IHE INSTITUTE FOR WATER EDUCATION

DEPARTMENT OF HYDROLOGY AND WATER RESOURCES

GROUNDWATER LEVEL MONITORING PROGRAM FOR THE UPPER BERG CATCHMENT IN SOUTH AFRICA

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MODULE: Groundwater Data Collection and Interpretation

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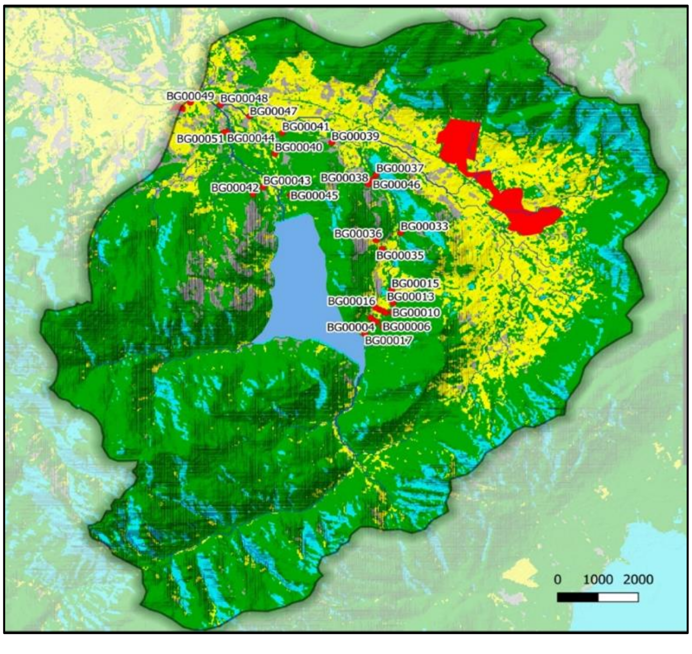
15TH MAY 2020



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Introduction

Semi-arid countries acknowledge groundwater to be the most important and scarce natural resource. There has thus been an objectification for quantity and quality groundwater mandated through policy. One of the main factors negatively affecting groundwater bodies is land use. Throughout history, intense land use activities (such as: damming, agriculture, urbanisation, over-abstraction, etc.) climate change have resulted in clear and significant changes and negative impact on the surface and groundwater system (Albhaisi, et al., 2012).

This report aims to understand the existing monitoring network and trends, changes, and possible reasons for groundwater fluctuations through the application of hydrostatistical methods. This analysis will result in the proposition of an optimised monitoring network aimed to meet the monitoring program objectives as well as to reduce the kridging standard deviation. The focus area is the quaternary catchment G10A of the Berg River Catchment located in the Western Cape Province, South Africa.

1.1 Study area

The Berg River Catchment is approximately 300 km in length with an area of 7715km^2 - *Figure 1* approximately two-thirds of the catchment is agricultural land (Greene, et al., 2011). Moreover, it supplies water for industrial use and is the primary water primary source of water for the city of Cape Town.

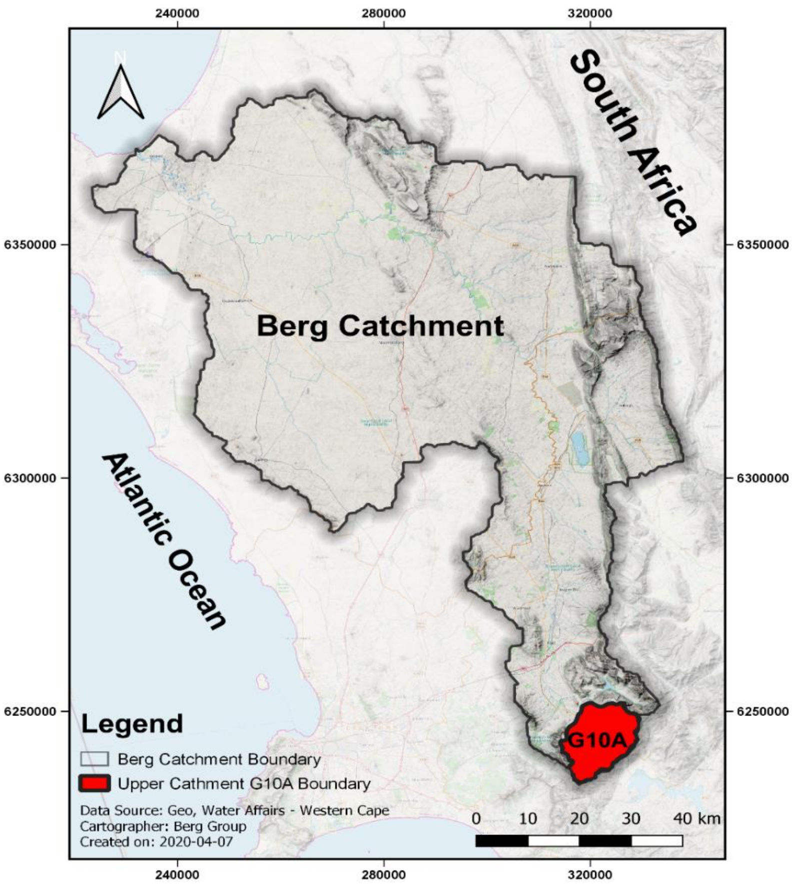

Figure 1: The Berg catchment and quaternary catchment G10A (berg Group, 2020).

The catchment is divided into 12 quaternary catchments starting from the source of the Berg River (G10A) and ending the Atlantic Ocean (G10M). Our main focus G10A – *Figure 2* – has a surface area of 172 km^2 and encompasses the Berg River Dam which was commissioned in the last quarter of 2007 (Albhaisi, Brendonck, and Batelaan, 2012).

G10A poses an important quaternary catchment for the Province of the Western Cape. This catchment houses the Berg River Dam which is the main water supply to the Metropolitan Cape Town city and agricultural, and urban development sects within the catchment (Clark, 2009). Subsequently, G10A was chosen to track the changes occurring in the system due to natural and of those induced by water impoundment –due to the construction of the dam. The former aspect is particularly important as the drought conditions that prevailed from 2015 to 2018 drastically lowered groundwater levels in the catchment, impacting ecosystems that were groundwater-dependent (Clark, 2007).

Moreover, the lowering trend observed in this catchment is attributed to over-abstraction, mainly from the agricultural sector. Though monitoring boreholes have been established in most of these areas, the need for more monitoring boreholes and the reinforcements of the National Water Act to licensees who are not complaint are the reasons behind the selection of catchment G10A (Horn, et al., 2018).

