Sustainable Utilisation of Groundwater Resources Under Climate Change: A Case Study of the Table Mountain Group Aquifer of South Africa

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Additional information is available at the end of the chapter

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1. Introduction

In a global sense, the term "sustainability" may be applied to the environment (ecological sustainability), society (social sustainability), the economy (economic sustainability) or an organization or people (organizational or human sustainability respectively). To understand the concept one needs to identify the focus or what needs to be sustained then one can work out how to sustain the thing or the condition. The United Nations Brundtland Report (1987) defined "Sustainable Development" as development that meets the needs of the present without compromising the ability of future generations to meet their own needs. The United Nations Conference on Environment and Development (UNCED) held in June, 1992 in Rio de Janeiro, became the symbol for the common responsibility of all Governments in the world in achieving a sustainable development. The conference stated that, "The holistic management of freshwater as a finite and vulnerable resource, and the integration of sectorial water plans and programs within the framework of national economic and social policy, is of paramount importance for actions beyond the 1990s. Integrated water resources management (IWRM) is based on the perception of water as an integral part of the ecosystem, a natural resource and social and economic good". The Outcome Document of the 2005 United Nations World Summit in New York referred to the interdependent and mutually reinforcing pillars of sustainable development as economic development, social development, and environmental protection. Why sustainability? Sustainability ensures that resources especially natural resources are kept within nature's ability to replenish them.

A sustainable water service delivery is the thrust of the Millennium Development Goals on water for African governments. With 75 percent of African population using groundwater as its main source of drinking water (ECA *et al.*, 2000) and about 300 million people in sub-Saharan Africa still without access to safe water supplies – approximately 80 percent of them live in rural areas (Xu & Braune, 2010), not only will a sustainable management of the groundwater resources benefit countless populations but also provide hope for improved quality of life. Fractured rock aquifers account for about 40% of all aquifers and maintains livelihood for more than 200 million people in Africa (Xu and Braune, 2010). They are found extensively in sub-Saharan Africa and play a vital role in meeting MDGs on water in the southern, west and east Africa due to their availability and portability. The Table Mountain Group (TMG) aquifer is a major fractured rock aquifer system in South Africa which has already proven to be a bulk water supply for agriculture, industry and domestic use in the Eastern and Western Cape provinces.

2. Background

The Table Mountain Group (TMG) aquifer is a major fractured rock aquifer system in South Africa which has already proven to be a bulk water supply for agriculture, industry and domestic use in the Eastern and Western Cape provinces.

The reported decline of groundwater levels in the TMG aquifer system in the little Karoo (Klein Karoo Rural Water Supply Scheme, KKRWSS) area since 1984 as a result of pumping from production wells in the Vermaaks River Catchment (Jolly & Kotze, 2002; Wu, 2005) has called for sustainable measures in the management practices at the Well fields. The reduction of pumping rates in an attempt to halt the decline in water levels could not arrest the situation because it is believed that there has been an over-estimation of the recharge rates in the TMG and for that matter the catchment area. Jolly (2002) reported that some shallow TMG boreholes have been pumped at rates in excess of 30 *l*/s. Other reported abstraction schemes within the TMG included the Arabella Country Estate, near Botrivier where 4 production wells supply about 30 *l*/s of groundwater to the estate (Parsons, 2002); Botrivier water supply project with 6 wells supplying about 20 *l*/s (Weaver, 1999); Ceres Municipality wellfields where 7 boreholes from the TMG supply 48 l/s and 3 boreholes from the Bokkeveld supply 50 *l*/s (Rosewarne, 2002); the Hex River valley project and the CAGE project at Citrusdal are also documented. Some of these drilling projects have little or no management plans while others are well managed even though ecological and environmental concerns are hardly integrated in the management programmes. The impact of these groundwater projects on the surface water regimes i.e. the baseflow into rivers, wetlands and estuaries which also control the availability of water for plant use are hardly evaluated or monitored.

