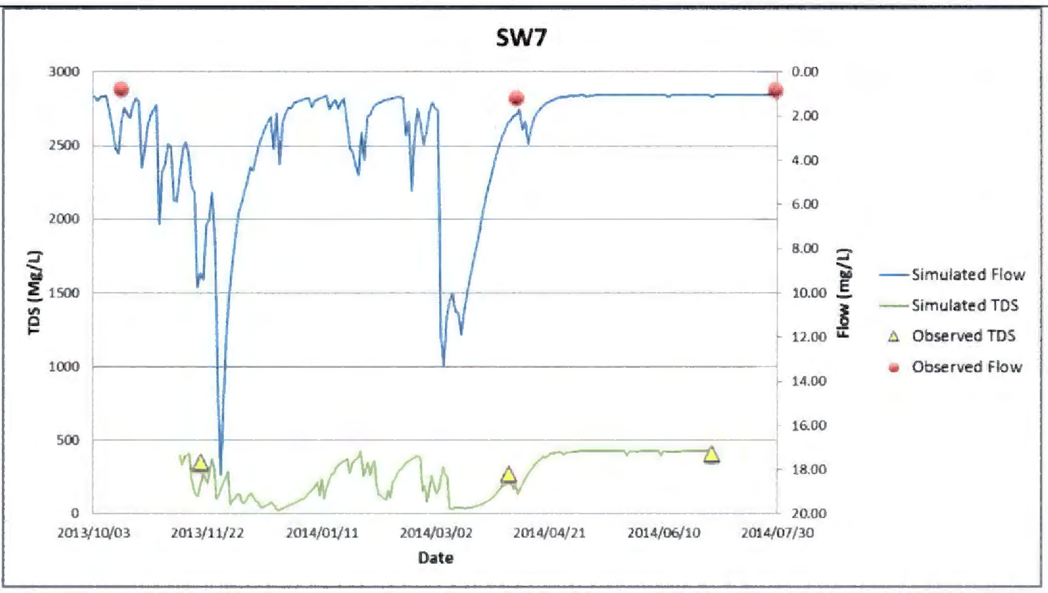
To test the performance of the calibrated model in terms of whether or not the model can make accurate predictions, the model is subjected to a validation process. To validate the model, field measurements for both the flow and TDS are plotted against simulated flow and simulated TDS as predicted by the model over the same time period.

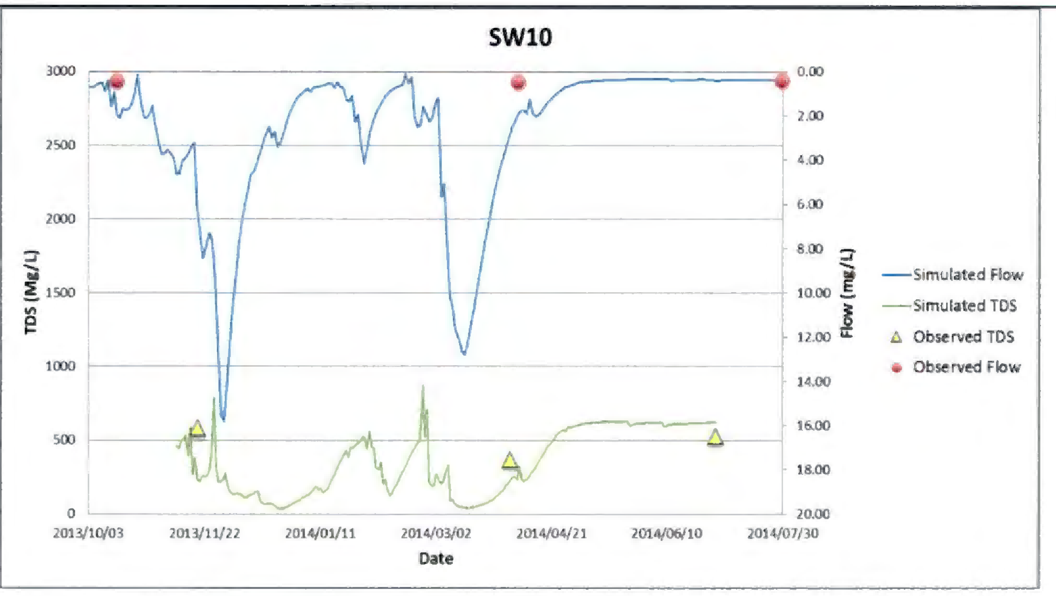
5.6.1 Blesbokspruit

Field measurements of five sites in the Blesbokspruit are included in the validation process, namely: SW2, SW6, SW7, SW8 and SW10 (Figure 28). Figure 25 shows the validation results of each site from upstream to downstream.

Table 25: Blesbokspruit validation results






SW10
TDS (Mg/L)
3000
2500
2000
1500
1000
500
0
Flow (mg/L)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
2013/10/03
2013/11/22
2014/01/11
2014/03/02
2014/04/21
2014/06/10
2014/07/30
Date
Simulated Flow
Simulated TDS
Observed TDS
Observed Flow


SW2
TDS (Mg/L)
3000
2500
2000
1500
1000
500
0
Flow (mg/L)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
2013/10/03
2013/11/22
2014/01/11
2014/03/02
2014/04/21
2014/06/10
2014/07/30
Date
Simulated Flow
Simulated TDS
Observed TDS
Observed Flow

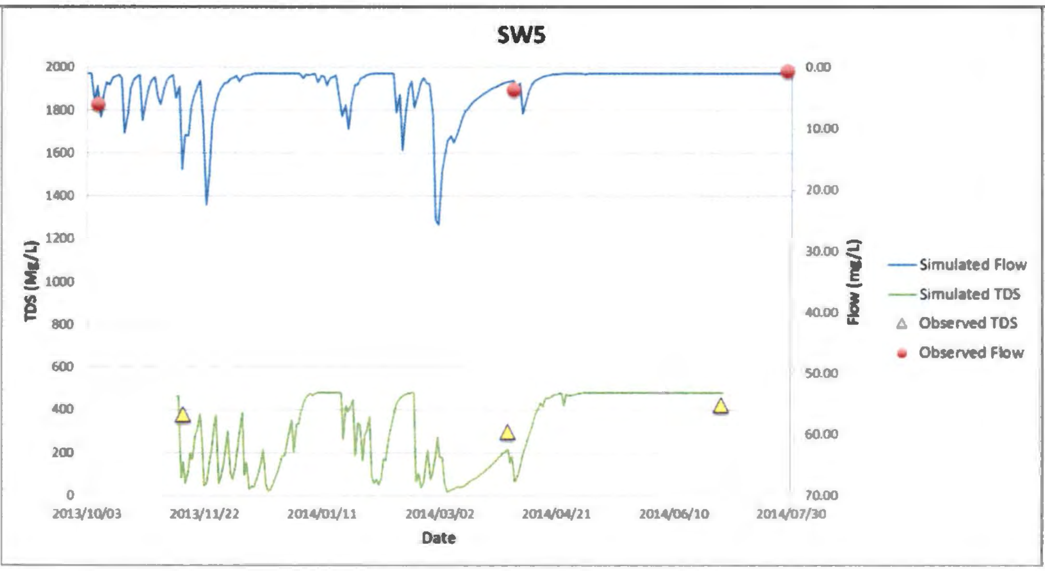

SW6
TDS (Mg/L)
3000
2500
2000
1500
1000
500
0
Flow (mg/L)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
2013/10/03
2013/11/22
2014/01/11
2014/03/02
2014/04/21
2014/06/10
2014/07/30
Date
Simulated Flow
Simulated TDS
Observed TDS
Observed Flow

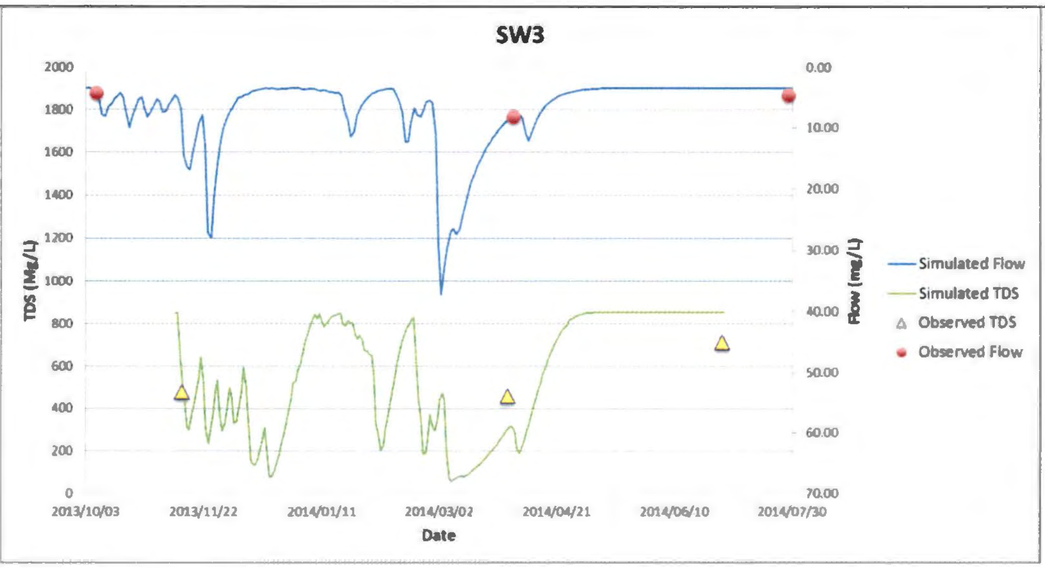
The observed flows and observed TDS from each site compares very well with the simulated values, although there is still a margin of error. Discrepancies in the simulated flows can be ascribed to errors in field measurements, as these were not done at formal weir structures. There may also be errors in calculated wetted perimeter as well as the resolution of the flow velocity meter. These errors in simulated flow will propagate to errors in the simulated TDS.

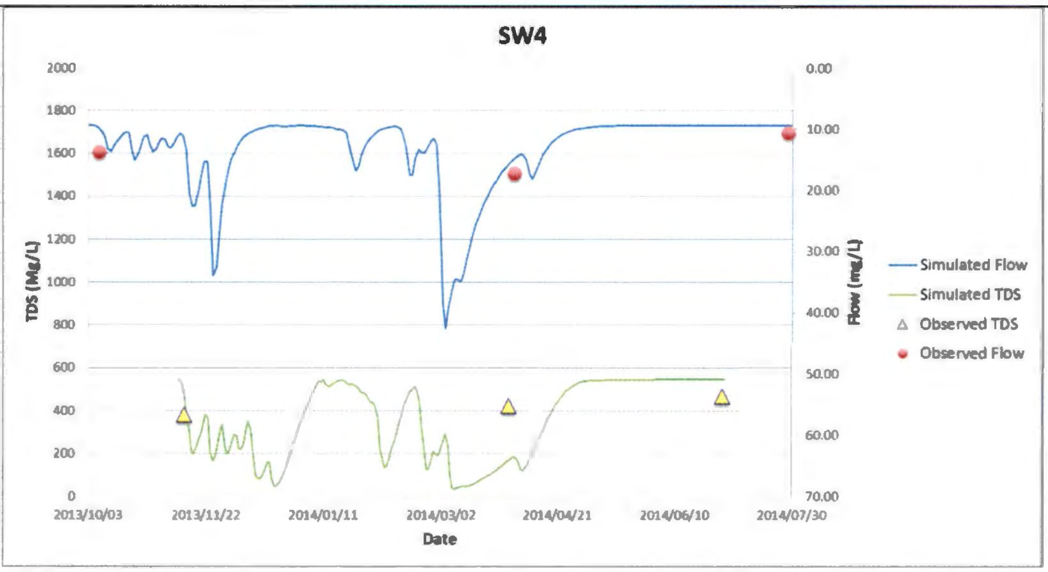
5.6.2 Rietspruit

Field measurements of three sites in the Rietspruit are included in the validation process, namely: SW3, SW4 and SW5 (Figure 28). Table 26 shows the validation results of each site from upstream to downstream.

Table 26: Rietspruit validation results







As was the case with the Blesbokspruit validation results, there are also discrepancies in the Rietspruit validation results. The same reasons that were adduced for discrepancies in the Blesbokspruit results above, can also be stated here for the Rietspruit results.

5.7 Model Application

The application of the developed surface water model, in terms of source apportionment, will be demonstrated by means of a scenario related to a section of the Blesbokspruit. Consider a schematic layout of this particular section in Figure 56.

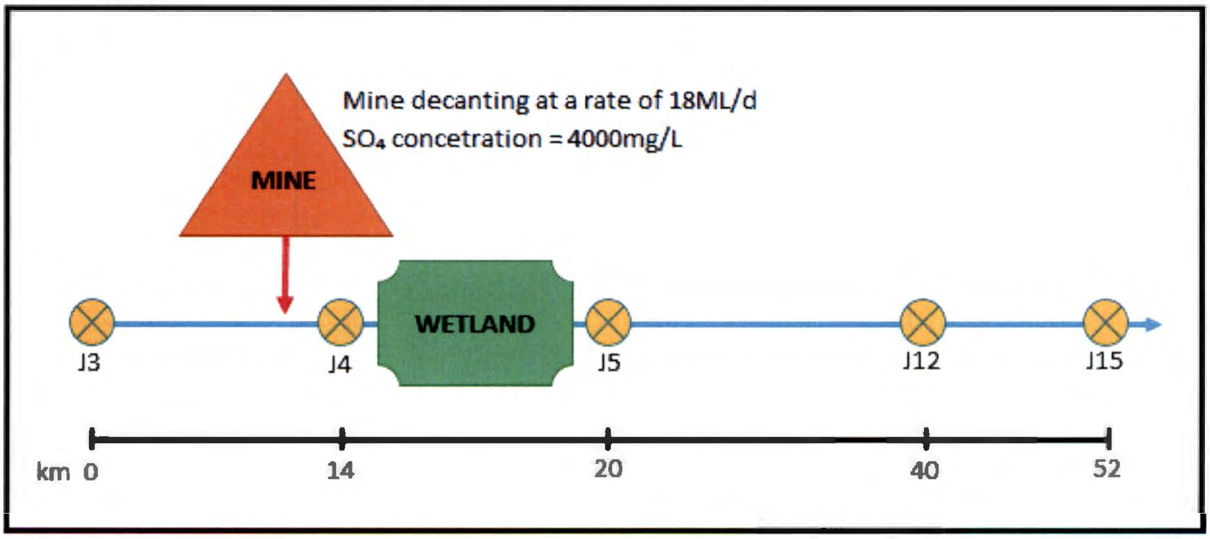


Figure 56: Schematic layout of section

In this section there are five measurement nodes stretching over a distance of 52 km, with J3 being the furthest upstream node and J15 being the furthest downstream node. A mine is situated just upstream of J4 and there is a wetland between J4 and J5. Consider the following scenario:

Pumping at the mine mentioned above is ceased, which can result in potential decant taking place. Decant from the mine into the Blesbokspruit is predicted at a rate of 18 ML/d with known sulphate concentrations of 4000 mg/L at the initial peak. This adds an additional sulphate load into the system.

To determine the effect that this additional load, the new sulphate load will have to be determined for the system and compared with the old sulphate load of the system before decant took place. For this scenario, the data which were gathered in the field over the full hydrological year, will be considered to be a representation of the system before decant took place. The flow rates of the system after decant took place is obtained by introducing the additional flow from the mine into the calibrated surface water model.

Figure 57 provides a comparison of the sulphate load at each node before and after decant took place.

