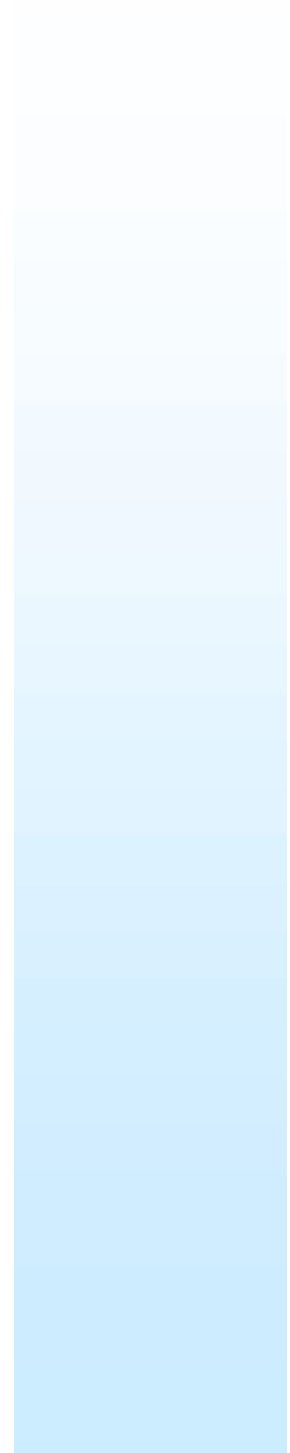
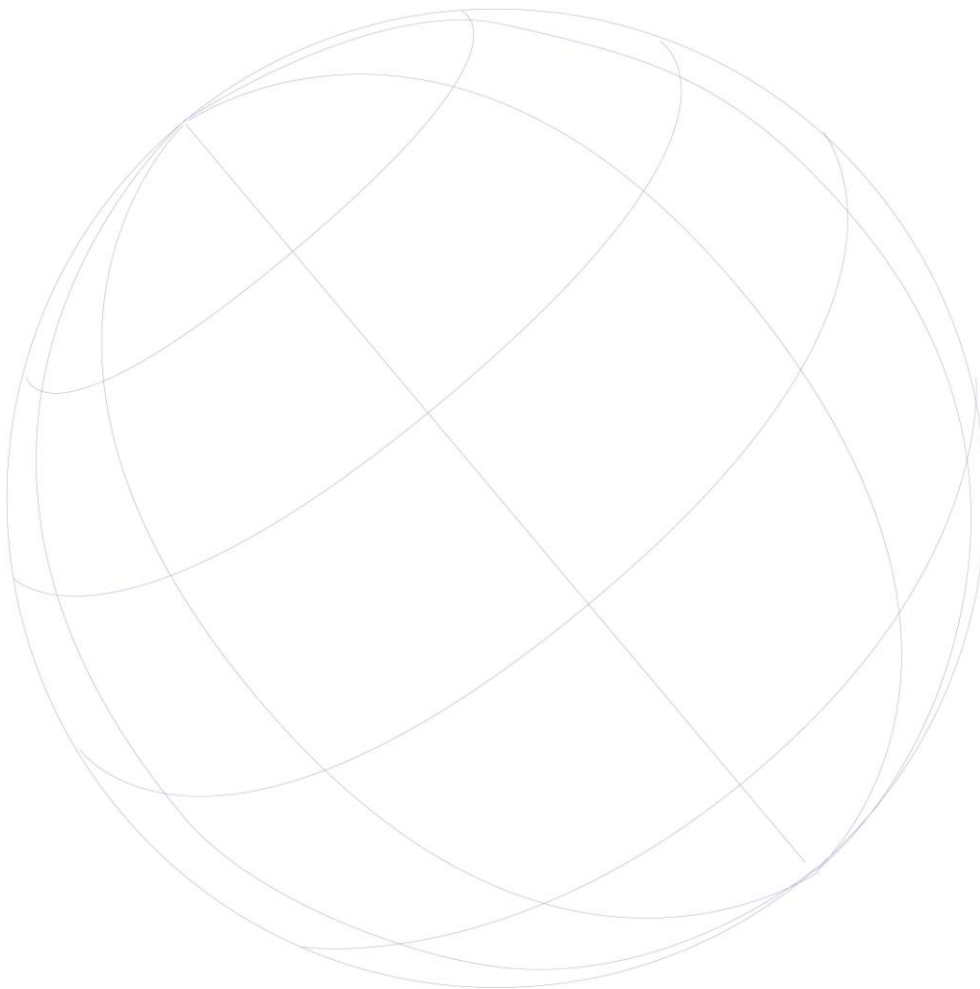


**WELBEDACHT BULK WATER SUPPLY: NUMERICAL
MODELLING OF GROUNDWATER POTENTIAL – 2005
MODEL UPDATE**



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Project Report

AQS/KHULANI/2005/001

Project:

Groundwater Modelling for Welbedacht Bulk Water Supply

Report:

**Welbedacht Bulk Water Supply: Numerical Modelling of
Groundwater Potential – 2005 Model Update**

August 2005

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EXECUTIVE SUMMARY

Terms of reference

Khulani GeoEnviro Consultants (KGC), a member of the Bogare Consultants Consortium (BCC) appointed AquiSim Consulting to update the existing groundwater model for the dolomitic compartments to the west and southwest of the Town of Zeerust in the Uitvalgrond, Tweefontein South and Paardenvallei areas. These areas fall within the larger modelled area that was constructed as part of a dolomitic modelling study conducted during 2003 by the PMA Consortium. The update of the 2003 model is required in order to determine the feasibility of supplying the Welbedacht Bulk Water with 40l/s over a 24 hour pumping cycle. This supply load has to be spread across the Uitvalgrond, Tweefontein South and Paardenvallei Compartments. The model is further required in order to determine the possible effect of a reduction in springflow from the Paardenvallei and Vergenoegd Springs and other natural losses as a result of this abstraction.

Objectives

The following study objectives were stipulated by KGC to be achieved at the end of the modelling study:

- Determine the feasibility to supply 6l/s from the Uitvalgrond Compartment;
- Determine the feasibility to supply 10l/s from the Tweefontein South Compartment;
- Determine the feasibility to supply 30l/s from the Paardenvallei Compartment. This rate is in addition to the current estimated abstraction rate of 29l/s being abstracted from this compartment;
- Determine the impact of this abstraction on water levels and springflow rates and other natural system losses.

Conclusions

With regards to the objectives the following is concluded:

- The minimum simulated long-term springflow from the Wolwekoppies Spring is in the order of 8l/s. It is therefore feasible to abstract 6l/s from the Uitvalgrond Compartment. Simulations indicate that at this rate there is an 80% chance that the Wolwekoppies Spring will stop flowing. At this rate there is a 40% chance to get a 6m or more water level drawdown. Recharge events to the aquifer has the effect however that water levels do

recover in the compartment even after periods of droughts. It can be concluded that the abstraction of 6l/s from the Uitvalgrond Compartment should have no detrimental effect on water levels in the long term.

- The minimum simulated long-term recharge rate to the Tweefontein South Compartment is in the order of 25l/s. It is therefore feasible to abstract 10l/s from the Tweefontein South Compartment. According to simulations there is a 60% chance to get a drawdown of 6m or more when considering the worst case scenario. Considering the most likely scenario, there is a 20% chance of a drawdown of more than 6m.in the compartment. Recharge events to the aquifer has the effect however that water levels do recover in the compartment even after periods of droughts. It can therefore be concluded that the abstraction of 10l/s from the Tweefontein South Compartment should have no detrimental effect on water levels in the long term. Water levels in the Tweefontein South Compartment will be influenced by abstraction from the Paardenvallei Compartment.
- The minimum simulated long-term compartment potential of the Paardenvallei Compartment is in the order of 146l/s. Current abstraction from this compartment is in the order of 30l/s. The compartment should therefore be able to sustain a further 30l/s. There is a 60% chance to get a drawdown of 6m or more when considering the worst case scenario. The most likely scenario indicates that there is a low risk of getting a drawdown of more than 6m in the compartment. It can therefore be concluded that the additional abstraction of 30l/s from the Paardenvallei Compartment should have no detrimental effect on water levels in the long term. The simulations indicated that water levels do recover in the compartment even after periods of droughts. Simulations indicated that the impact on the Paardenvallei Spring would be between 10 and 30l/s. Impact on the Vergenoegd Spring would be between 5 and 15l/s.

Recommendations

The following is recommended:

- Drilling of production boreholes as per the recommendation of KGC (2005);
- A water-monitoring program must be established from the start of wellfield inception with careful monitoring of abstraction rates and water level drawdown in pumping as well as in monitoring boreholes. Wellfield and aquifer performance must be evaluated every six months in order to take corrective actions if necessary. The groundwater flow model

established during this study must be updated on an annual basis using the monitoring information.

- No additional abstraction capacity should be installed within the compartments considered for this investigation as this may lead to overexploitation of the resource. Further exploitation must be preceded by a proper analysis of monitoring data.
- It is recommended that this FEFLOW model be used as the modelling basis for any future modelling exercises.
- It is further recommended that spring flow and other existing monitoring boreholes be monitored on a monthly basis.

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1 INTRODUCTION

1.1 Terms of reference

Khulani GeoEnviro Consultants (KGC), a member of the Bogare Consultants Consortium (BCC) appointed AquiSim Consulting to update the existing groundwater model for the dolomitic compartments to the west and southwest of the Town of Zeerust in the Uitvalgrond, Tweefontein South and Paardenvallei areas. These areas fall within the larger modelled area that was constructed as part of a dolomitic modelling study conducted during 2003 by the PMA Consortium. It covers the larger dolomitic area from Molopo Spring in the southeast to the Dinokana Spring and further to the northwest towards the Botswana border (see Figure 1).

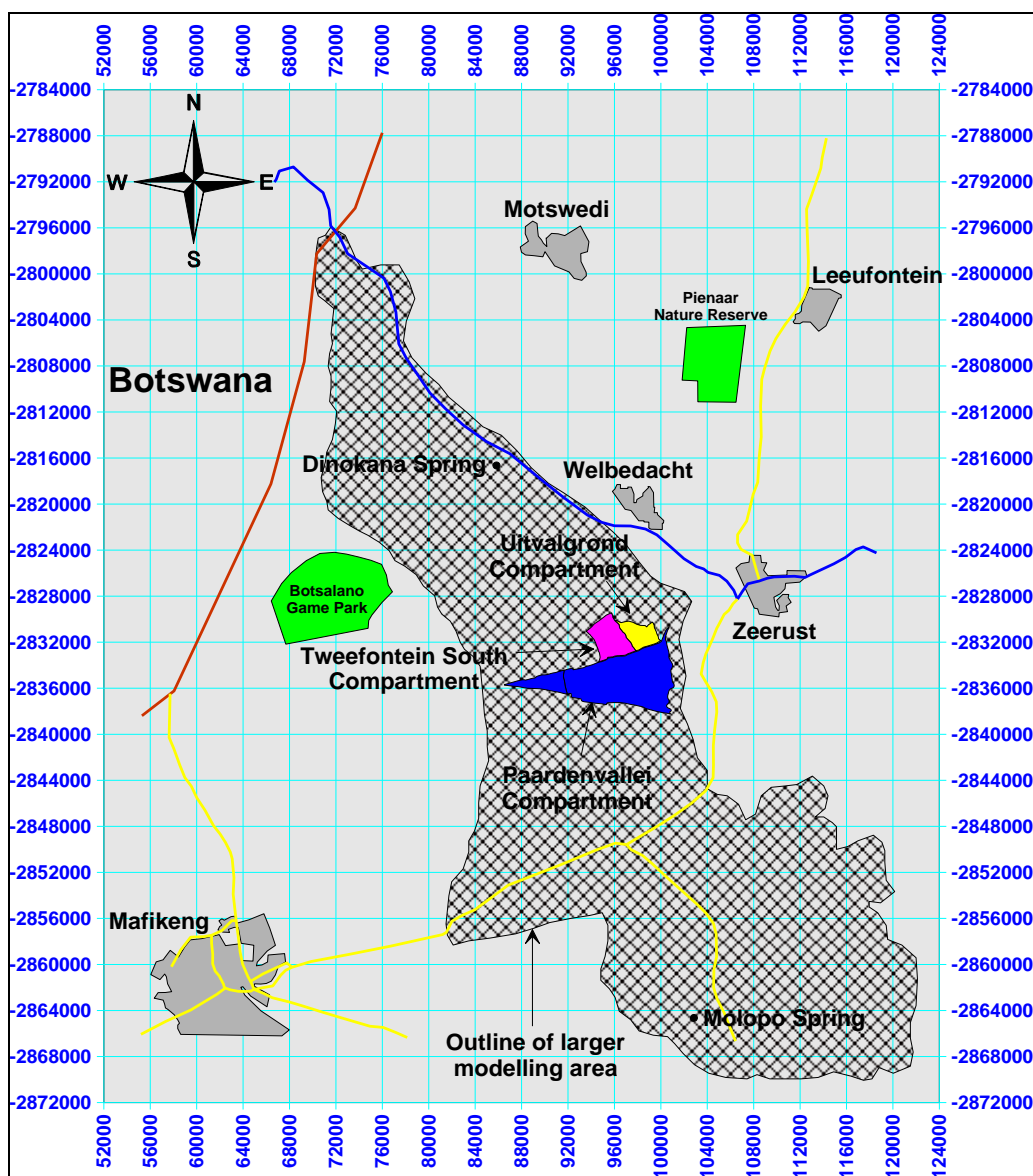


Figure 1 – Locality map showing study and modelled area.

As described in KGC (2005) the 2003 PMA Consortium study entailed:

- Detailed delineation of over 50 dolomite compartments, including the Dinokana, Doornfontein, Rietpoort and Slurry wellfields;
- A comprehensive and very detailed three-dimensional numerical model was compiled to study the rainfall to recharge relationship, spring flows, water level fluctuations and sustainable water supply potential within the various compartments over a 30-year rainfall period.

The update of the 2003 model is required in order to determine the feasibility of supplying the Welbedacht Bulk Water with 40l/s over a 24 hour pumping cycle. This supply load has to be spread across the Uitvalgrond, Tweefontein South and Paardenvallei Compartments (Figure 1). The model is further required in order to determine the possible effect of a reduction in springflow from the Paardenvallei and Vergenoegd Springs and other natural losses as a result of this abstraction. Figure 2 shows the position of these two springs within the Paardenvallei Compartment.

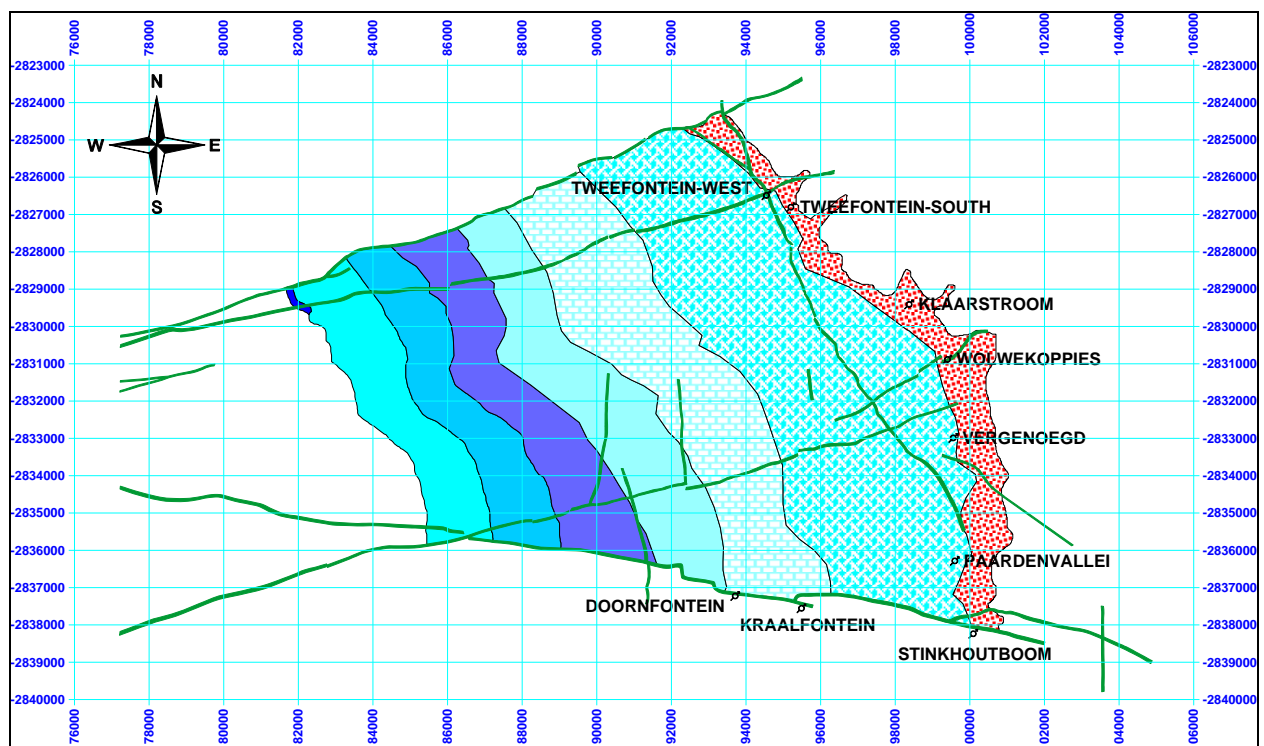


Figure 2 – Positions of springs in the Study Area.

1.2 Background

The request for the update of the larger 2003 model in the Uitvalgrond, Tweefontein South and Paardenvallei areas followed from additional aquifer information that was obtained by KGC during a geohydrological investigation conducted for the re-evaluation of the groundwater resource in the Uitvalgrond area. This groundwater resource re-evaluation was required following the failure of the Uitvalgrond wellfield supplying the recommended 30l/s to supply the Welbedacht area. Background information pertaining to the original development and failure of the Uitvalgrond wellfield is provided in Africon (2002) and KGC (2005). During the re-evaluation KGC conducted the following tasks:

- A desk study to review all existing data;
- An extensive gravity survey grid over an area of 45km² and combination thereof with the existing Africon (2002) survey in the area of the Uitvalgrond wellfield to determine the spatial distribution and depth extent of leached dolomite zones in target dolomite compartments;
- Hydrocensus survey of all existing boreholes and springs;
- Leveling of boreholes and springs and using this information as reference to refine compartment boundaries;
- Identification of major saturated leached dolomite zones in the different compartments and potential boundaries to groundwater flow related to shallow bedrock zones;
- Drilling and testing of exploration and monitoring boreholes.

The information collected and collated by KGC (2005) are used in this study to update and refine the regional 3D groundwater model of the Zeerust Dolomite Compartments to determine the long-term impact of the recommended groundwater abstraction on water levels and spring flows.

1.3 Study Objectives

The following study objectives were stipulated by KGC to be achieved at the end of the modelling study:

- Determine the feasibility to supply 6l/s from the Uitvalgrond Compartment;
- Determine the feasibility to supply 10l/s from the Tweefontein South Compartment;

- Determine the feasibility to supply 30l/s from the Paardenvallei Compartment. This rate is in addition to the current estimated abstraction rate of 29l/s being abstracted from this compartment;
- Determine the impact of this abstraction on water levels and springflow rates and other natural system losses.

1.4 Scope of Work

In order to achieve the study objectives the following scope of work was adopted:

- Refine the existing groundwater flow model using the interpreted spatial distribution and depth extent of leached dolomite zones in target dolomite compartments based on results obtained by the gravimetric survey (KGC, 2005);
- Calibrate the refined groundwater model for steady state groundwater flow conditions using the water level and spring flow information obtained;
- Calibrate the refined groundwater model for transient state groundwater flow conditions using the abstraction and water level data in the Uitvalgrond Wellfield over the period April 2003 to April 2005;
- Calibrate the refined groundwater model for transient state groundwater flow conditions using the spring flow, abstraction and water level data over the period 1971-2002 incorporating the long-term rainfall record available for the study area.
- Utilize the calibrated flow model to achieve the objectives of the study as outlined in Section 1.3.

2 PHYSICAL DESCRIPTION OF STUDY AREA

The groundwater flow in the aquifer depends on the physical properties of the site. For a numerical model to be useful as a predictive tool, it is necessary to integrate the physical geometry and properties of the site into the model. Controlling factors are the topography and relief, surface hydrology and rainfall, geology, as well as the properties of the aquifer system.

2.1 Locality of the Study Area

The Uitvalgrond dolomitic area is situated about 6km to the southwest of the town of Zeerust. This source is being used for augmentation purposes of the water supply to the Zeerust and Welbedacht areas. Welbedacht is located due north of the study area. The location of the study area is shown in Figure 1. The study area for the 2003 modelling area and the modelling area updated during the current investigation overlain on the regional geology map is shown on Figure 3.

2.2 Topography and Base of Dolomite

The topography and base of dolomite respectively form the upper and lower boundaries of the groundwater flow model. For the 2003 model these two surfaces are depicted in Figure 4.

KGC (2005) conducted field investigations comprising of surveying of an extensive gravity grid within the study area, covering an area of 45km². This survey was essential in order to determine the depth to bedrock, which also then determines the aquifer depth. The survey was performed across the study area along north-south (E) and east-west (S) lines at a 300m-line interval, and 50m-station interval along lines. The survey area, totalling 5483 stations, targeted the most productive chert-rich Eccles dolomite formations within the relevant compartments and identified as a minimum requirement drilling targets, major saturated leached dolomite zones and dolomite bedrock elevations. Figure 5 shows the altered bedrock configuration for the 2005-updated model using the gravimetric survey results. Figure 6 shows the area under investigation in more detail. The gravity survey indicates a prominent but localised highly leached or weathered dolomite zone at the existing production boreholes of the Uitvalgrond Wellfield. This implies a major but localised dolomite aquifer. The gravity further indicates a prominent east-west zone of solid dolomite with limited depths to bedrock located between the Wolwekoppies and Klaarstroom Springs. This east-west solid dolomite zone indicates poor hydraulic connectivity between the two springs, and may act as a compartment boundary. A similar solid bedrock zone is present, located to the south of the Uitvalgrond Wellfield production boreholes, which limits potential groundwater flow from the Vergenoegd/Paardenvallei compartment towards the Uitvalgrond Wellfield (see Figure 6).

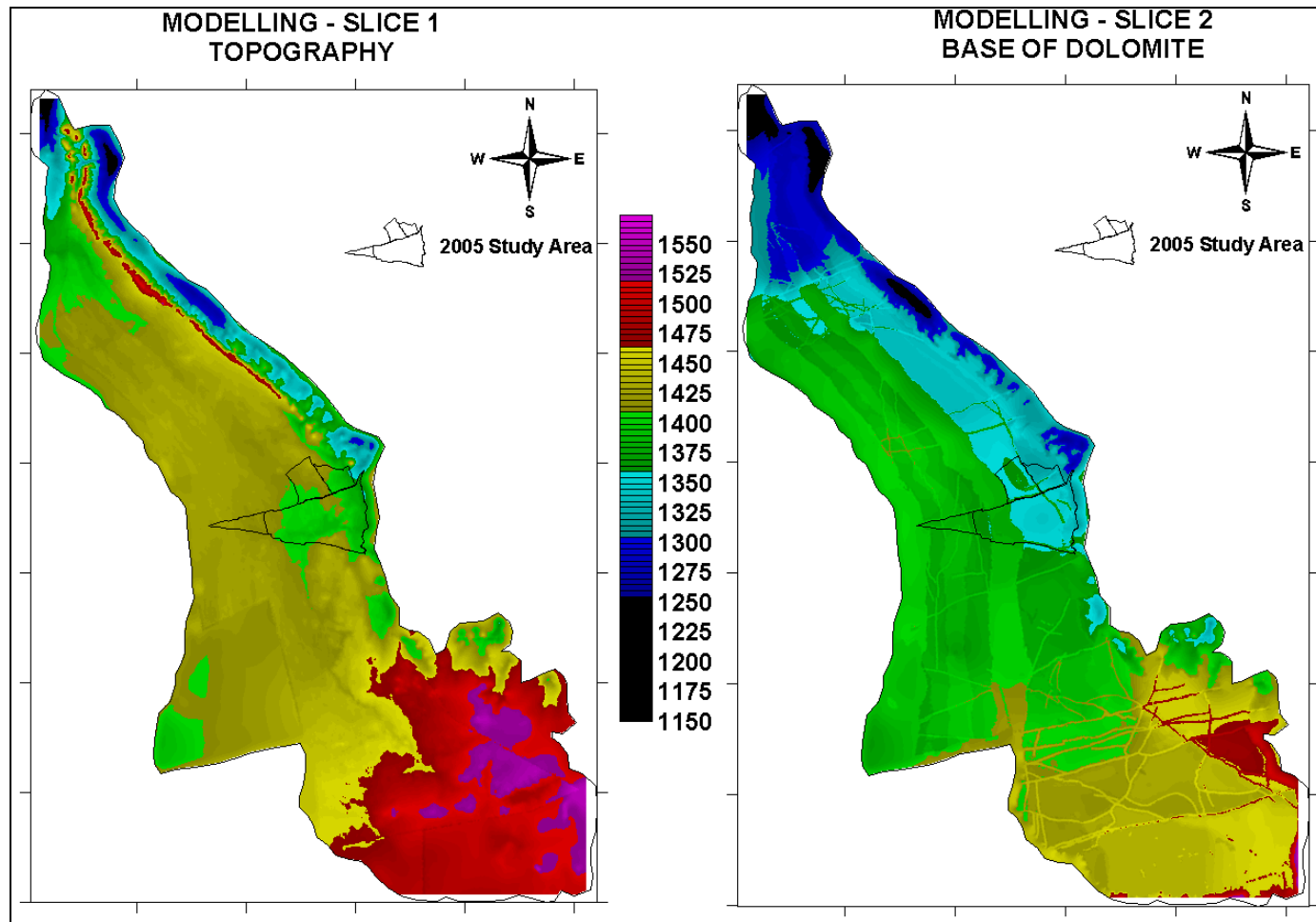


Figure 4 – Topography and base of dolomite used for the upper and lower modelling boundaries (2003 model).

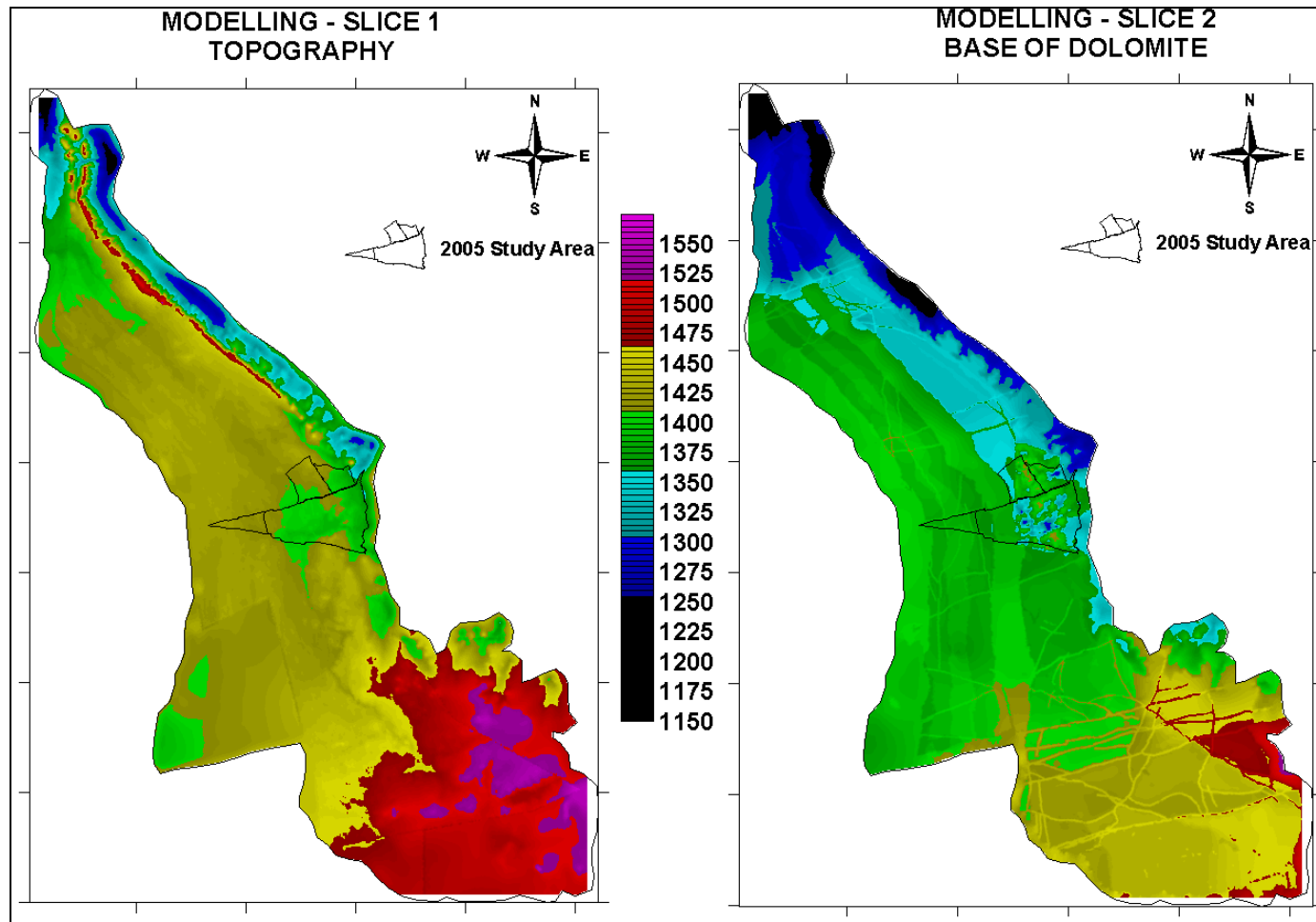


Figure 5 – Topography and base of dolomite used for the upper and lower modelling boundaries (2005 model).