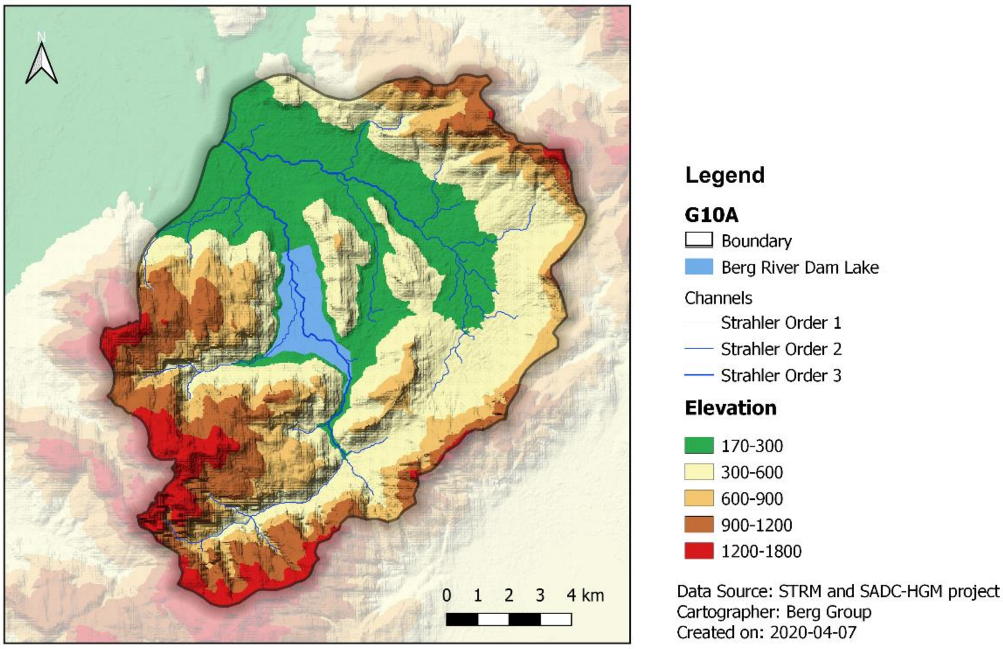

Figure 2: The quaternary catchment G10A with its relief variation, drainage network as well as the Berg River Dam (Berg Group, 2020).

a. Climate

G10A's climate is that of Mediterranean with annual mean precipitation and potential evaporation of 1063 and 1475 mm/yr respectively. The catchment has a relatively dense drainage network with an annual mean runoff of 1015 mm/yr (Albhaisi, Brendonck, and Batelaan, 2012).

The area is described as a winter rainfall region with wet, cool winters and dry, warm summers. Mean winter temperature is around 7 °C and snow falls on the mountain peaks annually. The largely montane area has relief ranging from 261 to 1560m and plays a major role in the significant change in micro-climate (Albhaisi, Brendonck and Batelaan, 2012).

b. Geology

The area is comprised of a sequence of rocks from the Malmesbury Group, Cape Granite Suite, Table Mountain Group (TMG), and younger Cenozoic sediments - *Figure 3*. The main rock type to outcrop is that of quartzitic sandstones from the TMG and gives the area its steep rugged topography. Moreover, to the north of the study area are outcrops of phyllite and greywacke shale from the Malmesbury Group. This group has lenses of quartzite schists and limestone (Drakenstein Municipality, n/d).

Erosion resistant outcrops from the Cape Granite Suite moderately cover the study area while fine to medium and coarse-grained Cenozoic sediments are present in the river channels of the Berg River.

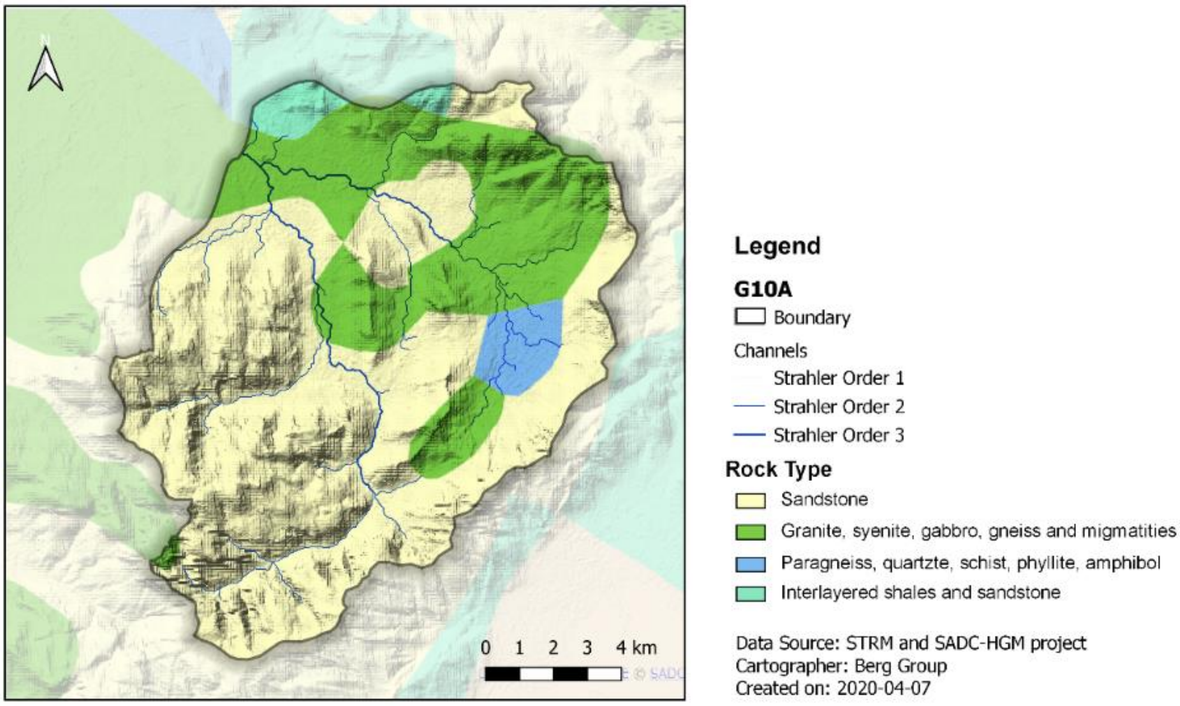

Figure 3: The lithological variation in G10A. (Berg Group, 2020).

The light yellow denotes the fractured sandstones of the Table Mountain Group, while the green and jade colours denote the Cape Granite Suite and Malmesbury Group (shales) respectively.

c. Hydrogeology

Groundwater is mainly stored in the Table Mountain Group (TMG) in G10A and plays a vital role in ensuring the base flow of rivers during dry seasons - *Figure 4*. It mainly hosts fractured aquifers, however, the Malmesbury Group is highly variable, thus highly variable aquifer conditions also prevail. Additionally, artesian conditions also occur due to the wide range of lithological types(DEADP WC DWA, n/d). The groundwater recharge in the Berg River catchment ranges from 5 Mm^3/a up to 36 Mm^3/a, with high recharge being from the Mountainous study area. This is again due to the relatively high rainfall conditions (DEADP WC DWA, n/d).

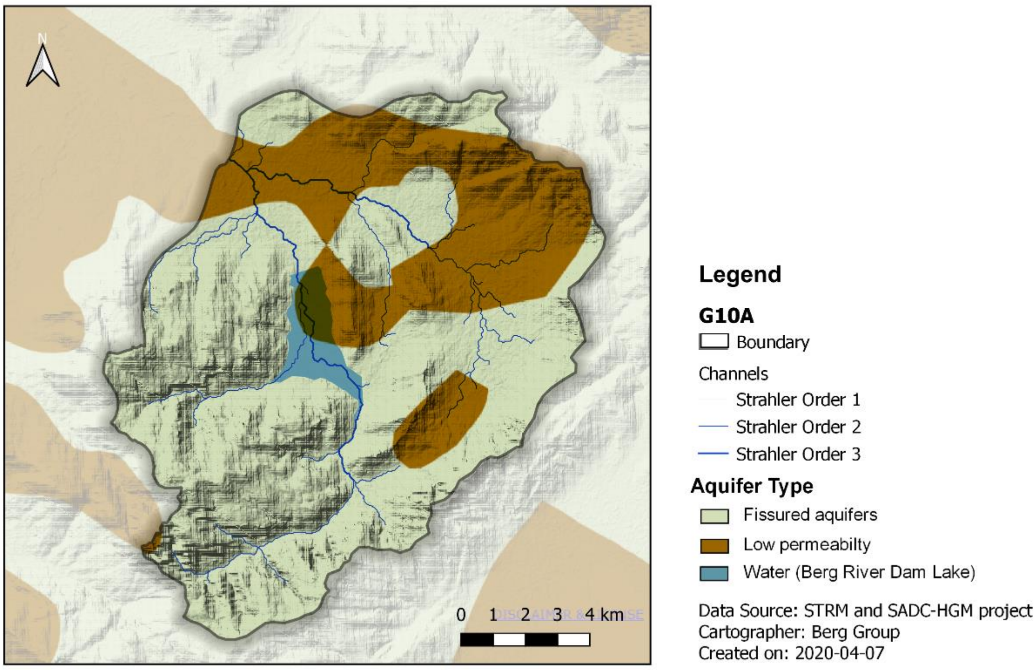

Figure 4: The aquifer types in G10A. (Berg Group, 2020).