2.1. Literature review

Custodio (2005) refers sustainability to the use of natural resources without jeopardizing their use by future generations. According to him it goes along with the concept of human beings living in peace and harmony with the environment, both now and in the future. He strongly believes that in reality, scientific, technical, and social as well as space and time frameworks, under which sustainability is evaluated, are continuously changing and that what may be sustainable now may not be in the future, and what may appear unsustainable today may be sustainable in the future. Present-day decisions must therefore take the future into consideration but the influence given to the future, however, will depend on the credibility of scenarios considered and the weight given by society and politicians.

Devlin and Sophocleous (2005) however differentiate between sustainability and sustainable pumping rates as two different concepts that are often misunderstood and therefore used interchangeably. They argued that the latter term refers to a pumping rate that can be maintained indefinitely without mining an aquifer, whereas the former term is broader and concerns such issues as ecology and water quality, among others, in addition to sustainable pumping. Another important difference between the two concepts according to Devlin and Sophocleous is that recharge can be very important to consider when assessing sustainability, but it is not necessary to estimate sustainable pumping rates. Sophocleous (2000) had reported that, in the past, the volume of recharge to an aquifer was accepted as the quantity of water that could be removed from the aquifer on a sustainable basis, the so-called safe yield, but it is now understood that the sustainable yield of an aquifer must be considerably less than recharge, if adequate amounts of water are to be available to sustain both the quantity and quality of streams, springs, wetlands, and groundwater-dependent ecosystems. Sustainable resource management demands the managing of groundwater for both present and future generations, and providing adequate quantities of water for the environment and thus quantifying what these environmental provisions are is presently an urgent research need (*Sophocleous*, 2000). Sophocleous (2005) again affirms that sustainable use of groundwater must ensure not only that the future resource is not threatened by overuse and depletion, but also that the natural environment that depend on the resource are protected. One agrees with his opinion that there will always be trade-offs between groundwater use and potential environmental impacts, and therefore a balanced approach to water use between developmental and environmental requirements needs to be advocated. However, to properly manage groundwater resources, managers need accurate information about the inputs (recharge) and outputs (pumpage and natural discharge) within each groundwater basin, so that the long-term behavior of the aquifer and its sustainable yield can be estimated or reassessed. Thus, without a good estimate of recharge, the impacts of withdrawing groundwater from an aquifer cannot be properly assessed, and the long-term behavior of an aquifer under various management schemes cannot be reliably estimated (*Sophocleous, 2005*).

2.2. Objective of the study

The study addresses the measures that are essential and relevant in sustainable utilitzation of Groundwater Resources in line with the Africa Water Vision thus:

To evaluate the factors and variables determining the sustainable utilization of the TMG regional aquifer using the KKRWSS as a case study, i.e. to determine the balance between recharge to and discharges from the Wellfield that will ensure a reasonable sustainability with minimum or no adverse impacts on the environment. This is done in the context of climate change and climate variability.

2.3. Previous work

The majority of aquifer-tests conducted in the TMG aquifers are aimed at obtaining a first-order estimate of the sustainable yield of a production borehole, as well as the design of the pump equipment and abstraction schedule. Various evaluation methods are used by geohydrologists with varied degrees of success. The case study of the Little Karoo Rural Water Supply Scheme - borehole safe-yield versus the sustainable yield of the aquifer as reported by Woodford (2002) provides a test case for the sustainable development of the TMG aquifer. The gross overestimation of the long-term supply potential of the Vermaaks River wellfield when relying solely upon conventional methods of aquifer-test analysis serves to highlight a problem that is currently being experienced by many groundwater practitioners working in the TMG fractured-rock aquifers and has led some to question the value of such tests (Woodford, 2002). In concluding his report on the interpretation and applicability of pumping-tests in TMG aquifers, Woodford (2002) suggested further research in order to improve the aquifer-testing and analysis techniques and thereby the understanding of the flow dynamics of the TMG.