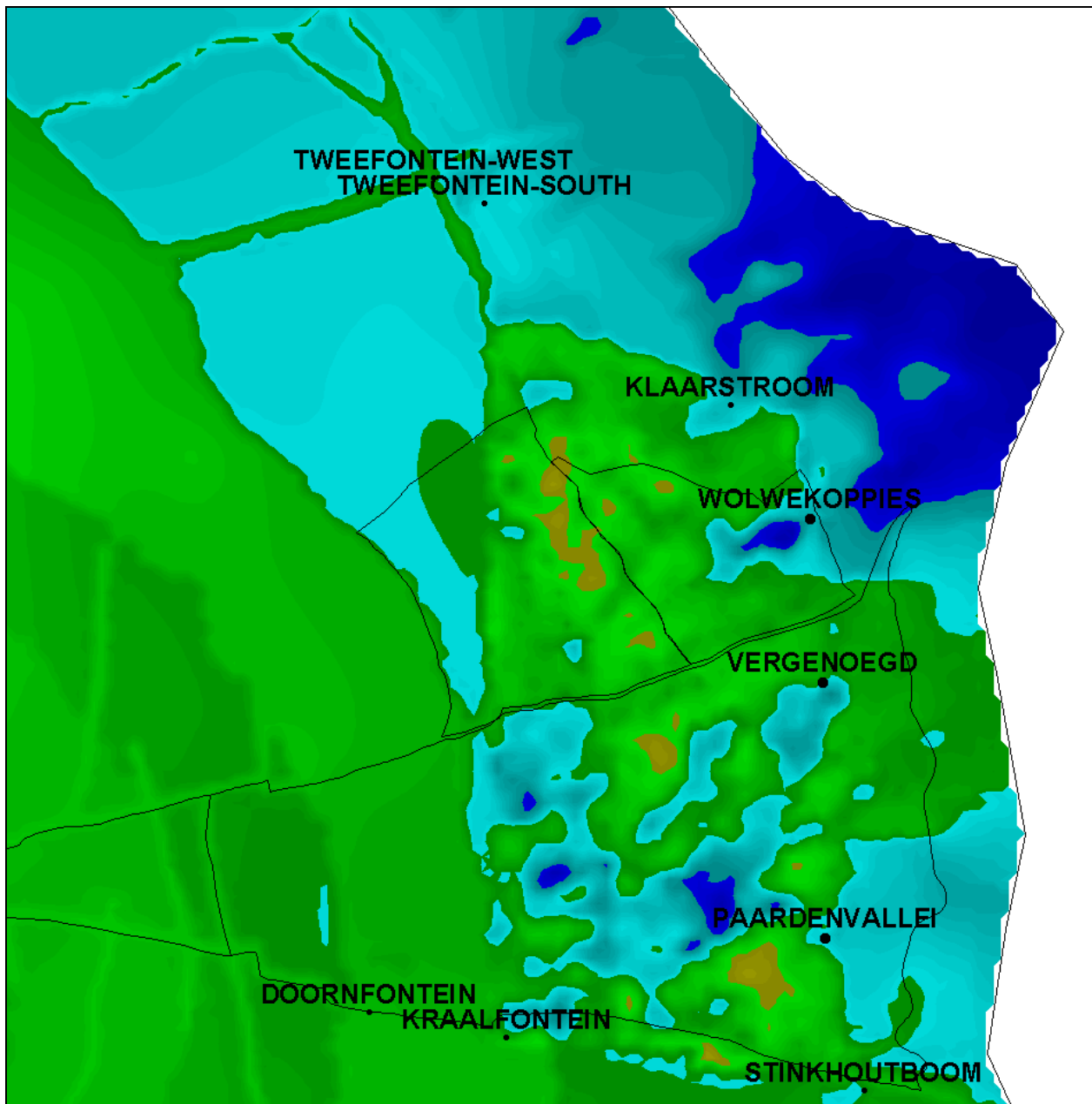


Figure 6 – Dolomite bedrock based on gravimetric results within the study area.

2.3 Rainfall and Climate

The study area falls within the summer rainfall region and rain occurs mainly in the form of thunderstorms. The annual average rainfall is in the order of between 480 and 560mm as measured at the rainfall stations of Rietpoort and Ottoshoop respectively. Seasonal fluctuations as well as persisting dry and wet years can cause much variability in monthly and yearly rainfall figures. The climate is characterised by high daytime temperatures during summer months, cold nights during the winter, and below freezing conditions occurring occasionally in the winter. Figure 7 shows the monthly figures as recorded at Ottoshoop.

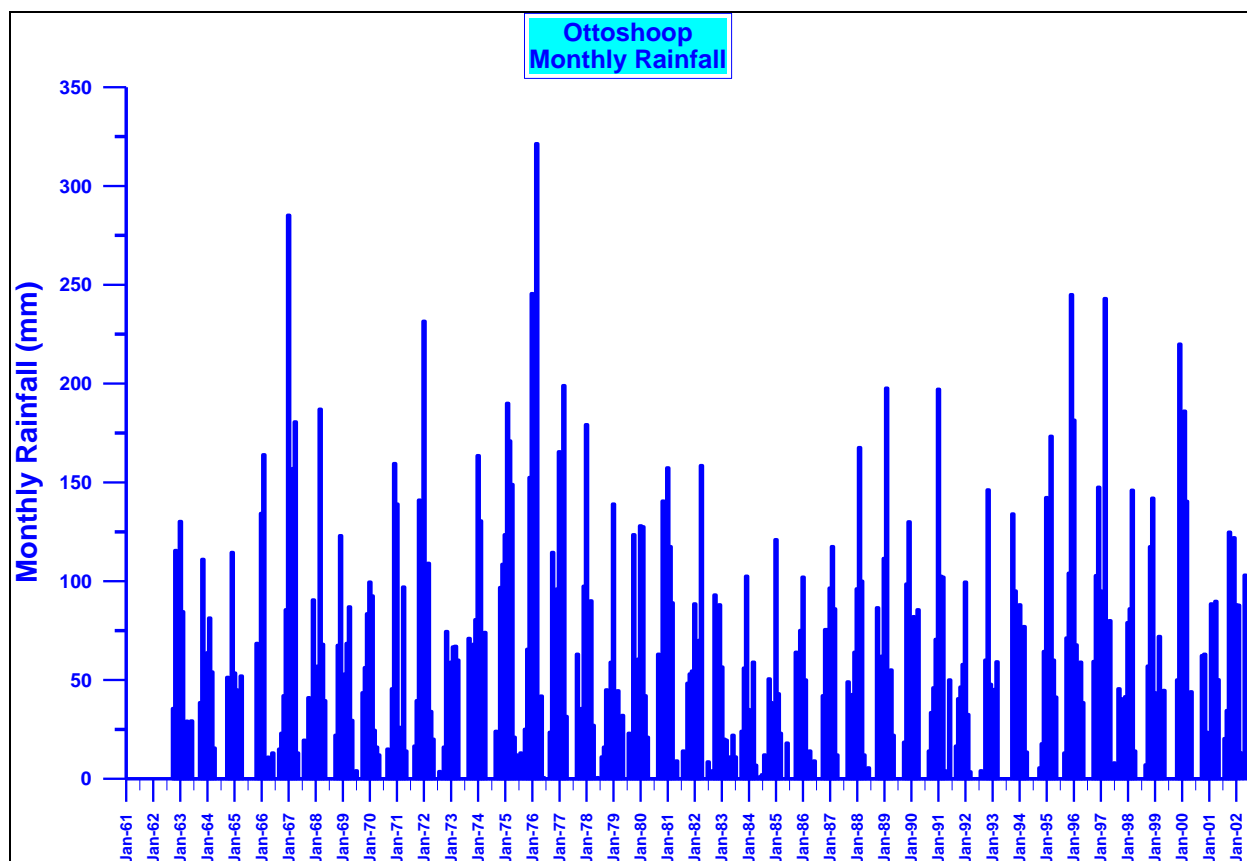


Figure 7 – Ottoshoop monthly rainfall.

2.4 Geology

The study area can geologically (Figure 8) be subdivided in:

2.4.1 Basement rock.

The basement rock consists of a light grey to pinkish granite-gneiss. Although the basement rock does not outcrop over the study area, the existence thereof was confirmed by gravimetric surveys over the Grootfontein Compartment.

2.4.2 Ventersdorp Supergroup

The granite-gneiss basement rock is overlain by the Ventersdorp Supergroup, which consists of quartzite, shale and andesitic lava.

2.4.3 Transvaal Supergroup

The Transvaal Supergroup consists of the Chuniespoort Group of which the Malmani Subgroup

forms a part. The Malmani Sugroup is divided into the following formations:

2.4.3.1 The Black Reef Formation

The rocks of this formation overlie the Ventersdorp Supergroup. It consists of feldspathic quartzite, shale and conglomerate; its thickness is in the order of 50m (Visser, 1970).

2.4.3.2 The Oaktree Formation

This formation is characterised by dark chert poor dolomite, which is not a good aquifer.

2.4.3.3 The Monte Christo Formation

This is the first of two of the most important water-bearing formations in the area and outcrops in the western study area. It consists of a chert-rich lighter colour dolomite.

2.4.3.4 The Lyttelton Formation

This formation is poor in groundwater because of the dolomite, which is chert-poor and less karstified.

2.4.3.5 The Eccles Formation

This formation is chert-rich and well karstified and forms the major water-bearing formation in the study area.

2.4.3.6 The Frisco Formation

This formation forms the upper part of the Malmanie Subgroup and consists of banded ironstones and shales.

2.4.4 Vertical Diabase intrusions.

The groundwater systems in the area are bounded by diabase dykes of unknown age. In the study area faulting in various areas has displaced these dykes.

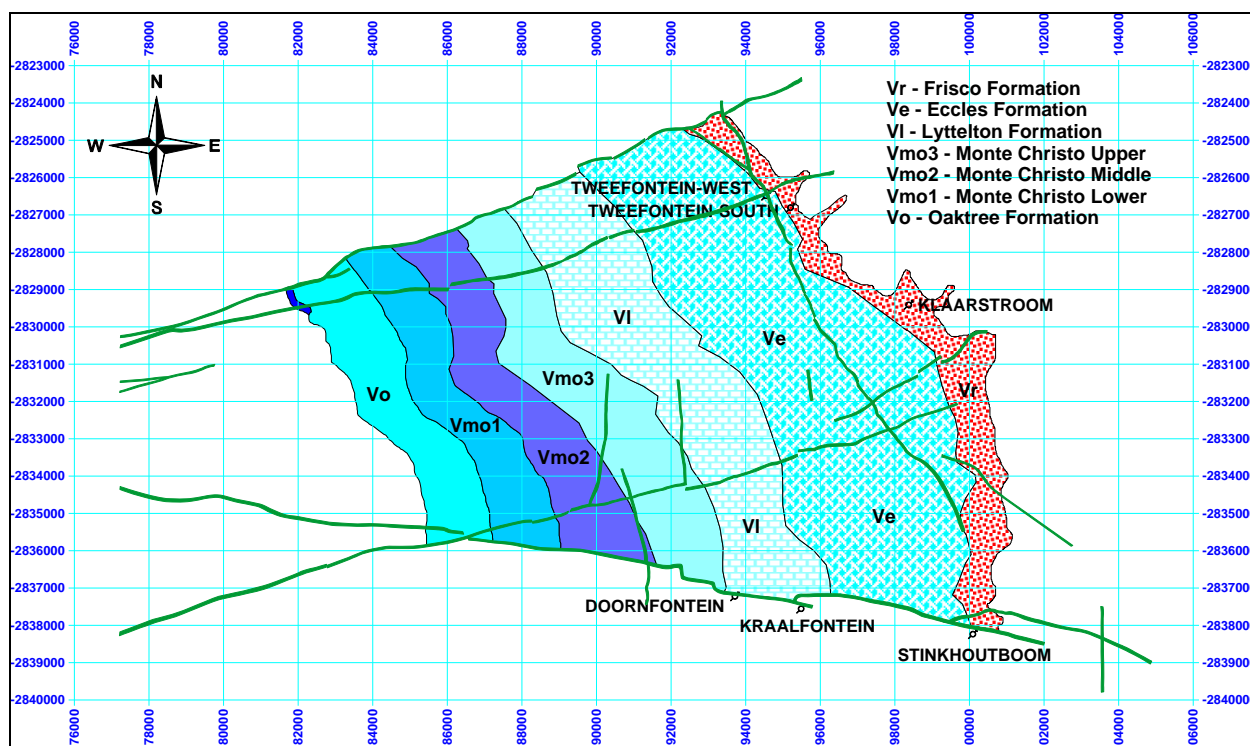


Figure 8 – Geology within the study area.

2.5 Groundwater recharge

Groundwater recharge may be defined as the downward percolation of water or soil moisture, which eventually reaches the water table, thereby forming an additional source to an already existing groundwater reservoir. Recharge from rainfall is a highly complex process in which numerous factors and their interaction play a role. The more important aspects affecting recharge from rainfall according to Vegter (1995) are:

- The amount, type, intensity, duration and temporal distribution of rainfall.
- Climate: potential evaporation.
- Surface slope and type of vegetation cover: storm runoff, interception and transpiration losses.
- Infiltration capacity of the materials at the surface be it rock or soil and subsoil; the presence of so-called macropores and fractured rock is of major importance; capillary movement.
- The moisture retention capacity of the aeration or unsaturated zone and temporal fluctuations of moisture.

During the PMA (2003) modelling investigation numerous approximations have been applied to estimate groundwater recharge from the recorded rainfall. Finally, a recharge to rainfall relationship based on an exponential curve was established which provided the best approximation to date. The relationship is provided by the following equation:

$$y = (x-65\text{mm}) * [0,1e^{(0,02(x-65\text{mm}))}]$$

where y = groundwater recharge(mm)

and x = rainfall(mm)

The recharge percentage is restricted to a maximum of 80% of the rainfall. The annualized recharge to rainfall relationship thus obtained for the Ottoshoop rainfall record over the period 1960-2002 is shown in Figure 9.

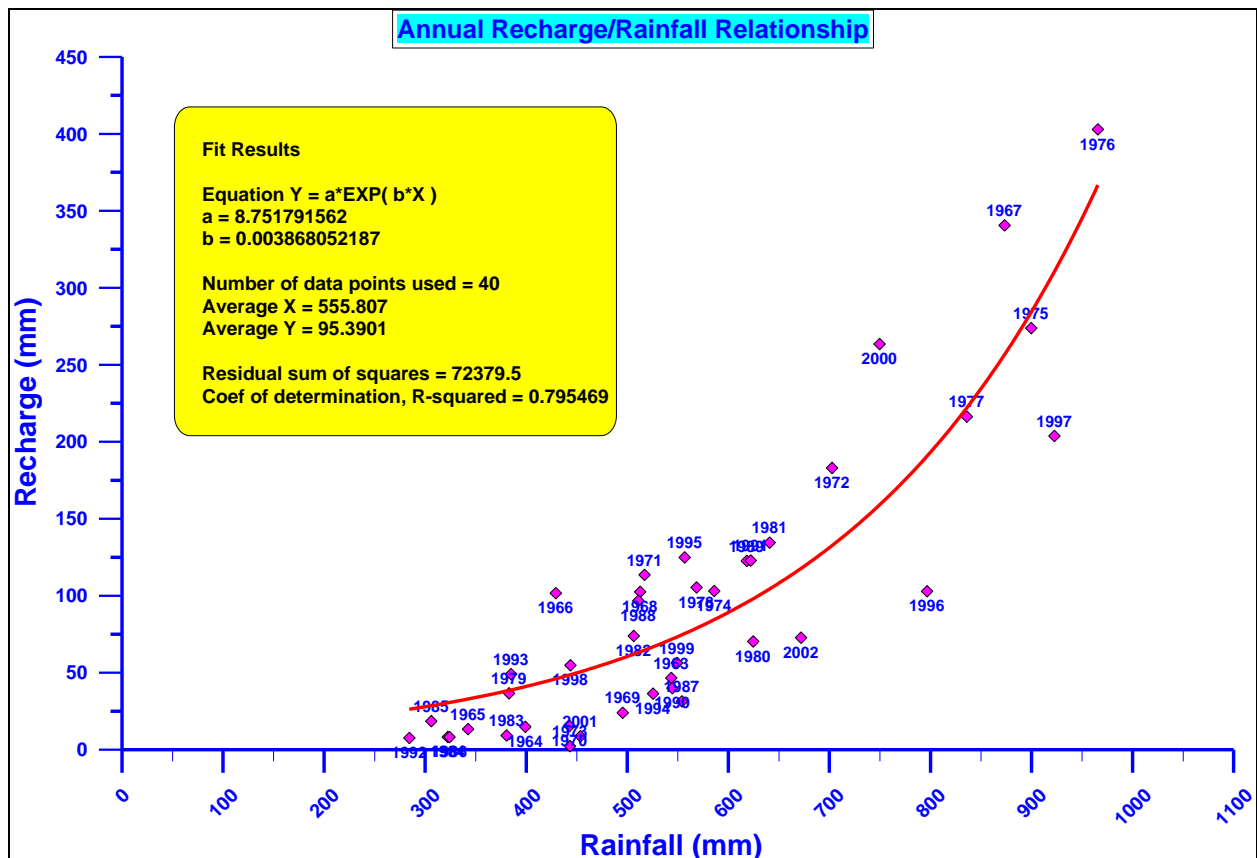


Figure 9 – Annual recharge to rainfall relationship obtained during 2003 PMA study.

Model calibration for the PMA (2003) modelling exercise further indicated that groundwater recharge is also stratigraphically controlled where for example the more permeable horizons (Monte Christo and Eccles Formations) will accept larger infiltration from rainfall events than the lower permeable zones (Oaktree and Lyttelton Formations). This is depicted in Figure 10.

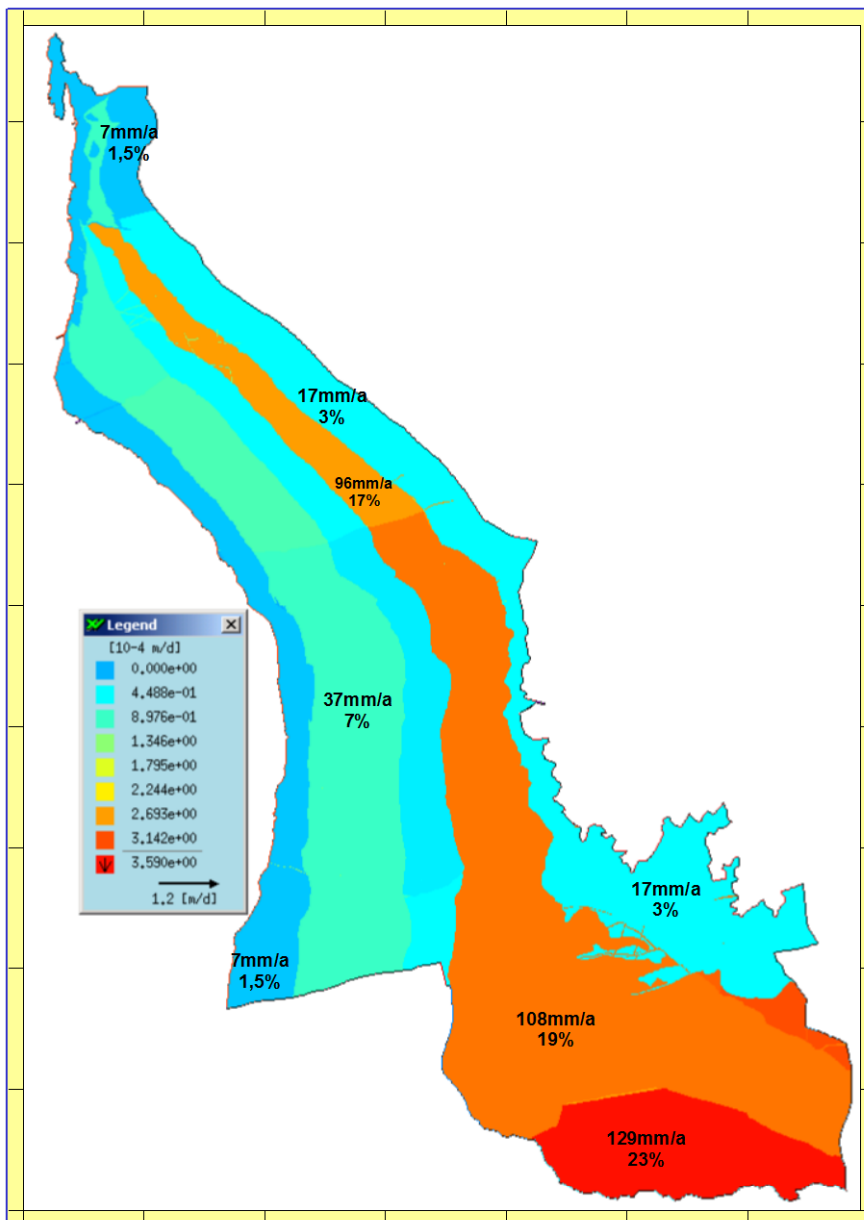


Figure 10 – Zones (stratigraphically controlled) depicting the recharge across the study area expressed as mm/annum and as a percentage of the average rainfall of 560mm/annum.

2.6 Aquifer Transmissivity and Storativity

Aquifer transmissivity can be defined as *the rate of flow of water in cubic metres per day through a unit width of aquifer under a unit hydraulic gradient (Units: $\text{m}^3/\text{day}/\text{m}$ or m^2/day).*

[Definition of Storage Coefficient: Specific storage (S_o) times aquifer thickness (B). The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head.]

[Definition of Specific Yield: The volume of water an aquifer releases from storage per unit surface area of the aquifer per unit change in head under gravity.]

Estimates of the transmissivity and storativity of the aquifer were obtained from the results of constant discharge hydraulic tests conducted during the field exploration program (Africon (2002). Aquifer tests were analysed using different methods of evaluation suitable for the specific criteria of the tests. Table 1 provides the results obtained from the aquifer tests conducted on selected boreholes (positions indicated on Figure 11).

Table 1 – Calculated aquifer parameters using observation borehole data.

Abstraction borehole	Observation Borehole	Transmissivity	Transmissivity	Storativity
		Cooper Jacob	Theis Recovery	
		m ² /d	m ² /d	
BH2100037	BH2100033	5910	952	-
BH2100037	BH2100035	8640	6600	0,0353
BH2100037	BH2100039	12800	6890	0,00241
BH2100036	BH2100035	1540	4100	0,0258
BH2100038	BH2100036	2080	3300	0,0382
BH2100038	BH2100039	2360	7290	0,0104
BH2100038	BH2100035	2330	9960	0,0483
BH2100038	BH3	2390	2570	0,00357
BH2100039	BH2100036	1990	2220	0,00838
BH2100039	BH2100038	3510	4310	0,0113
BH2100039	BH2100035	2080	1750	0,0119
BH2100039	BH2100033	3290	3870	0,0187
BH2100039	BH2	1210	6740	0,00391
BH2100035	BH2100036	1350	1090	0,0561
BH2100035	BH2100039	1340	2560	0,0182
BH2100035	BH2100038	2020	2240	0,0821
BH2100035	BH2100033	5450	-	0,00632
BH2100035	BH2	2050	1220	0,00462
BH2100035	BH4	4320		0,00194

From Table 1 it is evident that the aquifer transmissivity is large (thousands of m^2/day) and that the storativity is in the order of 1-8%. These are typical values, which are often obtained for the karstified portion of dolomite formations in Southern Africa.

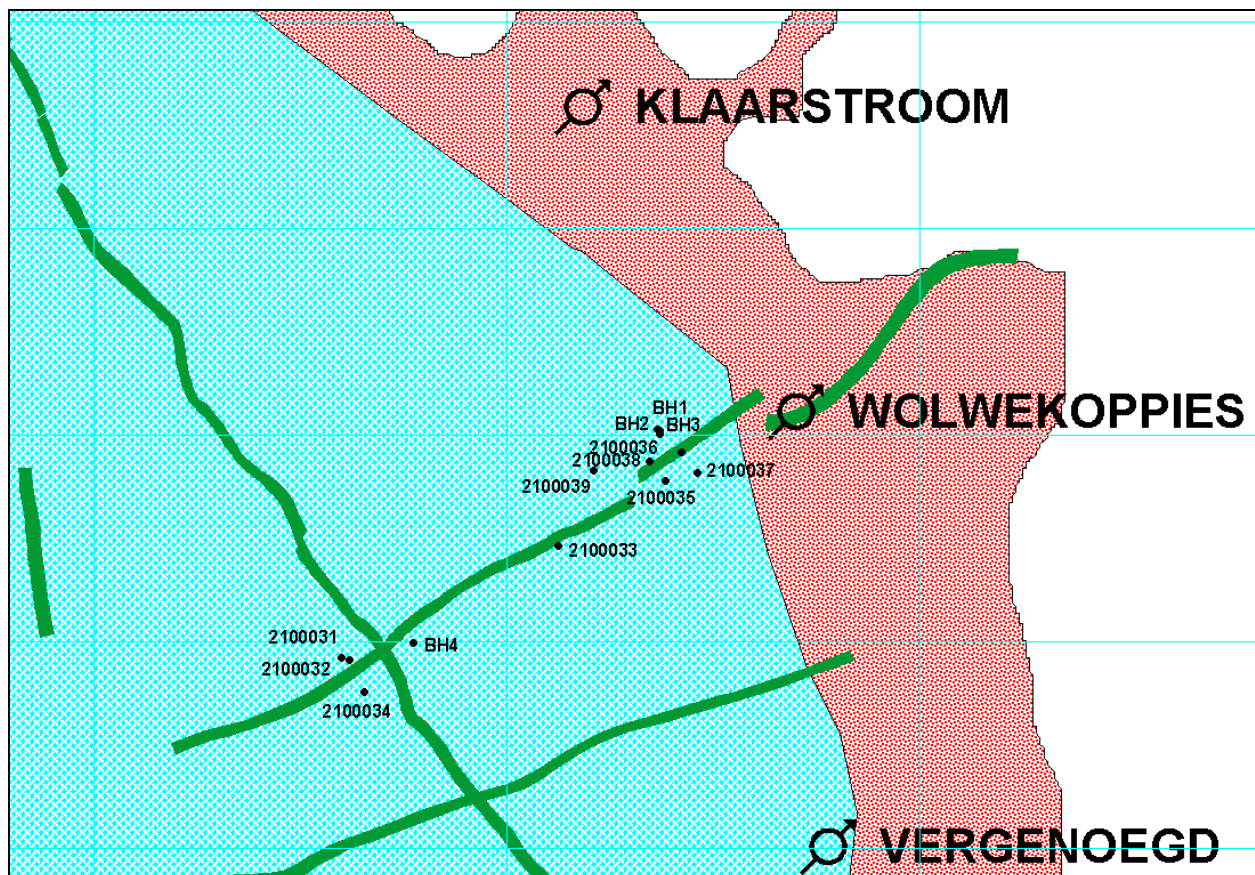


Figure 11 – Positions of boreholes in the Uitvalgrond Wellfield.

2.7 Groundwater levels and Flow directions

Groundwater level elevations at the boreholes and approximate groundwater flow directions are shown in Figure 12. These were calculated from the levelled topography and measured water levels. The following observations can be noted from Figure 12:

- A ten-metre difference in water level elevation between the Klaarstroom Spring and the Wolwekoppies Spring. This is clearly indicative that these two systems are not hydraulically well interconnected as previously assumed (Africon (2002));
- At least a 30-meter difference in water level elevation between the Tweefontein South and Wolwekoppies (Uitvalgrond) Compartments. This is indicative that the Wolwekoppies (Uitvalgrond Compartment) is very limited in extent with little lateral inflow occurring from the Tweefontein Compartment.

3 AQUIFER CONCEPTUALISATION, MODEL CONSTRUCTION AND CALIBRATION

3.1 Conceptual Model of the Aquifer System

The first step in the modelling procedure is the construction of a conceptual model of the problem and the relevant aquifer domain. The conceptual model consists of *a set of assumptions* that reduce the real problem and the real domain to simplified versions that are acceptable in view of the objectives of the modelling and of the associated management problem. The aquifer underlying the study area (Eccles Formation) is highly complex consisting of dolomite containing lenses and layers of chert. Chert (SiO_2) is hard and fine-grained and more weathering resistant than dolomite (CaMgCO_3). Solution phenomena invariably develop in carbonate terrain such as this. Waters percolating vertically through the unsaturated zone above the natural water table form a weak carbonic acid that will attack any crack such as a joint or a fault and solution of Ca and Mg from the dolomite will occur. In addition to the slots that develop through the opening up of any such crack solution is also taking place below in the phreatic zone below the water table. Here horizontal chambers are developed immediately below the water table and further slots are also corroded below them. Caves then develop immediately below the water table in any cycle of erosion.