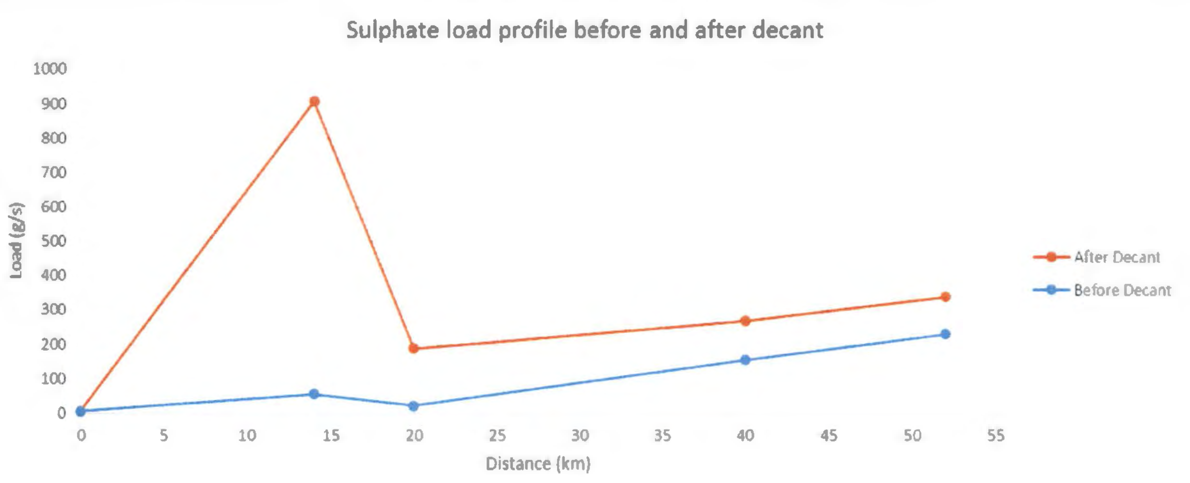


Figure 57: Sulphate load profile before and after decant

From the figure above can be seen that the mine has a significant influence on the sulphate load at its entry point into the system. What is interesting to note, is that the wetland also has a major effect on the load. This can be as a result of flow attenuation that occurs. Sulphate concentrations leaving the wetland are also lower, which may be attributed by the wetland's treatment function. Treatment did not form part of this study and therefore an exponential decay function for the sulphate concentrations was determined, based on the observed field response, which was implemented in the model.

On further assessment of the resultant load, the new sulphate load stabilises when reaching the downstream node at J15. It is expected that the new load will be proportionally higher than that of the previous load. In this case the load at J15 has increased by 108 g/s. That is a 32% increase in the sulphate load of the system. If, for example, a treatment plant should be established at this point, the mine would ultimately be responsible for 32% of the cost of treatment, should the decant volume and concentration remain the same. It is well known that the mine will exhibit a flushing effect and the sulphate concentrations will deplete with time, although the expected decant volume will stay the same.

5.8 CONCLUSION

SWMM was chosen as the most suitable model for this study, as it has the capability of utilising all the available data while taking into account all the key features needed for this study. A hydrological network was set up that would serve as a realistic representation of the study area. Data extracted from the database, were processed and compiled into the model. A lack of data related to wetlands made it difficult to determine the direct effects it has on the hydrological network. The buffering of flow by wetlands was however incorporated into the model through the use of roughness coefficients. No detail research was done on wetland treatment function.

The kinematic wave routing model was utilised to establish the best calibration for the model. Key calibration parameters were identified by conducting a sensitivity analysis. The final calibrated output of the model showed a positive outcome with correlations of 78% and 95% obtained for the Blesbokspruit and Rietspruit respectively. Discrepancies does exist and can be attributed by reasons ranging from physical changes in the system, errors in field measurements and channel changes to instrument limitations. In spite of discrepancies, it is still considered that the best possible calibration for the model was obtained, based on the good correlation and taking cognisance of the limitations related to availability of data.

The performance of the calibrated model was validated by comparing simulated and observed TDS. Although errors in simulated flows are propagated to errors in the simulated TDS, correlations against observed TDS were still found to be satisfactory. The application of the model was demonstrated through the use of a scenario where it was shown how the introduction of an external load will influence a downstream node where a possible treatment plant is considered. Apportionment can therefore be done based on the change in load.

SWMM was successfully employed to set up a calibrated surface water model of the study area. The surface water model translates the gathered input data and provides predictions which can be utilised to do source apportionment calculations.

6 CONCLUSIONS AND RECOMMENDATIONS

The effect that decanting mines could have on water quality which is already under tremendous strain, is a major concern in the ERB. This study aimed to develop and configure an appropriate surface water model as part of an integrated modelling approach that will assist with the complexities of source apportionment for the mining sector in the ERB. In its integrated format the surface water model forms the base from which source apportionment can be determined.

With model outputs showing good correlation with observed data, it can be said that SWMM was successfully utilised to develop and configure a calibrated surface water model. It has the ability to translate the gathered input data into outputs which closely represent the real world situation. A scenario demonstrated the application of the model which indicates that it can effectively assist with source apportionment.

When taking into account that SWMM is a storm-water model, specifically designed for urban drainage systems, this study has shown that it can be utilised for natural flow systems as well. This strengthens the findings from the study by Nakamura and Villagra (2009) that indicates that SWMM can be used successfully for non-urban applications.

Successful modelling of an active and dynamic hydrological system that constantly changes is a complex process in the sense that there are various important factors that need to be taken into account. In this study, wetlands was one of those factors, as it makes out a large part of the study area. The effect on flow rate and subsequent flow attenuation brought about by the wetlands needed to be integrated into the model to ensure that reality was represented in the most realistic way possible.

By the utilisation of appropriate roughness coefficients, the buffering of flow caused by the wetlands in the system was successfully simulated. Without this approach, validation would have been impossible. The effect on flow characteristics have now been modelled, but no research was done on the treatment function of wetlands. More detailed work is needed to determine the actual water quality buffering capabilities of these wetlands.

Based on the results, the model is shown to be fairly accurate, however it has to be stated that various assumptions had to be made as a consequence of limitations in data availability and other uncertainties. Three main issues will be discussed here.

Firstly, the limited amount of rainfall stations and their location are a major source of uncertainty. Rainfall data were found to be only available over short periods of time and was mostly incomplete with many gaps in the data, which complicated the calibration process.

These gaps extend over several months and in some cases even years, making the possibility for the infilling of gaps impossible.

Secondly, most hydrological models, including SWMM, assume a constant land use through the modelled period. With the study area being a highly industrialised area, it is highly unlikely that land use remained constant even over the short period that the model was run.

Land use data from 2009 were used to determine the CN values. From the sensitivity analysis that was conducted, CN values were found to be the most sensitive parameter, which means that by using outdated land use data there is definitely a margin of error in the way in which the CN values were determined for this study. Accurate and up to date land use data are therefore needed to re-evaluate CN values for the model.

Thirdly, as a result of limited data availability, a number of factors could not be accounted for in the model. The limited amount of cross sections measured in the field made profiling of the river system very difficult and as a result there are some areas of the hydrological system that are not accurately represented by the model. The 90m DEM could not be utilised to generate approximated cross-sections, as a large proportion of the streams in the river system are less than 90m wide. A detailed field survey is subsequently needed, where more cross-sections can be measured, in order to get a better representation of the river profile throughout the system.

More calibration points is also necessary to get an improved calibration with a smaller margin of error. It is challenging to run a large catchment through only one calibration point and may lead to errors in the output of the model.

In conclusion, although the lack of data necessitated the need to make assumptions in this study, it provides a good base to build on. With more work and improved data, this model could represent the real world situation more accurately, thereby providing even better outputs and the better management of the ERB.

7 REFERENCES

Arcement, G.J. & Schneider, V.R. 1984. Guide for selecting Manning's roughness coefficients for natural channels and flood plains. United States Geological Survey. Water-supply paper 2339.

ASTM (American Society of the International Association for Testing and Materials). 2002. Standard guide for conceptualisation and characterization of groundwater. West Conshohocken.

Bedient, P.B. & Huber, W.C. 2002. Hydrology and floodplain analysis. 3rd ed. Upper Saddle River: Pearson Prentice Hall.

Beven, K.J. 2003. Rainfall-runoff modelling: the primer. Chichester: John Wiley & Sons.

Boggs, K. 2015. U.S. releases enhanced shuttle land elevation data. http://www2.jpl.nasa.gov/srtm/ Data of access: February 2015.

Brooks, K.N., Ffolliott, P.F. & Magner, J.A. 2013. Hydrology and the management of watersheds. 4th ed. Chichester: John Wiley & Sons.

Cervantes, W.D.M. 2004. Modelling water quantity and water quality with the SWMM continuous streamflow model under non-stationary land-use condition using GIS. University of Maryland. (Thesis – Masters)

Chow, V. 1959. Open-channel hydraulics. New York: McGraw-Hill Book Company.

Chow, V., Maidment, D.R. & Mays, L.W. 1988. Applied hydrology. New York: McGraw-Hill Book Company.

Cowan, W.L. 1956. Estimating hydraulic roughness coefficients. *Agricultural Engineering*, 37(7):473-475.

Crawford, N.H. & Burges, J. 2004. The history of the Stanford watershed model. *Water Resources Impact*, 6(2):3-5.

Davie, T. 2008. Fundamentals of Hydrology. 2nd Ed. New York: Taylor & Francis Group.

Dennis, R., De Klerk, T., Dennis, I., Eckart, M. & Klinger, C. 2012. Pollution source apportionment in the East Rand basin: conceptual model. Council for geoscience. Draft Report.

Dennis, S.R. 2014. Pollution source apportionment in the East Rand basin: cross-section measurement. NWU internal report.

Elliott, A.H. & Trowsdale, S.A. 2006. A review of models for low impact urban stormwater drainage. *Environmental Modelling and Software*, 22:394-405.

ERWAT (East Rand Water Care Company). 2015. Plants. http://www.erwat.co.za/index.php/plants Date of access: June 2015

Galema, A.A. 2009. Vegetation resistance: evaluation of vegetation resistance descriptors for flood management. Faculty of Engineering Technology, University of Twente. (Thesis – Masters)

Gordon, N.D., McMahon, T.A., Finlayson, B.L., Gippel, C.J. & Nathan, R.J. 2004. Stream hydrology – an introduction for ecologists. 2nd Ed. Chichester: John Wiley & Sons.

Hall, B.R. & Freeman, G.E. 1994. Study of hydraulic roughness in wetland vegetation takes new look at Manning's n. *The Wetlands Research Program Bulletin*, 4(1):1-4.

Hodges, C.C. 1997. Resistance to flow through riparian wetlands. Virginia Polytechnic Institute and State University. (Thesis – Masters)

Jajarmizadeh, M., Harun, S. & Salarpour, M. 2012. A review on theoretical consideration and types of models in hydrology. *Journal of Environmental Science and Technology*, 5(5):249-261.

James, W. 2005. Rules for responsible modelling. 4th Ed. CHI, Ontatrio.

Johnson, D.B. & Hallberg, K.B. 2005. Acid mine drainage remediation options: a review. *Science of the Total Environment,* 338:3-14.

Johnson, M.R., Anhaeusser, C.R. & Thomas, R.J. 2006. Geology of South Africa. Geological Society of South Africa, Johannesburg/Council for Geoscience, Pretoria, 691pp.

Jones, J.A.A. 1997. Global hydrology. New York: Pearson Education

Kadlec, R.H. & Wallace, S.D. 2009. Treatment wetlands. 2nd Ed. New York: Taylor and Francis Group

Kotze, C. 2000. Wetlands and water quality enhancement. Mondi Wetlands Project.

Kovalevsky, V.S., Kruseman, G.P. & Rushton, K.R. 2004. An international guide for hydrological investigations. Paris: UNESCO.

Li, C., Wang, W., Xiong, J. & Chen, P. 2014. Sensitivity analysis for urban drainage modeling using mutual information. *Entropy*, 16:5738-5752.

Li, J. & Heap, A.D. 2008. A review of spatial interpolation methods for environmental scientists. *Geoscience Australia*, 23:1-137

Loucks, D.P. & Van Beek, E. 2005. Water resources systems planning and management: an introduction to methods, models and applications. United Nations Educational, Scientific and Cultural Organisation. Paris.

Ly, S., Charles, C. & Degré, A. 2012. Different methods for spatial interpolation of rainfall data for operational hydrology and hydrological modelling at watershed scale. A review. *Biotechnol. Agron. Soc. Environ.* 2013 17(2), 392-406

Lyon, J.S., Hilliard, T.J. & Bethell, T.N. 1993. Burdun of guilt. Mineral Policy Centre, Washington DC.

Middleton, B.J. & Bailey, A.K. 2005. Water resources of South Africa. Water Research Commission Report TT 380/08, Pretoria.

Malherbe, S. 2000. A perspective on the South African mining industry in the 21st century: an independent report prepared for the Chamber of Mines of South Africa. University of Cape Town.

Nakamura, J. & Villagra, N. 2009. Hydrologic modelling of the Little Crum Creek watershed with SWMM. Swathmore College.

Ollis, D.J., Snaddon, C.D. Job, N.M. & Mbona, N. 2013. Classification system for wetlands and other aquatic ecosystems in South Africa. User Manual: Inland Systems. *SANBI Biodiversity Series 22*. South African National Biodiversity Institute, Pretoria.

Parsons, R. 1995. A South African aquifer system management classification, Groundwater Programme Watertek, CSIR; Department: Water Affairs and Forestry, KV 77/95.

Peralvo, M. 2004. Influence of DEM interpolation methods in drainage analysis. GIS in Water Resources. University of Texas.

Pitman, W.V. 2011. Overview of water resource assessment in South Africa: Current state and future challenges. *Water SA,* 37(5):659–664

Pulles, W., Banister, S & Van Biljon, M. 2005. The development of appropriate procedures towards and after closure of underground gold mines from a water management perspective. WRC report no 1215/1/05.

Rauch, R., Bertrand-Krajewski, J.L., Krebs, P., Mark, O., Schilling, W., Schutze, M. & Vanrolleghem, P.A. 2002. Deterministic modelling of intergrated urban drainage systems. *Water Science and Technology*, 45(3):81-94

Rossman, L.A. 2010. Storm Water Management Model User's Manual Version 5.0, Environmental Protection Agency, EPA/600/R-05/040, USA.

SANBI (South African National Biodiversity Institute). 2009. Updating National Land Cover. http://bgis.sanbi.org/landcover/project.asp. Date of access: May 2015.

Salgado, I. 2011. Grootvlei's acid waters show pitfalls of old mines. Environment. http://www.environment.co.za/ Date of access: Nov. 2015.

Schulze, R.E., Schmidt, E.J. & Smithers, J.C. 1992. PC-Based SCS design flood estimates for small catchments in southern Africa. ACRU Report 40, Department of Agricultural Engineering, University of Natal, Pietermaritzburg.

Schulze, R.E. & Horan, M.J.C. 2006. Soils: hydrological attributes. (*In* Schulze, R.E., *ed.* South African Atlas of Climatology and Agrohydrology. Water Research Commission, Pretoria, RSA, WRC Report 1489/1/06, Section 4.2).

Schulze, R.E. 2012. Mapping Hydrological Soil Groups over South Africa for use with the SCS-SA design Hydrograph Technique: Methodology and results. University of Kwazulu Natal.

Scott, R. 1995. Flooding of Central and East Rand gold Mines: an investigation into controls over the inflow rate, water quality and the predicted impacts of flooded mine, Water Research Commission, WRC Report no 486/1/95, Pretoria.

Seath, S.G. & Van Niekerk, J.A. 2011. Witwatersrand Gold Fields: Acid Mine Drainage (Phase 1): Due Diligence. Report No J01599.