Jolly (2002) reported that the unscientific testing and evaluation of boreholes drilled in TMG aquifers has often created a false impression of the aquifer's long term sustainable potential. Often 'blow yields' measured at the end of drilling have been mistakenly taken as borehole yields. He affirmed that even the normal scientific assessment of the borehole's potential via step and 72 hour constant rate tests can grossly over-estimate sustainable yield, if assessments do not take into account issues like existing boundaries and matrix transmissivity and storativity. He believes that many schemes have failed because the abstraction has exceeded recharge, resulting in water levels declining to the depth of the pump. He however, advised that aquifer storage must be utilized before the next recharge event topped up the aquifer because not only is recharge low but it is also sporadic. According to Jolly (2002), the ultimate cause of borehole or wellfield failure in the TMG aquifers is the poor management of the resource and suggests that the decline in water levels must be carefully managed to make certain that water levels do not drop below the top water strikes in the hole. He believes the storativity in the TMG is lower than traditionally expected.

3. Methodology

3.1. Description of current research

In the current study the Vermaaks Well field Water Supply Scheme was used as a case study to determine the sustainable utilization of groundwater resources in the TMG.

The following analyses were done in reaching the desired objective:

- Determination of the recharge to the well field using different methods and comparing them with those obtained by previous studies;
- Analysis of the long-term climate trends in the study area on the backdrop of climate change and potential impact on groundwater resources of the TMG;
- Evaluate the abstraction rates of the production wells in the well field and the long-term effect on groundwater levels;
- Assess the effect of abstraction on hydrological and environmental resources (rivers, springs and groundwater dependent ecosystems).

3.2. The study area

The study area is located in the Little Karoo area of the TMG in the Western Cape Province (Figure 1). The project area between the towns of Calitzdorp and De Rust comprises a broad valley, with an elevation of approximately 500 m (amsl) and surrounded by mountain ranges, the Kammanassie Mountain range with elevation of up to 1950 m (amsl) on the east and the great Swartberg Mountain range in the north of up to 2150 m (amsl). The Rooiberg Mountains occur in the western part of the scheme and down south is the Outeniqua Mountains. The area is drained by two perennial rivers, the Olifants River to the north of the Kammanassie Mountain range and the Kammanassie River to the south. One minor but important river, the Vermaaks River drains the Vermaaks River wellfield which is the most important wellfield of the KKRWSS. The Marnewicks River drains the eastern part of the Vermaaks River wellfield. The two minor rivers are ephemeral in the steep upper reaches, with more sustained flow in the lower reaches, and drain northward into the Olifants River. Runoff from the mountains is captured in a number of dams and used for irrigation and water supply to Oudtshoorn. The area falls within seven quaternary catchments that controls the surface water drainage however, the groundwater flow regime is controlled by the boundaries of the geological formations. For example, the Cedarberg formation which is an aquitard and the contact between the Nardouw Subgroup and the Bokkeveld Group act as groundwater flow barriers. There is however an active interaction between the surface water and the groundwater regimes. Jia (2007) calculated the mean annual baseflow as approximately 22% of the mean annual river flow for this area. With the groundwater level decline over the years interaction will be restricted between rivers and the water in the shallow weathered zone.

The KKRWSS has two sections, the Western Section at Calitzdorp and the Eastern Section at the Kammanassie Mountain area near Dysselsdorp. The Eastern Section is the most productive section of the scheme and also where the highest declines in water levels have been recorded. The KKRWSS was designed to supply up to 4.7×10^6 m^3/a of groundwater from the two sections. The eastern section initially had 13 boreholes of which 5 constituted the Vermaaks River wellfield. There are now 4 production boreholes in the Vermaaks River wellfield. The western section at Calitzdorp had 5 boreholes. Some 400 km of pipeline delivered the groundwater to two purification plants at Dysselsdorp and Calitzdorp before it is supplied to end-users (Jolly and Kotze, 2002).