From the description above it is evident that the aquifer consists of a series of solution cavities that may or may not be interconnected with zones of solid dolomite and chert not contributing to groundwater flow also present. From this description it is clear that the aquifer is heterogeneous, i.e. hydraulic properties may vary over short distances in all directions. It is therefore clear that on a very small scale a porous media approach of modelling may lead to an inadequate description of the modelling problem with resulting inaccuracies if considered on a small scale. The realistic alternative, therefore, is to move to a coarser scale of aquifer description by introducing measurable phenomenological coefficients such as hydraulic gradients. In the continuum approach, the concept of the representative elementary volume (REV) is evoked. It is a theoretical approach in which representative values for flow (and transport) parameters are averaged over an appropriate volume. On a larger (macroscopic) scale, therefore, parameters are averaged and, for a sufficiently large modelling cell size (representative elementary volume), a porous media approach can be adopted by specifying regional representative aquifer parameters.

3.2 Construction of the Finite Element Grid

Compilation of the finite element grid for the 2003 model using the FEFLOW pre-processing software facilitated the requisite construction of 6-noded triangular prism elements over the area of investigation as shown in Figure 13, zoomed in on the area under investigation. The triangular grid consists of 172705 elements and 175170 nodes. The positions of the geological contact zones and dyke positions are incorporated in the modelling grid. Small cell sizes were specified

in the areas of abstraction around pumping boreholes where a more accurate solution of the groundwater flow is required. Larger cell sizes were specified in other areas. The advantage of using the finite element approach is that the boundaries of the various features represented in the model can be approximated accurately.

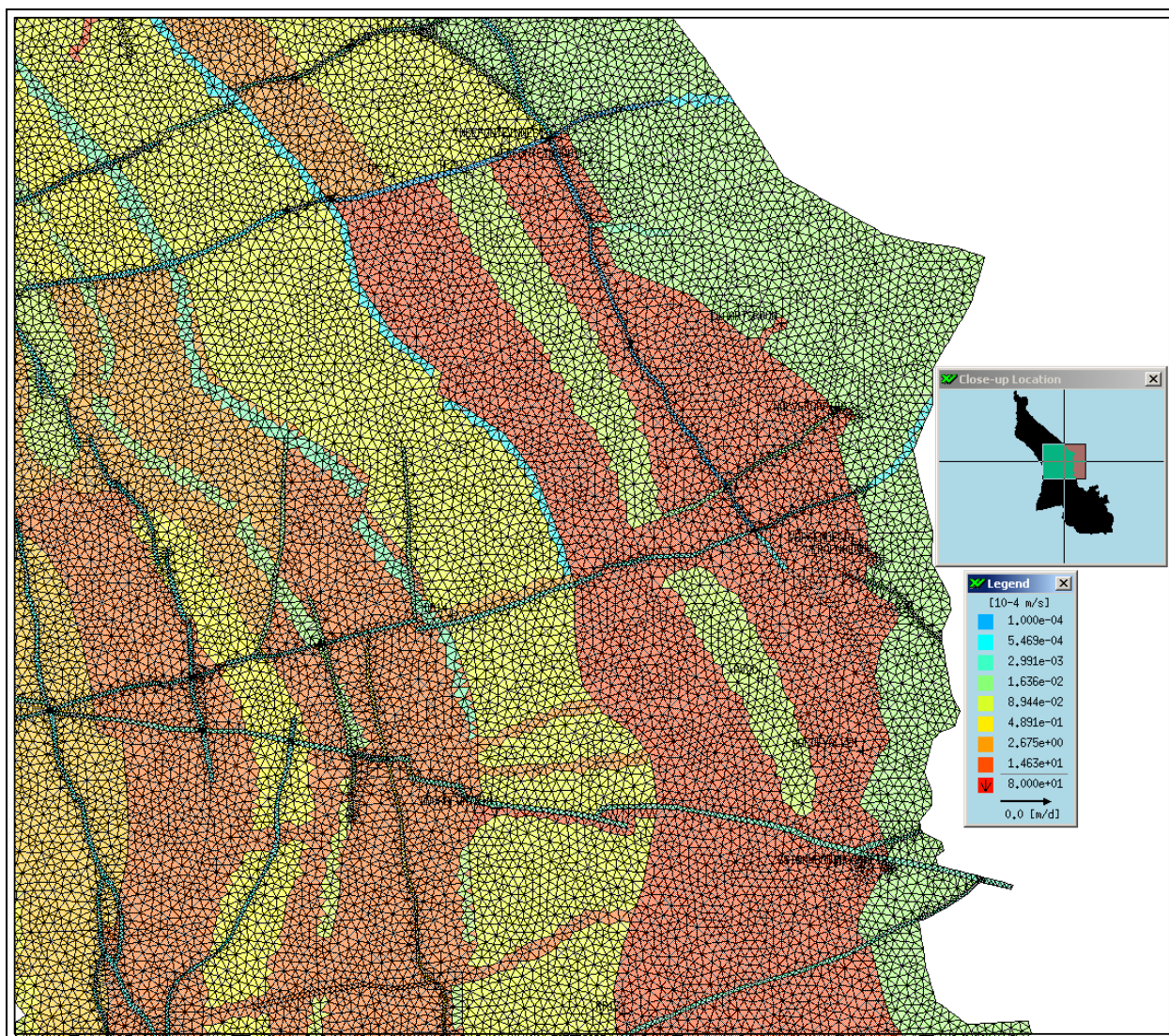


Figure 13 – Finite element network (2003 model).

For the 2005 model update the finite element grid was refined in the areas of the Uitvalgrond wellfield and the proposed new abstraction boreholes as indicated on Figure 14. The refined finite element network consists of 174413 elements and 176878 nodes.

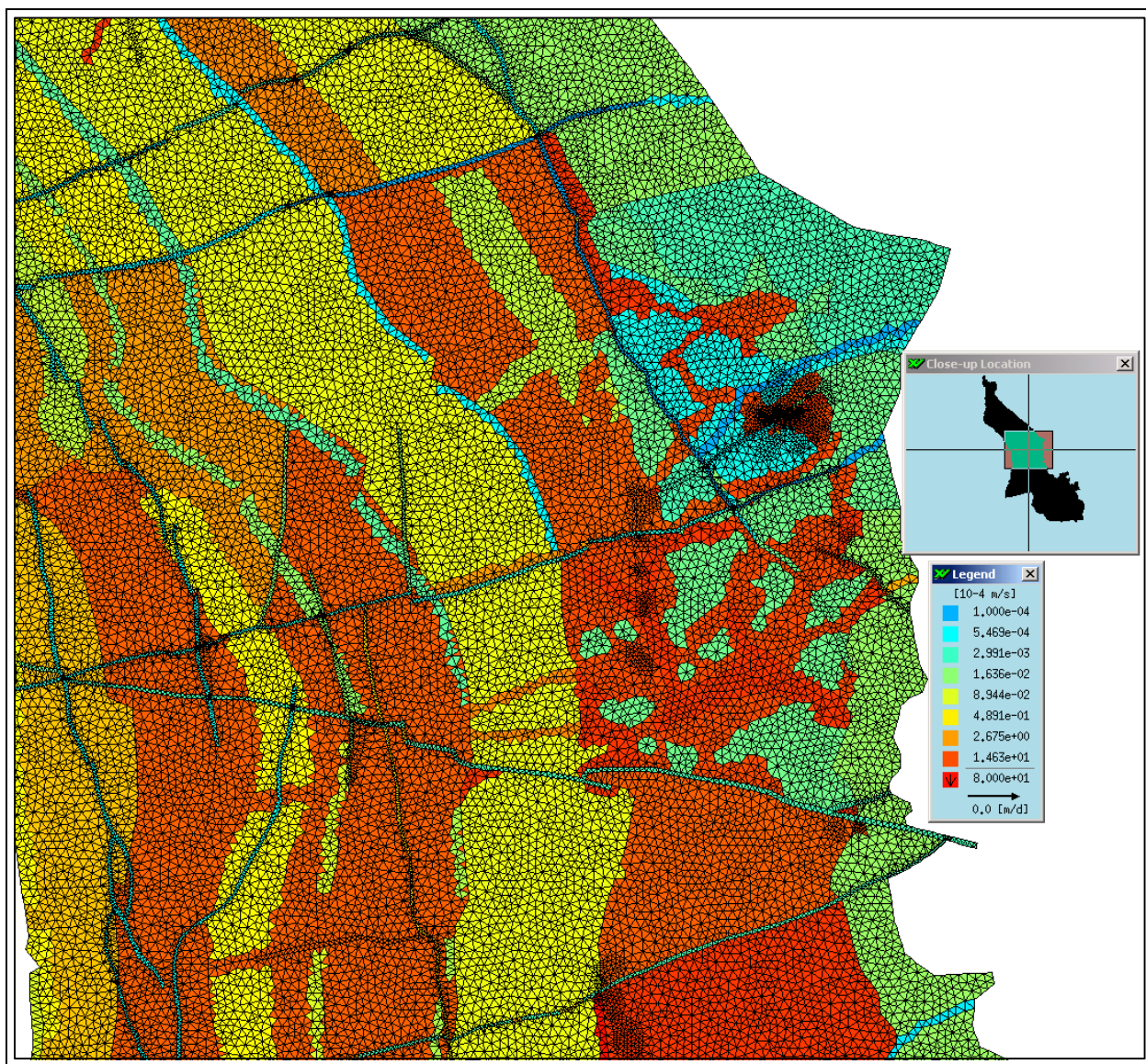


Figure 14 – Refined finite element network (2005 model update).

3.3 Boundary Conditions

Boundary conditions describe the manner in which the considered domain interacts with its environment by defining conditions of known water flux, or known variables, such as piezometric head. Different boundary conditions result in different solutions, hence the importance of stating the correct boundary conditions. Boundary conditions in a groundwater flow model can be specified either as:

- Dirichlet Type (constant head) boundary conditions,
- Neuman Type (specified flux) boundary conditions, or
- A mixture of the above (Cauchy Type).

Rainfall recharge is discharged through the springs as indicated in Figure 12 and conceptually discharge from the system will also occur through the Frisco Formation's contact. Constant head values were therefore assigned along the lower surface elevation of the Frisco Formation and at the positions of the springs. The positions of the constant head nodes are indicated as blue circles in Figure 15. Spring elevations are indicated on Figure 12.

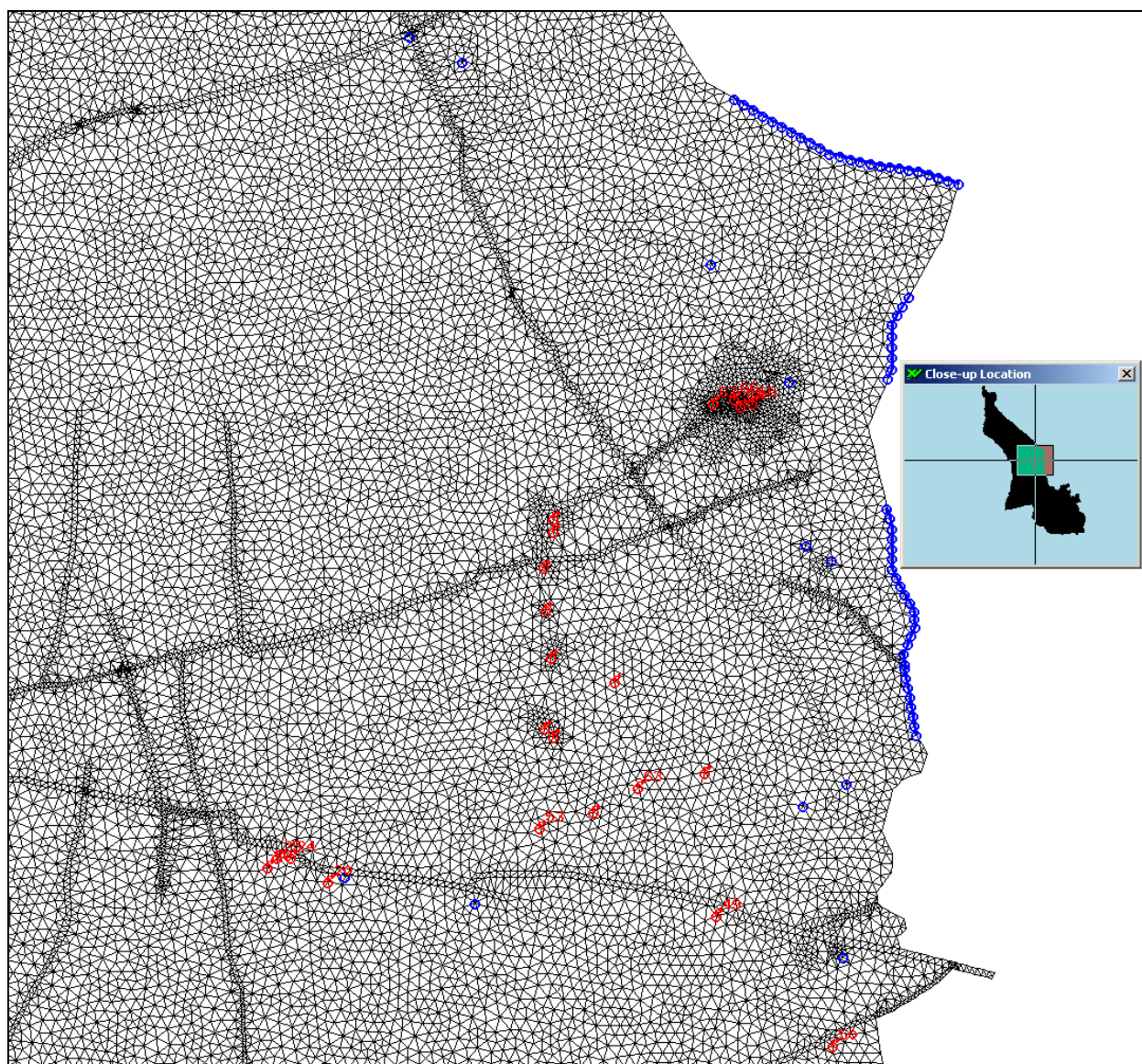


Figure 15 – Constant head boundaries indicated by blue coloured circles. Red coloured circles indicate abstraction borehole positions.

3.4 Steady State Calibration

The calculated head distribution is dependent on the recharge, hydraulic conductivity and specified boundary conditions. For a given recharge component and set of specified boundary conditions, the head distribution across the aquifer can be obtained for a specific K-value. This simulated head distribution can then be compared to the measured head distribution and the K-values or recharge values altered until an acceptable correspondence between measured and simulated heads is obtained.

The steady state calibration of the 2003 model was accomplished by altering the recharge from rainfall and the hydraulic conductivity values in the model until a good resemblance between the measured piezometric levels and the simulated piezometric levels and the simulated spring flow and observed spring flow were obtained for the entire modelling area. For the present update of this model the newly drilled monitoring boreholes in the Uitvalgrond/Tweefontein South and Paardenvallei compartments and other measured water levels were incorporated into the model. The calibrated steady state water level contours are presented in Figure 16 (entire modelling domain) and Figure 17 (zoomed in on study area) and the corresponding K-values are presented in Figure 14. Note the difference in K-value distribution between the 2003 model and the updated model by comparing Figures 13 and 14. The updated K-value distribution exactly matches with the leached dolomitic zones identified with the gravimetric survey (KGC, 2005). A good comparison between simulated and measured water levels was achieved during the steady state calibration. Actual measured values at boreholes versus simulated values at boreholes in the area are shown in Figure 18 and Figure 19 for the entire modelling area and in Figures 20 and 21 for the Uitvalgrond/Tweefontein South and Paardenvallei Compartments. The obtained steady state water level distribution was used as starting heads in the transient simulation. Figure 22 shows the simulated vs. observed spring flows for steady state conditions. Good comparisons between simulated spring flows and observed spring flows were obtained.

3.4.1 Steady State Calibration Statistics

Figure 23 shows the frequency distribution and the cumulative frequency distribution for the absolute modelling calibration error. According to the calculated statistics 12 out of the 39 boreholes (31%) used for the steady state calibration have an absolute error of 0,5m or less. Similarly calculated 31 out of the 39 boreholes (80%) have an absolute error of 3m or less. The largest modelling error is in the order of 4,5m.

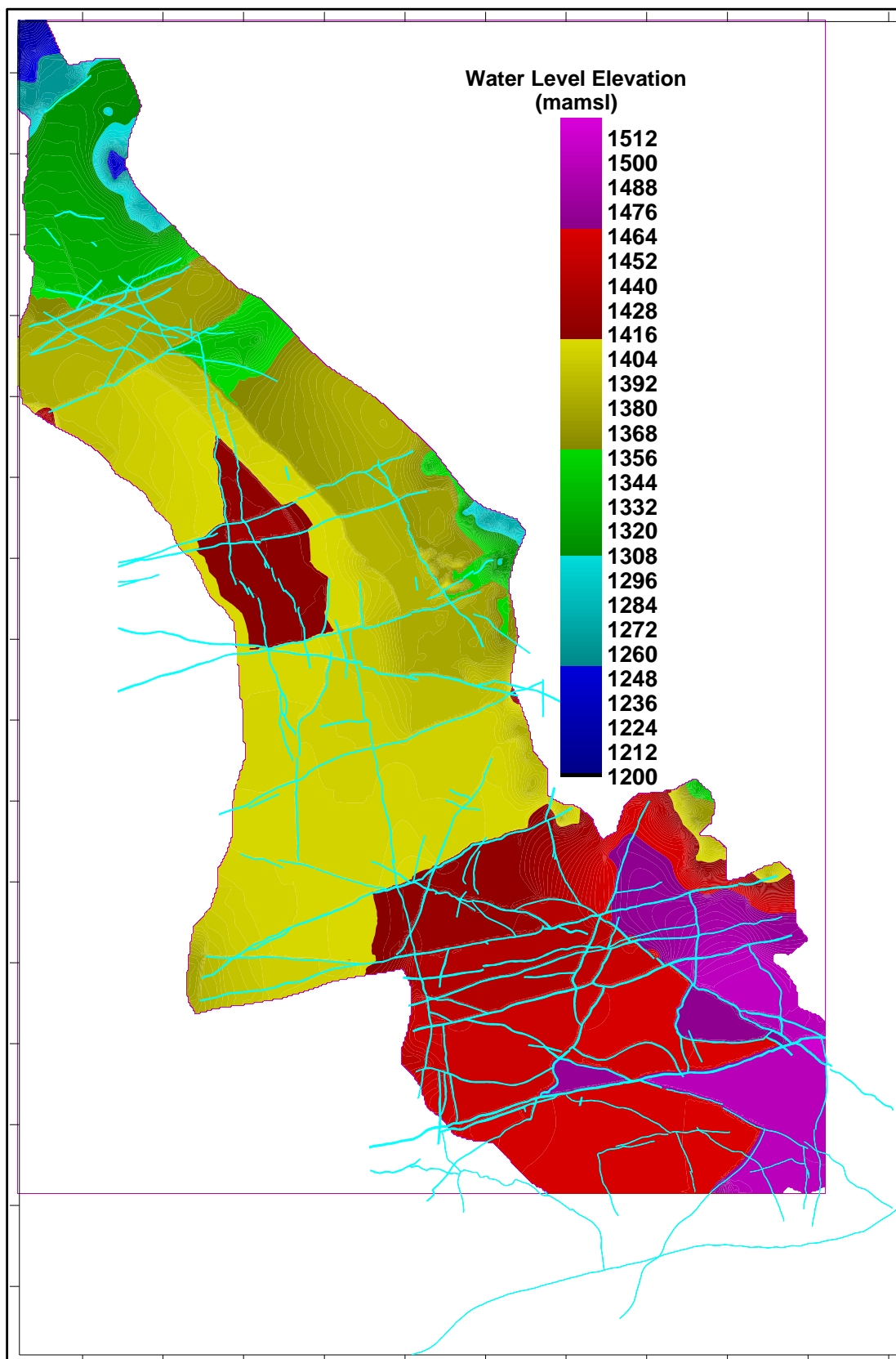


Figure 16 – Simulated water level elevation for steady state conditions (entire modelling domain).

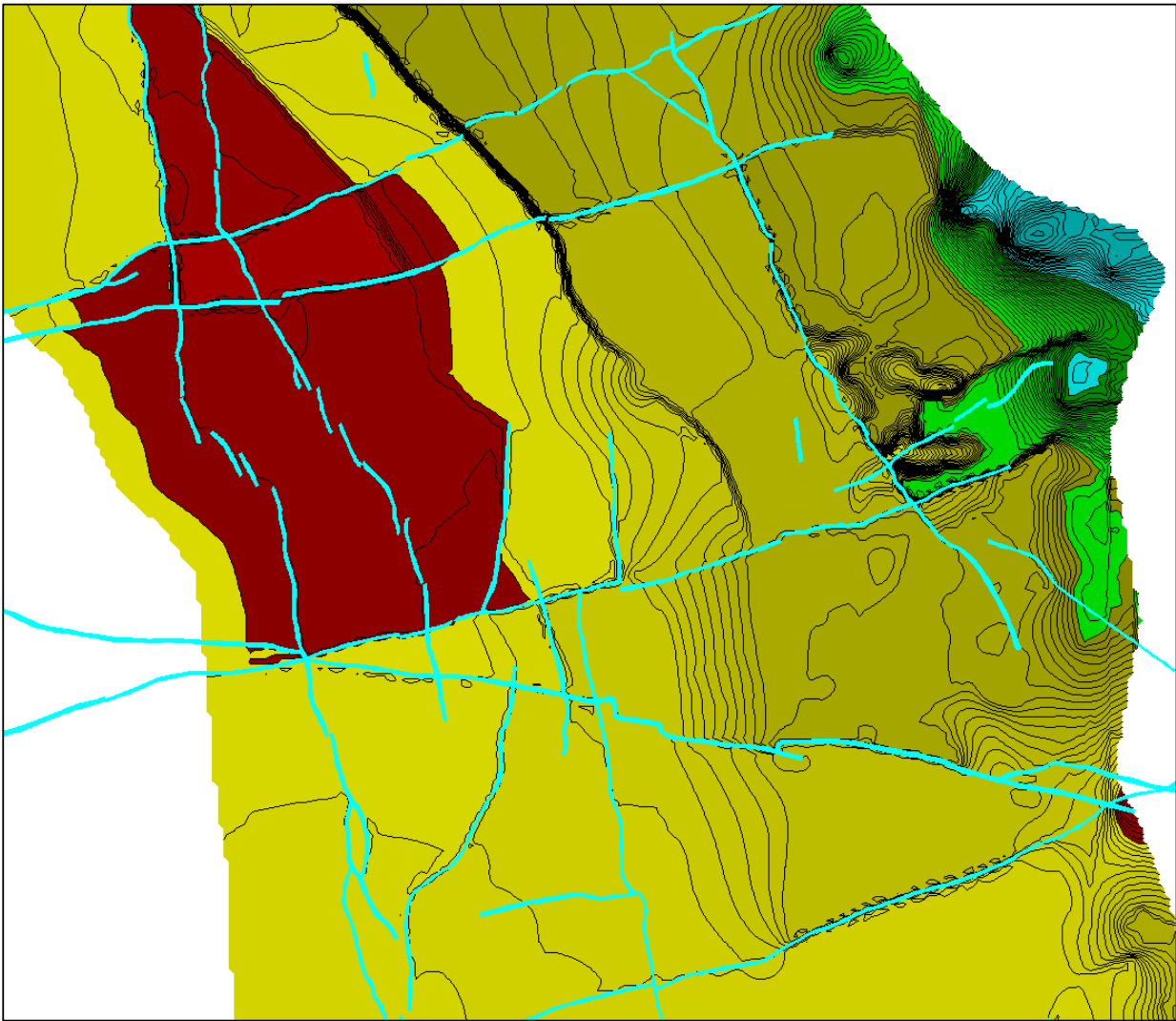


Figure 17 – Simulated water level elevation for steady state conditions (zoomed into study area).

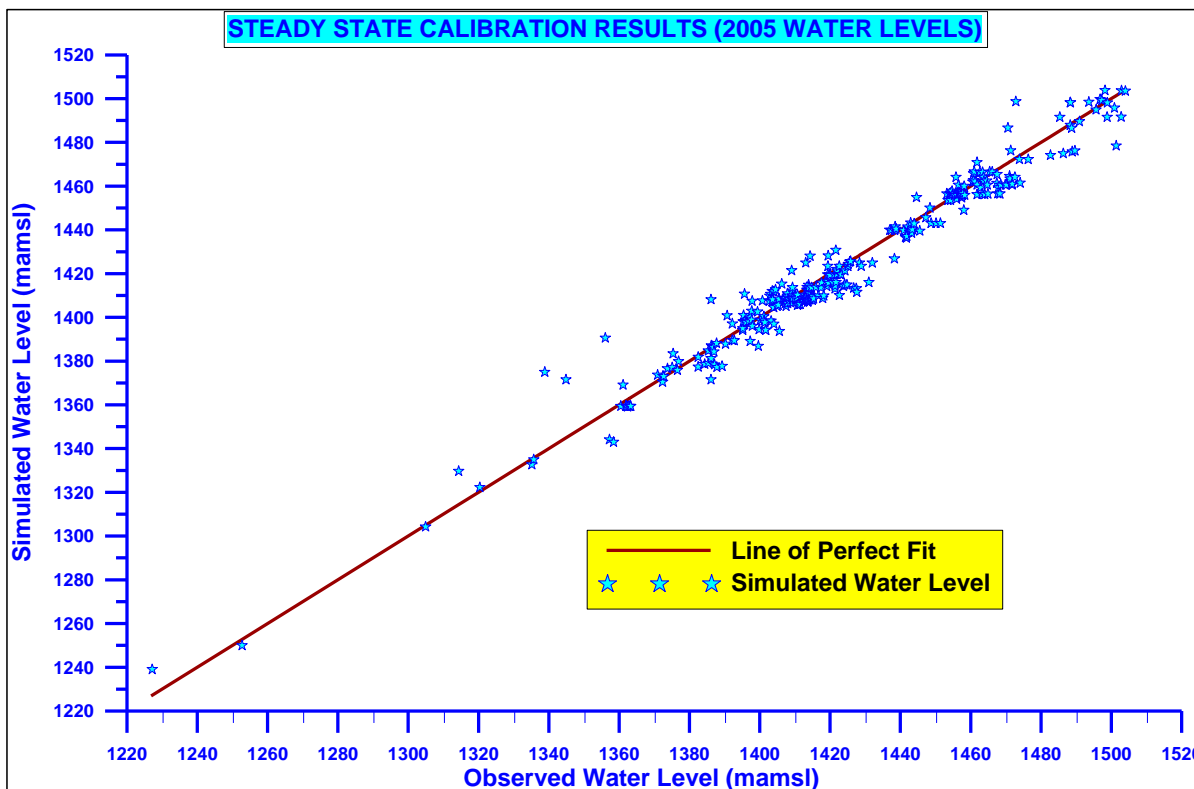


Figure 18 – Simulated vs. observed water levels for steady state calibration for the entire modelling domain (correlation coefficient = 98,4%).

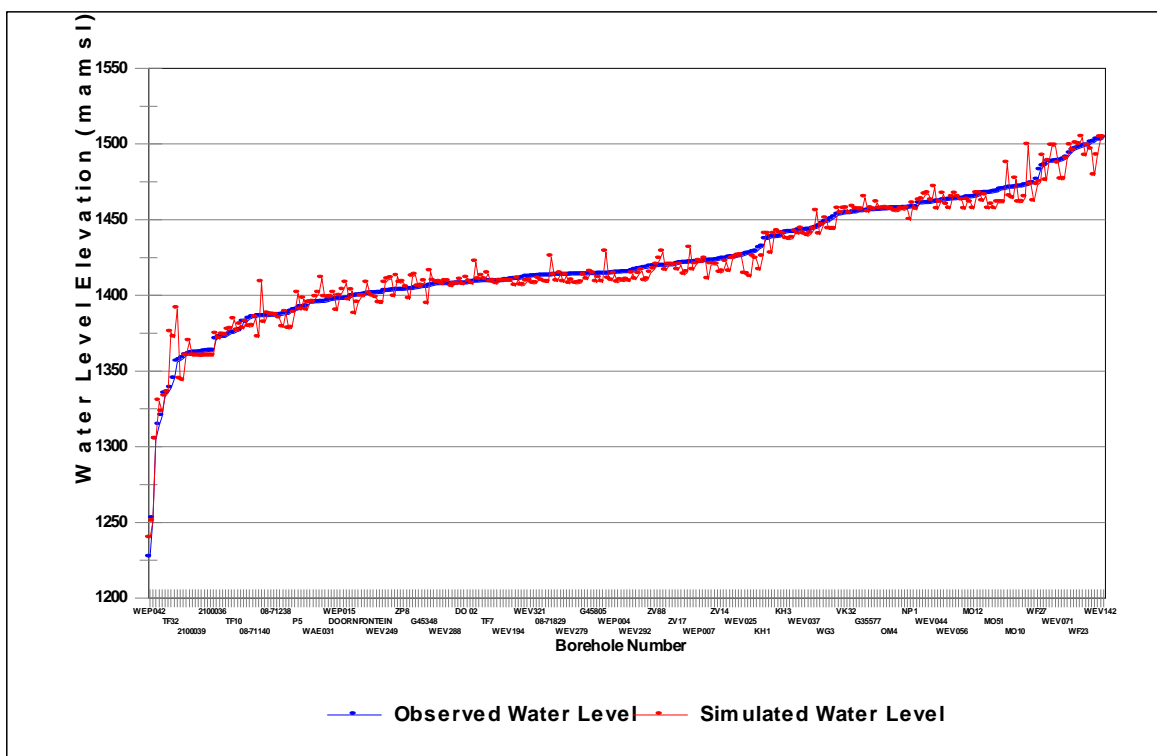


Figure 19 – Simulated vs. observed water levels for steady state calibration for the entire modelling domain (correlation coefficient = 98,4%).