Sim, C.H. 2003. The use of constructed wetlands for wastewater treatment. Selangor: Wetlands International

South Africa. Department Of Water Affairs. 2012. Resource Water Quality Objectives (RWQOs): Feasibility Study for a Long-Term solution to Address the Acid Mine Drainage Associated with the East, Central and West Rand Underground Mining Basins. DWA Report No.: P RSA 000/00/16512/2

South Africa. Department: Water and Sanitation. 2015. Hydrological services: surface water (data, dams, floods and flows). https://www.dwa.gov.za/hydrology/ Date of access: May 2015.

Straskraba, V. & Effner, S. 1998. Water control in underground mines – Grouting or Drainage? International Mine Water Association Symposium. Johannesburg.

TCTA (Trans-Caledon Tunnel Authority). 2011. Witwatersrand Gold Fields: Acid Mine Drainage (Phase 1): Due Diligence. Report No J01599.

Vanderlan, C.M. & Robinson, G.R. 2008. Effectiveness of riparian wetlands in improving water quality in an urban stream. Albany: Hudson River Foundation.

Van Wyk, J.J. & Munnik, R. 1998. Dewatering of the East Rand Mining Basin. Department of Water Affairs and Forestry. Pretoria.

WISA (Water Institute of South Africa). 2006. Wetland: Blesbokspruit. http://www.ewisa.co.za/frame.aspx?url=~/misc/Wetlands/default.htm Date of access: June 2015.

Wheather, H., Sorooshian, S. & Sharma, K.D. 2007. Hydrological Modelling in Arid and Semi-Arid Areas. Cambridge: Cambridge University Press.

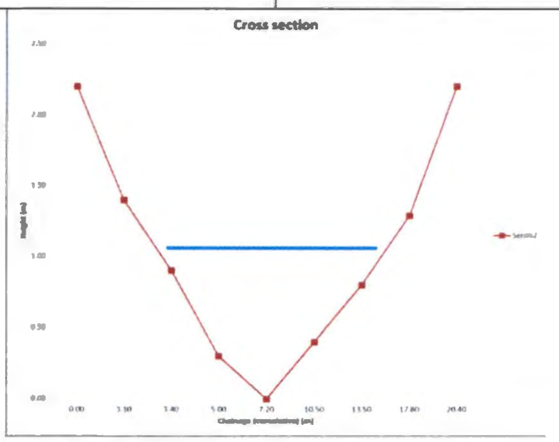
Xu, C. 2002. Textbook of Hydrologic Models. Department of Earth Sciences, Hydrology. Uppsala University.

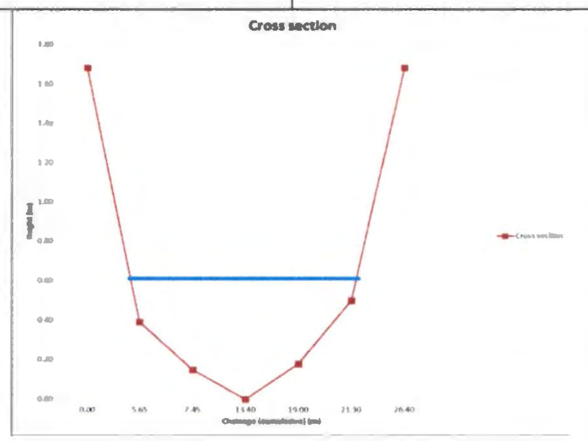
8 Appendices

8.1 Summary of cross-section measurements

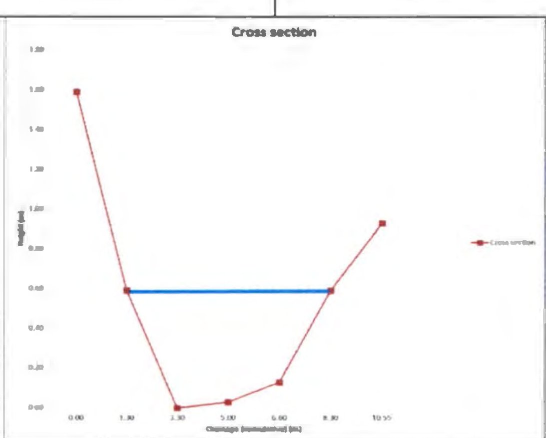
Cross-sections of Blesbokspruit

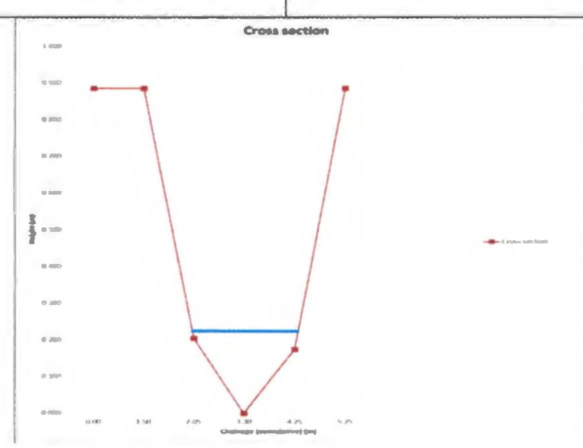
SW2		SW6	
Latitude:	-26.391	Latitude:	-26.478
Longitude:	28.497	Longitude:	28.425



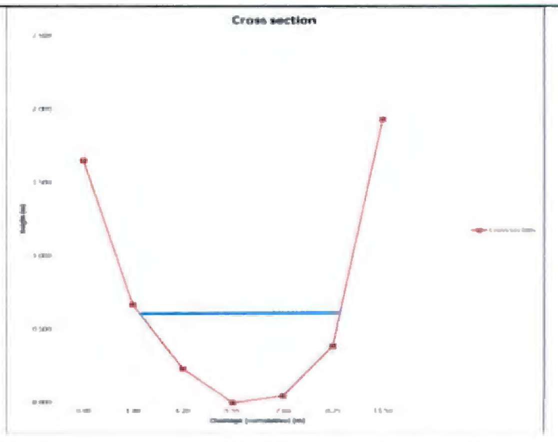
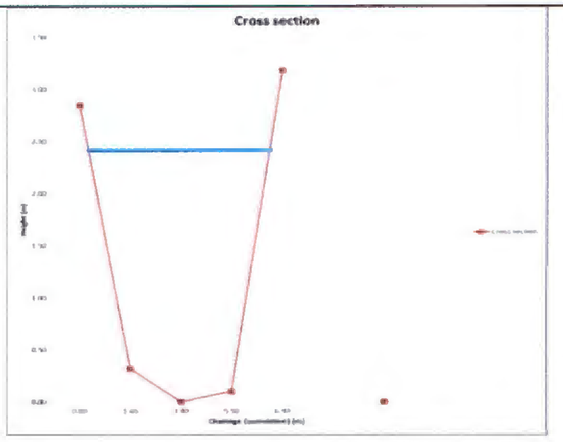


SW7		SW8	
Latitude:	-26.216	Latitude:	-26.159
Longitude:	28.440	Longitude:	28.364

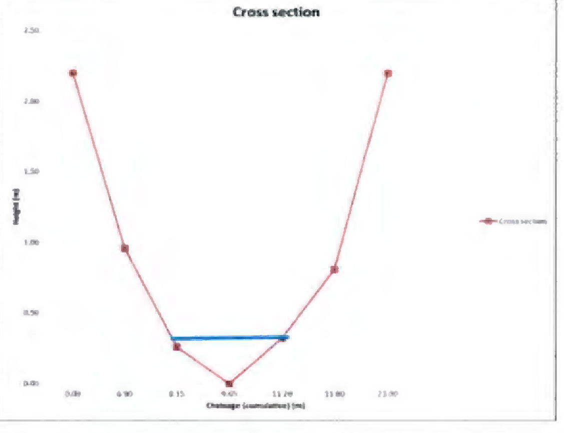
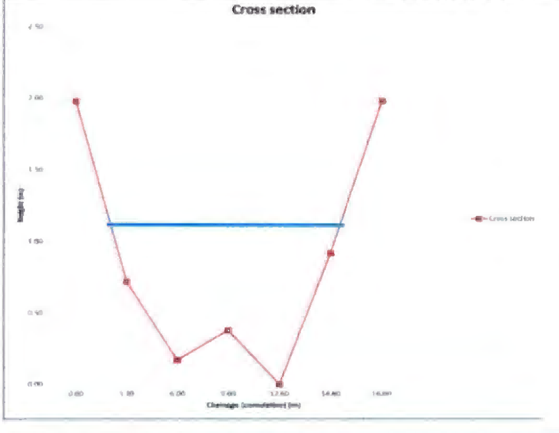
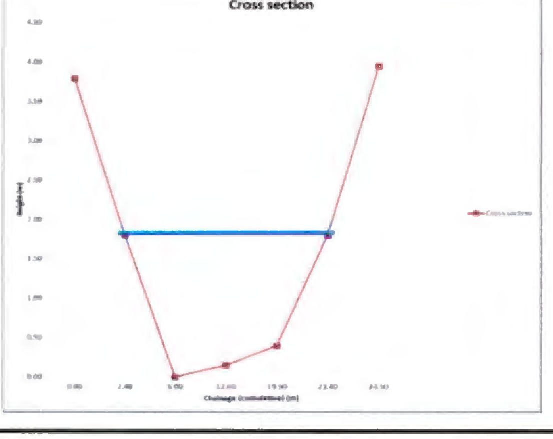
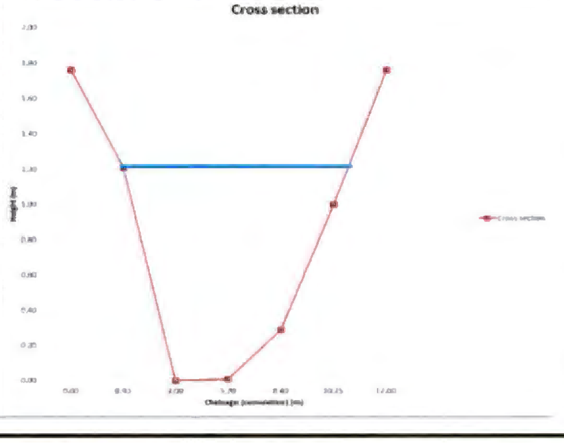




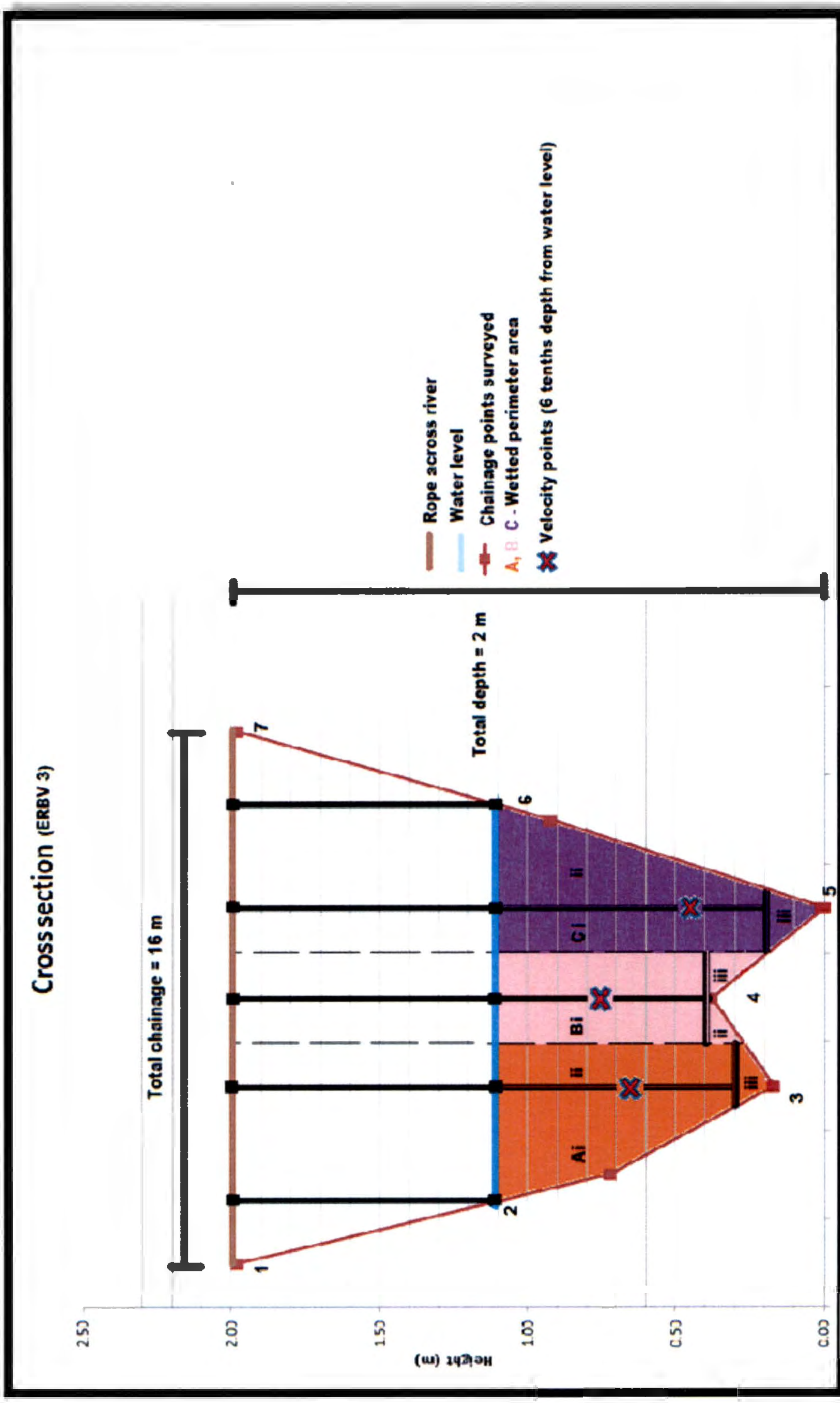
SW9		SW10	
Latitude:	-26.200	Latitude:	-26.255
Longitude:	28.391	Longitude:	28.500

Cross-sections of Rietspruit

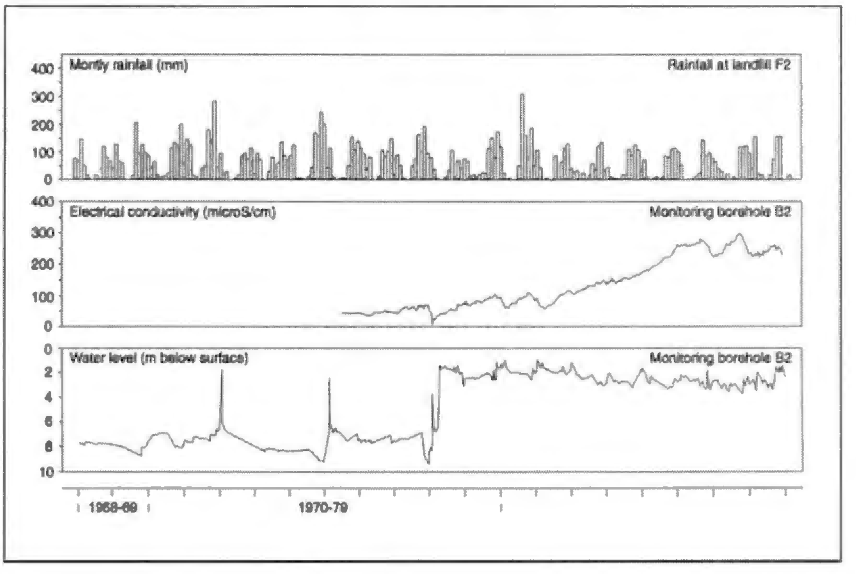
SW1		SW3	
Latitude:	-26.428	Latitude:	-26.426
Longitude:	28.182	Longitude:	28.164
			
SW4		**SW5**	
Latitude:	-26.453	Latitude:	-26.291
Longitude:	28.085	Longitude:	28.142
			

8.2 EXAMPLE OF MEASURED CROSS-SECTION, VELOCITY AND WETTED PERIMETER



8.3 PIPER AND EXPANDED DUROV DIAGRAMS (KOVALEVSKY ET AL., 2004)

Figure 4.2 Time dependent plot of water levels, electrical conductivity and rainfall



4.3.4 Specialised hydrochemical diagrams

Through the years, many special displays that meaningfully present hydrochemical data have been devised. Of these, six displays stand out in terms of clarity and significance.