The fissured aquifer originates from the Table Mountain Group, thus called the TMG Aquifer. While the brown colour that denotes low permeability represents the Cape Granite Suite Aquifer.

1.3 Choice of groundwater level

Cape Town is a metropolitan city and the water demand is rising both for domestic and agricultural use. Groundwater reliance has increased because surface water yield is reaching its exploitable limit and desalination option is expensive. (DEAP, 2011)

Drought is a recurring feature in the South African climate and the Upper Berg River Basin is not an exception. Rainfall in this region only occurs in the winter and the summers are dry which increases the dependency on groundwater resources (Rouault and Richard, 2003). Precipitation being the main source of recharge for the aquifers and lack of it leads to low recharge which does not balance with the extraction for the multiple uses. Agricultural activities and domestic use water demand do not reduce during this dry period.

The existing data analysis on groundwater level at the selected sites in the Basin shows a declining trend over the years. The monitoring of these wells and more should be made regular to determine what may be the main cause of the decline. This will also allow the enforcement of existing laws and regulations on over-abstraction and illegal drilling of boreholes. But concrete scientific evidence is needed to support the enforcement and the regulating body to come up with measures to reduce abstraction during low recharge periods.

Monitoring of the groundwater quantity ensures effective use of the available groundwater resource and be prepared in case another severe drought cycle occurs as it did before and led to the 'day zero' water crisis. This affected 3.7 million of the population in 2015. (Sousa, et al., 2018)

1.3 Data analysed

The water-level data used for the hydrogeostatistical analysis was from 34 monitoring well in the catchment area with the water level or depth data are taken once every month. The data available to us was from the years 2004 to 2015. There were some gaps in the data in the months where water levels were not recorded. It can be seen from figure 5 that the observation boreholes are located along the main Berg River branch, upstream and downstream of the dam. A higher density of wells can be noticed in the upper part of the monitoring network that was implemented to study the impact of the dam on groundwater.

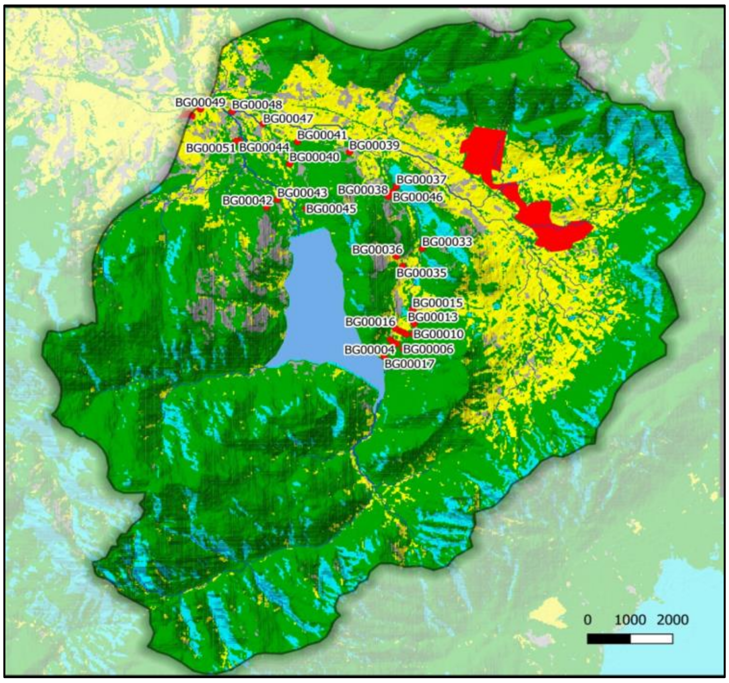

Figure 5: Spatial distribution of existing monitoring wells in the Upper Berg catchment

1.4 Collection of data and responsible organisation

The National government (the Department of Water and Sanitation - DWS) acting through the minister is the public trustee of water resources. It has the overall responsibility for all aspects of water resources management in South Africa. The National government (as well as other relevant authorities listed below) are mandated by the National Water Act. This is the legal basis under which the Constitution of South Africa is carried out to ensure clean and sufficient water for all, but also maintaining a healthy ecological system (Department of Human Settlements, n/d).

The management of water resources is assigned to the national government and that of water and sanitation services for all citizens to municipalities (the local government) under the guardianship of the Constitution. Thus, there is an Act that deals with the resource (national responsibility) and an Act that deals with water services (a local responsibility) – *figure 6*.

Figure 6: The National Water Act of 1998 and the Water Services Act of 1997(Department of Human Settlements, n/d).

The Act allows the Minister to delegate most of his or her powers and duties to departmental officials, water management institutions, advisory committees, and water boards.

The **relevant authorities in G10A in the Berg River Catchment are established by a government notice**. The statutory body known as the Catchment Management Agency consists of the Regional DWS, Cape Town Local Municipality, institutional authorities (the University of Cape Town, University of the Western Cape). Partnerships with important stakeholders include the Informal Settlement Network (ISN), Council for Scientific and Industrial Research (CSIR), farmers and industry.

Moreover, the NWA allows for the allocation of water for domestic, industrial, agricultural and urban development purposes whilst conserving a considerable portion for ecological health. Of recent, groundwater trends have mainly declined due to over abstraction of private boreholes. This, in turn, is not fully regulated nor frequently inspected even though it has been mandated in section 137(2)(c) of the National Water act 1998 (Department of Water and Sanitation, n/d).

1.5 Description of database and management

The National Groundwater Information System (NGIS) was set up to meet the increasing groundwater data demand (Borehole Water Association of Southern Africa, 2020). Under the NGIS, two databases for groundwater data management were developed:

- The National Groundwater Archive (NGA) - This allows registered users to view, modify and extract groundwater data. This is the largest monitoring and information system established in accordance with the National Water Act No. 36 of 1998. (Department of Water and Sanitation, 2020c)
- CHART- this is developed to assist hydrogeologist and hydrochemists during the analysis and assessment of hydrogeological and hydrochemical data. The information is displayed on a dashboard. (Department of Water and Sanitation, 2020a)