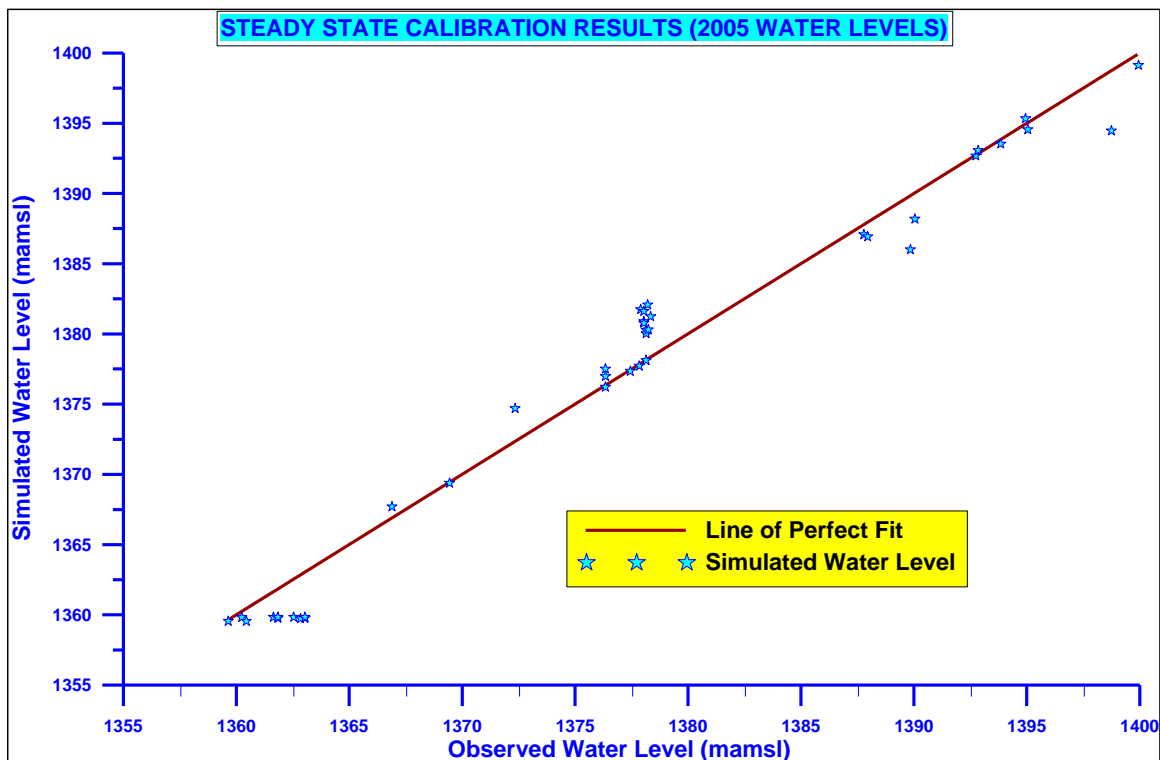


Figure 20 – Simulated vs. observed water levels for steady state calibration for the study area (correlation coefficient = 98,5%).

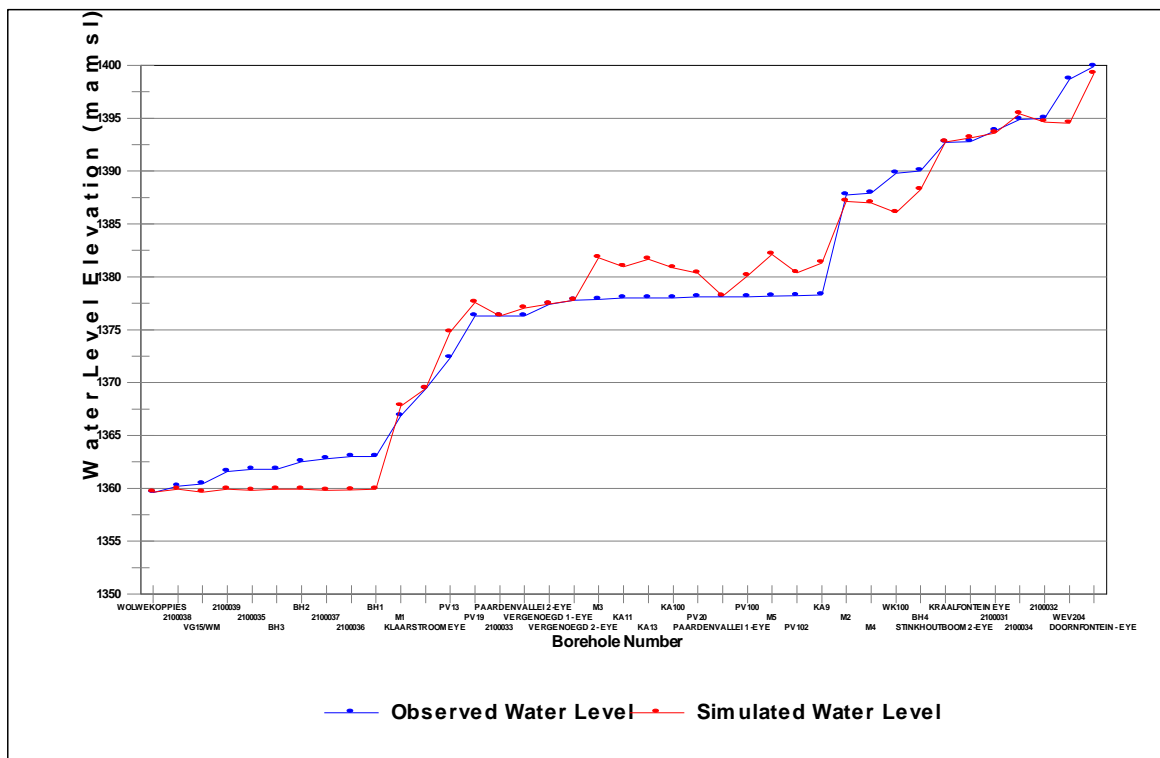


Figure 21 – Simulated vs. observed water levels for steady state calibration for the study area (correlation coefficient = 98,5%).

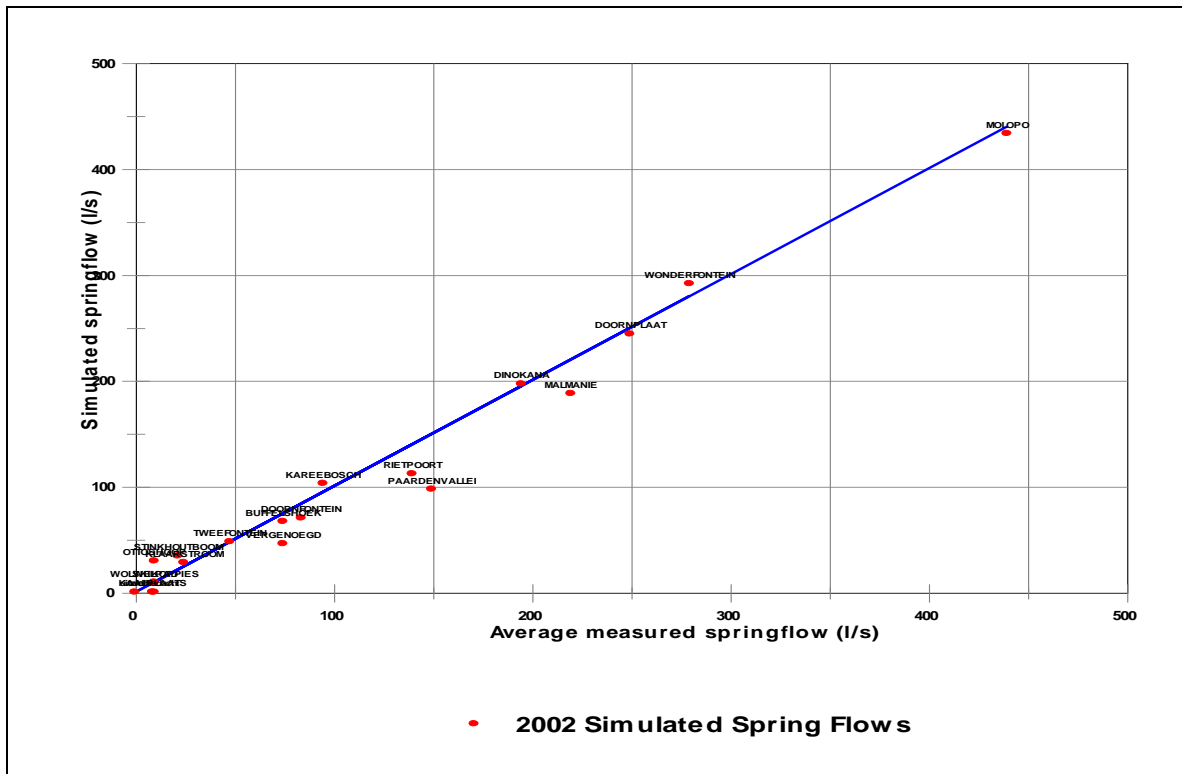


Figure 22 – Simulated steady state spring flow (correlation coefficient = 98,9%).

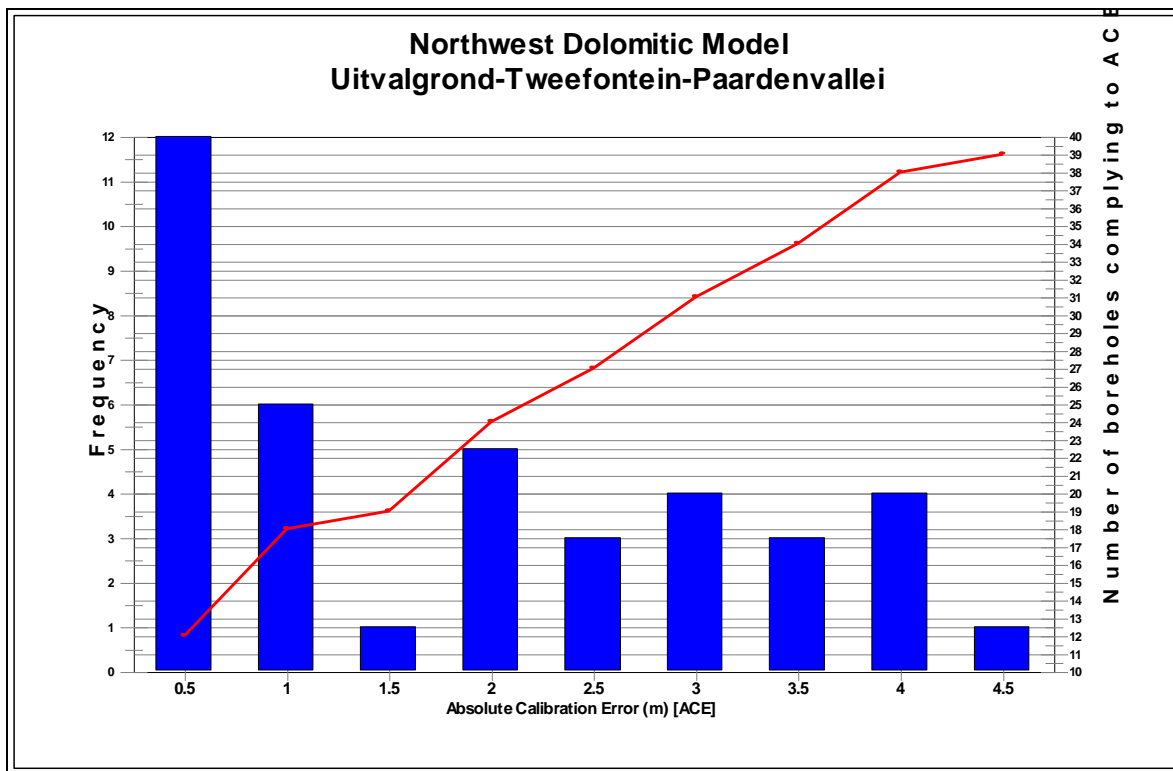


Figure 23 – Absolute calibration error.

3.5 Calibrate the model for transient state conditions using the estimated abstraction rates and water level drawdown from the Uitvalgrond Wellfield

The Central District Municipality commissioned production from the Uitvalgrond Wellfield in April 2003 (KGC, 2005). Water meters were installed to measure groundwater abstraction from each production borehole as well as piezometer tubes to enable measurement of water level depths within production boreholes. Groundwater abstraction following the commissioning continued until March 2004 when problems began with some of the production boreholes failing necessitating reduction of the abstraction (KGC, 2005). Recorded water level drawdowns of the boreholes were in excess of 12 metres indicating that the compartment was over utilised and unable to sustain 30l/s. By early September 2004 exploitation of the wellfield was completely discontinued as all production boreholes had failed. Aquifer monitoring data for the wellfield during groundwater abstraction is limited. KGC (2005) estimated that the average abstraction from the wellfield over a period of 17 months could have been in the order of 25,6l/s. This produced a drawdown in the wellfield of 12-13m. These figures were used in the groundwater flow model for transient calibration purposes.

Using the estimated abstraction rate of 25,6l/s from the wellfield the model was run over the period April 2003 up to September 2004 when abstraction ceased from the wellfield. Figure 24 shows the results for this simulation.

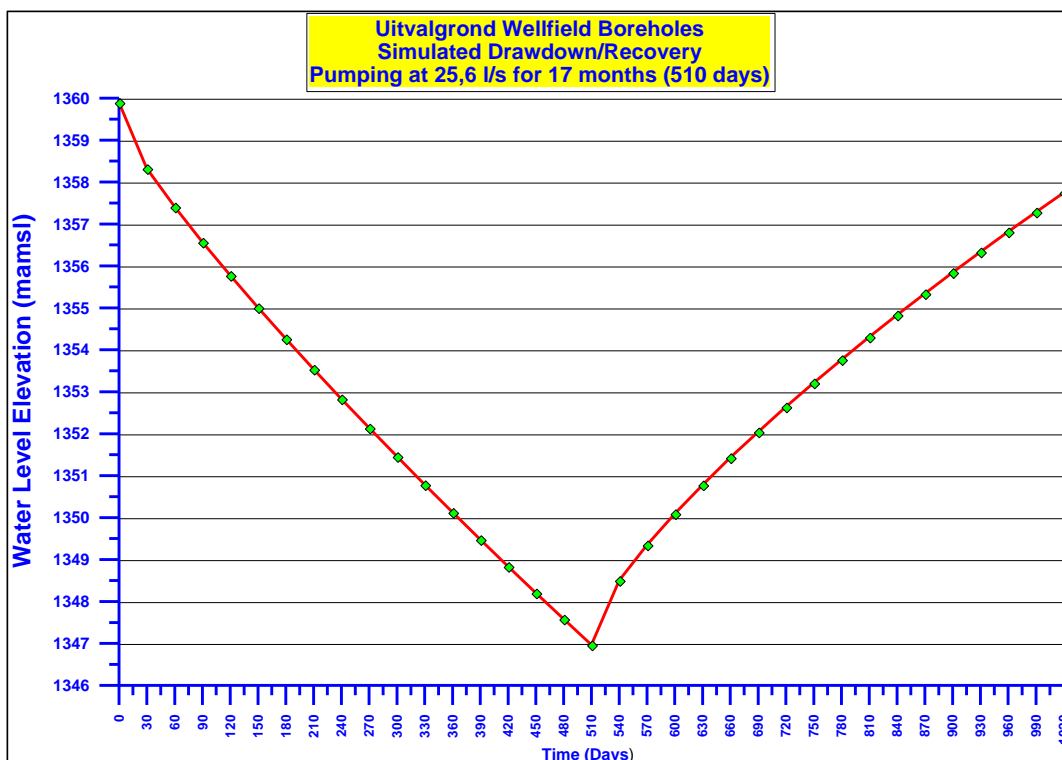


Figure 24 – Simulated drawdown/recovery in the Uitvalgrond Wellfield.

It can be seen from this graph that during the 17 months of pumping the model predicted that drawdown will be in the order of 13m. This is in excellent correspondence with the measured drawdown in the Uitvalgrond wellfield. The simulated recovery in the water level in the wellfield indicates that even after an additional 17 months of wellfield recovery the original water level of 1360 will not be reached and the Wolwekoppies spring will not have started to flow again. Water levels in the Uitvalgrond Wellfield will still need an additional 3m at that stage to recover to pre-pumping conditions.

3.6 Calibration of the groundwater flow model over the period 1971-2002.

The groundwater flow model was further utilised to simulate the response of the aquifer to temporal groundwater abstraction, rainfall recharge and springflows over the period 1971-2002. The abstraction from the Dinokana, Doornfontein, Rietpoort and Slurry wellfields were included and their respective abstraction rates for this period specified in the model. Irrigation abstraction from identified irrigation boreholes across the model domain was also specified in the model. Furthermore, rainfall recharge was specified temporally in the model according to the formula as discussed in Section 2.5 of this report and using the Ottoshoop rainfall record (see Figure 7). Figure 25 shows the monthly recharge input into the model.

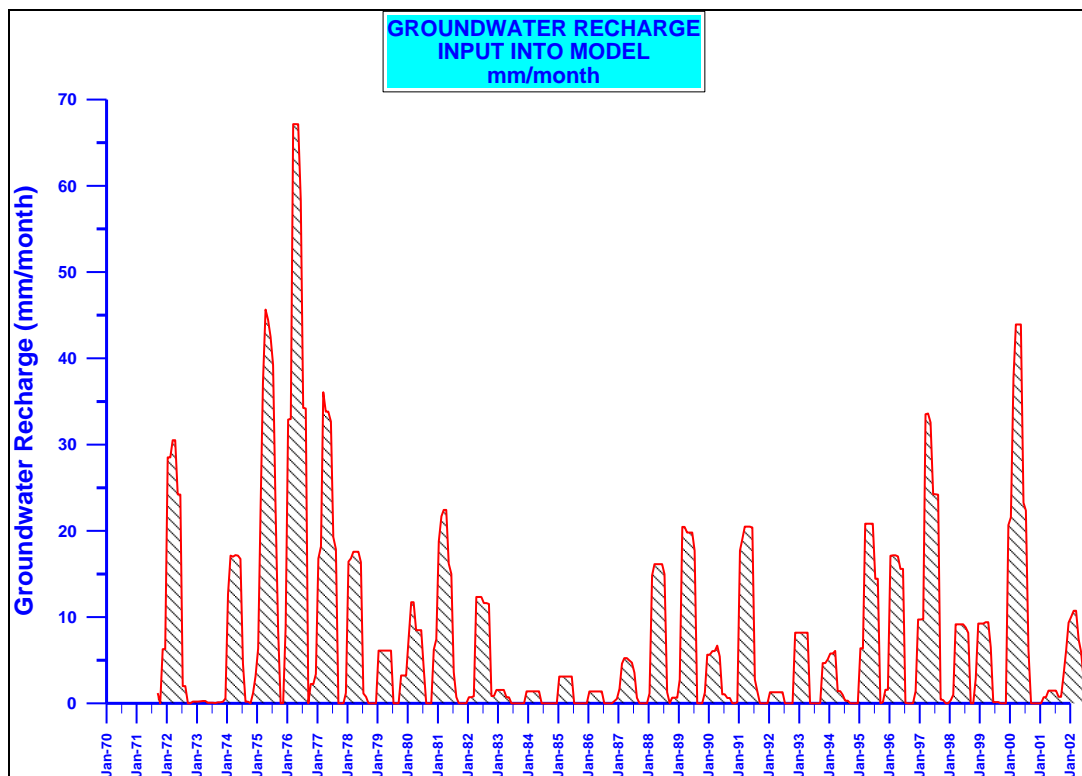


Figure 25 – Monthly groundwater recharge input into model.

The model calibration can be evaluated in terms of model simulated spring flows and model-simulated water levels and compared against the corresponding observed values. Figures 26-34

show the simulated vs. observed springflows at the Malmanie, Kareebosch, Buffelshoek, Doornfontein, Stinkhoutboom, Tweefontein, Paardenvallei and Vergenoegd Springs. The positions of these springs are shown in Figure 35.

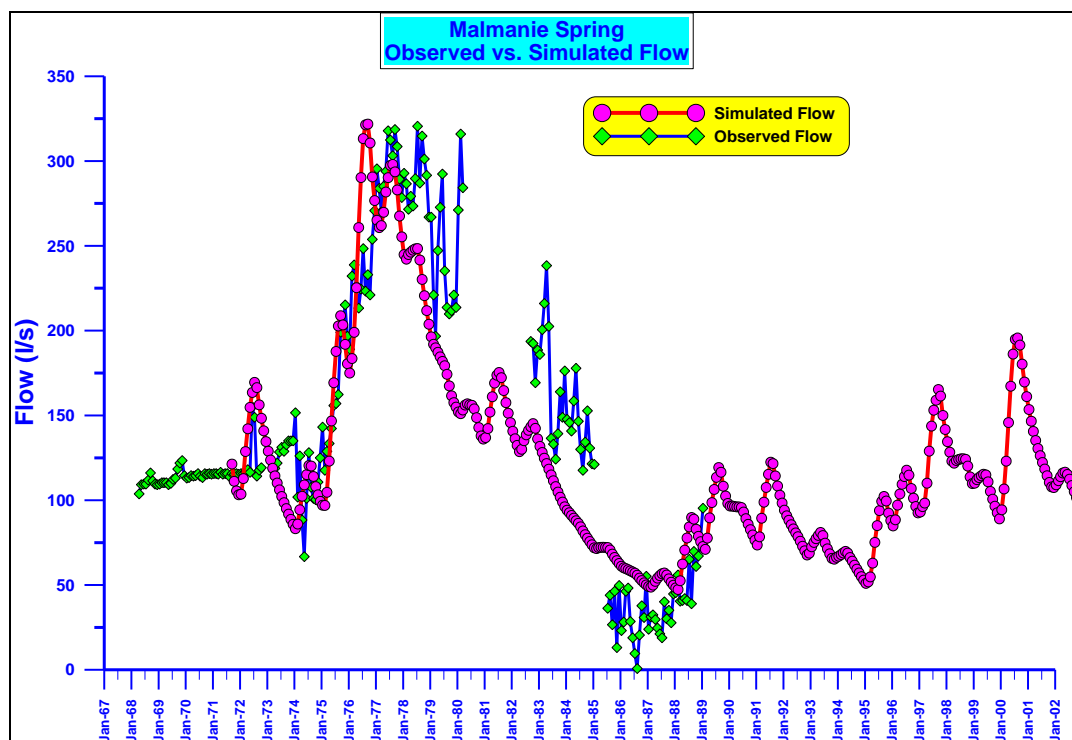


Figure 26 – Malmanie Spring Observed vs. Simulated Flow.

The following may be concluded from the figures:

- In general the recharge-rainfall relationship used provides a good calibration at most of the springs;
- An additional loss factor of 70l/s had to be specified in order to reduce flow from the Paardenvallei Spring (compare Figures 33 and 34) to obtain a better calibration result. This may be because of additional loss components e.g. from evapotranspiration from invading reed beds not previously occurring within the springs areas. It may also be because of unknown additional abstraction that may have occurred as a result of drought or channeling of the Paardenvallei springflow upstream of the measuring weir.
- The calibration for the Vergenoegd flow is not good as measured against the observed flow (observed flows are much higher). It is known however that substantial surface flow components are being measured at the measuring weir – the observed flow is therefore not representing groundwater flow only.

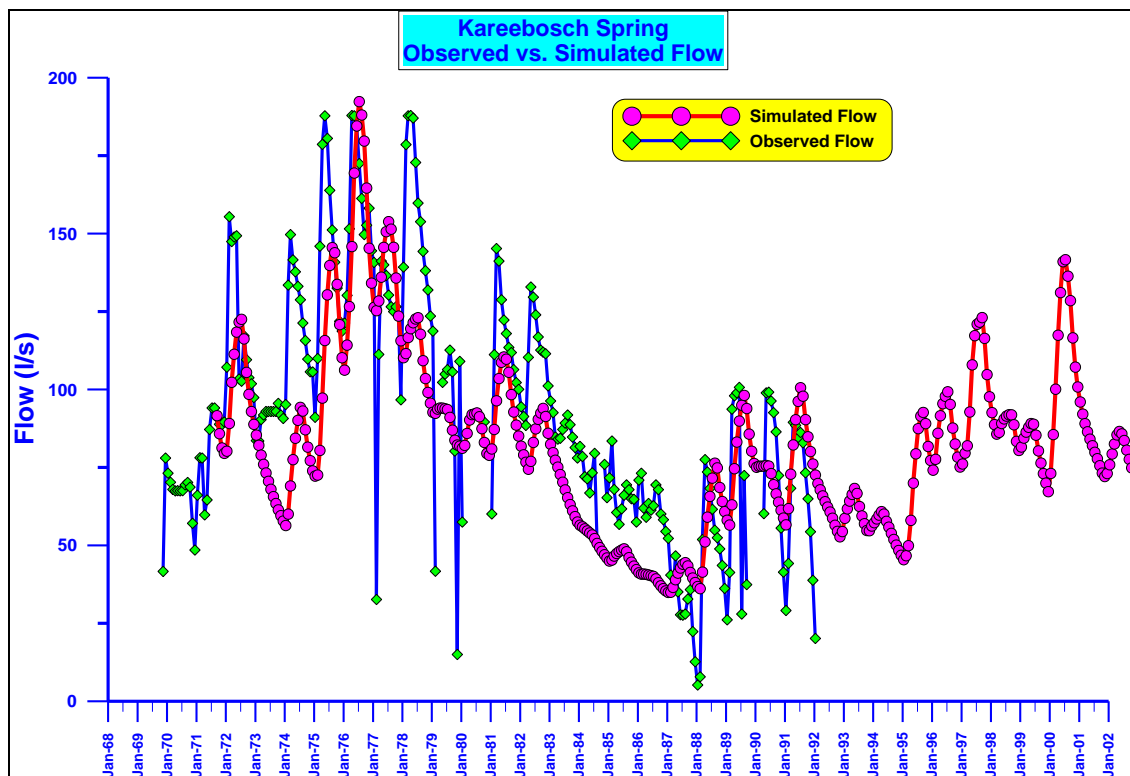


Figure 27 – Kareebosch Spring Observed vs. Simulated Flow.

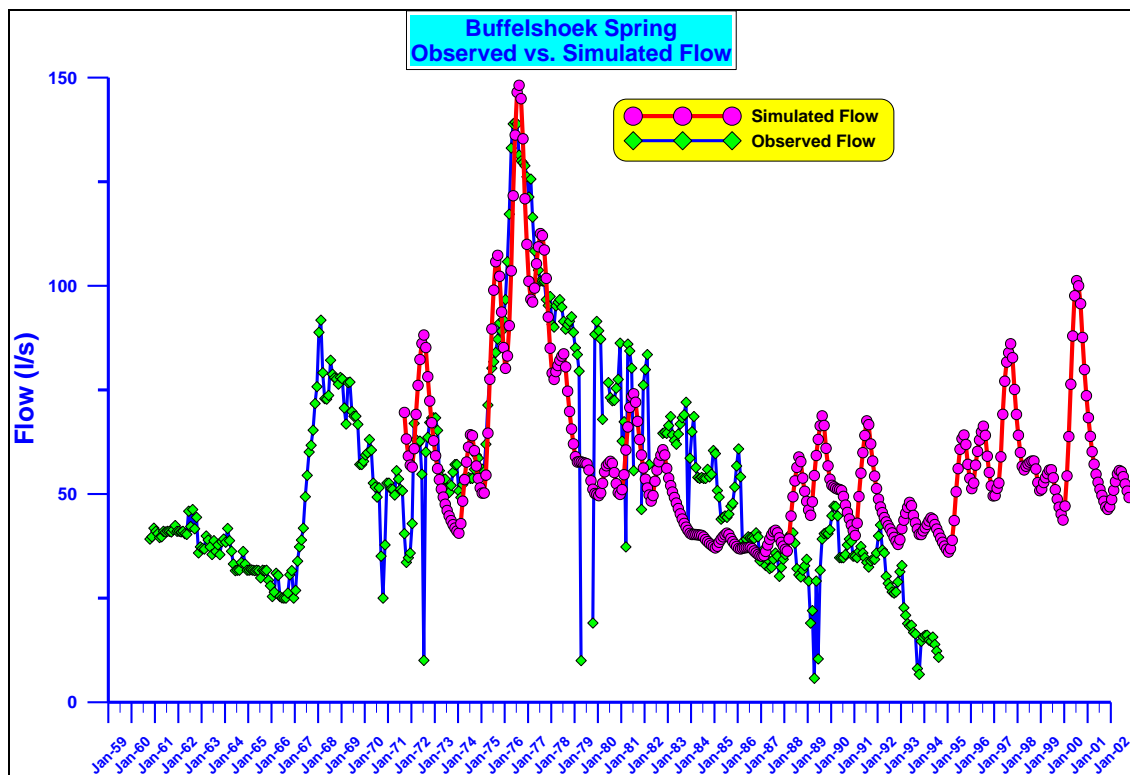


Figure 28 – Buffelshoek Spring Observed vs. Simulated Flow.