They are the Piper (Piper, 1944), Durov (Durov, 1948), Expanded Durov (Lloyd, 1965), SAR (Wilcox, 1955; Bower et al., 1968), Schoeller (Schoeller, 1962) and Stiff (Stiff, 1951) diagrams. All of these diagrams are so-called multivariate displays, simultaneously taking up to eight variables into consideration, often projecting these variables to a single point on the diagrams. Examples of the Piper and Expanded Durov diagrams, with their plotting procedures, are included in Figures 4.3 and 4.4.

Advantages of using these diagrams include:

- the plotting of numerous water analyses onto a single diagram,
- the classification of waters according to their chemical characteristics,
- the identification of trends.

Figure 4.3 **Plotting procedures for the Piper diagram: Convert mg/l to meq/l by division (Ca/20, Mg/12, Na/23, K/39, T.Alk./50, SO_4/48, Cl/35.5, NO_3/62. Add Na +K and Cl + NO_3. Calculate percentage of cations and anions. Plot cations by scaling off Ca, then Mg. Plot anions by scaling off T.Alk. then SO_4. Project cation and anion points to triangle**

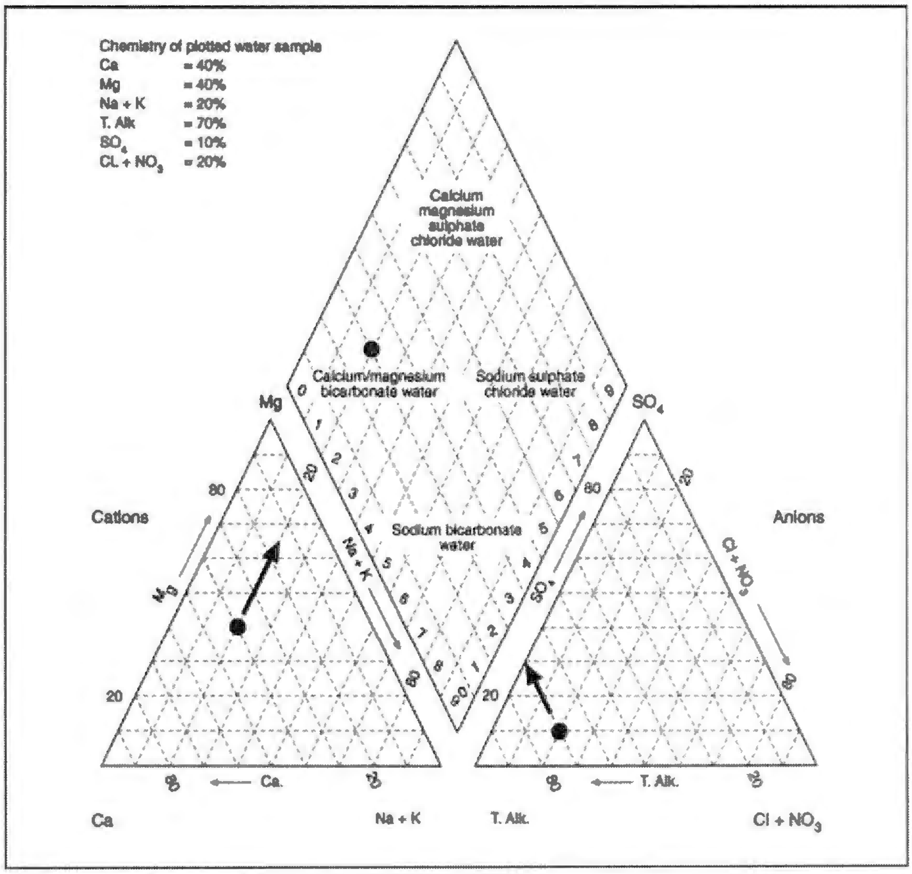
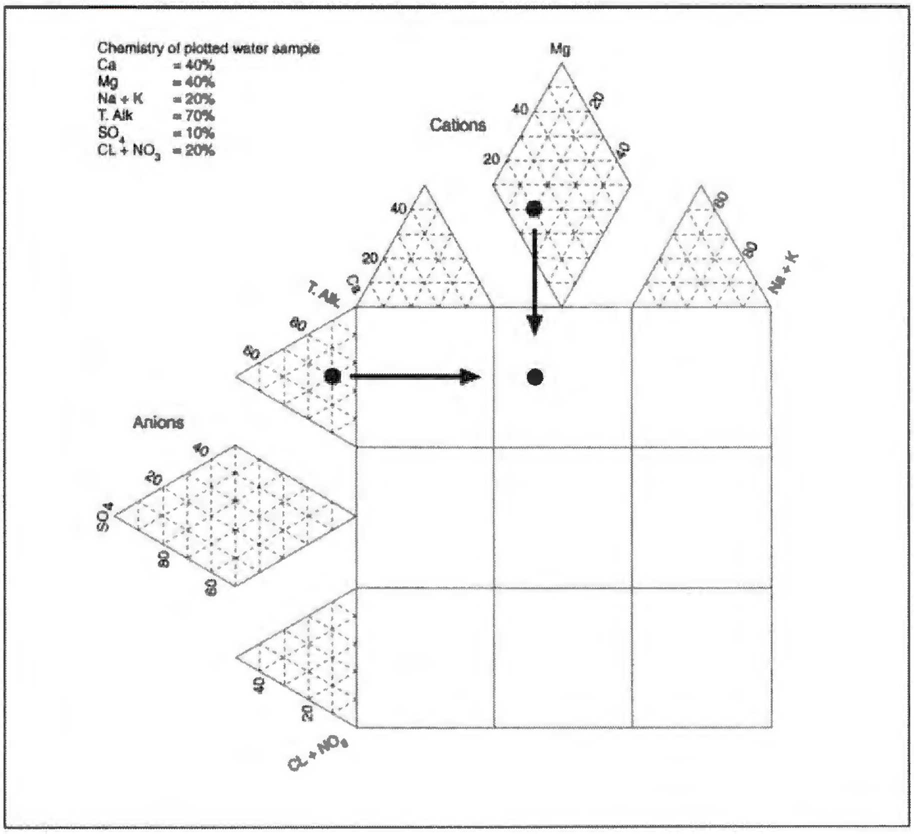


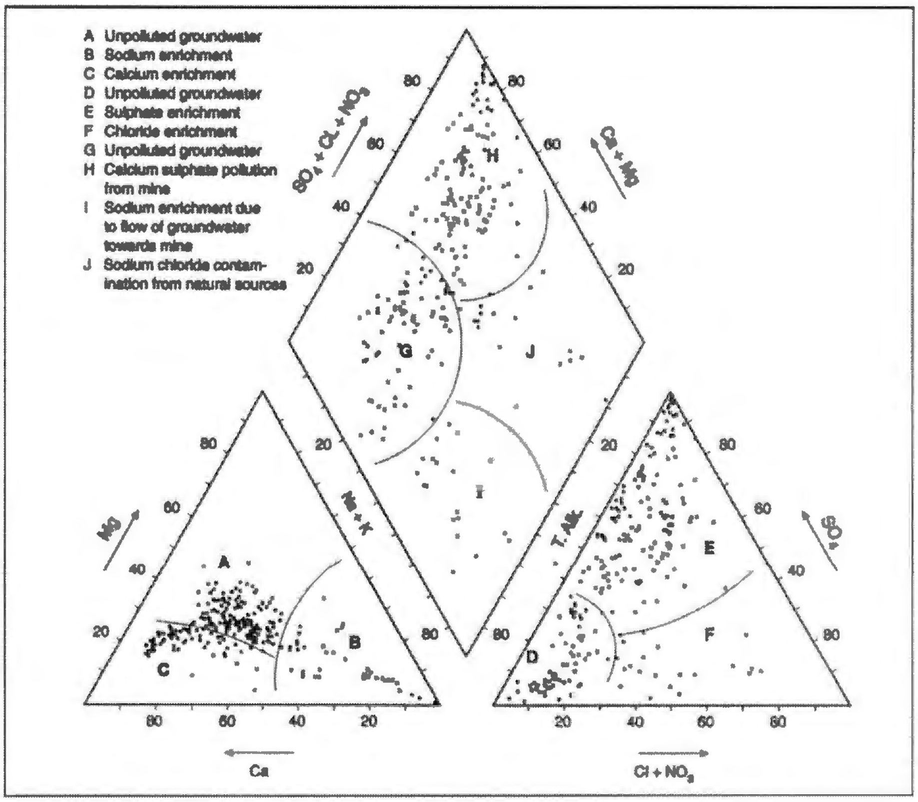
Figure 4.4 Plotting procedures for the Expanded Durov diagram: Convert mg/l to meq/l by division ($Ca/20$, $Mg/12$, $Na/23$, $K/39$, T.Alk./50, $SO_4/48$, $Cl/35.5$, $NO_3/62$. Add Na +K and Cl + NO_3. Calculate percentage of cations and anions. Plot cations by scaling off Ca, then Mg. Plot anions by scaling off T.Alk. then SO_4. Project cation and anion points to square



As an example of the advantages of these diagrams, a data set from a coal-mining environment has been selected and plotted in Figures 4.5– 4.8. To demonstrate the kind of conclusions that may be derived from these plots, the following information is provided:

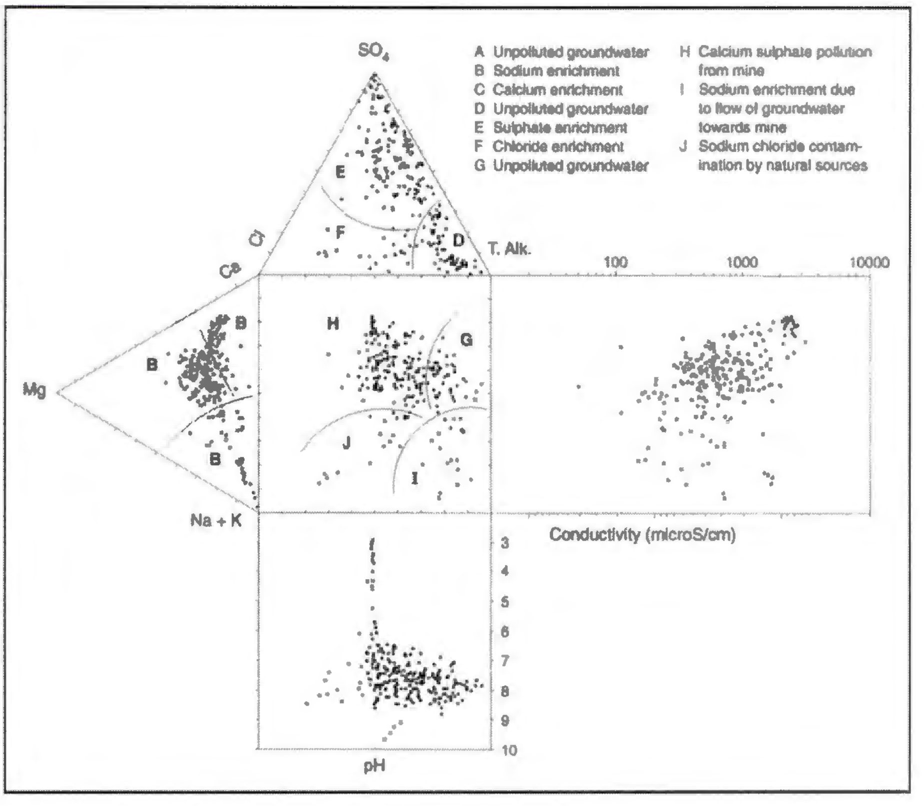
- Only about 30 per cent of the groundwater that has been sampled is unpolluted. The latter is characterised by water of a calcium/magnesium bicarbonate composition.
- The trend towards sodium enrichment, as depicted in the cation triangle, is due to cation exchange, as groundwater flows from surrounding aquifers towards the mine.
- The trend towards sulphate enrichment, as seen in the anion triangle, is due to pyrite oxidation in the coal-mine. This shows the extent to which the groundwater regime has already been polluted by mining.

Figure 4.5 Piper plot of groundwater chemistries from a mining environment



- The Durov diagram is particularly handy because it also includes the electrical conductivity of the water, thus giving a reflection of salt concentrations in the water. It suggests that the increase in the salt load is associated with mining activities.
- The calcium enrichment shown in the cation triangle of the trilinear diagrams originates from the neutralisation of acid water from the mine by calcium carbonate in the ground.
- The natural groundwater and aquifer have significant buffering potential against acidification, since only a few samples plot in the low pH range in the Durov diagram.
- The Expanded Durov diagram categorises waters into nine classes. For this reason, this diagram is for distinguishing between various groundwater populations, rather than for studying trends, as was the case for the diagrams discussed above.
- The SAR diagram suggests that sodium hazard to plants is low. Salinities are in the medium to high range. Crops with some resistance to salinity and soils with a sandy-loam character, may be irrigated successfully with the mine water.
- Nitrate pollution, which is derived from fertiliser application by farmers, is present in some borehole waters. This contamination cannot successfully be demonstrated by

Figure 4.6 Durov plot plot of groundwater chemistries from a mining environment



means of these diagrams, because of the dominance of other constituents. Other diagrams such as bar, line or scatter will have to be used for this purpose.

- The above example demonstrates the usefulness and limitations of these diagrams in the interpretation of hydrochemical data. Clearly, many variations of the above may be used to indicate values or demonstrate trends.

Through statistical methods, similar interpretations are possible. These methods will be discussed in Section 4.4. Statistical evaluations of this kind are usually complex and only understood by those familiar with statistical terminology. Reports for management should therefore always include diagrams, which may be backed up by statistical evidence if considered necessary.