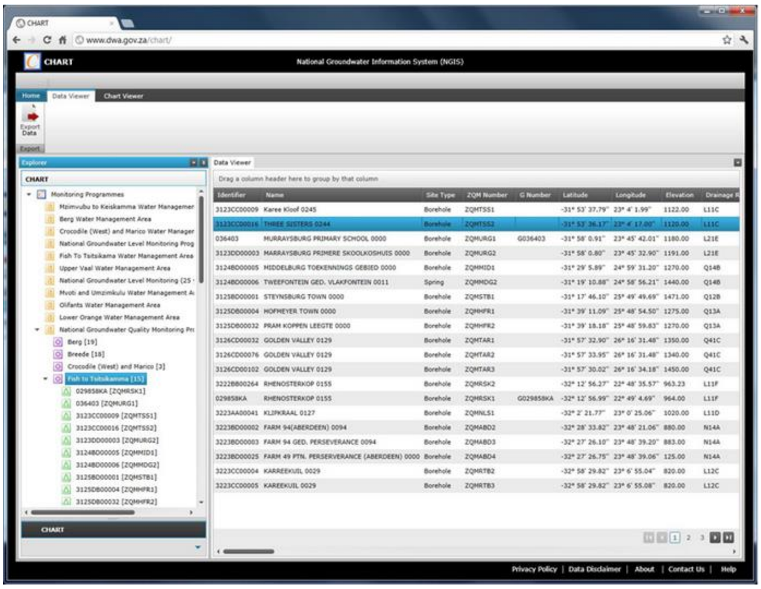

Figure 7: A representation of the CHART dashboard

- Geohydrological Report Systems- this database contains groundwater technical reports and there are currently 10,005 reports available for access. The reports are of any groundwater investigations that has been done. (Department of Water and Sanitation, 2020b)
- HYDSTRA - this database contains surface, groundwater and rainfall data of pumping and monitoring of registered and private boreholes. It is used to store long trend logger data, with the exception of hand measurements where loggers data is absent due to unforeseen circumstances - for instance, inability to access the site.

2 Groundwater level monitoring program objectives

a. Conceptual model

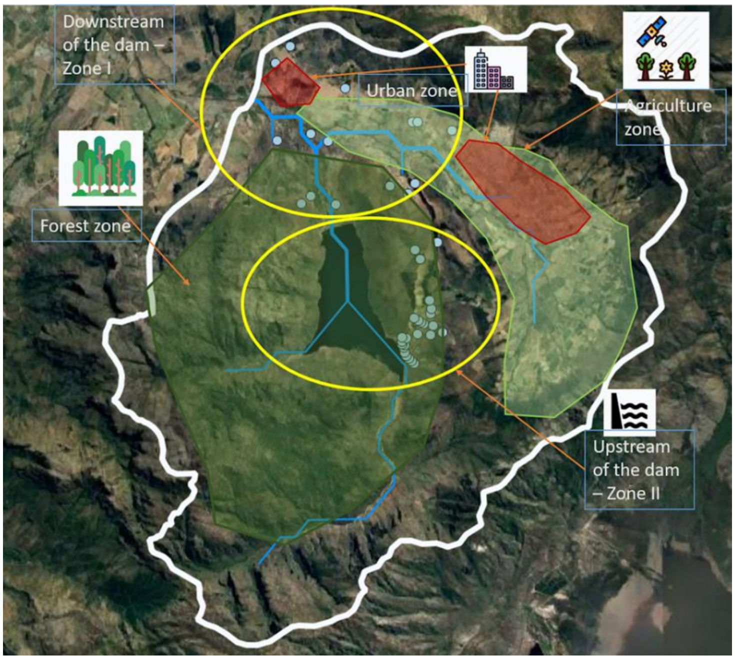

Figure 8: G10A conceptual model

Berg catchment has gone through many changes from 2004 to 2009. The construction of the dam has a predominant effect on the catchment characteristics. Thus, groundwater levels also changed with respect to water use and land use of the area. The conceptual model is divided into various zones based on land use and the topography. The groundwater observation monitoring network is plotted on the conceptual model and two zones can be distinguished to assess the effect of the dam on the groundwater levels: upstream and downstream of the dam. Most of the southwest part is a hilly area with forest cover and the northeast is under agricultural use. Over time, a rapid growth in population and the urban zone has been observed and is expected to continue.

b. Monitoring program objectives

Based on the study area analysis, the need to monitor groundwater levels and on the conceptual model presented in figure 8, the following objectives have been considered:

- Describe the present and future characteristics of the groundwater levels within the catchment
- Identify and monitor the crucial factors imposing a negative trend on water levels
- Monitor the long-term trend in water levels within the catchment and downstream of the catchment
- To populate the existing database with long-term accurate data

The groundwater monitoring network for catchment G10A envisions to describe the present and future characteristics of the groundwater bodies herein and identify the crucial factors imposing a negative trend on water levels. This objective covers three aspects:

- Collect data (water levels, and field readings such as Eh, EC, temperature and pH) to meet the directive set by the Regional and National Department of Water and Sanitation on a quarterly and annual basis, respectively,
- Identify the non-compliance of groundwater use in the agricultural section of G10A. So as to enforce Section 151 (1) of the National Water Act, 1998,
- And lastly, identify possible stresses on groundwater and monitor identified and current (in particular, the Berg River Dam) stresses on the groundwater system.

3. Characteristics of the groundwater level

a. Observation wells:

The existing groundwater level monitoring network is composed of 34 observation wells presented in the *figure 5*. The observation wells are all relatively shallow boreholes with a depth varying from 10m to 50m. The following scheme shows the basic components of the monitoring wells in the region:

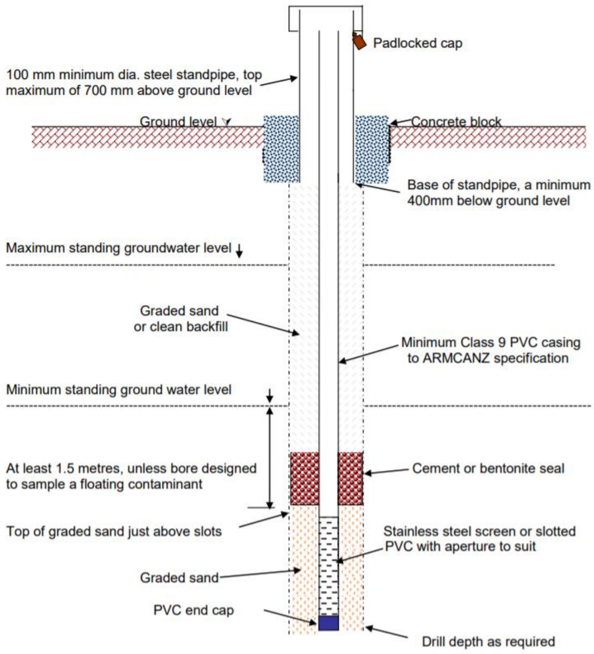

Figure 9: Observation well composition scheme

Each borehole is composed of a PVC tube (minimum class 9), followed by a stainless steel screen surrounded by graded sand. At the bottom of the well, a PVC end cap isolates the borehole.

On the ground surface, a steel standpipe is erected to protect the borehole and closed with a padlocked cap.

b. Instrumentation and procedure for groundwater level measurement

In the Berg catchment, each borehole is visited monthly to carry groundwater static level measurement as well as water sampling for laboratory analysis. The routine for groundwater level measurement is as follows:

1. Borehole inspection - The general aspect of the standpipe and the borehole surroundings are thoroughly inspected before opening the padlocked cap. Any damage needs to be fixed as soon as possible.
2. The static water level is measured, before any purging or sampling activity. In the berg catchment, the water level measurement is done manually by a technician using a Water Level Meter or a Temperature Level Conductivity meter

Figure 10: Water Level Meter - Solinst

In the Berg catchment, the brand used is Solinst. The principle is that a probe with a sensor located on the tip is linked to a graduated tape. When the probe touches water, an electrical signal is sent to the reel. The water depth from the borehole standpipe is then read.