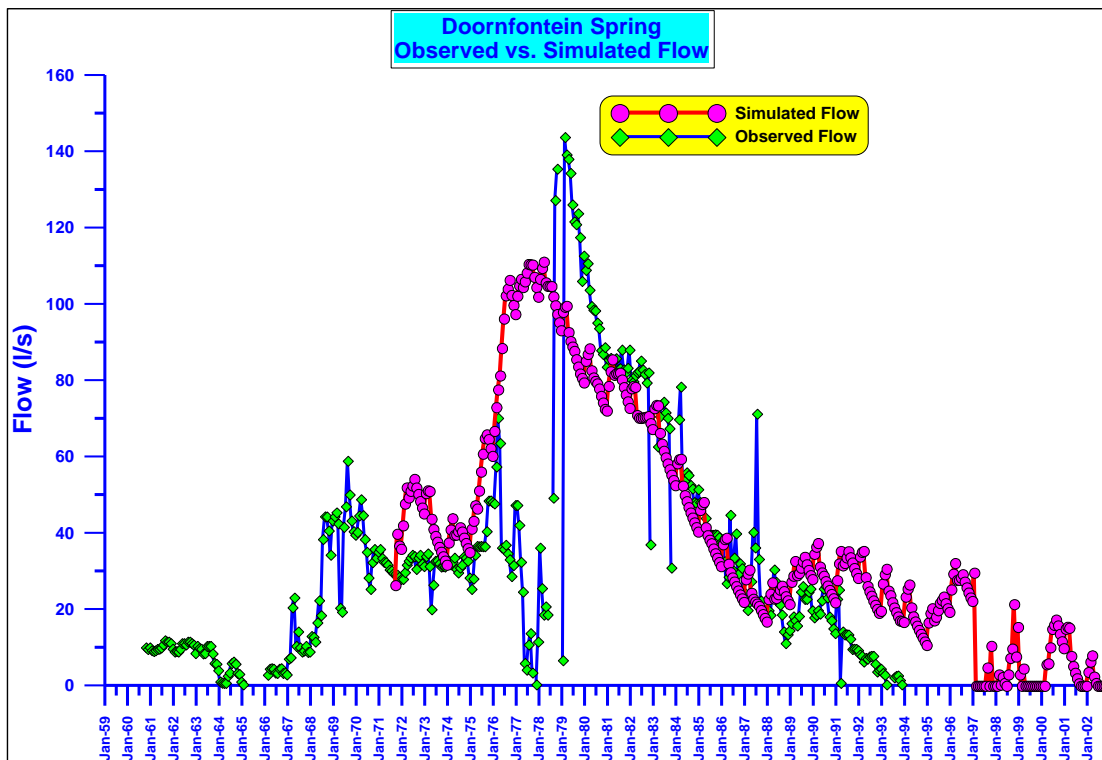


Figure 29 – Doornfontein Spring Observed vs. Simulated Flow.

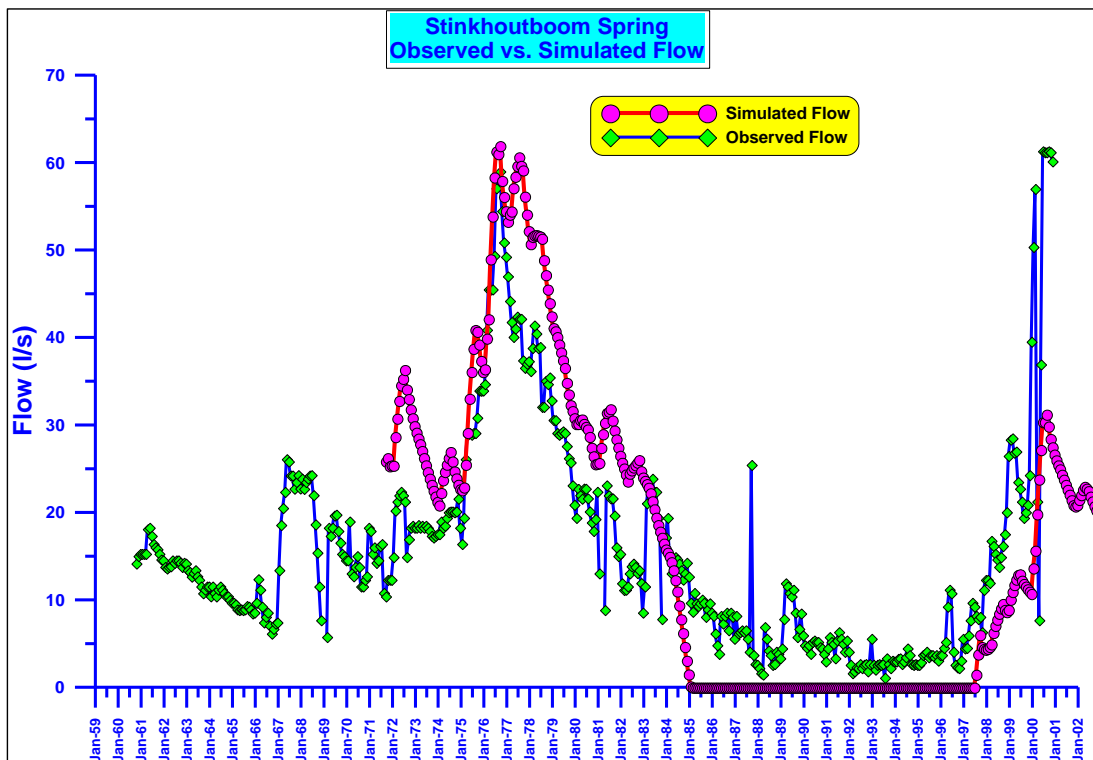


Figure 30 – Stinkhoutboom Spring Observed vs. Simulated Flow.

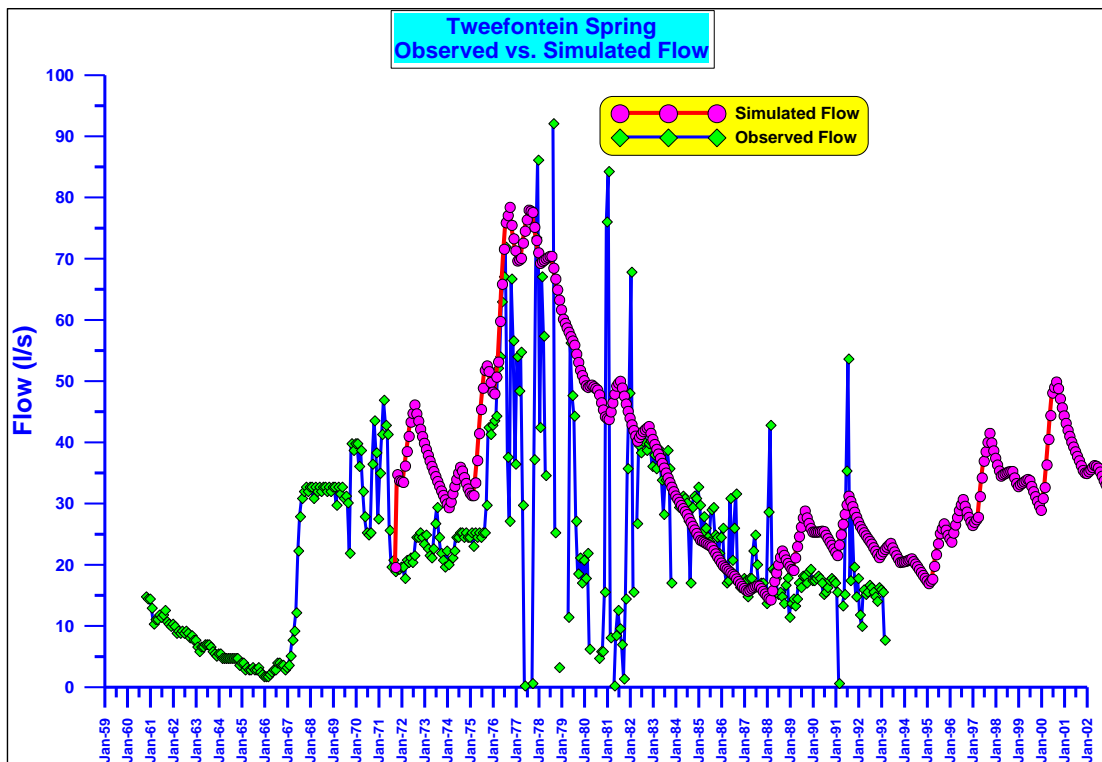


Figure 31 – Tweefontein Spring Observed vs. Simulated Flow.

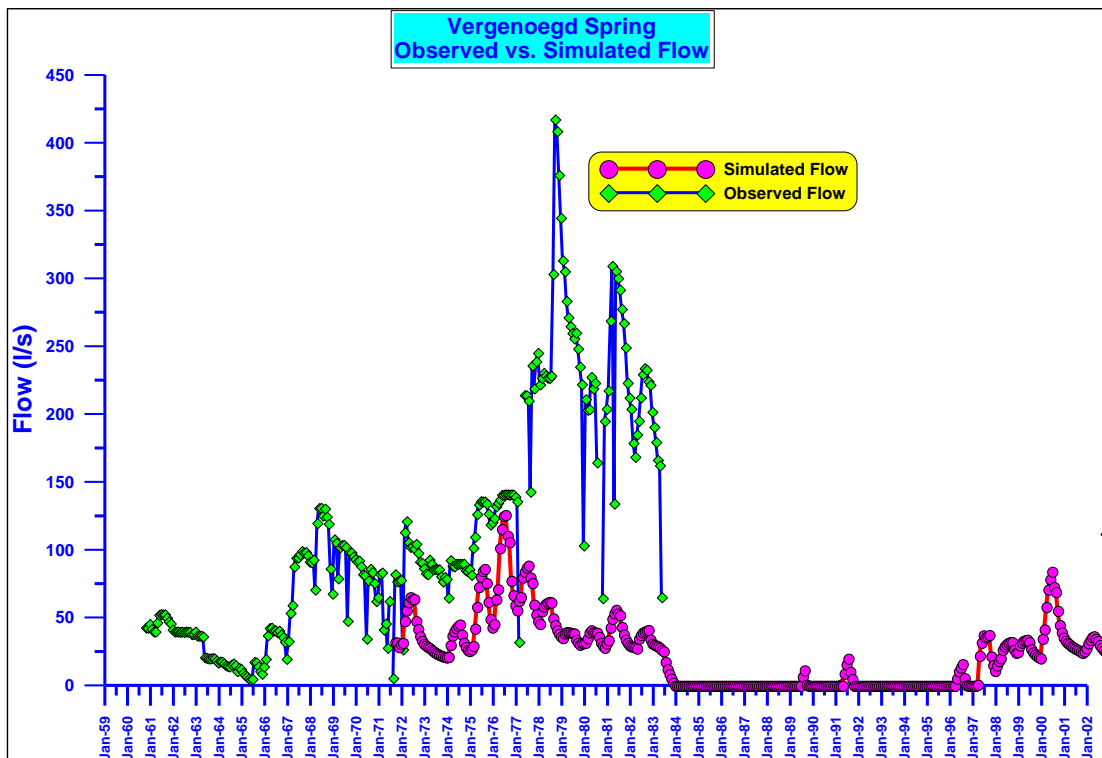


Figure 32 – Vergenoegd Spring Observed vs. Simulated Flow.

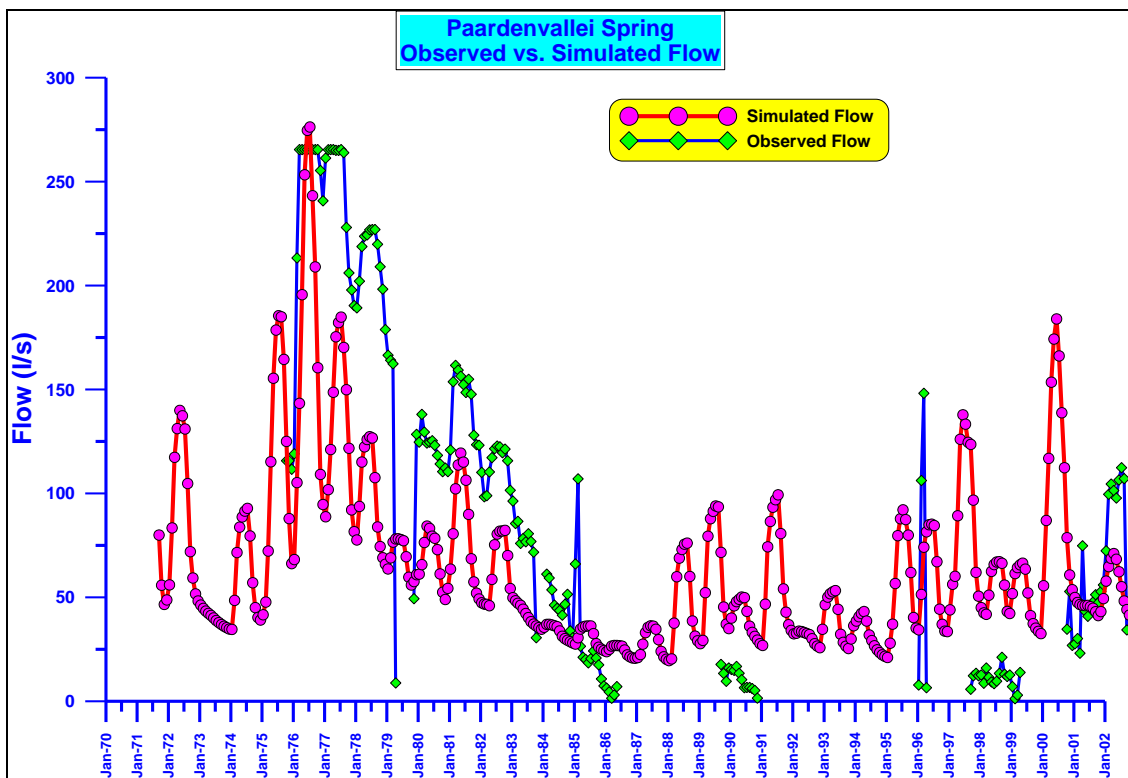


Figure 33 – Paardenvallei Spring Observed vs. Simulated Flow.

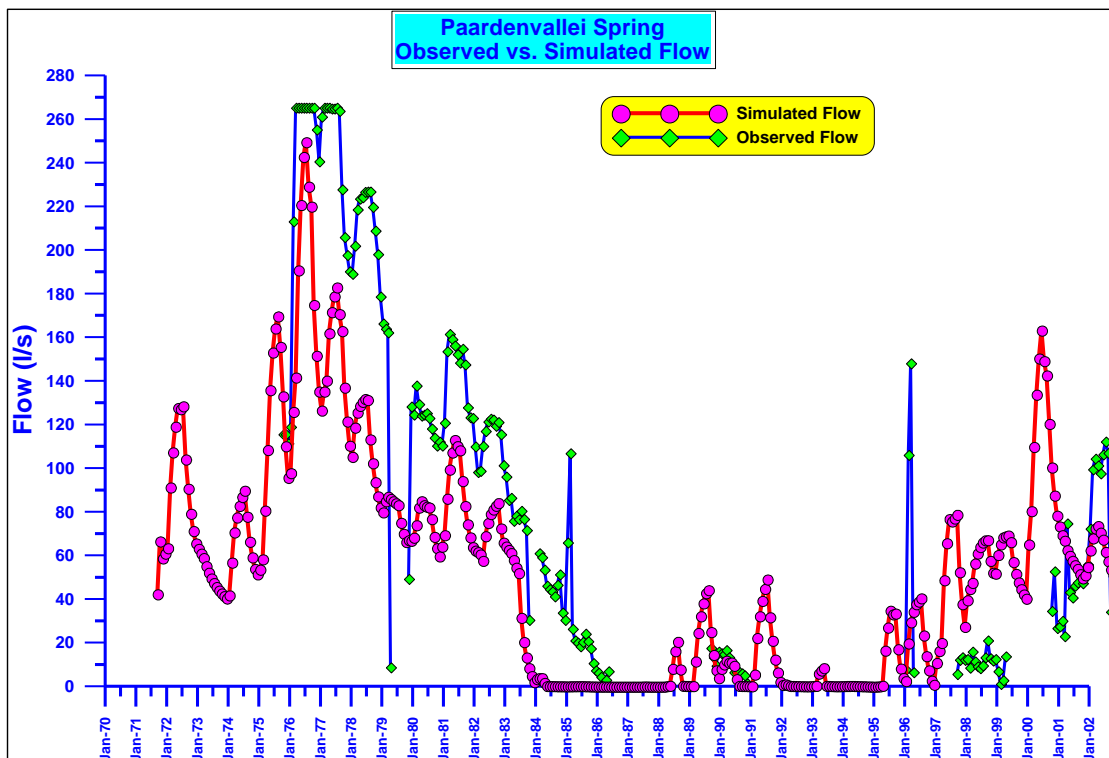


Figure 34 – Paardenvallei Spring Observed vs. Simulated Flow with an additional 70l/s abstracted from the Paardenvallei Compartment.

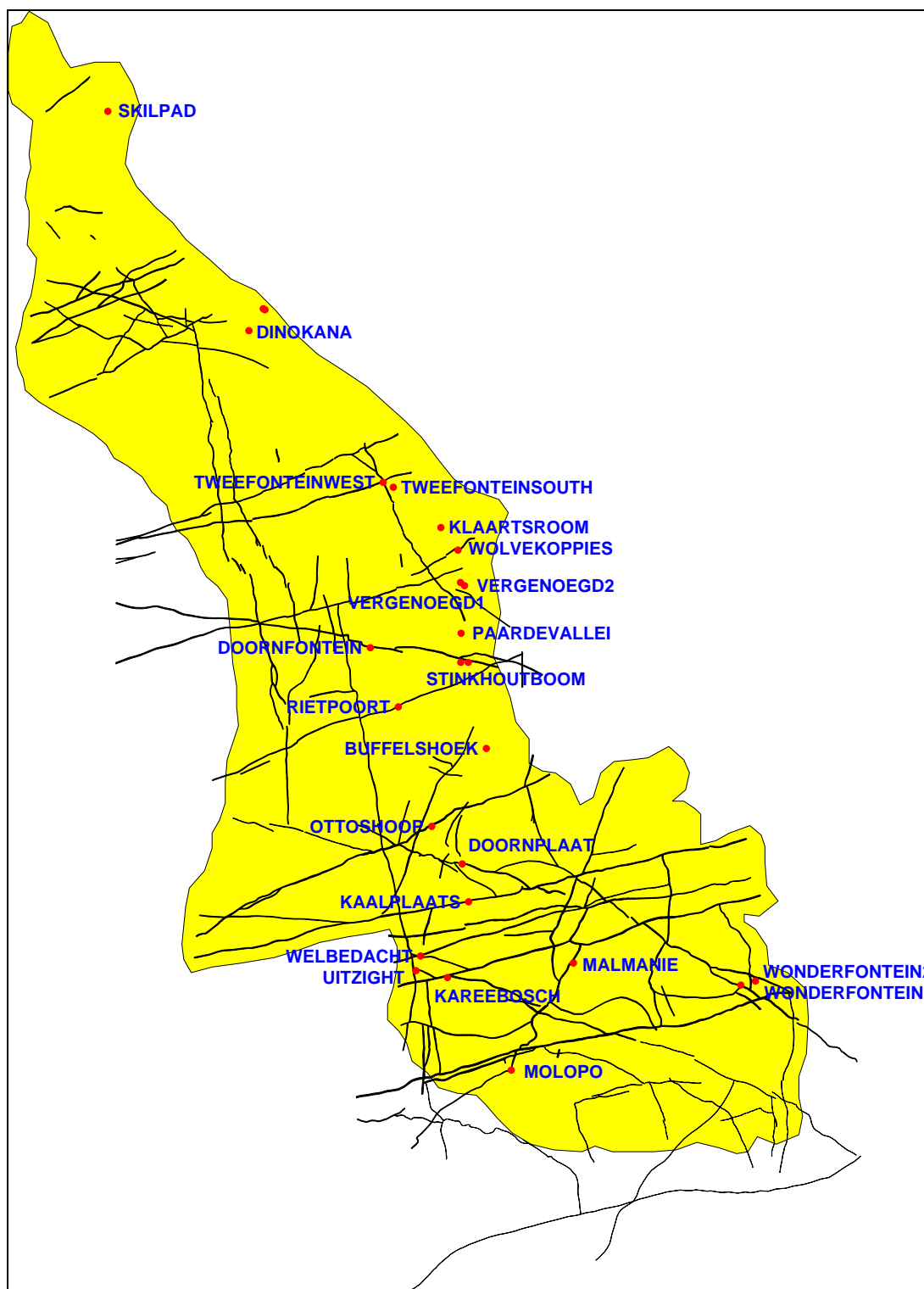


Figure 35 – Spring positions across modelling area.

Figures 36 to 41 show the simulated vs. observed water levels at boreholes, DO14, PV20, PV19, TF20, TF21 and RP12. Their positions are depicted on Figure 43.

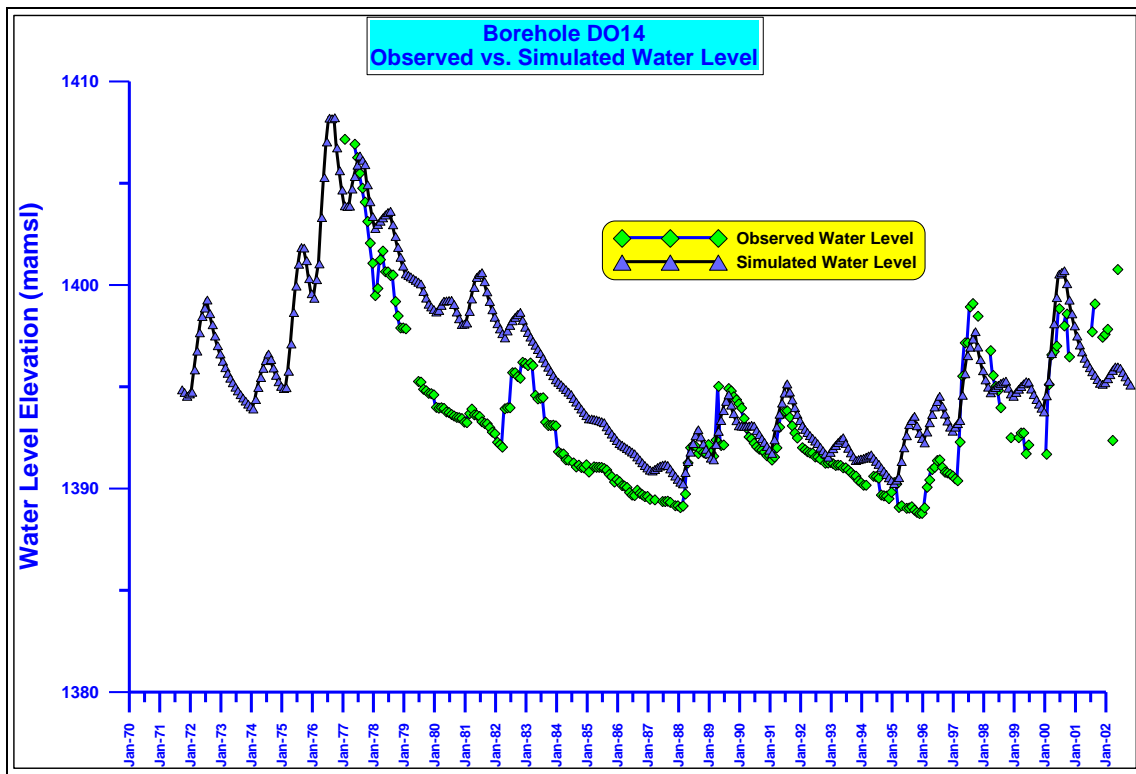


Figure 36 – Borehole DO14 – Simulated vs. observed water level.

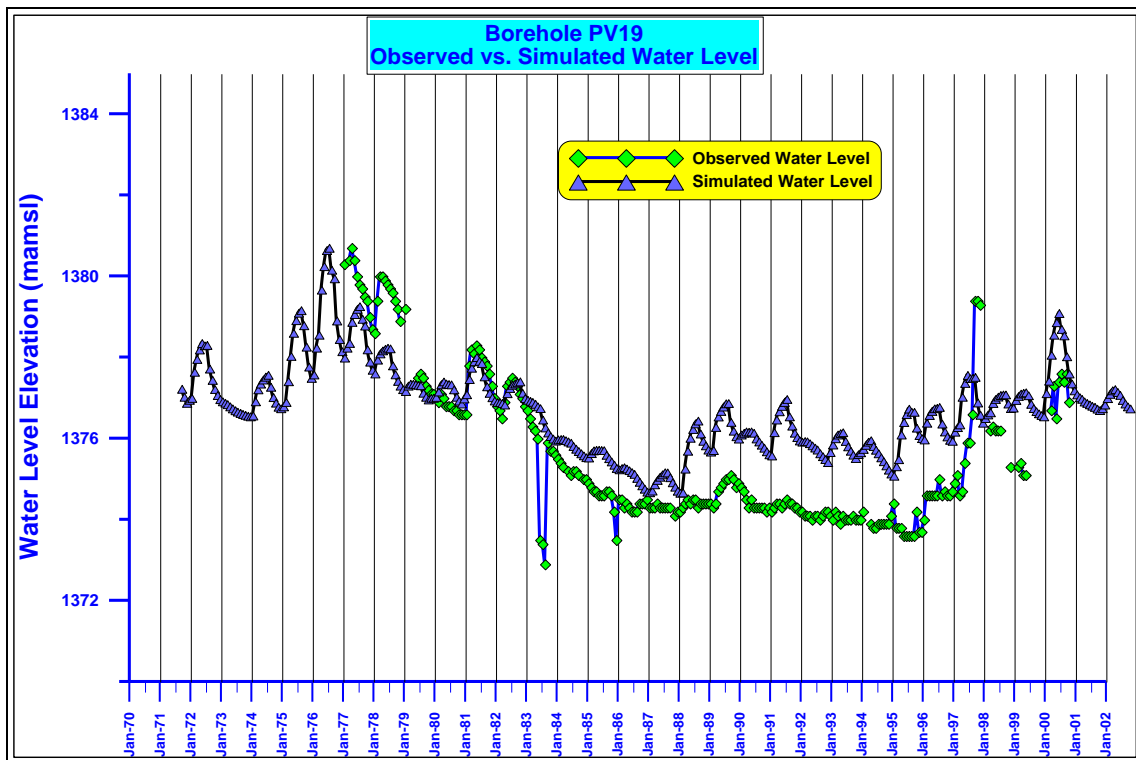


Figure 37 – Borehole PV19 – Simulated vs. observed water level.

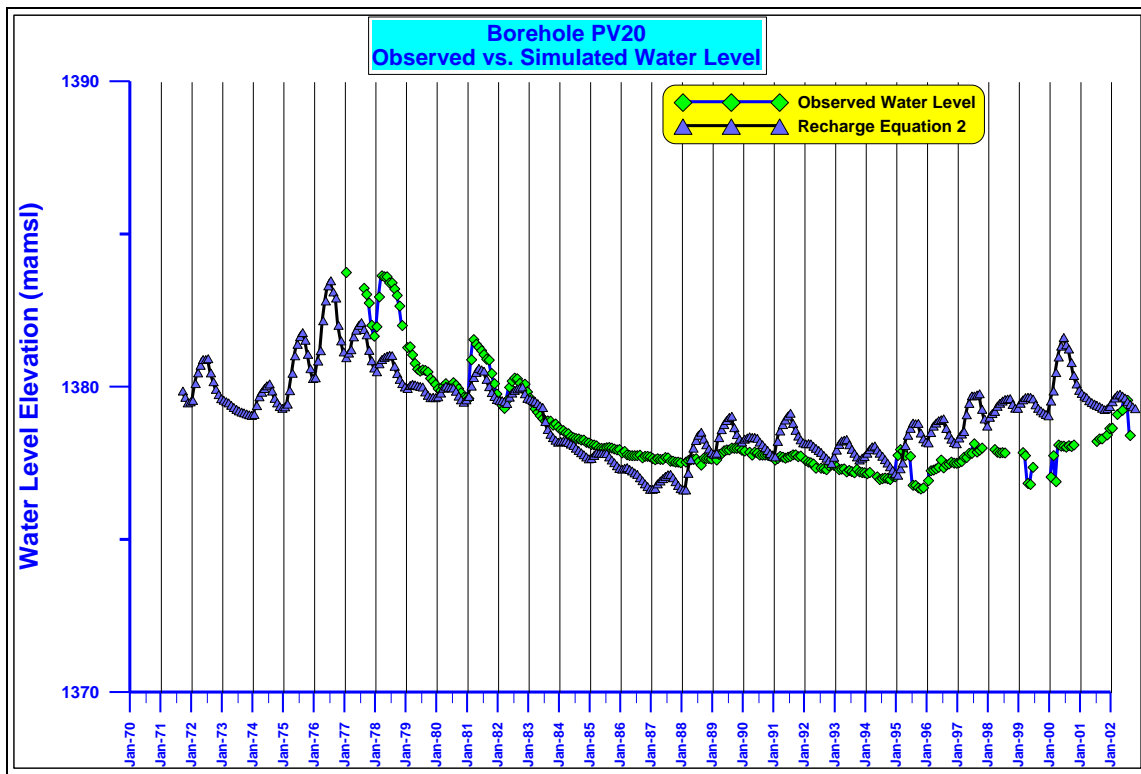


Figure 38 – Borehole PV20 – Simulated vs. observed water level.