Figure 4.7 SAR plot of groundwater chemistries from a mining environment

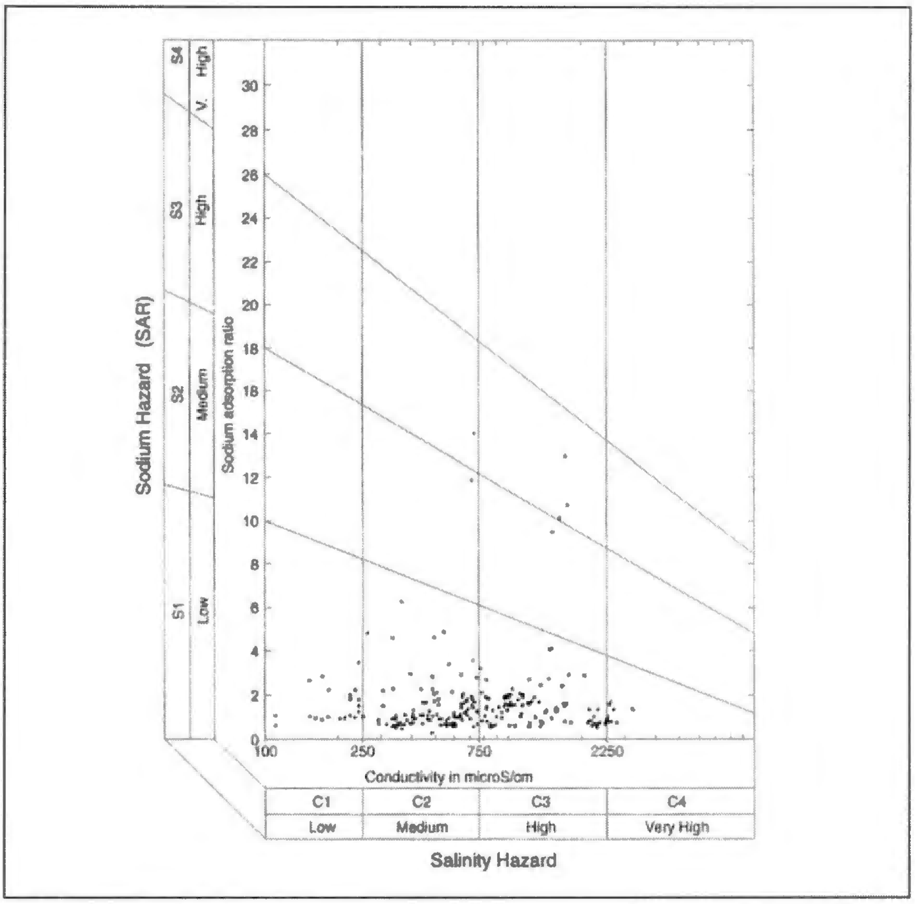
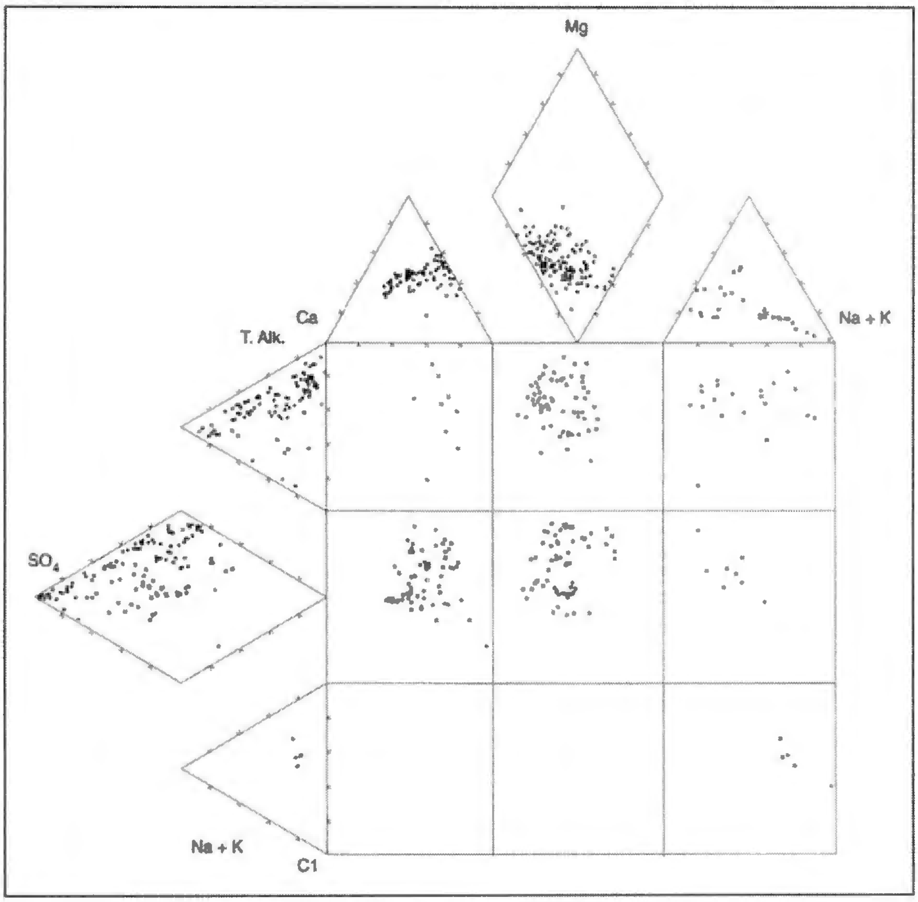


Figure 4.8 Expanded Durov plot of groundwater chemistries from a mining environment



8.4 DETAILED WATER QUALITY DATA

SANS241-1:2011		mS/m	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Acceptable	5<pH<9.7	0	0	-	-	-	0	0	0	0	-	0	0	0	-	-	0	0
Allowable		170	1200	-	-	-	1.5	200	70	0.3	-	300	50	150	-	-	0.2	0.05
Unacceptable	pH<4;pH>10	370	2400	-	-	-	1.5	400	100	0.5	-	600	100	300	-	-	0.5	0.5
Sample	pH	EC Electrical Conductivity	TDS Total Dissolved Solids	Li Lithium 6.9	Be 9.0	B 10.8	F 19.0	Na Sodium 23.0	Mg 24.3	Al 27.0	Si 28.1	Cl 35.5	K Potassium 39.1	Ca 40.1	Sc 45.0	Ti 47.9	V 50.9	Cr 52.0
SW1 (2013/11)	8.01	50.0	325.0		0.0000	0.0190		21.8	21.0	0.0605		29.0	6.7	42.54		1.45E-03	7.60E-05	2.50E-05
SW1 (2014/04)	7.98	122.0	793.0		0.0000	0.0039		65.2	46.9	0.0004		70.2	7.6	111.5		2.60E-05	2.00E-05	5.71E-03
SW1 (2014/07)	7.52	145.0	942.5		0.0002	0.0057		80.1	62.7	0.0043		93.9	10.5	129.8		2.76E-03	5.07E-04	1.75E-03
SW10 (2013/11)	8.35	90.0	585.0		0.0000	0.1450		86.9	18.0	0.0118		120.3	12.4	56.17		2.34E-03	1.32E-04	2.30E-05
SW10 (2014/04)	7.47	57.0	370.5		0.0000	0.0060		40.0	12.8	0.0004		60.4	7.2	31.07		3.20E-05	8.40E-05	4.80E-05
SW10 (2014/07)	7.43	81.0	526.5		0.0002	0.0080		40.6	9.3	0.0000		54.5	7.6	26.24		2.46E-03	3.00E-06	1.10E-03
SW2 (2013/11)	8.48	110.0	715.0		0.0000	0.1630		110.6	24.2	0.0029		108.7	12.6	78.13		9.70E-04	1.13E-04	2.20E-05
SW2 (2014/04)	7.87	58.0	377.0		0.0000	0.0033		39.0	13.3	0.0003		63.8	6.7	38.77		2.30E-05	7.40E-05	3.97E-04
SW2 (2014/07)	7.86	77.0	500.5		0.0002	0.0055		66.9	19.7	0.0154		97.0	10.7	57.92		2.69E-03	7.00E-06	1.88E-03
SW3 (2013/11)	8.14	74.0	481.0		0.0000	0.1350		60.3	17.8	0.0002		84.8	9.6	60.25		1.49E-04	1.29E-04	3.20E-05
SW3 (2014/04)	7.52	71.0	461.5		0.0000	0.0035		45.8	18.2	0.0004		79.3	8.6	51.47		2.60E-05	7.60E-05	1.70E-05
SW3 (2014/07)	7.23	110.0	716.0		0.0002	0.0063		77.4	28.8	0.1985		86.5	14.6	95.97		5.17E-03	7.00E-06	9.82E-03
SW4 (2013/11)	8.15	59.0	383.5		0.0000	0.0630		53.5	12.9	0.0006		67.7	10.1	39.08		2.07E-03	9.10E-05	2.80E-05
SW4 (2014/04)	7.58	65.0	422.5		0.0000	0.0043		50.9	16.9	0.0004		75.5	8.8	45.19		2.70E-05	6.40E-05	2.00E-05
SW4 (2014/07)	7.30	72.0	468.0		0.0002	0.0068		59.8	18.5	0.0160		83.9	10.9	48.96		3.58E-03	0.00E+00	1.18E-03
SW5 (2013/11)	7.46	58.0	377.0		0.0000	0.0410		26.8	12.1	0.0001		27.6	6.6	53.15		8.00E-06	1.36E-04	3.80E-05
SW5 (2014/04)	7.07	46.0	299.0		0.0000	0.0048		16.4	14.0	0.0001		30.4	4.4	37.09		3.50E-05	8.50E-05	3.40E-05
SW5 (2014/07)	7.01	65.0	422.5		0.0002	0.0067		28.1	20.8	0.0005		67.1	7.6	50.55		2.21E-03	1.40E-05	6.27E-04
SW6 (2013/11)	8.41	90.0	585.0		0.0000	0.1480		93.3	18.7	0.0002		124.4	12.2	60.46		5.00E-06	8.90E-05	1.70E-05
SW6 (2014/04)	7.82	54.0	351.0		0.0000	0.0050		42.1	13.9	0.0003		57.2	8.0	37.46		3.00E-05	6.90E-05	2.30E-05
SW6 (2014/07)	7.55	68.0	442.0		0.0002	0.0071		59.5	16.8	0.0299		82.6	9.7	47.53		3.24E-03	3.00E-06	1.81E-03
SW7 (2013/11)	8.11	60.0	390.0		0.0000	0.0860		64.0	12.0	0.0041		92.1	13.7	33.47		4.00E-06	1.18E-04	3.00E-05
SW7 (2014/04)	7.55	40.0	260.0		0.0000	0.0052		27.9	9.7	0.0003		37.9	6.1	21.65		3.40E-05	7.20E-05	3.60E-05
SW7 (2014/07)	8.07	57.0	370.5		0.0002	0.0075		57.6	13.8	0.0182		72.8	9.6	32.78		3.10E-03	2.00E-06	1.21E-03
SW8 (2013/11)	8.23	58.0	377.0		0.0000	0.0570		48.0	7.6	0.0001		80.9	11.4	24.55		1.91E-03	1.25E-04	3.60E-05
SW8 (2014/04)	7.39	57.0	370.5		0.0000	0.0058		47.2	10.1	0.0004		77.8	9.8	24.08		1.60E-05	7.90E-05	4.00E-05
SW8 (2014/07)	6.96	58.0	377.0		0.0002	0.0079		57.6	9.4	0.0000		106.2	13.8	22.52		4.04E-03	1.00E-05	1.18E-03
SW9 (2013/11)	7.89	48.0	312.0		0.0000	0.0810		51.5	9.9	0.0323		57.4	8.7	27.04		2.40E-03	1.30E-04	2.10E-05
SW9 (2014/04)	7.08	45.0	292.5		0.0000	0.0060		38.3	9.4	0.0004		53.5	6.7	20.43		1.80E-05	8.40E-05	3.70E-05
SW9 (2014/07)	7.29	70.0	455.0		0.0002	0.0079		85.4	11.8	0.0001		110.4	15.4	27.77		4.71E-03	8.00E-06	6.35E-03

SANS241-1:2011	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Acceptable	0	0	0	0	0	0	-	-	0	0	-	-	-	-	-	-	-	-
Allowable	0.5	2	0.5	0.07	2	5	-	-	0.01	0.01	-	-	-	-	-	-	-	-
Unacceptable	1	2	1	0.35	2	10	-	-	0.05	0.05	-	-	-	-	-	-	-	-
Sample	Mn 54.9	Fe 55.8	Co Cobalt 58.9	Ni 58.7	Cu 63.5	Zn 65.4	Ga Gallium 69.7	Ge 72.6	As 74.9	Se 79.0	Br 79.9	Rb Rubidium 85.5	Sr 87.6	Y Yttrium 88.9	Zr 91.2	Nb 92.9	Mo 95.9	Ru 101.1
SW1 (2013/11)	0.00E+00	2.20E-01	0.00E+00	1.60E-02	0.00E+00	4.70E-04			5.00E-05	3.71E-04		3.33E-03	8.16E-02				6.80E-04	
SW1 (2014/04)	3.60E-05	6.45E-01	1.92E-02	1.95E-02	1.70E-05	2.75E-04			4.56E-04	1.18E-04		6.08E-03	2.08E-01				5.96E-03	
SW1 (2014/07)	4.56E-03	1.28E-01	3.03E-02	2.33E-02	1.30E-05	1.45E-04			6.14E-04	9.00E-06		7.72E-03	2.40E-01				2.23E-03	
SW10 (2013/11)	8.00E-02	2.30E-01	0.00E+00	1.24E-02	0.00E+00	4.60E-04			1.06E-03	3.45E-04		1.06E-02	1.69E-01				9.10E-03	
SW10 (2014/04)	3.36E-02	1.88E-01	9.00E-06	2.90E-05	4.30E-05	3.24E-04			1.80E-05	1.66E-04		6.73E-03	1.19E-01				2.53E-02	
SW10 (2014/07)	1.46E-02	4.38E-02	1.19E-03	3.18E-02	1.15E-03	1.78E-04			2.56E-03	6.90E-04		7.30E-03	7.81E-02				2.72E-02	
SW2 (2013/11)	0.00E+00	2.90E-01	0.00E+00	8.80E-03	0.00E+00	4.70E-04			5.90E-05	3.50E-04		1.30E-02	2.25E-01				1.65E-03	
SW2 (2014/04)	2.11E-03	2.70E-01	1.60E-05	5.40E-05	3.80E-05	2.62E-04			2.90E-05	1.66E-04		8.83E-03	1.23E-01				7.58E-03	
SW2 (2014/07)	6.87E-03	6.13E-02	6.70E-04	5.12E-03	2.10E-05	1.69E-04			5.60E-04	2.70E-05		1.08E-02	1.67E-01				9.42E-03	
SW3 (2013/11)	0.00E+00	2.10E-01	1.90E-03	1.18E-02	1.00E-04	4.30E-04			6.90E-05	3.70E-04		7.76E-03	1.50E-01				1.12E-03	
SW3 (2014/04)	3.50E-05	3.72E-01	4.65E-04	6.16E-03	3.30E-05	1.99E-04			3.30E-05	1.64E-04		8.36E-03	1.44E-01				1.97E-03	
SW3 (2014/07)	4.30E-01	2.99E-01	3.83E-03	6.52E-02	8.41E-03	1.47E-01			7.00E-08	2.80E-05		1.48E-02	1.90E-01				2.89E-03	
SW4 (2013/11)	0.00E+00	1.60E-01	3.20E-03	1.90E-02	0.00E+00	3.20E-04			6.50E-05	3.55E-04		7.92E-03	1.17E-01				1.08E-03	
SW4 (2014/04)	1.70E-05	3.21E-01	3.63E-04	1.11E-02	3.00E-05	2.08E-04			3.30E-05	1.78E-04		7.77E-03	1.40E-01				1.79E-03	
SW4 (2014/07)	1.77E-02	7.21E-02	2.11E-03	1.48E-02	8.00E-06	1.60E-05			5.00E-06	3.40E-05		1.06E-02	1.33E-01				2.29E-03	
SW5 (2013/11)	1.54E+00	2.30E-01	1.51E-01	2.02E-01	2.10E-03	1.97E-01			6.20E-05	3.71E-04		6.07E-03	1.36E-01				7.03E-04	
SW5 (2014/04)	1.88E+00	3.44E-01	1.09E-01	1.31E-01	6.14E-03	4.19E-01			3.50E-05	1.76E-04		4.82E-03	1.27E-01				1.41E-03	
SW5 (2014/07)	2.95E+00	2.06E-01	1.10E-01	1.27E-01	1.41E-03	3.96E-01			1.00E-05	3.90E-05		9.49E-03	1.72E-01				2.03E-03	
SW6 (2013/11)	0.00E+00	2.20E-01	0.00E+00	9.50E-03	1.00E-04	5.00E-04			6.00E-05	3.64E-04		1.16E-02	1.82E-01				1.35E-03	
SW6 (2014/04)	2.80E-05	2.41E-01	1.60E-05	6.40E-05	3.80E-05	2.75E-04			3.10E-05	1.74E-04		8.33E-03	1.22E-01				6.12E-03	
SW6 (2014/07)	1.31E-02	7.73E-02	7.17E-04	8.51E-03	1.70E-03	1.06E-01			2.24E-04	1.70E-05		9.89E-03	1.45E-01				7.20E-03	
SW7 (2013/11)	0.00E+00	1.60E-01	0.00E+00	2.24E-02	0.00E+00	4.70E-04			1.22E-03	3.68E-04		1.11E-02	1.38E-01				2.32E-01	
SW7 (2014/04)	5.00E-06	1.53E-01	2.28E-03	1.03E-02	2.10E-05	2.89E-04			3.77E-04	1.76E-04		6.09E-03	1.05E-01				1.42E-01	
SW7 (2014/07)	1.02E-02	5.25E-02	5.27E-03	2.88E-02	7.32E-04	1.42E-04			4.77E-03	2.20E-05		1.00E-02	1.29E-01				2.29E-01	
SW8 (2013/11)	6.00E-02	5.00E-01	0.00E+00	0.00E+00	1.00E-04	4.80E-04			6.20E-05	3.71E-04		9.35E-03	8.70E-02				6.55E-03	
SW8 (2014/04)	5.00E-05	1.81E-01	1.90E-05	9.50E-05	5.00E-06	3.19E-04			3.60E-05	1.81E-04		9.43E-03	9.38E-02				3.36E-03	
SW8 (2014/07)	1.32E-02	3.78E-01	5.43E-04	3.15E-03	1.29E-03	1.75E-04			7.00E-06	3.20E-05		1.21E-02	8.39E-02				5.37E-03	
SW9 (2013/11)	0.00E+00	1.60E-01	0.00E+00	4.10E-03	0.00E+00	4.50E-04			3.30E-05	3.70E-04		7.10E-03	1.21E-01				2.16E-03	
SW9 (2014/04)	2.96E-02	1.49E-01	1.00E-06	5.80E-05	9.02E-03	2.34E-04			1.70E-05	1.80E-04		6.24E-03	9.92E-02				1.68E-03	
SW9 (2014/07)	2.40E-03	8.39E-02	1.66E-03	9.54E-03	7.98E-04	1.10E-04			3.00E-03	3.30E-05		1.42E-02	1.14E-01				3.50E-03	