In the Berg river basin, the groundwater level is measured monthly for the whole network. As mentioned earlier, the recharge in the area is relatively low so a monthly measurement is sufficient to identify any significant change in the water level.

However, when we analysed the set of data we received, we realised that some gaps exist in the water-level measurement for certain boreholes. A substantial amount of time is spent to fit the data to be able to carry statistical analysis such as regression on a set of data with consistent measurement date.

That is why an efficient database and management are crucial in groundwater level monitoring.
Hydrogeostatistics tools can also be used to help filling the missing data.

c. Hydrogeostatistic analysis – Regression analysis

With our set of data, we have carried 4 regression analysis on the groundwater level in the recharge area and the one in the discharge area.

To be able to draw consistent conclusions on the correlation between the recharge area and discharge area water levels, we have selected a set of four pairs of wells. Each pair is composed of a well in the recharge area and one in the discharge zone.

The discharge area water levels are considered as the dependent variable and thus the one in the recharge area as an independent.

This analysis can then be used to predict the water level in the discharge area knowing the one in the recharge area. This can be particularly useful to fill gaps in databases.

For the consistency of the analysis, the water level has been considered (and not the water depth). To do so, the water depths have been subtracted from the ground elevation at the well location.

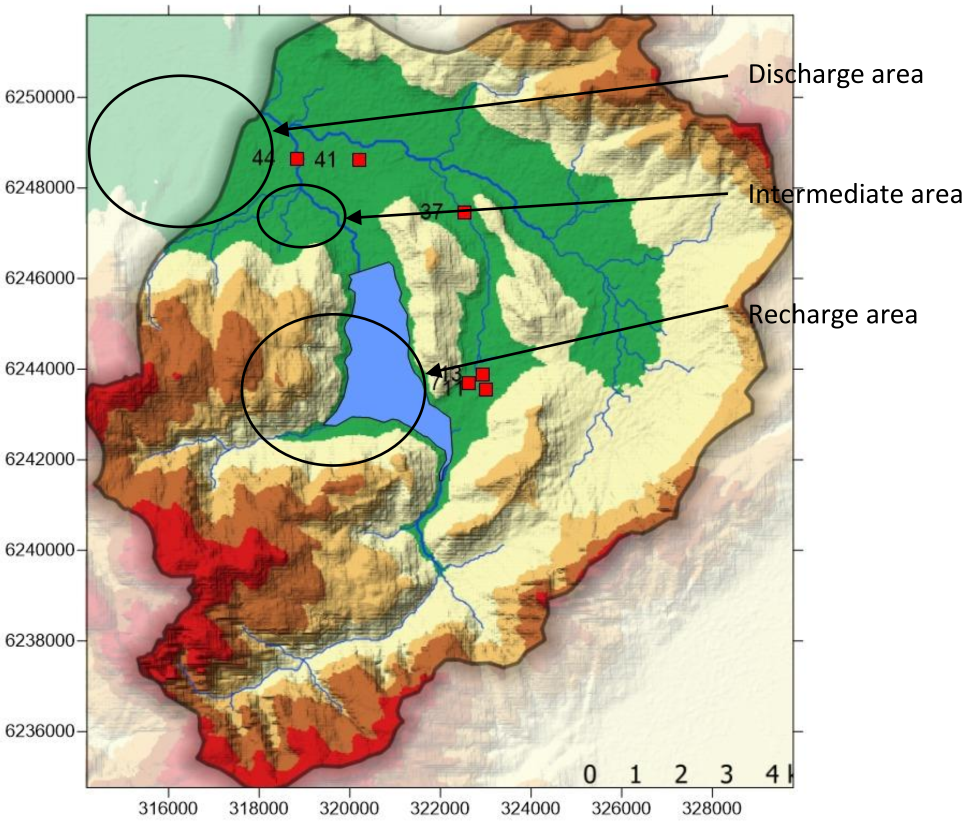

Figure 11: Observation well location used for regression analysis

BG00007 - Recharge area	BG00037 - Discharge area	BG00013 - Recharge area	BG00041 - Discharge area	BG00011 - Recharge area	BG00041 - Discharge area	BG00011 - recharge area	BG00044 - Discharge area
Assessment of the correlation between the recharge area and an intermediate zone		Assessment of the correlation between the recharge and the discharge area		Confirmation of the correlation between BG00013 and BG00041 carried earlier		Assessment of the correlation between the recharge and the discharge area	

Table 1: Regression analysis pairs of observation wells

The data analysis plug-in is used to carry the regression analysis on Excel. The output gives the regression statistics, the NOVA table (except the critical value $F_{\alpha}(\nu_1, \nu_2)$ that has to be computed manually) and the plots of the linear function as well as the residuals.

	X	Y	Elevation	No. of simultaneous measurement n	Correlation coefficient R	R^2 Value R^2	Standard error	Fstatistic	$F_{0.05}(1;n-2)$	Regression model intercept b_0	Regression model slope b_1
BG00007 - Recharge area	-33.9324	19.08084	253.9	83	0.75	0.57	0.26	106.6	3.96	172.964	0.21
BG00037 - Discharge area	-33.8984	19.08068	227								
BG00013 - Recharge area	-33.9307	19.08442	256	101	0.88	0.77	0.28	339.7	3.94	109.479	0.353
BG00041 - Discharge area	-33.8876	19.05572	200								
BG00011 - Recharge area	-33.9336	19.08505	263.5	101	0.88	0.77	0.28	340.6	3.94	166.079	0.125
BG00041 - Discharge area	-33.8876	19.05572	200								
BG00011 - recharge area	-33.9336	19.08505	263.5	116	0.7	0.49	0.28	109.2	3.92	155.086	0.064
BG00044 - Discharge area	-33.887	19.0409	174								

Table 2: Regression analysis results

The *table 2* shows the results of the regression analysis carried on the 4 pairs of wells. It can be seen that all of the linear regressions are significant as $F_\alpha(v_1, v_2) < F_{statistic}$ for all the pairs. The good correlation coefficients R (between 0.7 and 0.9) as well as quite good coefficients of determination R^2 (between 0.5 and 0.8) confirm this statement.

However, no explicit general trend can be noted in the correlation between the recharge area and the discharge area water levels. Indeed, the regression coefficients b_0 and b_1 are relatively scattered, considering how low the slope values are.

Therefore, no general linear function can be obtained for the whole recharge and discharge area using regression analysis. Only pairs of well or smaller areas can be correlated, which still constitute a handy analysis to predict the water level in a well in the discharge area, knowing the one in a well in the recharge area.

d. Hydrogeostatistic analysis – Time series analysis

The main objective in the assessment of time series analysis for the groundwater level monitoring program was to assess the effect of the dam on the ground water level. To do so, the observation wells BG00034 adjacent to the dam was analysed both for step trend and linear trend detection.

Step trend analysis

To determine the significance of the step trend, a hypothesis test using the following t statistic is used.

$$t_{statistic} = \frac{|\overline{x_1} - \overline{x_2}|}{2s_p/\sqrt{n}}$$

With:

$\overline{x_1}, \overline{x_2}$: mean process value for the first and second periods

s_p: Standard deviation of residual

n: Number of measurement

The $t_{statistic}$ value is then compared to the critical value $t_{\alpha/2}(n-2)$ for a significance level of $\alpha =$ 5%. If $t_{statistic} > t_{\alpha/2}(n-2)$, the step trend hypothesis is accepted and the step trend is significant.

The first period and the second period corresponding to before and after the dam construction, respectively.

In this analysis, the water depth from the ground surface to the static water surface was considered.