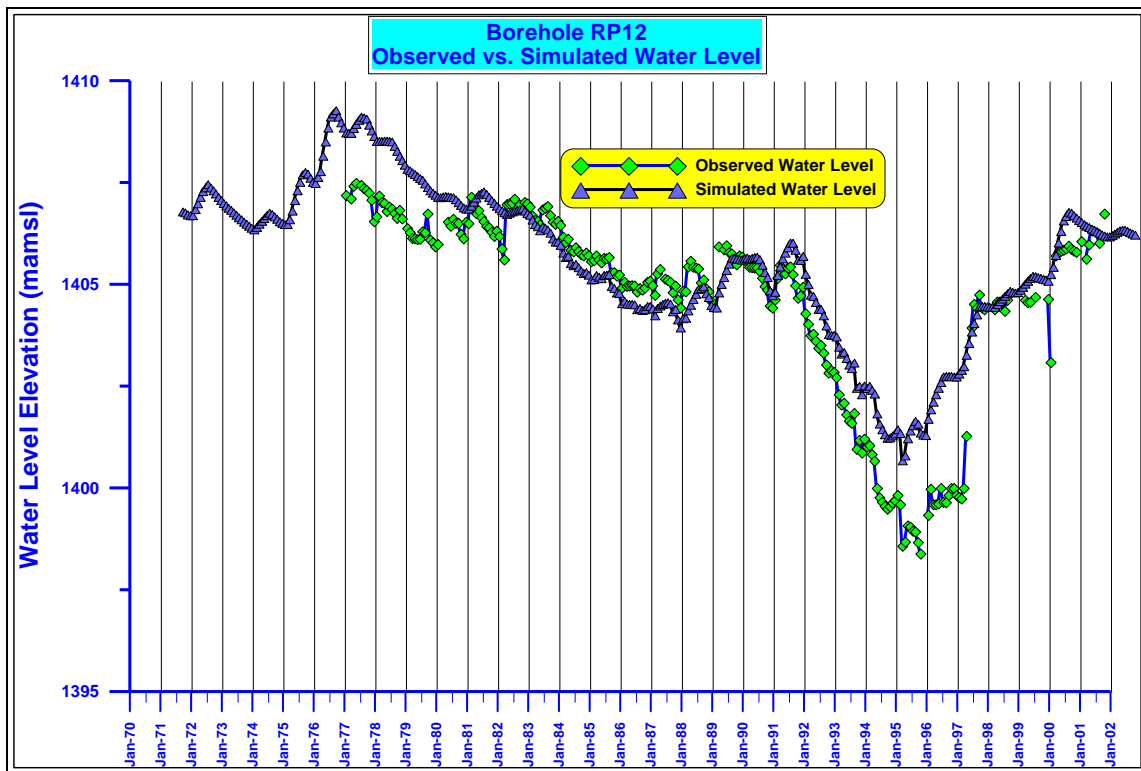


Figure 39 – Borehole RP12 – Simulated vs. observed water level.

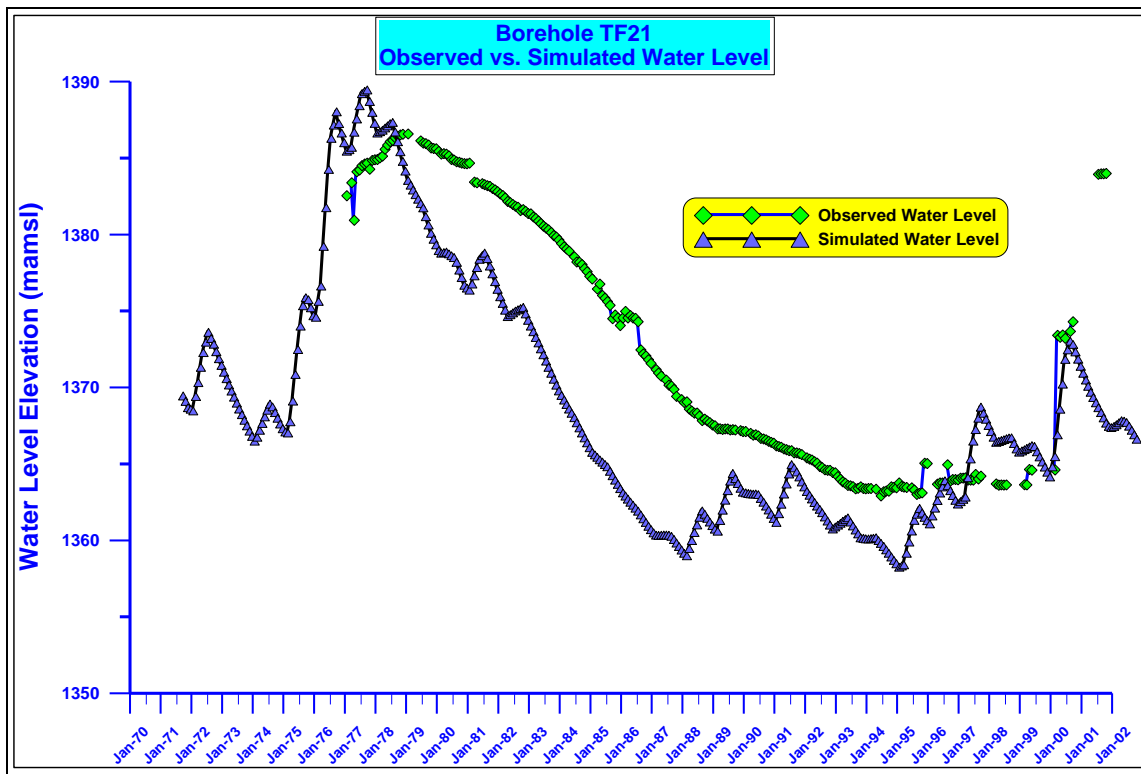


Figure 40 – Borehole TF21 – Simulated vs. observed water level.

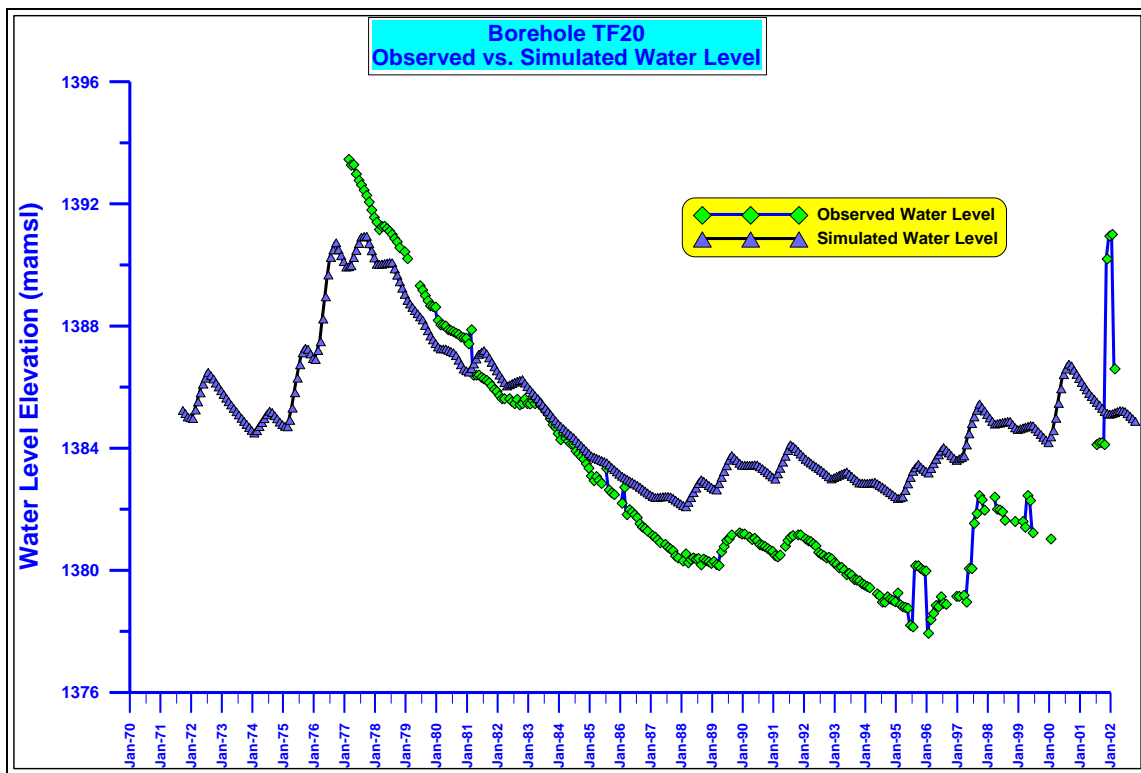


Figure 41 – Borehole TF20 – Simulated vs. observed water level.

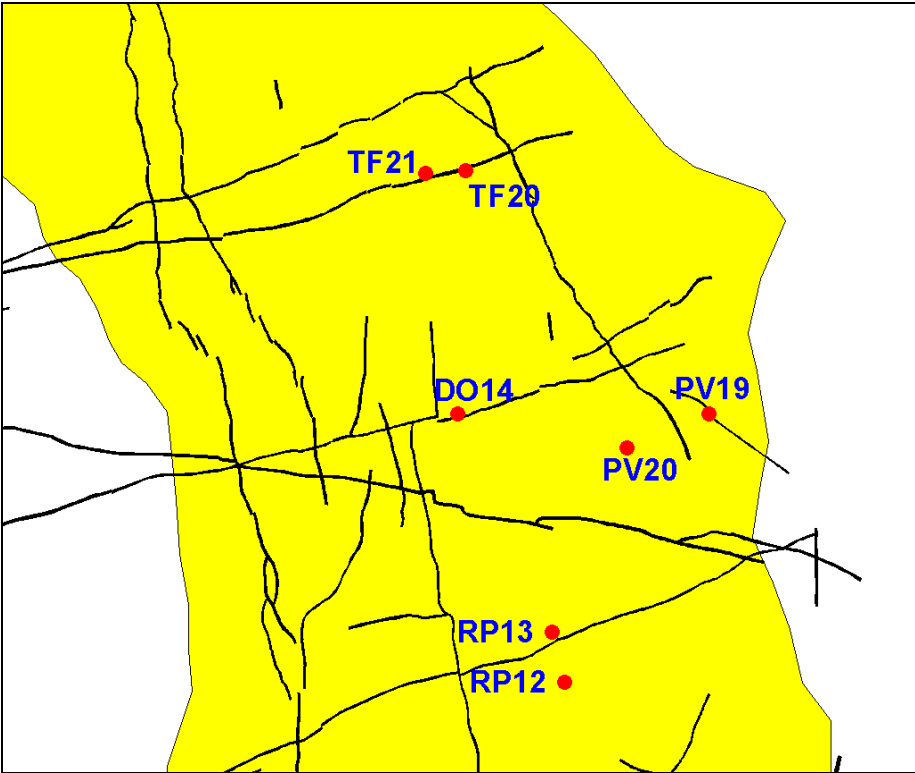


Figure 42 – Monitoring borehole positions across the study area.

4 DETERMINATION OF AQUIFER PERFORMANCE UTILISING THE CALIBRATED AQUIFER MODEL

4.1 Introduction

The calibrated groundwater flow model can now be utilised to forecast the aquifer response due to different wellfield abstraction scenarios. According to the objectives listed in Section 1 the following needs to be determined:

- Determine the feasibility to supply 6l/s from the Uitvalgrond Compartment;
- Determine the feasibility to supply 10l/s from the Tweefontein South Compartment;
- Determine the feasibility to supply 30l/s from the Paardenvallei Compartment. This rate is in addition to the current estimated abstraction rate of 29l/s being abstracted from this compartment;
- Determine the impact of this abstraction on water levels and springflow rates and other natural system losses.

It is clear that the long-term sustainable abstraction from the aquifer is constrained by the long-term recharge from rainfall and the nett effect of the difference between natural inflow and outflow across compartment boundaries. According to the steady state calibration results this rate is balanced by spring flow from the system and natural losses through the system's boundaries. The recharge obtained by means of the steady state and transient calibration is in good correspondence with results obtained by other researchers and the obtained spring flows are in good correspondence with the measured flows. The natural recharge occurs however across the entire modelling area and is obviously not available for abstraction from a single area, as the capture zone of such an area may be limited in extent. The objective of this exercise is therefore to determine the impact of abstraction at the required rates from the system from the position of the proposed production boreholes and to determine the impact of this abstraction on the reduction in spring flow and the natural losses from the system.

4.2 Assumption

The capture zone of a specific abstraction scenario is dependent on the amount of drawdown allowed. The probability of subsidence and sinkhole formation increases with drawdown of the groundwater level. The risk appears to be slight if drawdown is restricted, particularly where the groundwater level lies within 30m from the surface. On the basis of observations about the onset of sinkhole formation, it appears that a 6m drawdown on average would not be excessive (Vegter, 1988). With this in mind 6m will be used as criterion against which the abstraction

scenarios will be evaluated.

4.3 Abstraction Simulations

Four simulations were conducted in transient state mode using the available rainfall record for the period 1971-2002 (31 years). **It is assumed that a similar rainfall pattern will repeat itself in future.** Contained in this 31-year rainfall period are extremely wet and dry cycles that may provide a representation of what may be expected from forthcoming rainfall cycles.

The following four abstraction scenarios were simulated:

Scenario 1: No additional wellfield abstraction to the abstraction already assigned in the model. An amount of 70l/s from the Paardenvallei Compartment is however abstracted additionally in order to compensate for the possibility of natural system losses or unknown abstraction that may have occurred over the calibration period (see Section 3.6). This scenario serves as a worst base case to compare the scenario of additional wellfield abstraction against.

Scenario 2: No additional wellfield abstraction to the abstraction already assigned in the model. The additional amount of 70l/s from the Paardenvallei Compartment is however now omitted in the event of this assumption being overly pessimistic. This scenario serves as a best base case to compare the scenario of additional wellfield abstraction against.

Scenario 3: Pump 6l/s from the Uitvalgrond Wellfield, 10l/s from the Tweefontein South Wellfield and 30l/s from the Paardenvallei Wellfield in addition to the abstraction already assigned in the model. An amount of 70l/s from the Paardenvallei Compartment is abstracted additionally in order to compensate for the possibility of natural system losses or unknown abstraction that may have occurred over the calibration period (see Section 3.6).

Scenario 4: Pump 6l/s from the Uitvalgrond Wellfield, 10l/s from the Tweefontein South Wellfield and 30l/s from the Paardenvallei Wellfield in addition to the abstraction already assigned in the model. The additional amount of 70l/s from the Paardenvallei Compartment is however now omitted in the event of this assumption being overly pessimistic. This is probably the most likely scenario.

Figure 43 shows the abstraction positions from the various wellfields.

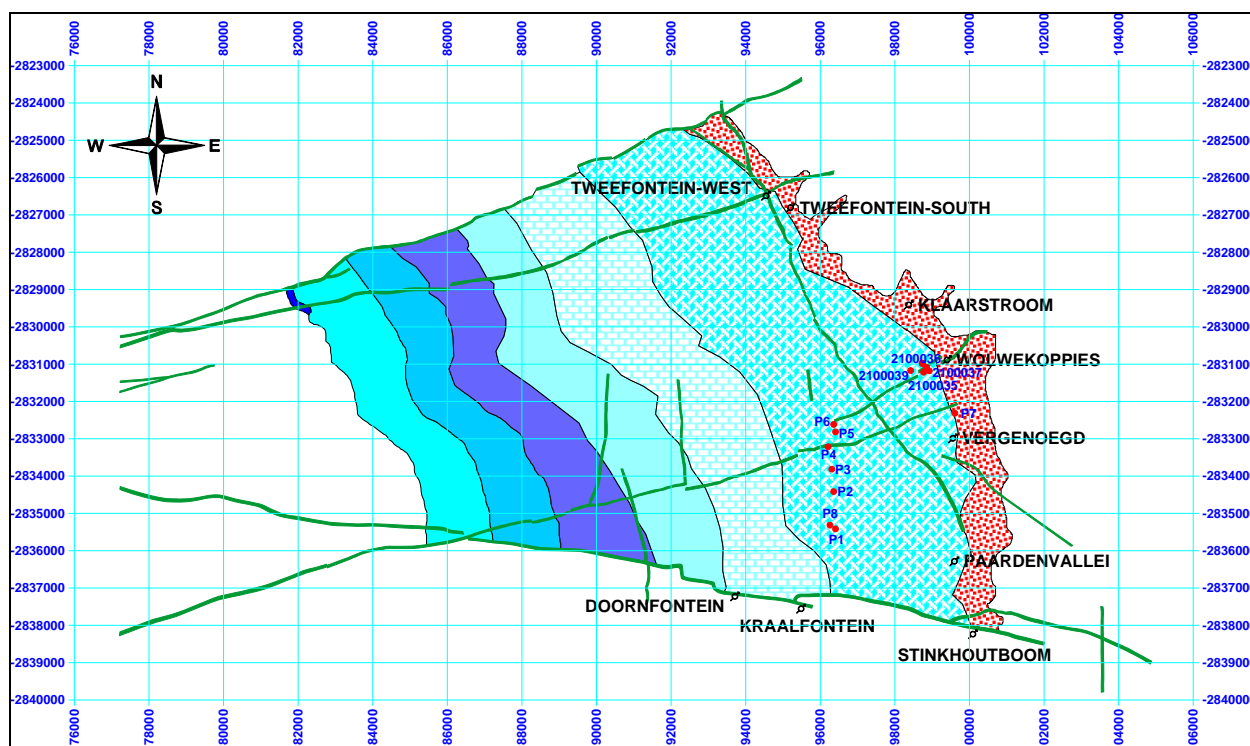


Figure 43 – Proposed abstraction borehole positions from the Uitvalgrond, Tweefontein South and Paardenvallei Compartments.

4.4 Simulation Results

4.4.1 Simulated Water Levels in Paardenvallei Compartment

Figure 44 shows the simulated temporal water level response for each of the scenarios conducted in the Paardenvallei Compartment. It is clear (as could be expected) that Scenario 3 produces the most dramatic effect on the water level where a drawdown of up to 12-13m can be observed over the long term. For Scenarios 1,2 and 4 this effect is much less pronounced and maximum drawdown is in the order of 7m. The recharge events to the aquifer has the effect however that water levels do recover in the compartment even after periods of droughts. The effect of the different scenarios on drawdown is better depicted in Figure 45 which shows the relative cumulative frequency distribution of the water level drawdown from the reference elevation of 1382.18 mamsl simulated for 2002. According to Figure 45 there is about a 60% chance to get a drawdown of 6m or more when considering the worst case scenario (Scenario 3). Considering the best case scenario (Scenario 2) there is only a 30% chance to get a drawdown of more than 2m. Considering the most likely scenario (Scenario 4) there is almost no risk of getting a drawdown in the compartment of more than 6m. It can therefore be concluded that the additional abstraction of 30l/s from the Paardenvallei Compartment should have no detrimental effect on water levels in the long term.

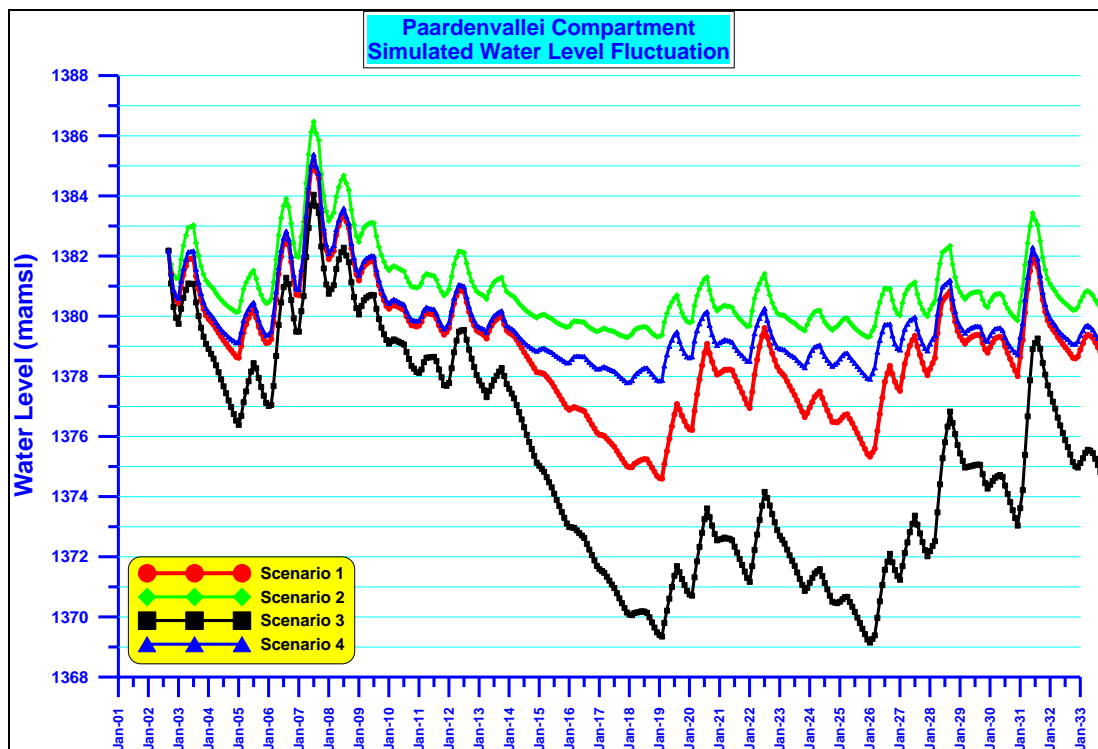


Figure 44 – Simulated temporal water level response in the Paardenvallei Compartment for each of the four scenarios.

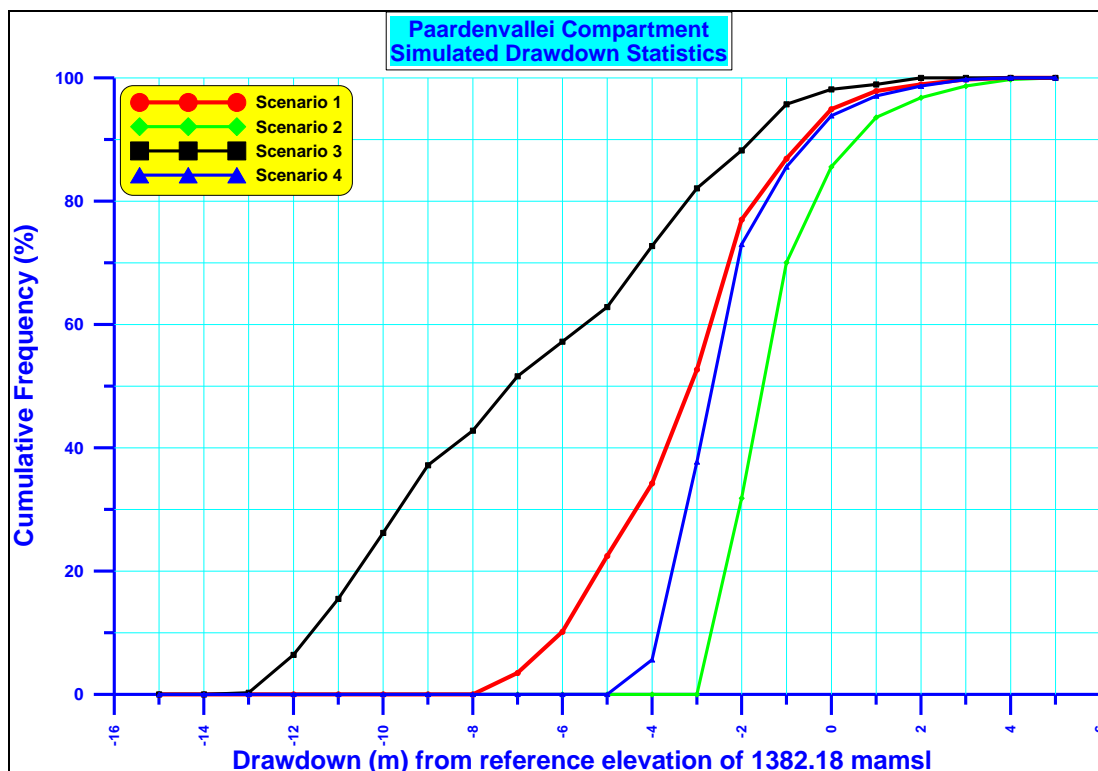


Figure 45 – Paardenvallei Compartment – Simulated drawdown statistics for each abstraction scenario.

4.4.2 Simulated water levels in the Tweefontein South Compartment

Figure 46 shows the simulated temporal water level response for each of the scenarios conducted in the Paardenvallei Compartment. It is again clear (as could be expected) that Scenario 3 produces the most dramatic effect on the water level where a drawdown of up to 13-14m can be observed over the long term. For Scenarios 1,2 and 4 this effect is much less pronounced and maximum drawdown is in the order of 8m. Again the recharge events to the aquifer has the effect however that water levels do recover in the compartment even after periods of droughts. The effect of the different scenarios on drawdown is better depicted in Figure 47 which shows the relative cumulative frequency distribution of the water level drawdown from the reference elevation of 1386.98 mamsl simulated for 2002. According to Figure 47 there is about a 60% chance to get a drawdown of 6m or more when considering the worst case scenario (Scenario 3). Considering the best case scenario (Scenario 2) there is only a 20% chance to get a drawdown of more than 4m. Considering the most likely scenario (Scenario 4) there is a 20% chance of getting a drawdown in the compartment of more than 6m. It can therefore be concluded that the abstraction of 10l/s from the Tweefontein South Compartment should have no detrimental effect on water levels in the long term. It is clear from Scenarios 1 and 2 that water levels in the Tweefontein South Compartment are being influenced by abstraction from the Paardenvallei Compartment.

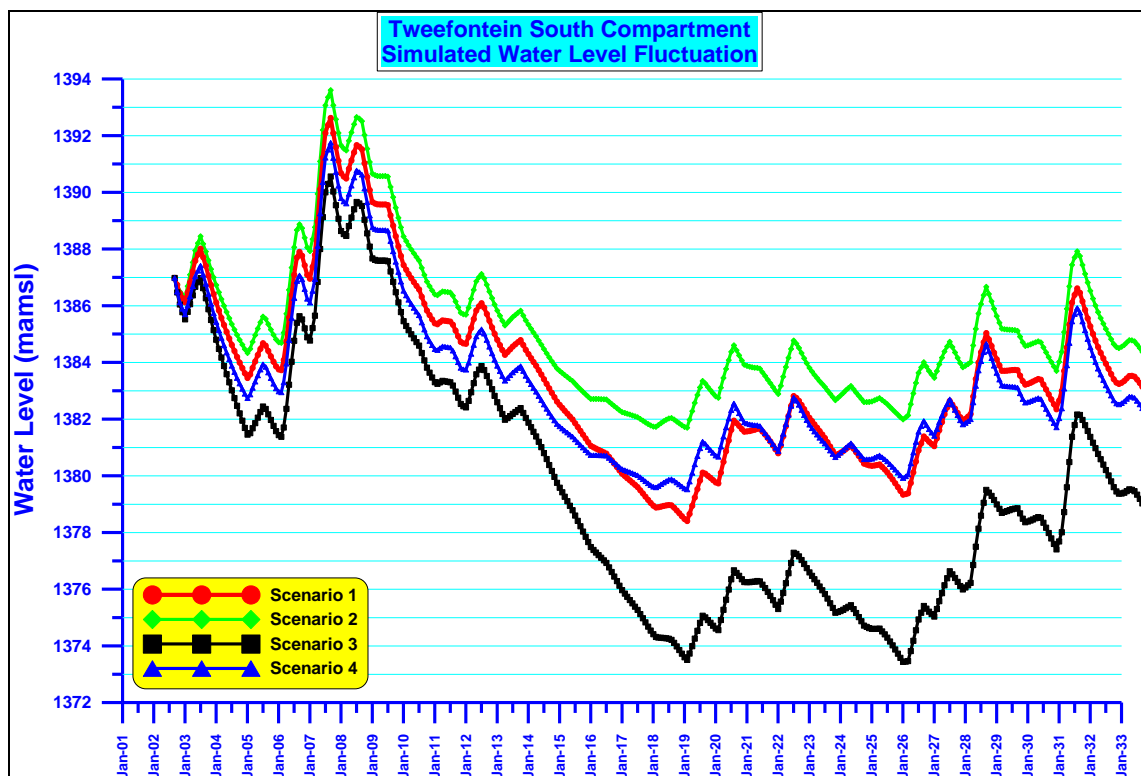


Figure 46 - Simulated temporal water level response in the Tweefontein South Compartment for each of the four scenarios.