SANS241-1:2011	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Acceptable	-	-	-	0	-	-	0	-	-	-	-	-	-	-	-	-	-	-
Allowable	-	-	-	0.003	-	-	0.02	-	-	-	-	-	-	-	-	-	-	-
Unacceptable	-	-	-	0.01	-	-	0.05	-	-	-	-	-	-	-	-	-	-	-
Sample	**Rh** Rhodium 102.9	**Pd** Palladium 106.4	**Ag** Silver 107.9	**Cd** Cadmium 112.4	**In** Indium 114.8	**Sn** Tin 118.7	**Sb** Antimony 121.8	**Te** Tellurium 127.6	**I** Iodine 126.9	**Cs** Cesium 132.9	**Ba** Barium 137.3	**Ce** Cerium 140.1	**Nd** Neodymium 144.2	**Sm** Samarium 150.4	**Gd** Gadolinium 157.3	**Dy** Dysprosium 162.5	**Hf** Hafnium 178.5	**Ta** Tantalum 180.9
SW1 (2013/11)		1.32E-04	5.10E-05	2.77E-05			3.43E-03				3.69E-02							
SW1 (2014/04)		1.30E-03	4.80E-05	1.40E-05			4.81E-03				4.88E-02							
SW1 (2014/07)		7.75E-04	2.50E-05	4.00E-06			3.80E-03		0.01860		6.57E-02							
SW10 (2013/11)		2.56E-04	5.20E-05	2.72E-05			4.18E-03				5.31E-02							
SW10 (2014/04)		4.23E-04	5.70E-05	1.60E-05			3.29E-03				3.56E-02							
SW10 (2014/07)		5.92E-04	2.30E-05	4.00E-06			6.08E-03		0.01602		5.13E-02							
SW2 (2013/11)		3.63E-04	4.30E-05	2.74E-05			3.27E-03				5.22E-02							
SW2 (2014/04)		6.31E-04	5.60E-05	1.50E-05			3.60E-03				4.13E-02							
SW2 (2014/07)		7.35E-04	2.50E-05	4.00E-06			3.87E-03		0.01226		6.74E-02							
SW3 (2013/11)		2.32E-04	5.10E-05	2.83E-05			3.52E-03				4.12E-02							
SW3 (2014/04)		1.09E-03	5.70E-05	1.60E-05			3.57E-03				3.94E-02							
SW3 (2014/07)		7.90E-04	2.40E-05	3.00E-06			4.08E-03		0.03490		8.18E-02							
SW4 (2013/11)		1.75E-04	5.00E-05	2.83E-05			3.54E-03				4.36E-02							
SW4 (2014/04)		5.77E-04	5.80E-05	1.50E-05			3.37E-03				4.17E-02							
SW4 (2014/07)		6.61E-04	2.30E-05	4.00E-06			3.98E-03		0.02691		6.96E-02							
SW5 (2013/11)		2.69E-04	5.10E-05	2.58E-05			3.70E-03				5.52E-02							
SW5 (2014/04)		5.31E-04	5.70E-05	1.40E-05			3.29E-03				5.88E-02							
SW5 (2014/07)		7.17E-04	2.40E-05	3.00E-06			3.79E-03		0.03337		8.77E-02							
SW6 (2013/11)		2.09E-04	5.10E-05	2.82E-05			3.37E-03				4.49E-02							
SW6 (2014/04)		3.95E-04	5.60E-05	1.60E-05			3.10E-03				4.04E-02							
SW6 (2014/07)		7.09E-04	2.30E-05	4.00E-06			3.85E-03		0.01370		7.06E-02							
SW7 (2013/11)		2.02E-04	5.10E-05	2.54E-05			4.67E-03				3.24E-02							
SW7 (2014/04)		6.39E-04	5.70E-05	1.40E-05			3.48E-03				3.64E-02							
SW7 (2014/07)		8.88E-04	2.20E-05	0.00E+00			4.86E-03		0.02655		6.12E-02							
SW8 (2013/11)		1.25E-04	5.10E-05	2.81E-05			3.39E-03				2.00E-02							
SW8 (2014/04)		3.82E-04	5.70E-05	1.60E-05			3.07E-03				2.29E-02							
SW8 (2014/07)		6.31E-04	2.30E-05	4.00E-06			3.84E-03		0.03684		4.56E-02							
SW9 (2013/11)		3.21E-04	5.10E-05	2.78E-05			3.70E-03				2.76E-02							
SW9 (2014/04)		4.33E-04	5.70E-05	1.60E-05			3.37E-03				4.39E-02							
SW9 (2014/07)		6.61E-04	2.20E-05	4.00E-06			5.25E-03		0.03473		6.10E-02							

SANS241-1:2011	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Acceptable	-	-	-	-	-	-	0	-	0	-	D	0	-	0	0	0	-	-
Allowable	-	-	-	-	-	-	0.006	-	0.01	-	0.015	500	-	1.5	11	0.9	-	-
Unacceptable	-	-	-	-	-	-	0.006	-	0.05	-	0.015	600	-	2	20	20	-	-
Sample	**W** Tungsten 183.8	**Re** Rhenium 186.2	**Os** Osmium 190.2	**Ir** Iridium 192.2	**Pt** Platinum 195.1	**Au** Gold 197.0	**Hg** Mercury 200.6	**Tl** Thallium 204.4	**Pb** Lead 207.2	**Bi** Bismuth 209.0	**U** Uranium 238.0	**SO_4** Sulphate 96.1	**PO_4** Phosphate 95.0	**NH_4** Ammonium 56.5	**NO_3** Nitrate 62.0	**NO_2** Nitrite 46.0	**HCO_3** Bicarbonate 61.0	**CO_3** Carbonate 60.0
SW1 (2013/11)					1.70E-05	3.45E-03	4.56E-06	3.10E-05	1.26E-04	1.27E-02	2.00E-06	158.4	0.11	0.27	7.40		69.5	0.0
SW1 (2014/04)					1.20E-05	1.08E-02	6.07E-04	1.60E-05	9.50E-05	1.36E-02	8.97E-03	417.7	0.19	0.18	4.60		193.0	0.0
SW1 (2014/07)					0.00E+00	3.13E-03	1.00E-06	6.00E-06	4.70E-05	1.17E-02	2.38E-02	475.8	0.21	4.91	8.91		210.0	0.0
SW10 (2013/11)					1.60E-05	3.38E-03	4.96E-06	3.10E-05	1.18E-04	1.27E-02	4.32E-04	157.1	8.57	5.10	5.35		197.5	7.5
SW10 (2014/04)					1.30E-05	5.39E-03	2.00E-06	1.90E-05	9.60E-05	1.23E-02	0.00E+00	106.93	3.03	0.92	0.21		118.0	0.0
SW10 (2014/07)					1.00E-06	3.05E-03	1.00E-06	6.00E-06	4.90E-05	1.16E-02	3.82E-03	68.9	0.75	1.10	0.99		82.5	0.0
SW2 (2013/11)					1.40E-05	3.38E-03	1.81E-06	3.10E-05	1.33E-04	1.27E-02	1.83E-03	142.3	0.66	0.32	1.76		257.5	10.0
SW2 (2014/04)					1.20E-05	6.67E-03	2.67E-04	1.80E-05	9.60E-05	1.28E-02	4.00E-06	89.1	4.11	0.07	0.11		145.0	0.0
SW2 (2014/07)					1.00E-06	3.11E-03	1.00E-06	6.00E-06	4.10E-05	1.17E-02	4.18E-03	137.9	0.76	1.23	0.13		172.5	0.0
SW3 (2013/11)					1.70E-05	3.42E-03	4.85E-06	3.10E-05	1.33E-04	1.27E-02	9.81E-04	168.9	0.24	0.40	25.86		112.5	0.0
SW3 (2014/04)					1.20E-05	6.43E-03	1.04E-04	1.80E-05	9.50E-05	1.26E-02	1.14E-03	184.3	0.83	0.13	14.73		112.5	0.0
SW3 (2014/07)					0.00E+00	3.11E-03	1.00E-06	6.00E-06	6.00E-06	1.17E-02	2.66E-03	308.7	0.85	2.62	23.48		107.5	0.0
SW4 (2013/11)					1.40E-05	3.38E-03	4.73E-06	3.00E-05	1.29E-04	1.27E-02	1.00E-06	98.1	0.49	1.61	13.33		107.0	0.0
SW4 (2014/04)					1.30E-05	5.71E-03	3.10E-05	1.80E-05	9.20E-05	1.25E-02	6.99E-04	145.7	0.52	0.05	18.43		105.0	0.0
SW4 (2014/07)					1.00E-06	3.08E-03	1.00E-06	8.00E-06	1.00E-05	1.17E-02	2.15E-03	174.5	0.50	1.44	21.33		105.0	0.0
SW5 (2013/11)					1.70E-05	3.65E-03	4.96E-06	3.00E-05	1.32E-04	1.27E-02	1.58E-03	255.0	0.01	4.29	4.13		35.0	0.0
SW5 (2014/04)					1.30E-05	5.64E-03	0.00E+00	1.80E-05	9.10E-05	1.24E-02	1.10E-04	199.62	0.01	0.78	5.19		27.5	0.0
SW5 (2014/07)					0.00E+00	3.11E-03	1.00E-06	6.00E-06	4.50E-05	1.16E-02	9.83E-04	247.4	0.01	4.13	5.78		50.0	0.0
SW6 (2013/11)					1.60E-05	3.36E-03	4.91E-06	3.10E-05	1.32E-04	1.27E-02	1.64E-03	139.1	1.00	0.87	15.29		187.5	5.0
SW6 (2014/04)					1.20E-05	5.44E-03	1.00E-06	1.80E-05	8.70E-05	1.24E-02	3.00E-06	83.5	2.31	0.13	2.68		127.5	0.0
SW6 (2014/07)					3.61E-04	3.07E-03	1.00E-06	6.00E-06	3.60E-05	1.16E-02	3.54E-03	115.71	0.90	1.43	5.98		142.5	0.0
SW7 (2013/11)					1.70E-05	3.44E-03	4.83E-06	3.10E-05	1.29E-04	1.27E-02	6.45E-03	77.4	0.07	0.34	2.58		115.0	0.0
SW7 (2014/04)					1.10E-05	5.51E-03	2.00E-06	1.90E-05	1.01E-04	1.23E-02	2.27E-04	86.0	0.02	0.13	3.55		67.5	0.0
SW7 (2014/07)					1.00E-06	3.22E-03	1.00E-06	6.00E-06	3.70E-05	1.17E-02	7.76E-03	99.2	0.27	1.03	4.26		105.0	0.0
SW8 (2013/11)					1.60E-05	3.35E-03	4.93E-06	3.10E-05	1.33E-04	1.27E-02	6.00E-06	34.71	5.90	11.02	0.49		142.5	0.5
SW8 (2014/04)					1.30E-05	5.48E-03	2.00E-06	1.90E-05	9.50E-05	1.23E-02	9.00E-06	45.9	3.31	7.04	0.56		60.0	0.0
SW8 (2014/07)					1.00E-06	3.10E-03	1.00E-06	6.00E-06	5.10E-05	1.16E-02	3.13E-04	47.3	7.32	9.06	1.86		110.0	0.0
SW9 (2013/11)					1.70E-05	3.37E-03	4.91E-06	3.10E-05	1.13E-04	1.27E-02	5.00E-06	27.3	7.55	1.55	3.61		120.0	0.0
SW9 (2014/04)					1.30E-05	5.40E-03	2.00E-06	1.90E-05	9.10E-05	1.23E-02	7.00E-06	39.12	6.52	1.91	2.50		90.0	0.0
SW9 (2014/07)					1.00E-06	3.08E-03	1.00E-06	6.00E-06	3.80E-05	1.17E-02	9.01E-04	42.1	10.68	9.72	8.51		162.5	0.0

SANS241-1:2011	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	
Acceptable	0	-	-	-	-	0	-	-
Allowable	0.07	-	-	-	-	0.01	-	-
Unacceptable	0.07	-	-	-	-	0.07	-	-
Sample	**CN** Cyanide	**TAL** Total Alkalinity	**THA** Total Hardness	**TSS** Total Suspended Solids	**OIL** Oil and Grease	**Phen** Phenols	**COD** Chemical Oxygen Demand	**SAR** Sodium Absorbsion Ratio
SW1 (2013/11)								0.682
SW1 (2014/04)								1.306
SW1 (2014/07)								1.444
SW10 (2013/11)								2.582
SW10 (2014/04)								1.525
SW10 (2014/07)								1.734
SW2 (2013/11)								2.804
SW2 (2014/04)								1.378
SW2 (2014/07)								1.938
SW3 (2013/11)								1.754
SW3 (2014/04)								1.398
SW3 (2014/07)								1.779
SW4 (2013/11)								1.899
SW4 (2014/04)								1.639
SW4 (2014/07)								1.847
SW5 (2013/11)								0.928
SW5 (2014/04)								0.582
SW5 (2014/07)								0.840
SW6 (2013/11)								2.689
SW6 (2014/04)								1.490
SW6 (2014/07)								1.889
SW7 (2013/11)								2.418
SW7 (2014/04)								1.254
SW7 (2014/07)								2.129
SW8 (2013/11)								2.168
SW8 (2014/04)								2.039
SW8 (2014/07)								2.572
SW9 (2013/11)								2.155
SW9 (2014/04)								1.761
SW9 (2014/07)								3.422