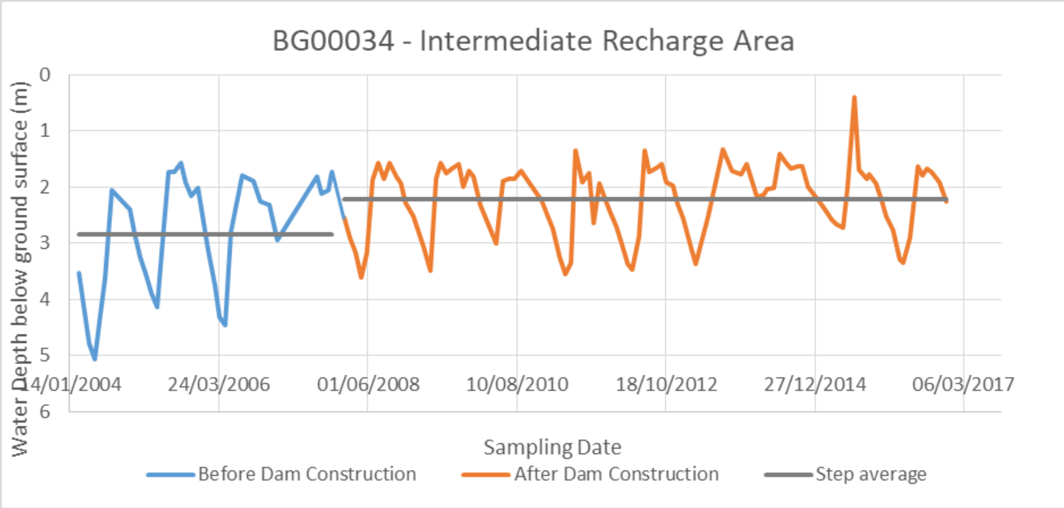

Figure 12: Step trend analysis BG00034

Well	n	$\overline{x_1}$	$\overline{x_2}$	s_p	$t_{statistic}$	$t_{0025}(n\text{-}2)$
BG00034	128	2.84	2.23	0.77	4.53	1.98

Table 3: hypothesis test for the step trend analysis - BG00034

The hypothesis test reveals a significant step trend as $t_{statistic} > t_{0.025}(n-2)$. On *figure 12* the step can be seen as a decrease in the water depth – i.e. an increase in the water level – after the dam construction. This observation led to the conclusion that the intermediate area has been influenced by the dam construction and the water levels have increased in this area.

Linear trend analysis

A series with a linear trend can be approximated by a classical linear regression model as:

$$h_t = b_0 + b_1 t$$

With h_t the groundwater depth at time t; b_1 and b_0 the estimates of respectively the trend magnitude and the process base level.

To assess the linear trend significance, a hypothesis against the slope, using the t-statistic value is carried. The manual calculation of the t-statistic value is as follow:

$$t_{stat,man} = \frac{|b1|}{\sqrt{12} \times s_l / \sqrt{n(n+1)(n-1)}}$$

With:

s_l: Standard deviation of residuals

n: Number of measurement

t statistic follows a Student t distribution with a degree of freedom of n-2. To use this relation, the assumption is made that the time interval is the same in the measured data.

The $t_{statistic}$ value is then compared to the critical value $t_{\alpha/2}(n-2)$ for a significance level of $\alpha = 5\%$. If $t_{statistic} > t_{\alpha/2}(n-2)$ the non-zero slope value hypothesis can be accepted, in other words, we can say that the linear trend is significant.

The determination of the linear model as well has been done using the regression analysis function of the data analysis excel add-in. The output also contains a calculated value for the t-statistic that takes into account the non-consistency in the measurement dates (non-consistency in the dataset). Thus we are using this value $t_{stat,comp}$ to assess the significance of the linear relation.

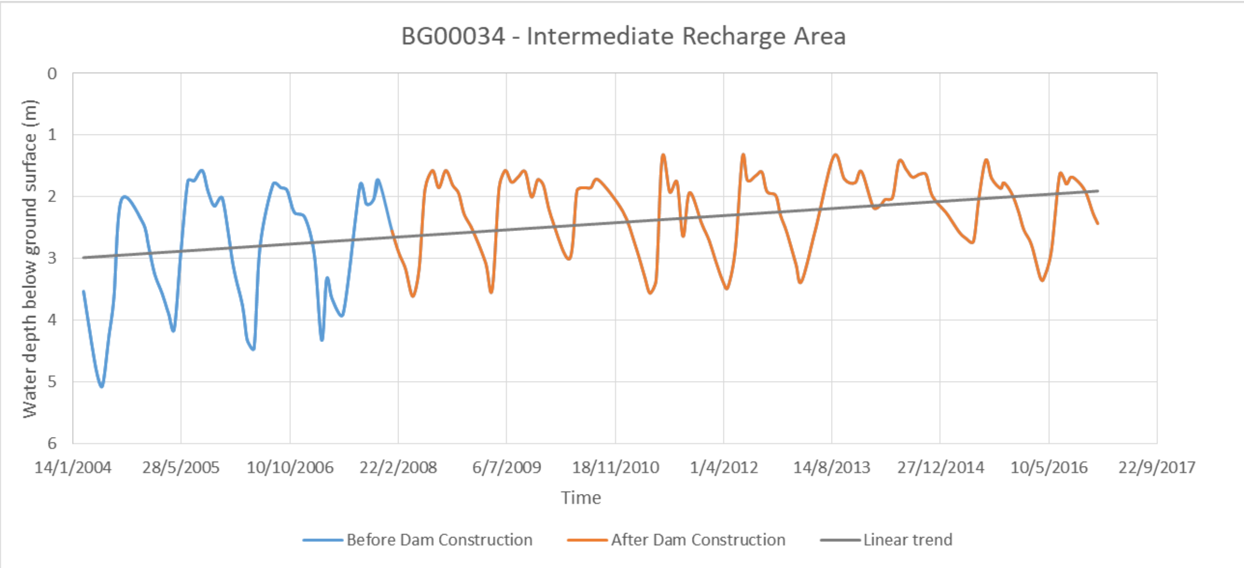

Figure 13: Linear trend analysis BG00034

Well	n	Slope - b_1	Intercept b_0	s_l	$t_{stat, man}$	$t_{stat, comp}$	$t_{0025}(n-2)$
BG00034	132	-2.31E-04	11.76	0.76	0.1335	4.83	1.98

Table 4: Hypothesis test for the linear trend analysis – BG00034

It can be seen from the regression analysis that the linear model decrease from 3m below ground surface to less than 2 m between 2004 and 2016. The increase in water levels correlate the conclusion drew in the previous section. The hypothesis test also confirms the increasing linear trend in the groundwater level at this location as $t_{stat,comp} > t_{critical}$ standing for a significant linear trend.

4 Optimisation of the monitoring network

As we could have observed in the previous sections, there are no monitoring wells located within the agriculture and urban areas of the catchment, and a high density of wells in the upstream of Berg Dam at the previous introduction, as shown in *figure 14*. The kriging estimation was used in order to optimise the network of observation wells for monitoring the agriculture area and urban area. Because it has the advantage to draw a contour map of the estimated error variance for indicating the accuracy of estimation.