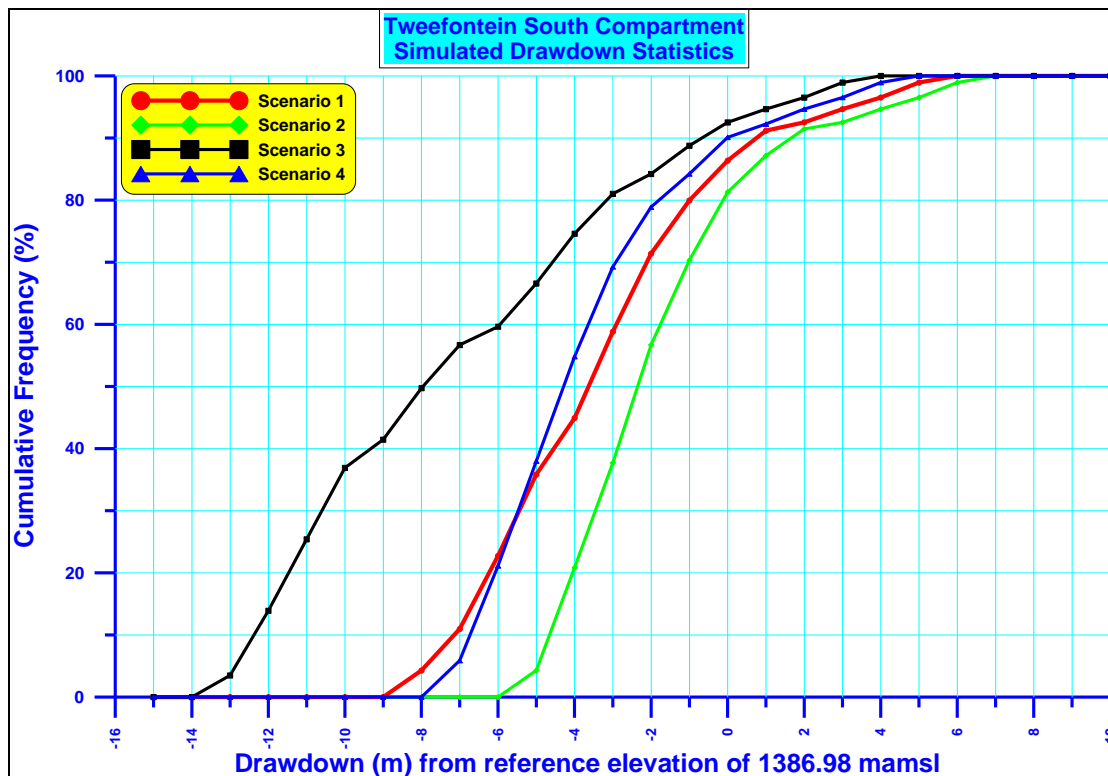


Figure 47 – Tweefontein South Compartment – Simulated drawdown statistics for each abstraction scenario.

4.4.3 Simulated water levels in the Uitvalgrond Compartment

Figure 48 shows the simulated temporal water level response for each of the scenarios conducted in the Uitvalgrond Compartment. It is clear that the abstraction from the Paardenvallei and Tweefontein South Compartments has no effect on the water levels in the Uitvalgrond Compartment. Over the long term the maximum drawdown in the compartment is in the order of 11m as a result of abstracting 6l/s. Again the recharge events to the aquifer has the effect however that water levels do recover in the compartment even after periods of droughts. The effect of the different scenarios on drawdown is better depicted in Figure 49 which shows the relative cumulative frequency distribution of the water level drawdown from the reference elevation of 1359.86 mamsl simulated for 2002. According to Figure 49 there is about a 40% chance to get a drawdown of 6m or more when considering the worst case scenario (Scenario 3). Considering the best case scenario (Scenario 2) there is no chance to get a drawdown of more than 1m. It can be concluded that the abstraction of 6l/s from the Uitvalgrond Compartment should have no detrimental effect on water levels in the long term.

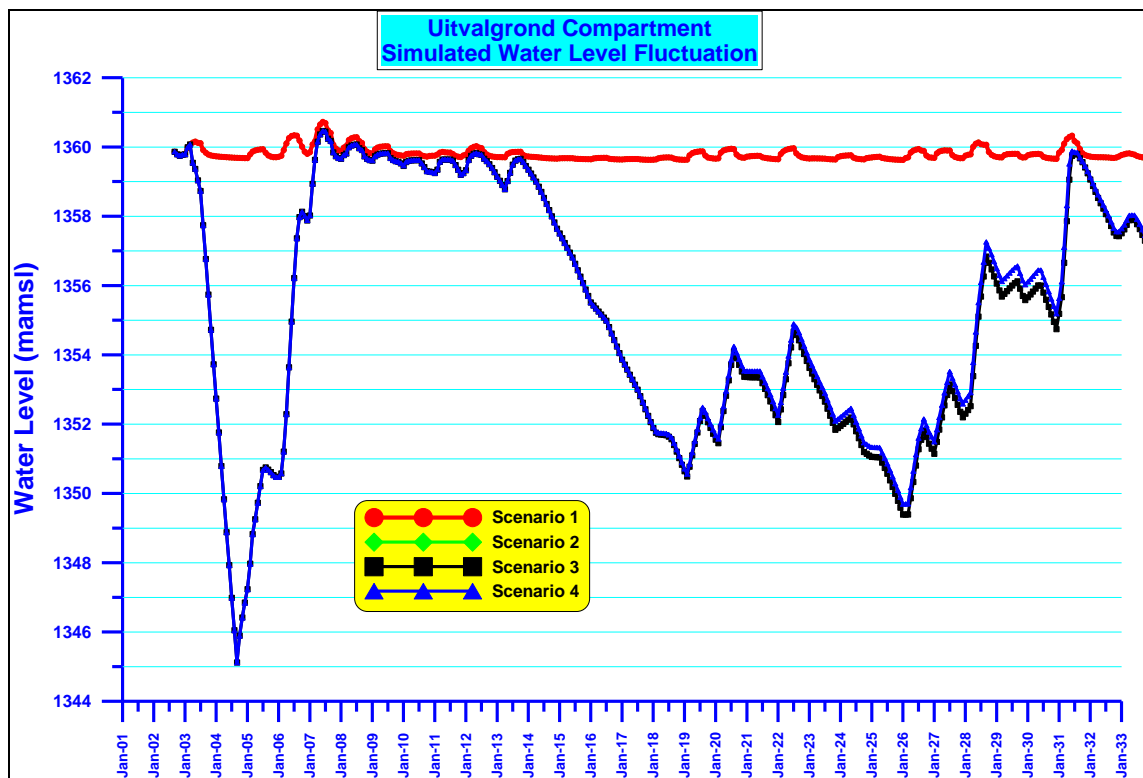


Figure 48 - Simulated temporal water level response in the Uitvalgrond Compartment for each of the four scenarios.

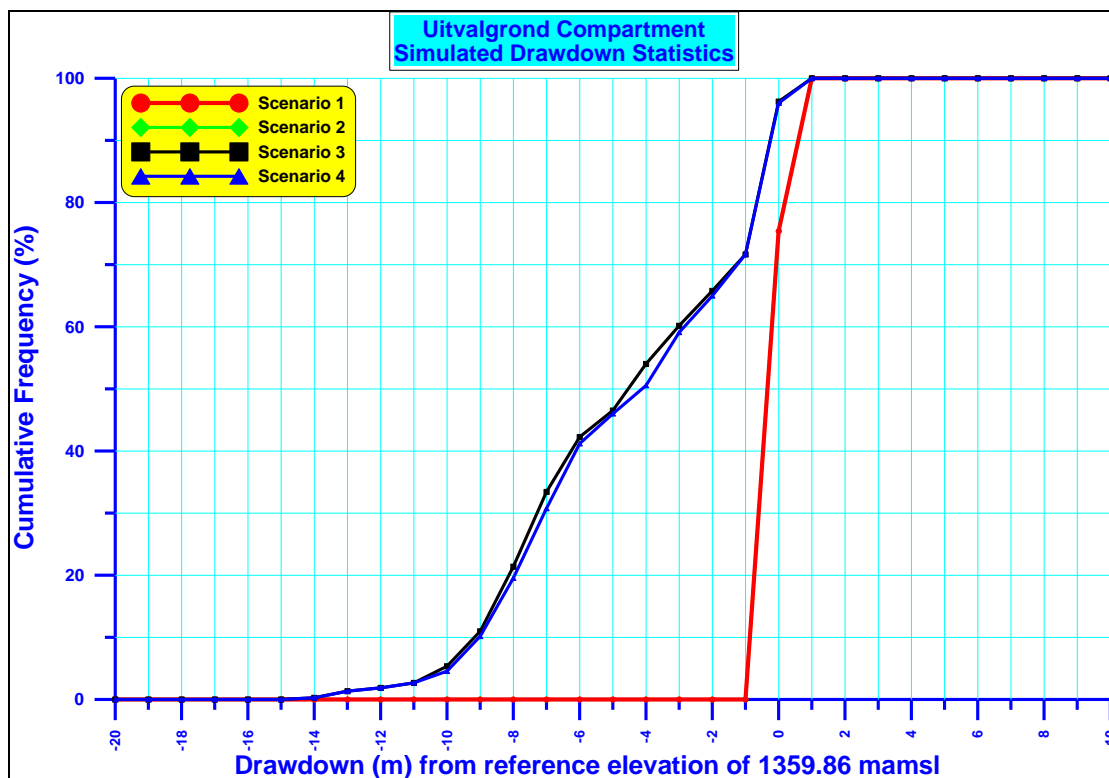


Figure 49 – Uitvalgrond Compartment – Simulated drawdown statistics for each abstraction scenario.

4.4.4 Simulated Spring Flow from Paardenvallei Spring

Figures 50 and 51 respectively show the additional impact of the 30l/s being abstracted from the Paardenvallei Compartment on the simulated flow from the Paardenvallei Spring for assuming a natural loss of 70l/s (Scenarios 1 and 3) and no additional natural loss (Scenarios 2 and 4). From Figure 50 the effect of the additional abstraction of 30l/s with the loss of 70l/s due to evapotranspiration on the Paardenvallei springflow can be observed (see Section 3.6). It is clear that the additional 30l/s pumping will reduce the flow from the spring. Similarly Figure 51 shows the effect of the additional abstraction of 30l/s without assuming the additional loss of 70l/s on the Paardenvallei springflow. Again it is clear from Figure 51 that the additional abstraction will impact on the spring and will reduce the flow.

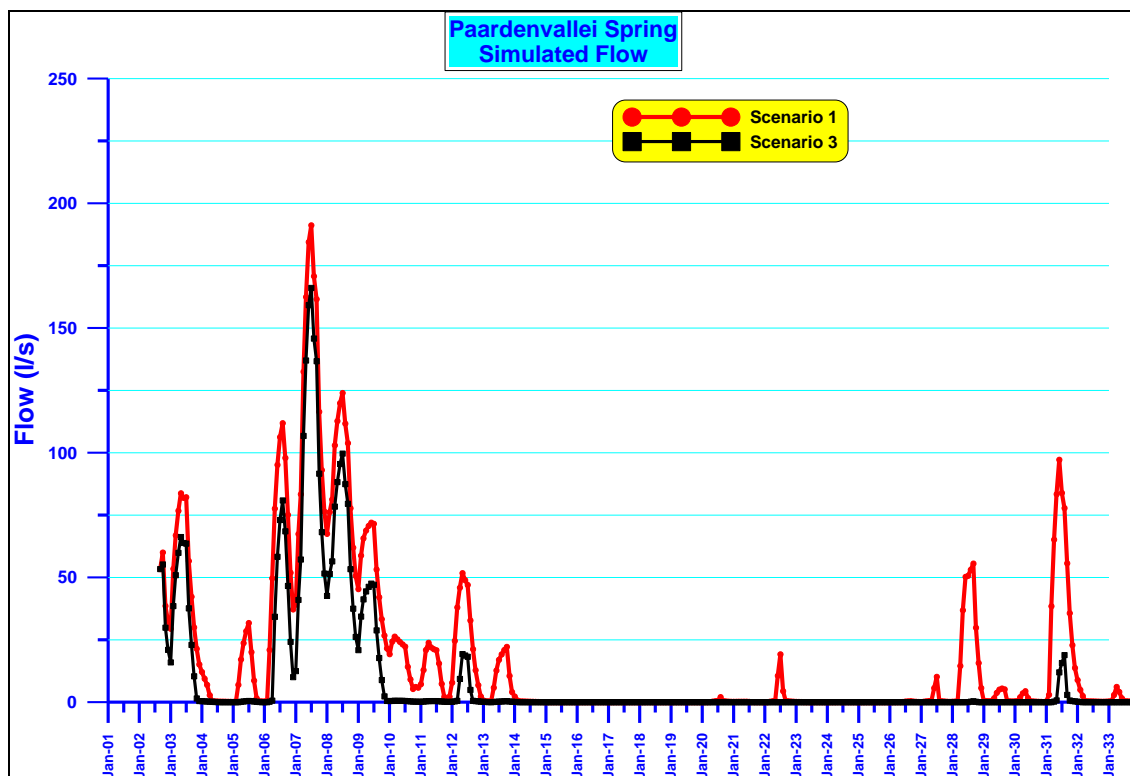


Figure 50 - Simulated temporal springflow from the Paardenvallei spring for Scenarios 1 and 3.

Figure 52 shows the simulated springflow statistics for each of the scenarios conducted. From this figure it is evident that there is a 80% chance that the Paardenvallei spring will flow at a rate of 27,5l/s or higher for Scenario 2. Similarly there is a 80% chance that the spring will flow at a rate of 7l/s or higher for Scenario 4 (which denotes the additional abstraction of 30l/s from the Paardenvallei Compartment). Figure 53 shows the simulated reduction in springflow statistics for the difference between Scenarios 1 and 3 and Scenarios 2 and 4. From this figure it is evident that it is 99% sure that the reduction in springflow will be between 10 and 30l/s i.e. chances are 1% that it will be less than 10l/s and 1% that it will be more than 30l/s.

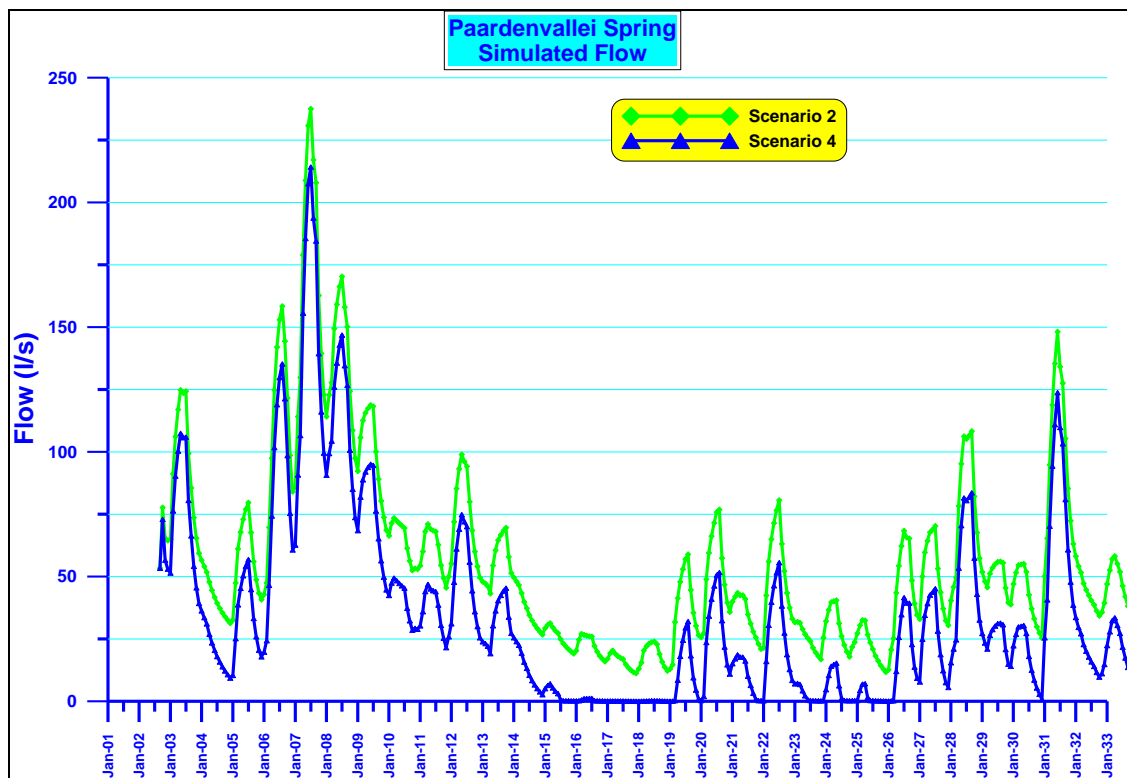


Figure 51 - Simulated temporal springflow from the Paardenvallei spring for Scenarios 2 and 4.

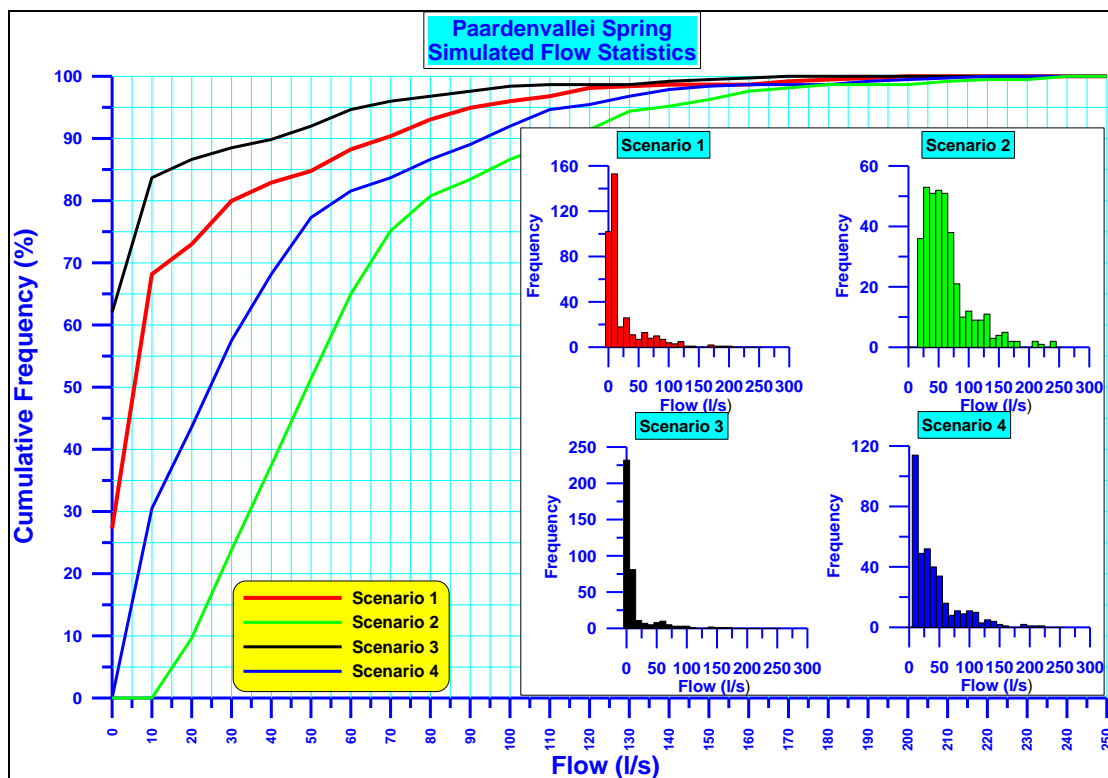


Figure 52 – Paardenvallei Spring simulated springflow statistics for each scenario.

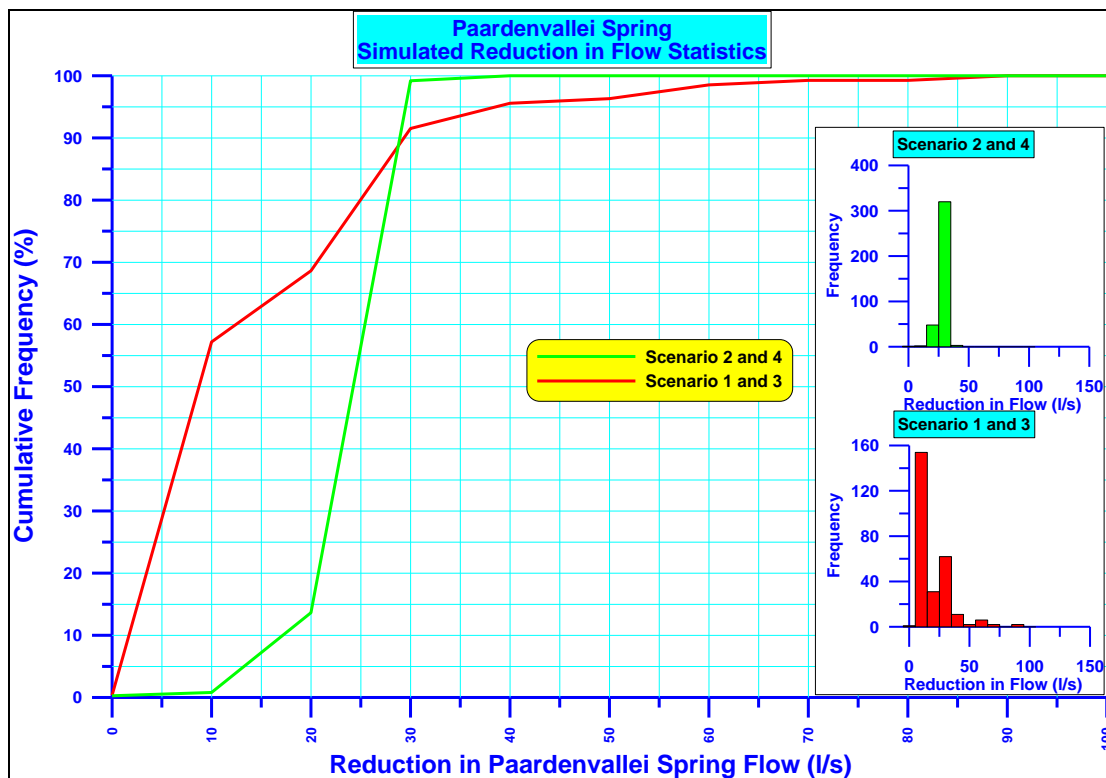


Figure 53 – Reduction in simulated Paardenvallei Springflow statistics for each scenario.

4.4.5 Simulated Spring Flow from Vergenoegd Spring

Figures 54 and 55 respectively show the additional impact of the 30l/s being abstracted from the Paardenvallei Compartment on the simulated flow from the Vergenoegd Spring for assuming a natural loss of 70l/s (Scenarios 1 and 3) and no additional natural loss (Scenarios 2 and 4). From Figure 54 the effect of the additional abstraction of 30l/s with the loss of 70l/s due to evapotranspiration on the Vergenoegd springflow can be observed (see Section 3.6). It is clear that the additional 30l/s pumping will reduce the flow from the spring. Similarly Figure 55 shows the effect of the additional abstraction of 30l/s without assuming the additional loss of 70l/s on the Vergenoegd springflow. Again it is clear from Figure 55 that the additional abstraction will impact on the spring and will reduce the flow.

Figure 56 shows the simulated springflow statistics for each of the scenarios conducted. From this figure it is evident that there is a 80% chance that the Paardenvallei spring will flow at a rate of 17l/s or higher for Scenario 2. Similarly there is a 80% chance that the spring will flow at a rate of 7l/s or higher for Scenario 4 (which denotes the additional abstraction of 30l/s from the Paardenvallei Compartment). Figure 57 shows the simulated reduction in springflow statistics for the difference between Scenarios 1 and 3 and Scenarios 2 and 4. From this figure it is evident that it is 99% sure that the reduction in springflow will be between 5 and 15l/s i.e. chances are 1% that it will be less than 5l/s and 1% that it will be more than 15l/s.

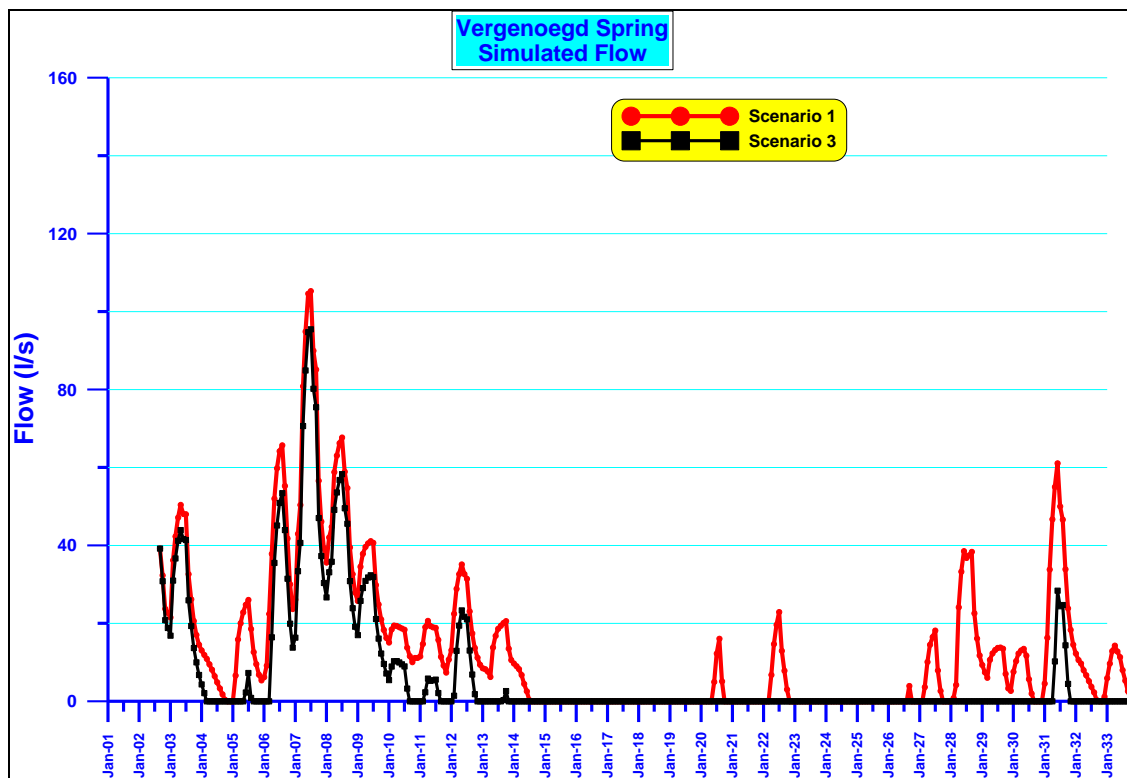


Figure 54 - Simulated temporal springflow from the Vergenoegd spring for Scenarios 1 and 3.

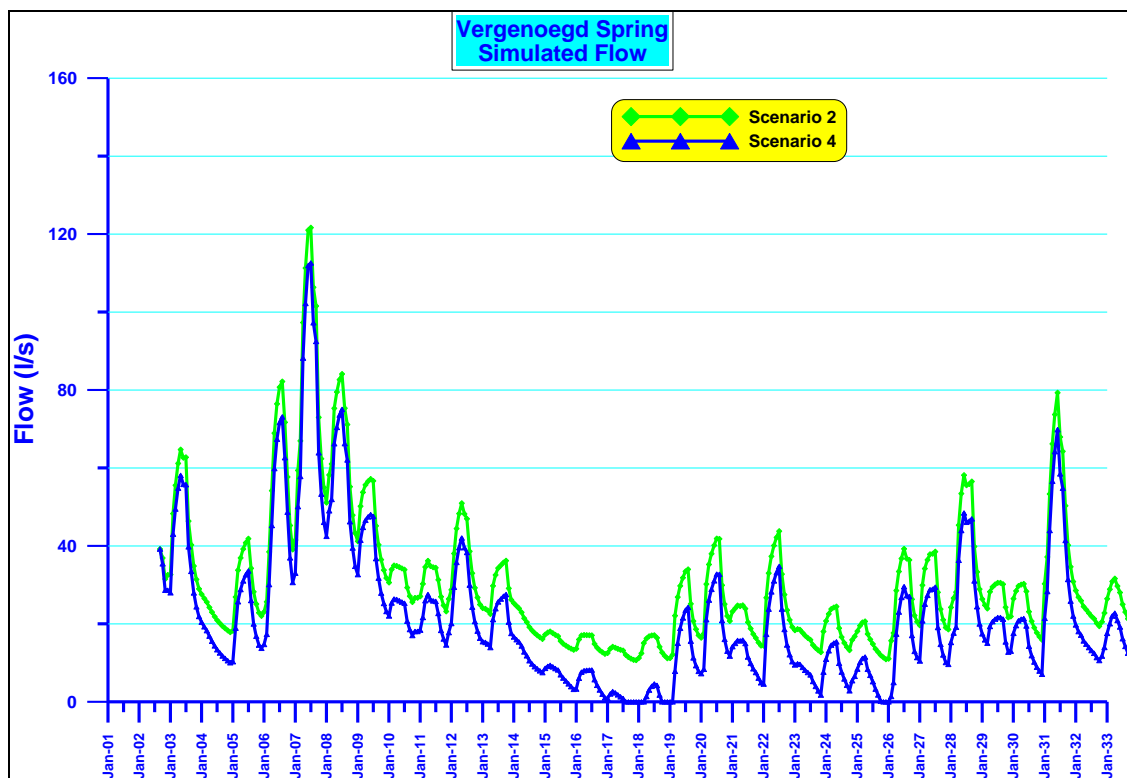


Figure 55 - Simulated temporal springflow from the Vergenoegd spring for Scenarios 2 and 4.