8.5 EXAMPLE OF HOW CN VALUES WERE DETERMINED

	Land Cover Class	HRU1	HRU2	HRU3	HRU4	HRU5
	Natural	16.4%	46.5%	14.4%	12.9%	19.6%
	Cultivation	63.8%	29.8%	46.9%	13.8%	34.5%
	Degraded	0.3%	0.1%	0.1%	7.4%	0.1%
	Urban Built-up	5.0%	18.0%	29.0%	56.2%	36.4%
	Waterbodies	14.5%	5.4%	9.1%	7.8%	3.5%
	Plantations	0.0%	0.2%	0.0%	0.0%	0.0%
	Mines	0.0%	0.0%	0.5%	1.9%	5.9%
	Soil Group	C	C	C	C	C
Curve Number	Natural	74	74	74	74	74
	Cultivation	80	80	80	80	80
	Degraded	90	90	90	90	90
	Urban Built-up	87	87	87	87	87
	Waterbodies	100	100	100	100	100
	Plantations	71	71	71	71	71
	Mines	90	90	90	90	90
	Final CN (AVERAGE)	**82**	**80**	**83**	**86**	**83**

8.6 CN VALUES BASED ON LAND COVER AND SOIL TYPE (SCHULZE ET AL, 1992)

Land Cover Class	Land Treatment/ Practice/Description	Stormflow Potential	Hydrological Soil Group A	A/B	B	B/C	C	C/D	D
Veld (range) and Pasture	1 = Veld/pasture in poor condition	High	68	74	79	83	86	88	89
	2 = Veld/pasture in fair condition	Moderate	49	61	69	75	79	82	84
	3 = Veld/pasture in good condition	Low	39	51	61	68	74	78	80
	4 = Pasture planted on contour	High	47	57	67	75	81	85	88
	5 = Pasture planted on contour	Moderate	25	46	59	67	75	80	83
	6 = Pasture planted on contour	Low	6	14	35	59	70	75	79
Irrigated Pasture		Low	35	41	48	57	65	68	70
Meadow		Low	30	45	58	65	71	75	81
Woods and Scrub	1 = Woods	High	45	56	66	72	77	80	83
	2 = Woods	Moderate	36	49	60	68	73	77	79
	3 = Woods	Low	25	47	55	64	70	74	77
	4 = Brush - Winter rainfall region	Low	28	36	44	53	60	64	66
Orchards	1 = Winter rainfall region, understory of crop cover		39	44	53	61	66	69	71
Forests & Plantations	1 = Humus depth 25mm; Compactness:	compact	52	62	72	77	82	85	87
	2 = " " "	moderate	48	58	68	73	78	82	85
	3 = " " "	loose/friable	37	49	60	66	71	74	77
	4 = Humus depth 50mm; Compactness:	compact	48	58	68	73	78	82	85
	5 = " " "	moderate	42	54	65	70	75	78	81
	6 = " " "	loose/friable	32	45	57	62	67	71	74
	7 = Humus depth 100mm; Compactness:	compact	41	53	64	69	74	77	80
	8 = " " "	moderate	34	47	59	64	69	72	75
	9 = " " "	loose/friable	23	37	50	56	61	64	67
	10 = Humus depth 150mm; Compactness:	compact	37	49	60	66	71	74	77
	11 = " " "	moderate	30	43	56	61	66	69	72
	12 = " " "	loose/friable	18	33	47	52	57	61	65
Urban/Sub-urban Land Uses	1 = Open spaces, parks, cemeteries 75% grass cover		39	51	61	68	74	78	80
	2 = Open spaces, parks, cemeteries 75% grass cover		49	61	69	75	79	82	84
	3 = Commercial/business areas 85% grass cover		89	91	92	93	94	95	95
	4 = Industrial districts 72% impervious		81	85	88	90	91	92	93
	5 = Residential: lot size 500m^2 65% impervious		77	81	85	88	90	91	92
	6 = " " 1000m^2 38% impervious		61	69	75	80	83	85	87
	7 = " " 1350m^2 30% impervious		57	65	72	77	81	84	86
	8 = " " 2000m^2 25% impervious		54	63	70	76	80	83	85
	9 = " " 4000m^2 20% impervious		51	61	68	75	78	82	84
	10 = Paved parking lots, roofs, etc.		98	98	98	98	98	98	98
	11 = Streets/roads: tarred, with storm sewers, curbs		98	98	98	98	98	98	98
	12 = " gravel		76	81	85	88	89	90	91
	13 = " dirt		72	77	82	85	87	88	89
	14 = " dirt-hard surface		74	79	84	88	90	91	92

8.7 MANNING'S N FOR GENERIC SURFACES (ROSSMAN, 2010)

Manning's n – Overland Flow

Surface	n
Smooth asphalt	0.011
Smooth concrete	0.012
Ordinary concrete lining	0.013
Good wood	0.014
Brick with cement mortar	0.014
Vitrified clay	0.015
Cast iron	0.015
Corrugated metal pipes	0.024
Cement rubble surface	0.024
Fallow soils (no residue)	0.05
Cultivated soils	
Residue cover < 20%	0.06
Residue cover > 20%	0.17
Range (natural)	0.13
Grass	
Short, prarie	0.15
Dense	0.24
Bermuda grass	0.41
Woods	
Light underbrush	0.40
Dense underbrush	0.80

Manning's n – Open Channels

Channel Type	Manning n
Lined Channels	
- Asphalt	0.013 - 0.017
- Brick	0.012 - 0.018
- Concrete	0.011 - 0.020
- Rubble or riprap	0.020 - 0.035
- Vegetal	0.030 - 0.40
Excavated or dredged	
- Earth, straight and uniform	0.020 - 0.030
- Earth, winding, fairly uniform	0.025 - 0.040
- Rock	0.030 - 0.045
- Unmaintained	0.050 - 0.140
Natural channels (minor streams, top width at flood stage < 100 ft)	
- Fairly regular section	0.030 - 0.070
- Irregular section with pools	0.040 - 0.100

8.8 FINAL MODEL PARAMETERS

```
[TITLE]
;;Project Title/Notes

[OPTIONS]
;;Option             Value
FLOW_UNITS           CMS
INFILTRATION         CURVE_NUMBER
FLOW_ROUTING         KINWAVE
LINK_OFFSETS         DEPTH
MIN_SLOPE            0.37
ALLOW_PONDING        NO
SKIP_STEADY_STATE    NO

START_DATE           07/01/2004
START_TIME           00:00:00
REPORT_START_DATE    07/01/2004
REPORT_START_TIME    00:00:00
END_DATE             03/31/2015
END_TIME             00:00:00
SWEEP_START          07/01
SWEEP_END            06/30
DRY_DAYS             0
REPORT_STEP          24:00:00
WET_STEP             24:00:00
DRY_STEP             24:00:00
ROUTING_STEP         1:00:00

INERTIAL_DAMPING     PARTIAL
NORMAL_FLOW_LIMITED  BOTH
FORCE_MAIN_EQUATION  H-W
VARIABLE_STEP        0.75
LENGTHENING_STEP     0
MIN_SURFAREA         1.14
MAX_TRIALS           8
HEAD_TOLERANCE       0.0015
SYS_FLOW_TOL         5
LAT_FLOW_TOL         5

[EVAPORATION]
;;Evap Data       Parameters
;;--------------  ----------------
MONTHLY           4.7    4.2    3.6    3      2.7    2.4    2.6    3.6    4.5    5.2    5      4.9
```

```
DRY_ONLY          YES

[RAINGAGES]
;;Gage            Format    Interval SCF      Source
;;--------------  --------- ------ ------ ----------
0476762W          VOLUME    24:00    1.0      FILE       "H:\ERB\Rainfall data\Test\0476762W.dat" 0476762W   MM
0476399W          VOLUME    24:00    1.0      FILE       "H:\ERB\Rainfall data\Test\0476399W.dat" 0476399W   MM

[SUBCATCHMENTS]
;;Subcatchment    Rain Gage         Outlet            Area     %Imperv  Width    %Slope   CurbLen  Snow Pack
;;--------------  ----------------  ----------------  -------- -------- -------- -------- -------- ----------------
S1                0476762W          J1                4807     4.0      541.3    0.68     0
S2                0476762W          J1                2416     1.3      702.3    0.81     0
S3                0476762W          J2                6310     1.5      559.9    0.64     0
S4                0476399W          J3                3613     2.1      561.9    0.95     0
S5                0476399W          J3                7623     23.0     498.9    0.92     0
S6                0476762W          J4                12200    8.6      866.5    0.88     0
S7                0476762W          J2                2651     0.3      417.5    0.79     0
S8                0476762W          J4                367      0.0      244.7    0.69     0
S9                0476762W          J5                4792     6.7      798.7    0.9      0
S10               0476399W          J20               5767     21.5     625.5    1.08     0
S11               0476762W          J6                5808     0.1      702.3    0.69     0
S12               0476399W          J19               3533     12.8     521.9    1.31     0
S13               0476399W          J22               10054    27.7     601.7    1.64     0
S14               0476399W          J19               2255     40.4     1682.8   1.25     0
S15               0476399W          J20               1011     16.1     227.7    1.82     0
S16               0476762W          J7                1992     0.4      350.1    0.84     0
S17               0476762W          J6                6995     0.3      413.2    0.67     0
S18               0476762W          J7                1210     0.8      295.1    0.61     0
S19               0476762W          J5                4578     11.7     385.0    0.83     0
S20               0476399W          J23               7264     4.5      569.7    0.80     0
S21               0476399W          J21               170      52.3     134.3    0.77     0
S22               0476399W          J22               4271     25.4     627.2    0.81     0
S23               0476399W          J21               2567     1.3      389.5    0.72     0
S24               0476762W          J8                1229     2.4      386.5    0.95     0
S25               0476399W          J27               8507     5.8      533.0    0.65     0
S26               0476762W          J8                6119     0.0      351.7    0.83     0
S27               0476762W          J9                146      0.0      51.4     0.37     0
S28               0476762W          J23               7147     3.0      573.6    0.96     0
S29               0476399W          J24               1088     0.0      375.2    1.08     0
S30               0476762W          J9                2606     0.0      285.1    0.74     0
S31               0476762W          J10               2683     3.0      274.9    0.80     0
```

S32	0476762W	J10	1727	0.0	279.0	0.56	0
S33	0476762W	J14	7467	4.7	469.3	0.82	0
S34	0476762W	J24	2927	0.0	351.4	1.11	0
S35	0476399W	J26	7327	0.5	597.1	0.72	0
S36	0476782W	J12	2151	3.0	280.1	0.40	0
S37	0476762W	J11	3510	0.0	471.8	0.96	0
S38	0476762W	J12	2639	0.4	283.8	1.19	0
S39	0476762W	J11	2986	0.0	294.8	1.04	0
S40	0476762W	J16	2576	0.8	325.3	0.96	0
S41	0476399W	J26	1259	0.2	341.2	0.79	0
S42	0476399W	J27	2806	0.2	356.5	1.91	0
S43	0476762W	J25	5743	0.0	552.7	1.38	0
S44	0476399W	J25	4760	0.0	436.7	3.55	0
S45	0476762W	J16	5112	0.1	478.2	1.21	0
S46	0476762W	J17	1169	0.0	200.2	1.17	0
S47	0476762W	J13	1670	1.0	313.1	1.76	0
S48	0476399W	C2H136	5566	1.4	409.8	1.74	0
S49	0476762W	J17	2277	0.5	201.0	0.97	0
S50	0476762W	J15	3829	2.4	595.5	1.06	0
S51	0476762W	J14	720	2.3	240.8	1.21	0
S52	0476762W	J13	2267	0.0	263.3	1.88	0
S53	0476762W	J18	1598	0.0	380.5	1.57	0
S54	0476762W	J18	1174	1.8	170.6	1.29	0
S55	0476762W	J15	2384	0.0	335.8	1.48	0
S56	0476762W	C2H133	4964	2.6	691.4	2.03	0

[SUBAREAS]