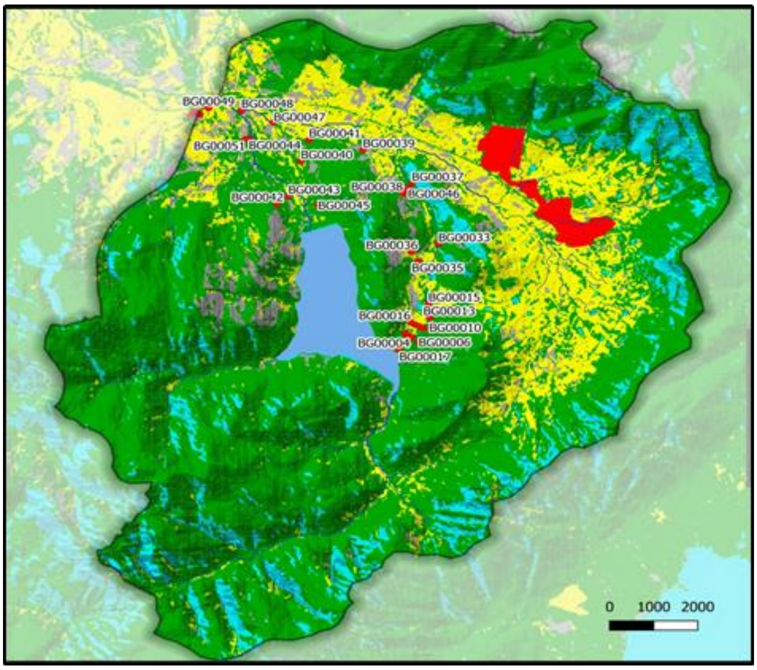

Figure 14: location distribution of the observation wells within the catchment

a. Fit of Variogram

The plot of the experimental variogram of the groundwater levels in the berg (G10A) catchment increases at the origin and, then, irregular fluctuates with a separation distance of 500. Thus, the linear variogram model with the nugget effect was used to fit the first five observation values, as shown in *figure 15*. According to the figure, the slope of the linear line is 0.18 and the nugget effect C is equal to 2. The Cross-validation was automatically calculated by Surfer 11, and the mean error calculated is 0.032. Moreover, the standard deviation of the residuals is similar to that of the measurement values with 3.08 metres and 3.23 metres respectively, showing a reasonably good fit of the estimated variogram model.

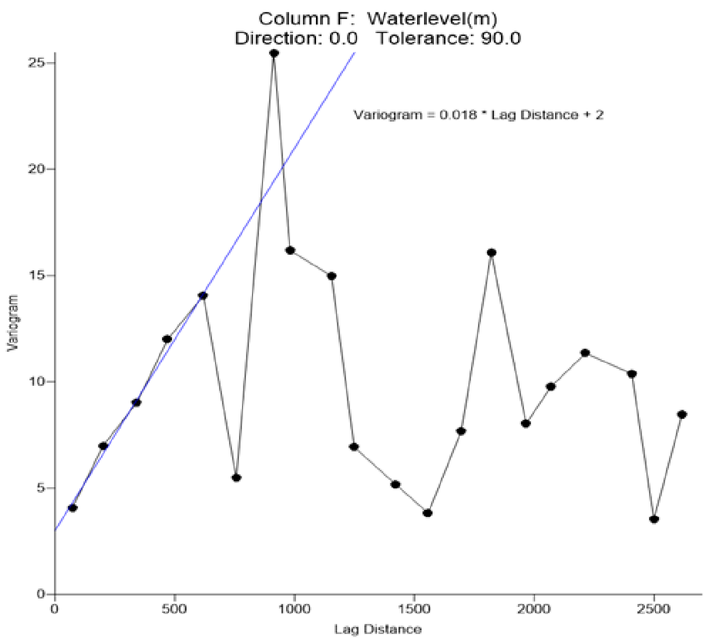

Figure 15: The fit of the Varigoram for the values of the groundwater level

b. Kriging estimation

The kriging estimation of the groundwater levels can be analysed on the area that does not have the observation data, after fitting the Variogram. The default shape of contour map of the estimation values in Surfer 11 is a regular rectangular. In this case study, the contour map was blanked by the boundary of the mountain to reduce errors, as shown in *figure 16*. The contour map shows clearly that the south and west area close to the mountain have relatively high values of the groundwater levels (7.5 metres to 12 metres). To the north further, the groundwater levels gradually decrease to 2.5 metres.

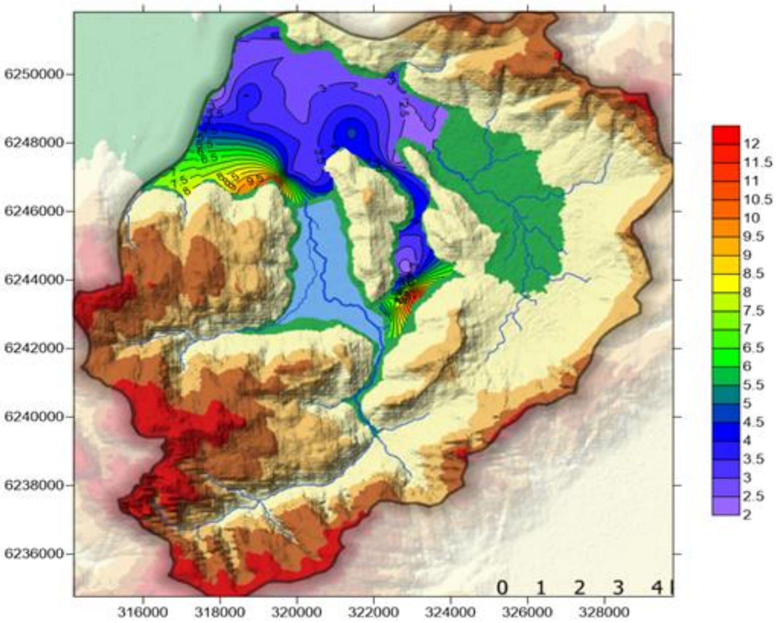

Figure 16: Contour map of the estimated groundwater levels in the Berg (G10A) area

Figure 17 shows the contour map of estimation error variance for groundwater levels with the plot of the boreholes in the Berg (G10A) area. It is clear that the network density of the wells is too high in the dam area, especially in the south area, and the estimation errors of west and north areas are high without any measurements. Therefore, it is necessary to dissipate some of the observation boreholes towards the north and east sections.

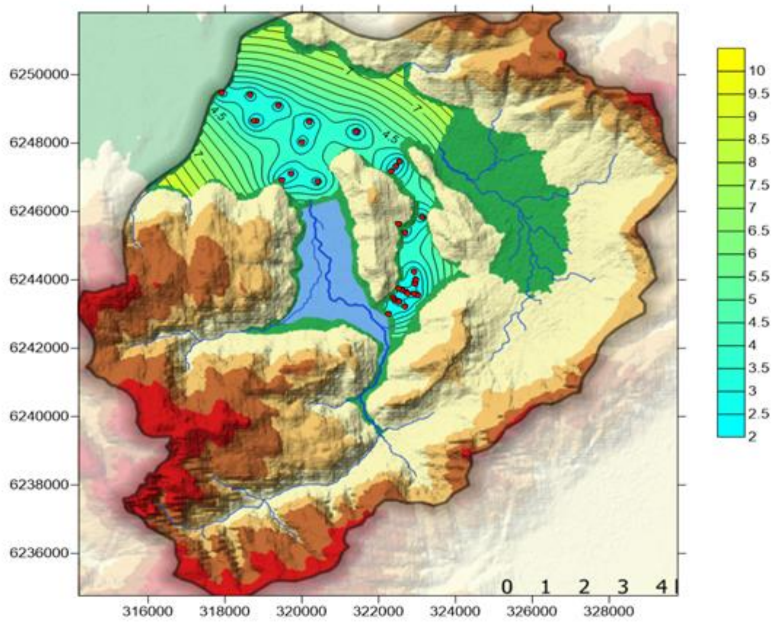

Figure 17: Contour map of the estimated errors (meter) in the Berg (G10A) area

c. Results of the optimisation

Figure 18 shows clearly the distribution of the observation wells after optimisation by kriging estimation, and the variance of estimated errors fluctuates slightly to the extent from 2 metres to 3 metres. Then, the classification of the observation wells of total 64 was to be done according to land use.