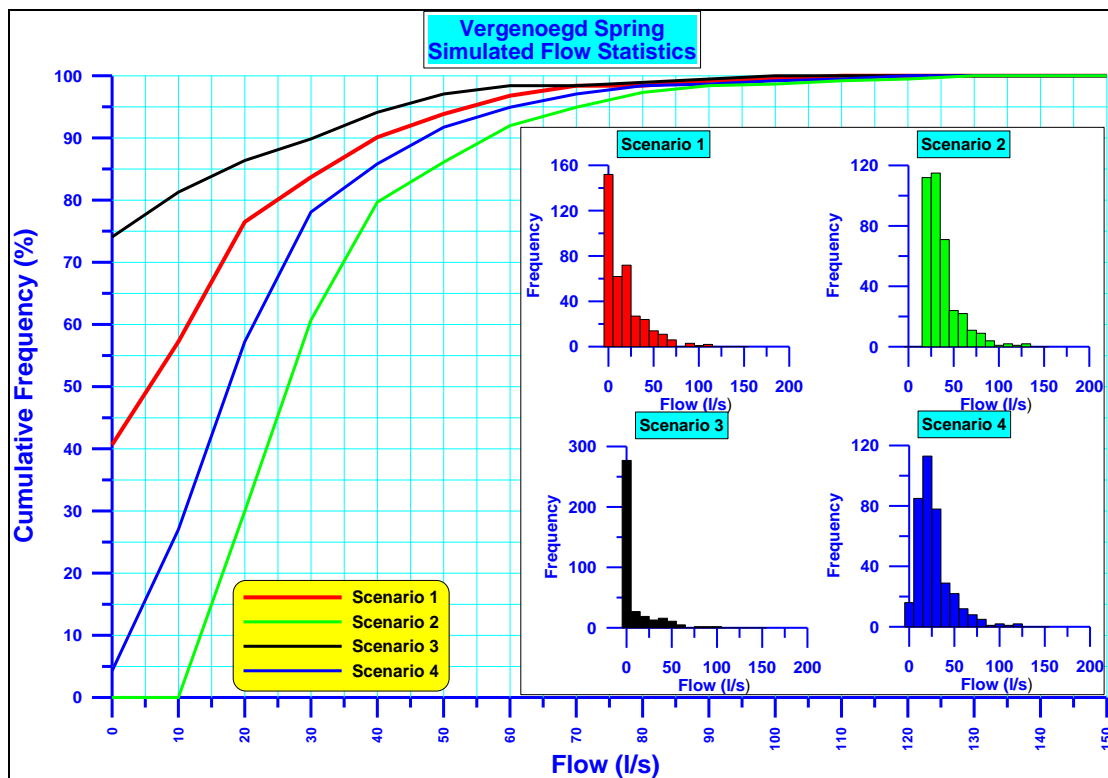


Figure 56 – Vergenoegd Spring simulated springflow statistics for each scenario.

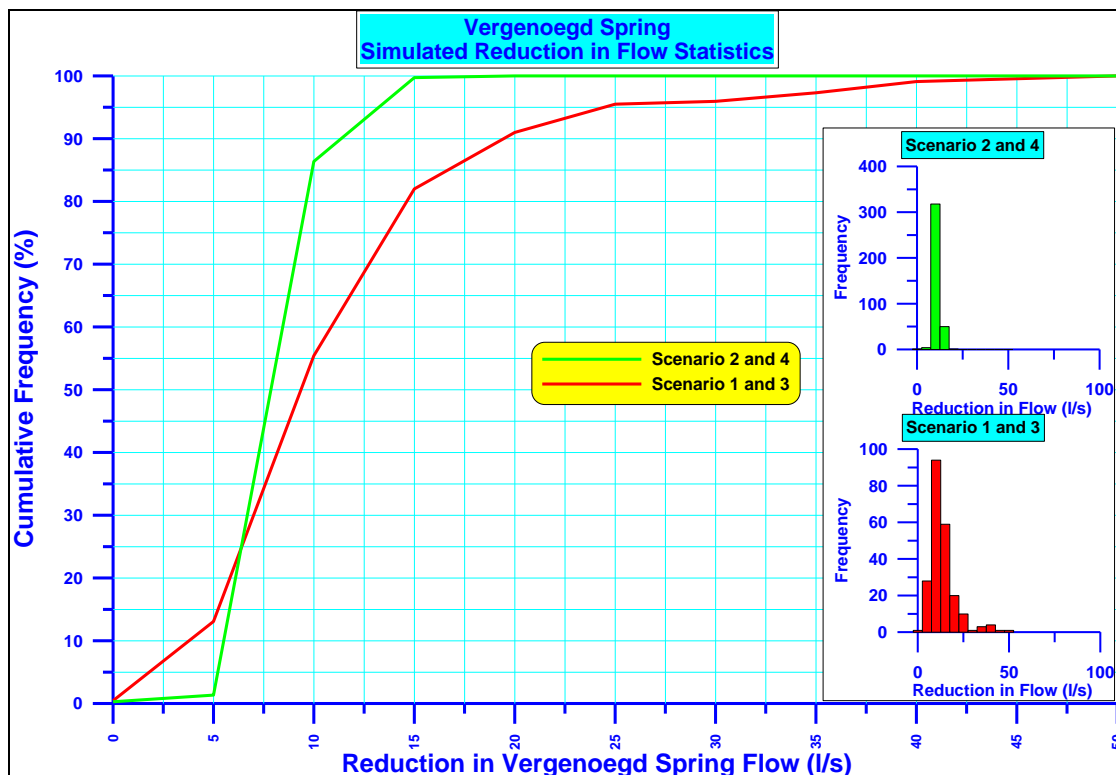


Figure 57 – Reduction in simulated Vergenoegd Springflow statistics for each scenario.

4.4.6 Simulated Spring Flow from Wolwekoppies Spring

Figure 58 shows the additional impact of the 6l/s being abstracted from the Uitvalgrond Compartment on the simulated flow from the Wolwekoppies Spring for assuming a natural loss of 70l/s (Scenarios 1 and 3) and no additional natural loss (Scenarios 2 and 4) from the Paardenvallei Compartment. It is clear that abstraction from the Paardenvallei and Tweefontein South Compartments has absolutely no influence on the water levels or springflow from the Uitvalgrond Compartment. This can be observed from Figure 58 where Scenarios 1 and 2 and Scenarios 3 and 4 plot exactly on top of each other.

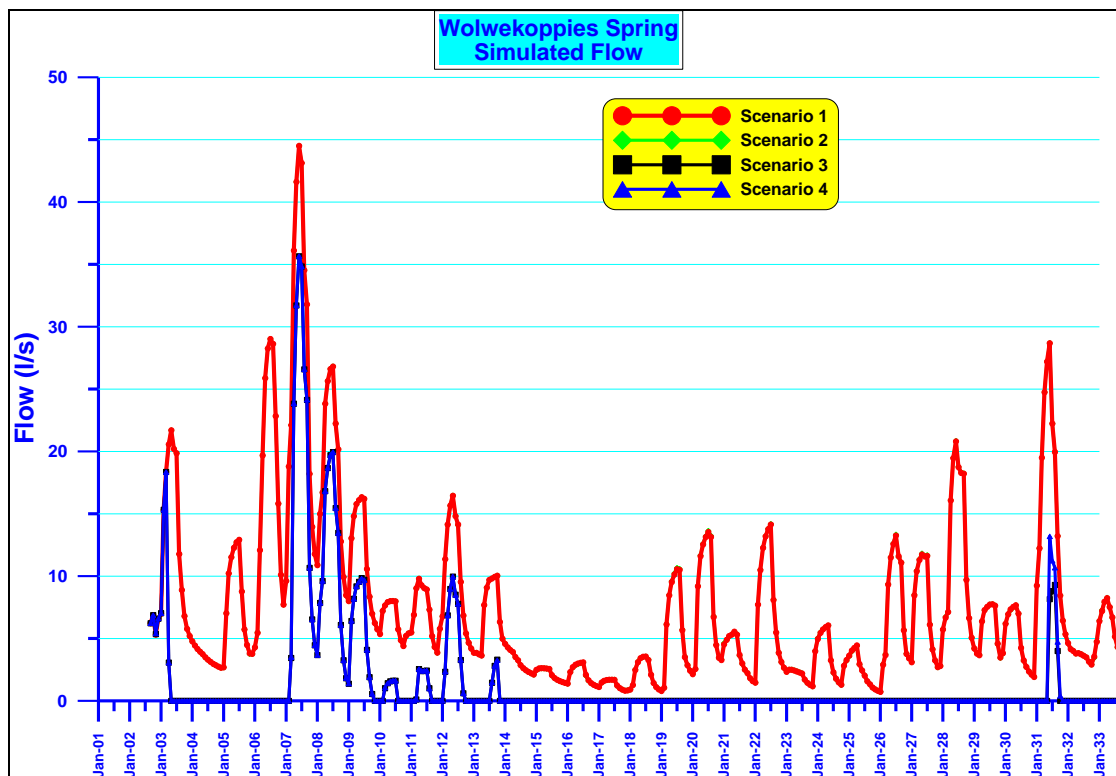


Figure 58 - Simulated temporal springflow from the Wolwekoppies Spring for Scenarios 1-4.

The effect of abstraction of the 6l/s from the Uitvalgrond Compartment on the flow of the Wolwekoppies is clearly visible and it is abundantly clear that the flow from the Wolwekoppies Spring will reduce. Figure 59 shows the simulated springflow statistics for each of the scenarios conducted. From this figure it is evident that there is a 75% chance that the Wolwekoppies Spring will flow at a rate of 10l/s or less for Scenarios 1 and 2. Similarly there is only a 10% chance that the spring will flow at a rate of 5l/s or higher for Scenarios 3 and 4.

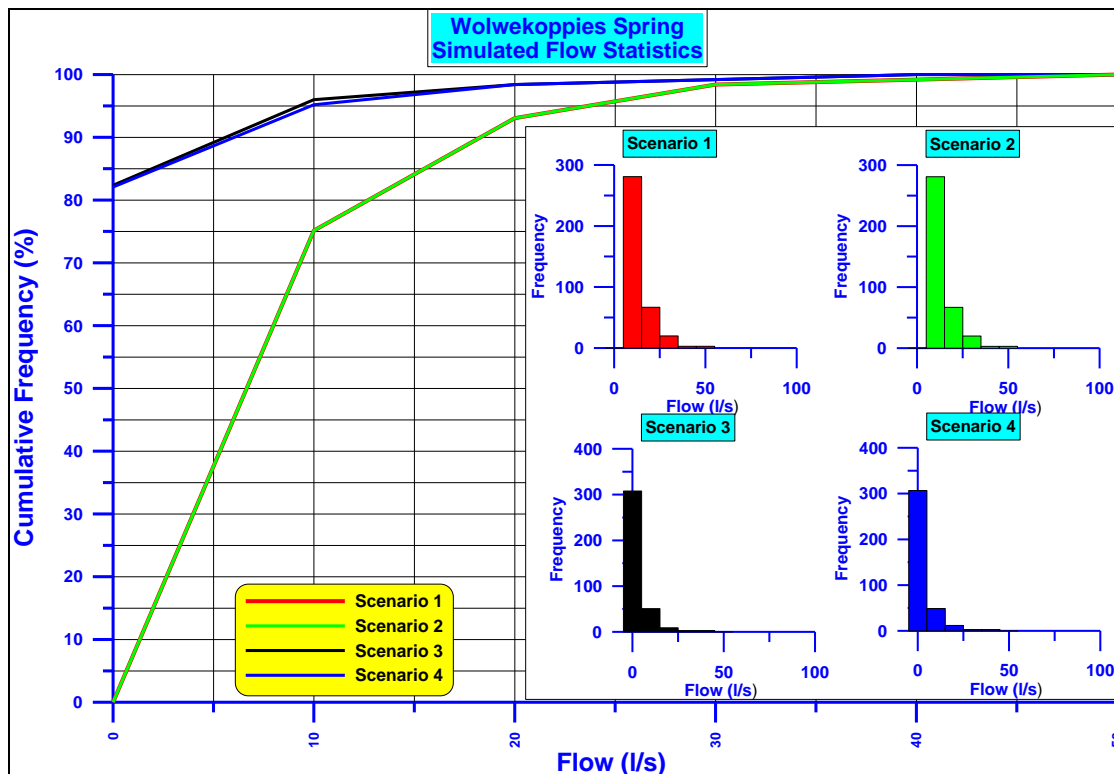


Figure 59 - Wolwekoppies Spring simulated springflow statistics for each scenario.

4.4.7 Simulated Spring Flow from Klaarstroom Spring

Figure 60 shows that abstraction from the Uitvalgrond, Tweefontein South and Paardenvallei Compartments has no effect on the springflow from the Klaarstroom Spring. This can be observed from Figure 60 where all scenarios plot exactly on top of each other. Figure 61 shows the simulated springflow statistics for each of the scenarios conducted. From this figure it is evident that there is a 80% chance that the Wolwekoppies Spring will flow at a rate of 12,5l/s or more for all scenarios.

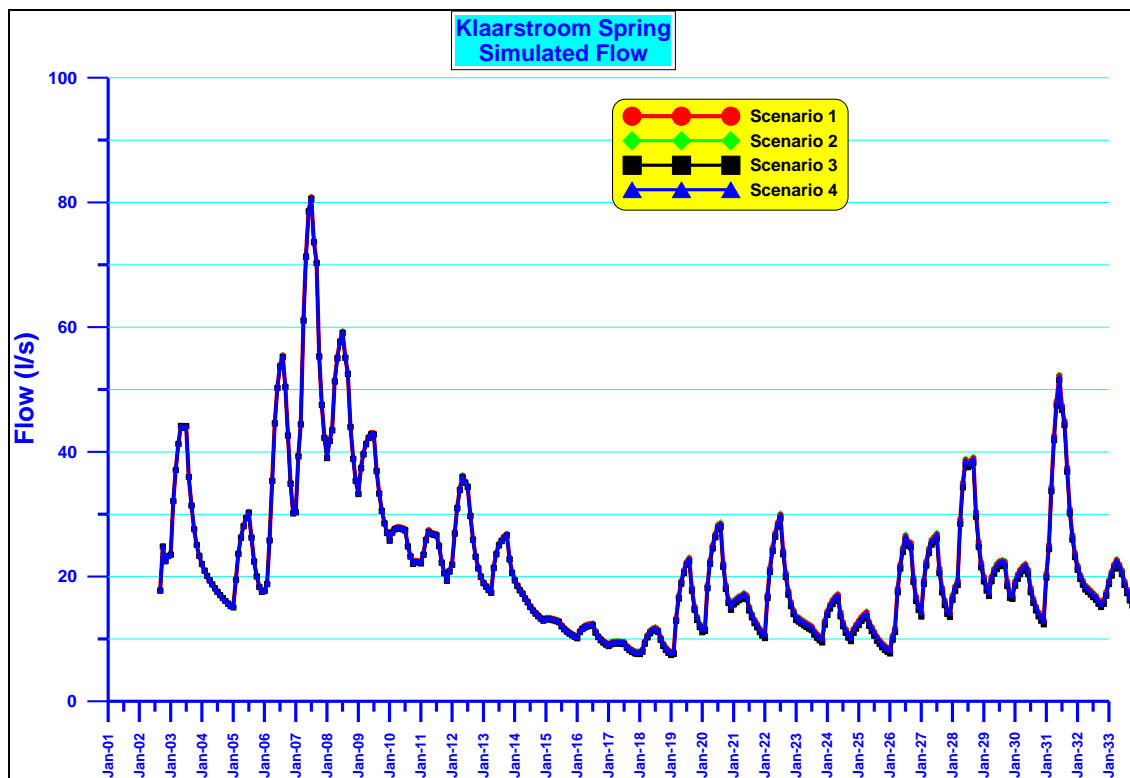


Figure 60 - Simulated temporal springflow from the Klaarstroom Spring for Scenarios 1-4.

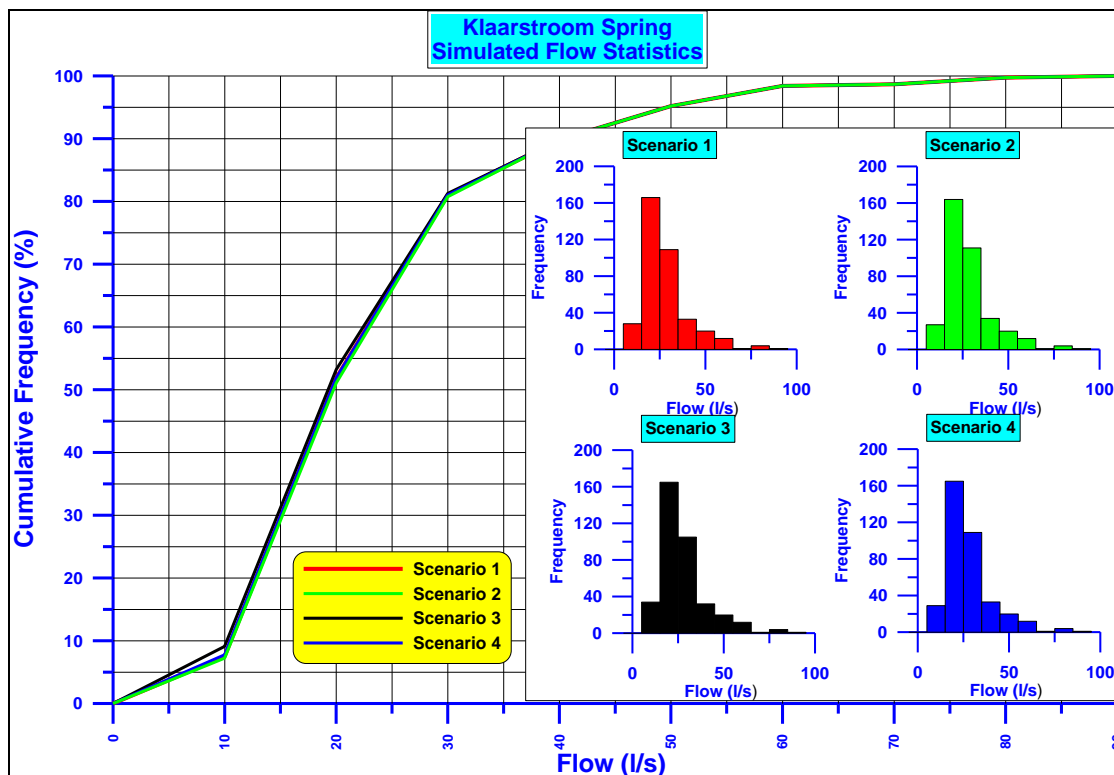


Figure 61 - Klaarstroom Spring simulated springflow statistics for each scenario.

4.5 Long term aquifer potential based on recharge, springflow and natural outflow from compartments

According to the model calibration of the groundwater flow model certain dykes and geological zones were assigned particular hydraulic conductivities. Depending on the values for hydraulic conductivity assigned the particular geological area will either be acting as an aquifer or an aquitard. The hydraulic conductivity distribution assigned for the area in order to achieve good calibration results is shown in Figure 14. The corresponding simulated water level distribution is shown in Figures 16 and 17 and again in Figure 62 below. According to this figure three compartments are identified based upon the groundwater level contour distribution which is of course a function of the hydraulic conductivity distribution assigned. The three compartments are the Paardenvallei, Tweefontein South and Uitvalgrond Compartments and are demarcated on Figure 62. Based upon simulation Scenario 2 discussed in Section 4.3 the average water balance components for the three compartments were determined and they will provide an estimate of the long term potential for each of the compartments. Scenario 2 were chosen for these calculations as it probably represents the most realistic situation where water levels do not change significantly over the long term with the starting water level and the end water level at the end of the 31-year simulation period very similar. This is indicative of a sustainable situation where inflow and outflows are balanced.

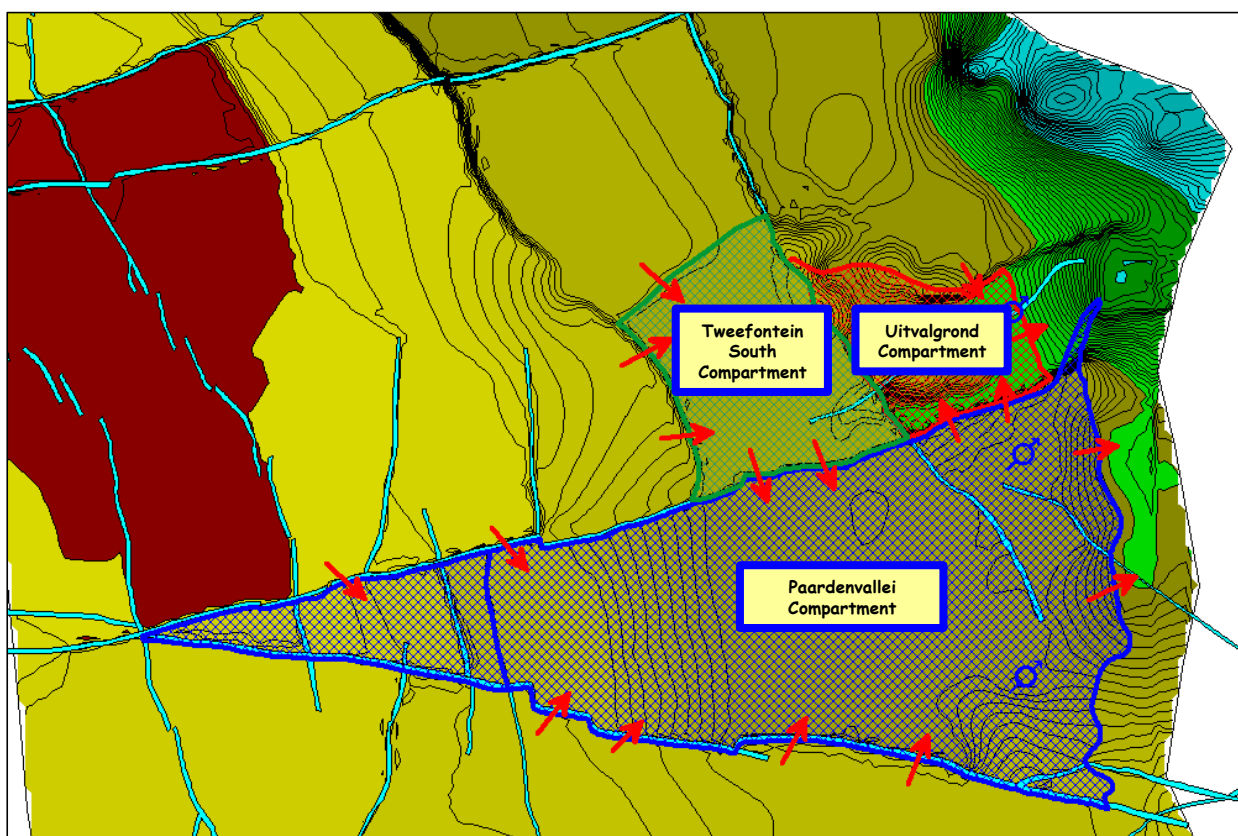


Figure 62 – Compartments identified based upon identified groundwater flow regimes.

In the calculation of the different flow components use is made of Feflow's Budget Flux Analyser which calculates fluxes through boundary conditions and which is very accurate. Cross boundary flows can also be calculated within the modelling domain using the Fluid Flux Analyser but this is less accurate for reasons as described in the Feflow manual (Diersch, 1979). In this instance this tool is therefore not used due to the possible inherent inaccuracies of this approach. This however means that cross boundary flows within the modelling domain can not be accurately done if no boundary conditions exist. A conservative approach is then followed in order to estimate the required particular flow component in question.

4.5.1 Long term potential of the Paardenvallei Compartment

According to conceptual understanding of the flow regime the Paardenvallei Compartment is supplied by groundwater from rainfall recharge and lateral leakage across the dyke boundaries from the north and from the south. These inflow components are in turn balanced by outflow from the Paardenvallei and Vergenoegd Springs and lateral leakage across the eastern boundary (out through the constant head boundary conditions specified). In the instance of Scenario 2 an additional loss component exists in the form of borehole abstraction of 28,5l/s.

The other outflow components from the Paardenvallei Compartment calculated over the 31-year simulation period is as follows:

- Natural (vertical) recharge to the system = 70l/s;
- Outflow from Paardenvallei Spring = 58l/s;
- Outflow from Vergenoegd Spring = 31l/s;
- Outflow across eastern boundary = 29l/s.

Total outflow from the compartment is therefore in the order of 146l/s and this represents the compartment's long-term potential. This rate is balanced by corresponding inflow components in order to maintain stable long-term water levels.

4.5.2 Long term potential of the Tweefontein South Compartment

According to the conceptual understanding of the flow regime the Tweefontein South Compartment is supplied by groundwater from rainfall recharge and lateral leakage across the Lyttelton/Eccles contact zone from the west and across the low permeability zone dividing the Tweefontein South Compartment from the Tweefontein North Compartment. These gains are balanced by an outflow component to the south across the dyke separating the Tweefontein Compartment from the Paardenvallei Compartment. No boundary conditions were specified on these boundaries and as a result of potential inaccuracies no cross boundary flows could be

calculated. A conservative approach to follow however is to assume that the minimum potential of the compartment is equal to the vertical rainfall recharge received over the long term. In this instance the long-term recharge to the Tweefontein South Compartment is in the order of 25l/s. This represents the minimum potential for the compartment.

4.5.3 Long term potential of the Uitvalgrond Compartment

According to the conceptual understanding of the flow regime the Uitvalgrond Compartment is supplied by groundwater by groundwater from rainfall recharge and lateral leakage across the southern dyke boundary with the Paardenvallei Compartment and the western dyke boundary with the Tweefontein South dyke. These gains are balanced by outflow from the Wolwekoppies Spring. According to calculations performed by Feflow's budget calculator the long-term outflow from the Wolwekoppies Spring is in the order of 8l/s. This represents the minimum potential for the compartment.

5 CONCLUSIONS AND RECOMMENDATIONS

The following study objectives were stipulated by KGC to be achieved at the end of the modelling study:

- Determine the feasibility to supply 6l/s from the Uitvalgrond Compartment;
- Determine the feasibility to supply 10l/s from the Tweefontein South Compartment;
- Determine the feasibility to supply 30l/s from the Paardenvallei Compartment. This rate is in addition to the current estimated abstraction rate of 29l/s being abstracted from this compartment;
- Determine the impact of this abstraction on water levels and springflow rates and other natural system losses.

With regards to the objectives the following is concluded:

- The minimum simulated long-term springflow from the Wolwekoppies Spring is in the order of 8l/s. It is therefore feasible to abstract 6l/s from the Uitvalgrond Compartment. Simulations indicate that at this rate there is an 80% chance that the Wolwekoppies Spring will stop flowing. At this rate there is a 40% chance to get a 6m or more water level drawdown. Recharge events to the aquifer has the effect however that water levels do recover in the compartment even after periods of droughts. It can be concluded that the abstraction of 6l/s from the Uitvalgrond Compartment should have no detrimental effect on water levels in the long term.
- The minimum simulated long-term recharge rate to the Tweefontein South Compartment is in the order of 25l/s. It is therefore feasible to abstract 10l/s from the Tweefontein South Compartment. According to simulations there is a 60% chance to get a drawdown of 6m or more when considering the worst case scenario. Considering the most likely scenario, there is a 20% chance of a drawdown of more than 6m.in the compartment. Recharge events to the aquifer has the effect however that water levels do recover in the compartment even after periods of droughts. It can therefore be concluded that the abstraction of 10l/s from the Tweefontein South Compartment should have no detrimental effect on water levels in the long term. Water levels in the Tweefontein South Compartment will be influenced by abstraction from the Paardenvallei Compartment.

- The minimum simulated long-term compartment potential of the Paardenvallei Compartment is in the order of 146l/s. Current abstraction from this compartment is in the order of 30l/s. The compartment should therefore be able to sustain a further 30l/s. There is a 60% chance to get a drawdown of 6m or more when considering the worst case scenario. The most likely scenario indicates that there is a low risk of getting a drawdown of more than 6m in the compartment. It can therefore be concluded that the additional abstraction of 30l/s from the Paardenvallei Compartment should have no detrimental effect on water levels in the long term. The simulations indicated that water levels do recover in the compartment even after periods of droughts. Simulations indicated that the impact on the Paardenvallei Spring would be between 10 and 30l/s. Impact on the Vergenoegd Spring would be between 5 and 15l/s.

The following is recommended:

- Drilling of production boreholes as per the recommendation of KGC (2005);
- A water-monitoring program must be established from the start of wellfield inception with careful monitoring of abstraction rates and water level drawdown in pumping as well as in monitoring boreholes. Wellfield and aquifer performance must be evaluated every six months in order to take corrective actions if necessary. The groundwater flow model established during this study must be updated on an annual basis using the monitoring information.
- No additional abstraction capacity should be installed within the compartments considered for this investigation as this may lead to overexploitation of the resource. Further exploitation must be preceded by a proper analysis of monitoring data.
- It is recommended that this FEFLOW model be used as the modelling basis for any future modelling exercises.
- It is further recommended that spring flow and other existing monitoring boreholes be monitored on a monthly basis.

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