;;Subcatchment	N-Imperv	N-Perv	S-Imperv	S-Perv	PctZero	RouteTo	PctRouted
S1	0.01	0.4	0.05	5	0	OUTLET	
S2	0.01	0.4	0.05	5	0	OUTLET	
S3	0.01	0.4	0.05	5	0	OUTLET	
S4	0.01	0.4	0.05	5	0	OUTLET	
S5	0.01	0.4	0.05	5	0	OUTLET	
S6	0.01	0.4	0.05	5	0	OUTLET	
S7	0.01	0.4	0.05	5	0	OUTLET	
S8	0.01	0.4	0.05	5	0	OUTLET	
S9	0.01	0.4	0.05	5	0	OUTLET	
S10	0.01	0.4	0.05	5	0	OUTLET	
S11	0.01	0.4	0.05	5	0	OUTLET	
S12	0.01	0.4	0.05	5	0	OUTLET	
S13	0.01	0.4	0.05	5	0	OUTLET	
S14	0.01	0.4	0.05	5	0	OUTLET	
S15	0.01	0.4	0.05	5	0	OUTLET	
S16	0.01	0.4	0.05	5	0	OUTLET	
S17	0.01	0.4	0.05	5	0	OUTLET	
S18	0.01	0.4	0.05	5	0	OUTLET	
S19	0.01	0.4	0.05	5	0	OUTLET	
S20	0.01	0.4	0.05	5	0	OUTLET	
S21	0.01	0.4	0.05	5	0	OUTLET	
S22	0.01	0.4	0.05	5	0	OUTLET	
S23	0.01	0.4	0.05	5	0	OUTLET	
S24	0.01	0.4	0.05	5	0	OUTLET	
S25	0.01	0.4	0.05	5	0	OUTLET	
S26	0.01	0.4	0.05	5	0	OUTLET	
S27	0.01	0.4	0.05	5	0	OUTLET	
S28	0.01	0.4	0.05	5	0	OUTLET	
S29	0.01	0.4	0.05	5	0	OUTLET	
S30	0.01	0.4	0.05	5	0	OUTLET	
S31	0.01	0.4	0.05	5	0	OUTLET	
S32	0.01	0.4	0.05	5	0	OUTLET	
S33	0.01	0.4	0.05	5	0	OUTLET	
S34	0.01	0.4	0.05	5	0	OUTLET	
S35	0.01	0.4	0.05	5	0	OUTLET	
S36	0.01	0.4	0.05	5	0	OUTLET	
S37	0.01	0.4	0.05	5	0	OUTLET	
S38	0.01	0.4	0.05	5	0	OUTLET	
S39	0.01	0.4	0.05	5	0	OUTLET	
S40	0.01	0.4	0.05	5	0	OUTLET	
S41	0.01	0.4	0.05	5	0	OUTLET	
S42	0.01	0.4	0.05	5	0	OUTLET	
S43	0.01	0.4	0.05	5	0	OUTLET	
S44	0.01	0.4	0.05	5	0	OUTLET	
S45	0.01	0.4	0.05	5	0	OUTLET	
S46	0.01	0.4	0.05	5	0	OUTLET	
S47	0.01	0.4	0.05	5	0	OUTLET	
S48	0.01	0.4	0.05	5	0	OUTLET	
S49	0.01	0.4	0.05	5	0	OUTLET	
S50	0.01	0.4	0.05	5	0	OUTLET	
S51	0.01	0.4	0.05	5	0	OUTLET	
S52	0.01	0.4	0.05	5	0	OUTLET	
S53	0.01	0.4	0.05	5	0	OUTLET	
S54	0.01	0.4	0.05	5	0	OUTLET	
S55	0.01	0.4	0.05	5	0	OUTLET	

```
S56              0.01       0.4        0.05       5          0          OUTLET

[INFILTRATION]
;;Subcatchment   CurveNum   HydCon     DryTime
;;-------------- ---------- ---------- ----------
S1               82         0.5        7.0
S2               80         0.5        7.0
S3               83         0.5        7.0
S4               86         0.5        7.0
S5               83         0.5        7.0
S6               83         0.5        7.0
S7               80         0.5        7.0
S8               84         0.5        7.0
S9               84         0.5        7.0
S10              76         0.5        7.0
S11              83         0.5        7.0
S12              76         0.5        7.0
S13              74         0.5        7.0
S14              77         0.5        7.0
S15              83         0.5        7.0
S16              81         0.5        7.0
S17              79         0.5        7.0
S18              85         0.5        7.0
S19              84         0.5        7.0
S20              81         0.5        7.0
S21              81         0.5        7.0
S22              84         0.5        7.0
S23              83         0.5        7.0
S24              86         0.5        7.0
S25              85         0.5        7.0
S26              80         0.5        7.0
S27              89         0.5        7.0
S28              83         0.5        7.0
S29              81         0.5        7.0
S30              79         0.5        7.0
S31              83         0.5        7.0
S32              84         0.5        7.0
S33              81         0.5        7.0
S34              82         0.5        7.0
S35              81         0.5        7.0
S36              88         0.5        7.0
S37              78         0.5        7.0
S38              79         0.5        7.0
S39              78         0.5        7.0
S40              82         0.5        7.0
S41              82         0.5        7.0
S42              82         0.5        7.0
S43              74         0.5        7.0
S44              79         0.5        7.0
S45              73         0.5        7.0
S46              72         0.5        7.0
S47              78         0.5        7.0
S48              80         0.5        7.0
S49              81         0.5        7.0
S50              79         0.5        7.0
S51              79         0.5        7.0
S52              77         0.5        7.0
S53              77         0.5        7.0
S54              77         0.5        7.0
S55              78         0.5        7.0
S56              78         0.5        7.0

[JUNCTIONS]
;;Junction       Invert     Dmax       Dinit      Dsurch     Aponded
;;-------------- ---------- ---------- ---------- ---------- ----------
J1               1591.65    0          0          0          0
J2               1580       0          0          0          0
J3               1578.98    0          0          0          0
J4               1575.30    0          0          0          0
J5               1571.94    0          0          0          0
J6               1571.74    0          0          0          0
J7               1569.20    0          0          0          0
J8               1566.33    0          0          0          0
J9               1566.15    0          0          0          0
J10              1566.14    0          0          0          0
J11              1566.13    0          0          0          0
J12              1566.12    0          0          0          0
J13              1556.21    0          0          0          0
J14              1543.02    0          0          0          0
J15              1529.41    0          0          0          0
J16              1528.80    0          0          0          0
J17              1527.26    0          0          0          0
J18              1525.99    0          0          0          0
J19              1523.98    0          0          0          0
```

```
J20              1521.99    0          0          0          0
J21              1519.46    0          0          0          0
J22              1518       0          0          0          0
J23              1516.98    0          0          0          0
J24              1513.48    0          0          0          0
J25              1512.09    0          0          0          0
J26              1509.90    0          0          0          0
J27              1496.96    0          0          0          0

[OUTFALLS]
;;Outfall        Invert     Type       Stage Data       Gated
;;-------------- ---------- ---------- ---------------- --------
C2H133           1512.53    FREE                        NO
C2H136           1476.02    FREE                        NO

[CONDUITS]
;;Conduit        From Node        To Node          Length     Roughness  InOffset   OutOffset  InitFlow   MaxFlow
;;-------------- ---------------- ---------------- ---------- ---------- ---------- ---------- ---------- ----------
C1               J1               J2               11270      4.0        0          0          0          0
C2               J2               J4               1500       4.0        0          0          0          0
C3               J3               J4               14080      0.4        0          0          0          0
C4               J4               J5               6000       4.0        0          0          0          0
C5               J5               J7               4100       4.0        0          0          0          0
C6               J6               J7               5690       4.0        0          0          0          0
C7               J7               J8               3180       4.0        0          0          0          0
C8               J8               J9               2840       4.0        0          0          0          0
C9               J9               J10              4150       4.0        0          0          0          0
C10              J10              J12              7680       4.0        0          0          0          0
C11              J11              J12              9300       0.4        0          0          0          0
C12              J12              J13              5360       4.0        0          0          0          0
C13              J13              J14              2990       4.0        0          0          0          0
C14              J14              J15              6430       0.4        0          0          0          0
C15              J16              J17              5840       0.4        0          0          0          0
C16              J17              J18              4200       0.4        0          0          0          0
C17              J15              J18              6800       0.4        0          0          0          0
C18              J18              C2H133           7180       0.4        0          0          0          0
C19              J19              J20              4440       0.4        0          0          0          0
C20              J20              J21              1266       4.0        0          0          0          0
C21              J21              J22              6810       4.0        0          0          0          0
C22              J22              J27              15960      4.0        0          0          0          0
C23              J23              J24              2900       0.4        0          0          0          0
C24              J24              J26              12270      0.4        0          0          0          0


C25              J25              J26              3690       0.4        0          0          0          0
C26              J26              J27              7870       0.4        0          0          0          0
C27              J27              C2H136           14560      0.4        0          0          0          0

[XSECTIONS]
;;Link           Shape        Geom1            Geom2      Geom3      Geom4      Barrels
;;-------------- ------------ ---------------- ---------- ---------- ---------- ----------
C1               TRAPEZOIDAL  2                10         45         45         1
C2               TRAPEZOIDAL  2                10         45         45         1
C3               TRAPEZOIDAL  1.9              11.5       45         45         1
C4               TRAPEZOIDAL  3                400        45         45         1
C5               TRAPEZOIDAL  3.19             400        45         45         1
C6               TRAPEZOIDAL  2                10         45         45         1
C7               TRAPEZOIDAL  2                10         45         45         1
C8               TRAPEZOIDAL  2                10         45         45         1
C9               TRAPEZOIDAL  2                20         45         45         1
C10              TRAPEZOIDAL  2.2              100        45         45         1
C11              TRAPEZOIDAL  2                10         45         45         1
C12              TRAPEZOIDAL  2                30         45         45         1
C13              TRAPEZOIDAL  2                30         45         45         1
C14              TRAPEZOIDAL  1.7              30         45         45         1
C15              TRAPEZOIDAL  2                10         45         45         1
C16              TRAPEZOIDAL  2                10         45         45         1
C17              TRAPEZOIDAL  2                30         45         45         1
C18              TRAPEZOIDAL  2                10         45         45         1
C19              TRAPEZOIDAL  2                10         45         45         1
C20              TRAPEZOIDAL  2                10         45         45         1
C21              TRAPEZOIDAL  2                200        45         45         1
C22              TRAPEZOIDAL  3                400        45         45         1
C23              TRAPEZOIDAL  2                10         45         45         1
C24              TRAPEZOIDAL  2                10         45         45         1
C25              TRAPEZOIDAL  2                10         45         45         1
C26              TRAPEZOIDAL  2.2              10         45         45         1
C27              TRAPEZOIDAL  3.95             10         45         45         1

[LOSSES]
;;Link           Kin        Kout       Kavg       Flap Gate  SeepRate
;;-------------- ---------- ---------- ---------- ---------- ----------

[POLLUTANTS]
;;Pollutant      Units  Cppt       Cgw        Crdii      Kdecay     SnowOnly   Co-Pollutant     Co-Frac    Cdwf
Cinit
```

```
;;-------------- ------ ---------- ---------- ---------- ---------- ---------- ---------------- ---------- ---------- ---
-------
TDS              MG/L   0.0        0.0        0.0        0.0        NO         *                0.0        0.0        0.0
SO4              MG/L   0.0        0.0        0.0        0.0        NO         *                0.0        0.0        0.0

[LOADINGS]
;;Subcatchment   Pollutant        InitLoad
;;-------------- ---------------- ----------

[INFLOWS]
;;Node           Inflow           Time Series      Type     Funits   Fscale   Baseline Pattern
;;-------------- ---------------- ---------------- -------- -------- -------- -------- --------
J2               FLOW             ""               FLOW     1.0      1.0      0.185185
J3               FLOW             ""               FLOW     1.0      1.0      0.150463
J4               FLOW             ""               FLOW     1.0      1.0      0.694445
J8               FLOW             ""               FLOW     1.0      1.0      0.37037
J11              FLOW             ""               FLOW     1.0      1.0      -0.0243
J14              FLOW             ""               FLOW     1.0      1.0      0.023148
J16              FLOW             ""               FLOW     1.0      1.0      0.115741
J27              FLOW             ""               FLOW     1.0      1.0      2.5

[PATTERNS]
;;Pattern        Type       Multipliers
;;-------------- ---------- -----------
J12              MONTHLY    535   513   435   526   579   581
J12                         582   582   581   562   548   469

[REPORT]
;;Reporting Options
INPUT      NO
CONTROLS   NO
SUBCATCHMENTS ALL
NODES ALL
LINKS ALL

[TAGS]

[MAP]
DIMENSIONS 0.000 0.000 10000.000 10000.000
Units      None

[COORDINATES]




;;Node           X-Coord            Y-Coord
;;-------------- ------------------ ------------------
J1               6342.513           8332.616
J2               6936.317           7058.950
J3               5275.387           7446.213
J4               6996.558           6884.682
J5               7228.916           5957.401
J6               7933.590           6088.609
J7               7421.590           5528.609
J8               7501.590           5096.609
J9               7605.590           4706.609
J10              7441.590           4074.609
J11              7637.590           3714.609
J12              7393.590           3274.609
J13              7121.590           2978.609
J14              6693.590           3146.609
J15              6113.590           2426.609
J16              5233.590           3326.609
J17              5469.590           2906.609
J18              5801.590           2418.609
J19              2545.590           6396.609
J20              2689.590           5868.609
J21              2629.590           5728.609
J22              1953.590           5244.609
J23              4029.590           4852.609
J24              3825.590           4496.609
J25              2908.590           3420.609
J26              2441.590           3516.609
J27              1901.590           3260.609
C2H133           4909.639           1825.559
C2H136           717.590            2824.609

[VERTICES]
;;Link           X-Coord            Y-Coord
;;-------------- ------------------ ------------------

[Polygons]
;;Subcatchment   X-Coord            Y-Coord
;;-------------- ------------------ ------------------
S1               5994.055           9047.226
S1               5994.055           9043.923
S1               5994.055           9050.526
```

S2	5723.250	8254.624
S2	5723.250	8254.624
S2	5726.552	8254.624
S3	6515.852	7861.625
S3	6512.550	7861.625
S3	6519.155	7864.927
S4	4838.177	7980.515
S4	4834.875	7970.608
S4	4838.177	7970.608
S5	3754.954	7521.466
S5	3758.256	7524.768
S5	3754.954	7524.769
S6	5647.292	6798.217
S6	5647.292	6798.217
S6	5647.292	6798.217
S7	7381.110	7372.853
S7	7374.505	7372.853
S7	7377.807	7379.458
S8	6974.901	6953.435
S8	6971.598	6953.435
S8	6978.203	6953.435
S9	7315.059	6520.806
S9	7315.059	6524.108
S9	7311.757	6524.108
S10	3421.400	6646.301
S10	3428.005	6646.301
S10	3414.795	6646.301
S11	8550.198	6587.703
S11	8546.896	6591.005
S11	8546.896	6594.308
S12	2496.697	6963.342
S12	2503.303	6969.947
S12	2503.303	6963.342
S13	1030.383	6500.991
S13	1023.778	6500.991
S13	1030.383	6500.991
S14	2021.136	6560.436
S14	2021.136	6560.436
S14	2014.531	6567.041
S15	2523.118	6144.320
S15	2529.723	6150.925
S15	2523.118	6150.925

S16	7800.528	5900.780
S16	7797.226	5897.478
S16	7800.528	5897.478
S17	9071.995	5524.273
S17	9065.390	5520.971
S17	9068.692	5520.971
S18	7255.614	5732.352
S18	7258.917	5729.050
S18	7258.917	5729.050
S19	6198.811	5530.878
S19	6202.114	5537.483
S19	6195.509	5530.878
S20	4260.238	5873.514
S20	4260.238	5860.304
S20	4253.633	5873.514
S21	2589.168	5858.653
S21	2589.168	5858.653
S21	2589.168	5855.350
S22	2133.421	5564.729
S22	2136.724	5558.124
S22	2133.421	5561.427
S23	3130.779	5701.783
S23	3143.989	5688.573
S23	3143.989	5688.573
S24	7331.572	5203.930
S24	7328.269	5207.232
S24	7331.572	5213.838
S24	7328.269	5203.930
S25	2252.310	4676.375
S25	2252.312	4683.980
S25	2258.917	4676.375
S26	9154.557	4781.209
S26	9151.255	4777.906
S26	9154.557	4784.511
S27	7603.270	5046.262
S27	7607.573	5013.990
S27	7515.060	5011.839
S27	7515.060	5052.716
S28	5191.546	5224.592
S28	5191.546	5224.592
S28	5190.151	5217.987
S29	3834.214	4741.599

829	3830.911	4739.548
829	3829.260	4741.559
830	8378.468	4559.941
830	8368.560	4556.638
830	8368.560	4559.941
831	6872.523	4969.452
831	6875.826	4969.452
831	6879.128	4964.452
832	7767.503	4285.832
832	7767.503	4285.832
832	7767.503	4279.227
833	6449.802	4242.900
833	6453.104	4239.597
833	6449.802	4242.900
834	4547.556	4261.063
834	4547.556	4257.761
834	4550.859	4257.761
835	3279.392	4284.181
835	3276.090	4280.878
835	3272.787	4280.878
836	7367.900	3919.254
836	7367.900	3915.951
836	7371.202	3919.254
837	8503.963	3952.279
837	8503.963	3955.581
837	8503.963	3952.279
838	7869.881	3057.299
838	7866.579	3063.904
838	7863.276	3060.601
839	8368.560	3176.189
839	8368.560	3179.491
839	8368.560	3179.491
840	5217.968	4006.770
840	5217.968	4010.073
840	5224.571	4006.770
841	3031.704	3484.974
841	3028.402	3488.276
841	3025.099	3481.671
842	2341.480	2887.219
842	2341.480	2877.312
842	2341.480	2880.614
843	3639.366	3082.067

843	3639.366	3072.160
843	3639.366	3075.462
844	2955.746	2623.018
844	2955.746	2616.413
844	2955.746	2613.111
845	4633.421	3270.310
845	4630.119	3270.310
845	4630.119	3267.008
846	5155.218	2986.295
846	5158.520	2986.295
846	5158.520	2982.992
847	7559.445	2786.493
847	7562.748	2789.795
847	7562.748	2786.493
848	1651.255	3088.672
848	1651.255	3095.277
848	1654.557	3095.277
849	5785.997	3851.552
849	5795.905	3854.855
849	5799.207	3848.250
850	6314.399	3002.807
850	6317.701	3006.110
850	6314.399	2999.505
851	6938.573	2956.572
851	6945.178	2963.177
851	6938.573	2963.177
852	7308.454	2476.057
852	7311.757	2479.359
852	7308.454	2472.754
853	5591.149	2738.606
853	5587.847	2745.211
853	5587.847	2748.514
854	6159.181	2094.617
854	6162.483	2104.524
854	6165.786	2097.919
855	6829.590	2107.827
855	6829.590	2104.524
855	6826.288	2104.524
856	5445.839	2025.264
856	5442.536	2028.567
856	5449.141	2031.869

```
[SYMBOLS]
;;Gage            X-Coord            Y-Coord
;;--------------  ------------------ ------------------
04767620W         6184.000           6916.000
04763950W         2878.864           7701.453

[BACKDROP]
FILE       "H:\ERB\Background\Background2.bmp"
DIMENSIONS 0.000 367.012 10000.000 9632.988
```