In the Berg Dam area, a total of 26 monitoring boreholes is to monitor the impact of the Berg River Dam to the aquifer system, which is indicated by red dots and blue squares in *figure 19*. In the agricultural area, a number of 33 wells, the brown dots in the figure, have been established to guarantee a kriging standard deviation below a threshold value. In the urban area, the purple dots in the figure with 5 wells are implemented to monitor the water level in this region.

To sum up, the kriging estimation is good for the optimisation of the monitoring network, and there are **a total of 64 wells** to monitor the groundwater level in this study area, including **26 wells for Berg Dam**, **33 wells for agricultural** overdraft and **5 wells for urban** water.

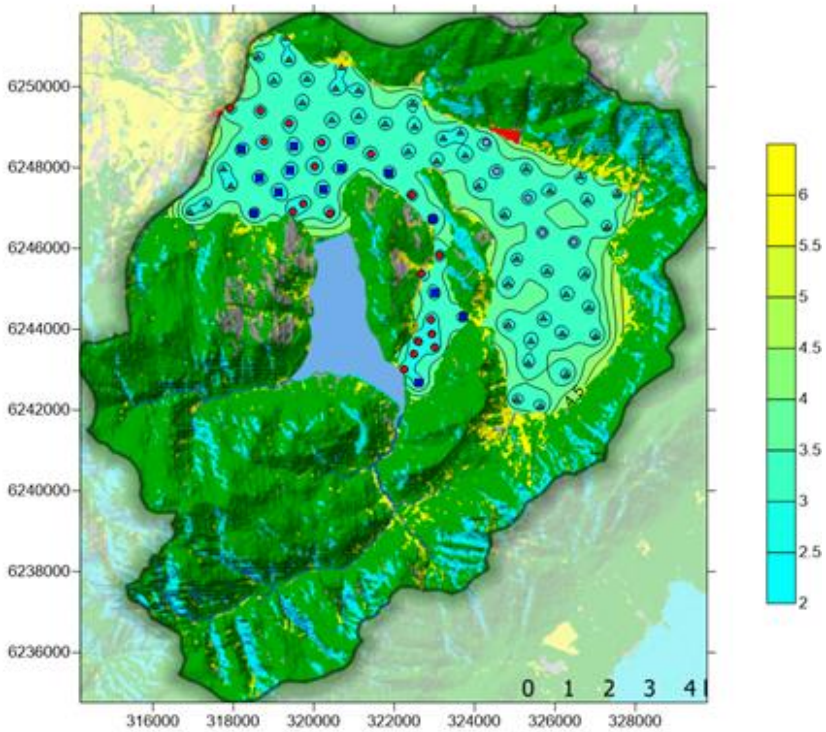

Figure 18: Contour map of the estimated error variance for the groundwater levels after the optimisation

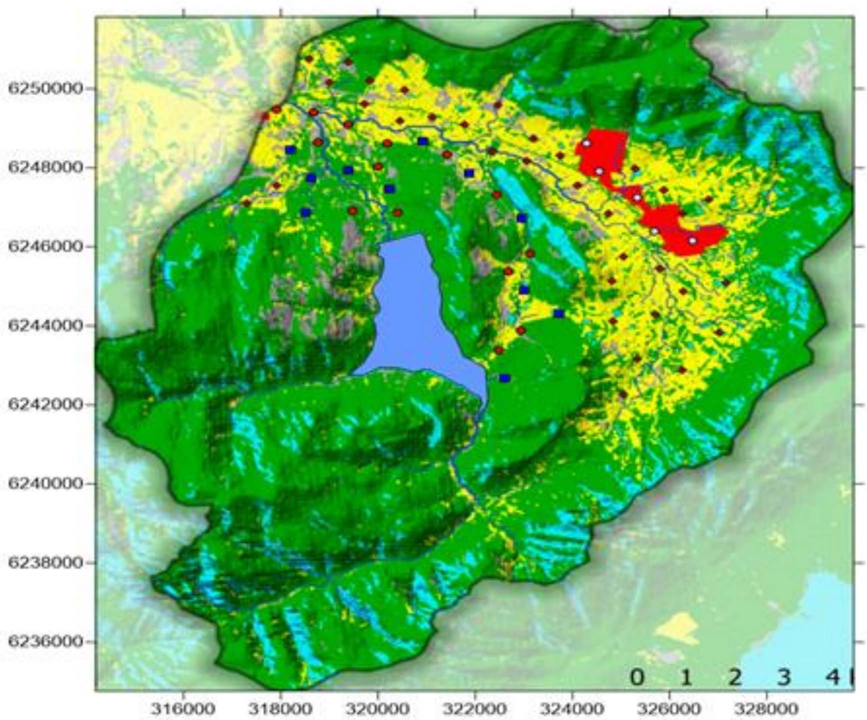

Figure 19: Optimised groundwater level monitoring network

5. Conclusion

The time series and regression analysis show that the construction of the dam brought a positive trend in the groundwater level in that there was an increase in the surface water level after the completion of the dam construction. The well located near the dam has a difference in mean before and after the dam construction is 0.6m which shows the increase in the water level.

The current monitoring network does not allow for monitoring of the agricultural impact within the catchment. The kriging standard error goes as high as 8 before the optimisation of the monitoring network and this was reduced after the optimisation to a value of 3. The optimised monitoring network consists of 64 as opposed to 26 that was there previously and it is now well distributed within the study area. This covers the agricultural and urban areas.

The current data collection and storage database proves to be sufficient for the collection of long-term data, thus long-term trend analysis. This will make the population of the database possible as the systems are in place and functional.

The optimisation of the monitoring network allows for the spatial and temporal study of the aquifer both in the recharge and discharge areas of the catchment. This brings an understanding of the important factors that bring about the trend (positive or negative) of the groundwater level.

Data collected, stored and analysed through the optimised monitoring network will allow for the directive set by the Regional and National Department of Water and Sanitation to be met on a quarterly and annual basis, respectively.

6. Recommendation

A reviewed water level monitoring frequency, with a lower sampling interval during the dry (summer) period, would allow us to identify earlier any critical groundwater level and avoid over abstraction in this area where day 0 is likely to come.

Moreover, the proposed monitoring network will enable the identification of non-compliant groundwater users in the agricultural section of G10A. This will ensure the enforcement of Section 151 (1) of the National Water Act, 1998 should any person contravene the NWA. And finally to identify possible stresses on groundwater and monitor identified and current (in particular, the Berg River Dam) stresses on the groundwater system.

Long-term trends should be monitored and analysed to assess the effect of the pressures on the groundwater quantity, especially the growing water demand in Cape Town metropolitan.

A future comprehensive study of the flow systems in the aquifer would give a better understanding of the flow systems both locally and regionally in the main recharge and discharge area. This would help the assessment and prediction of the groundwater level response to different abstraction schemes.

Installation of barometers and loggers for monitoring boreholes in high relief areas are crucial so as to aid with the data collection process. After this, the recorded data can be manually collected quarterly and a hand measurement should be taken as well.

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