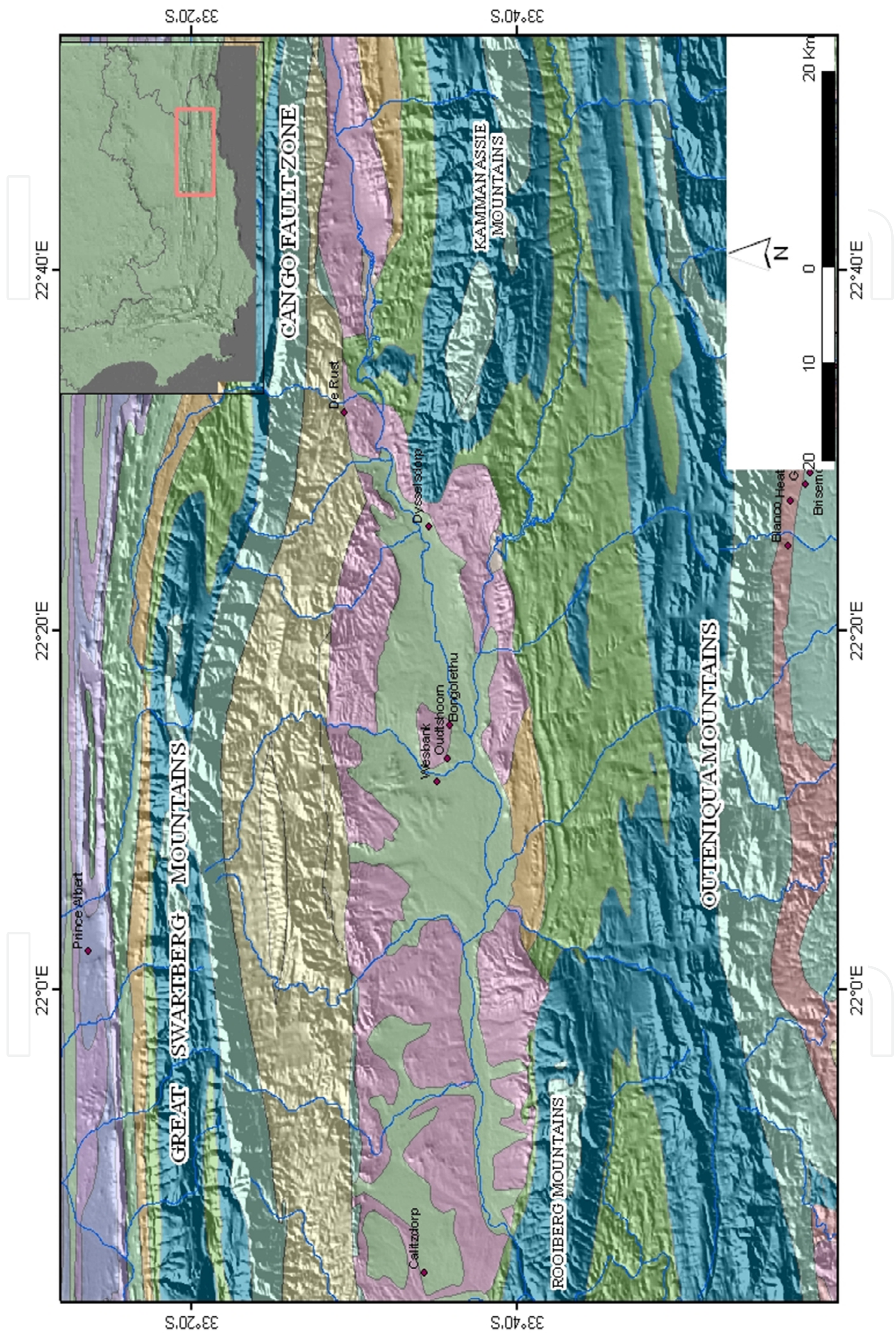

Figure 1. Location of KKRWSS area and Kammanassie Mountains

4. Results and discussions

4.1. Recharge to aquifers

Scanlon *et al*. (2002) and Xu and Beekman (2003) presented a comprehensive review on choosing the appropriate technique for quantifying groundwater recharge, including the applicable space and time scales, the range of recharge rates that have been estimated with each method, the reliability of the estimates, and important factors that promote or limit the use of the various methods have been outlined.

A comprehensive review and analysis of four methods namely, Chloride Mass Balance (CMB), Cumulative Rainfall Departure (CRD), spring flow and water balance, were evaluated and integrated resulting in a recommended recharge range of 1.63% - 4.75% of MAP for the Kammanassie area. The major factors limiting the accuracy of these recharge estimation methods were identified as the accurate measurements of the recharge area and aquifer storativity among other factors. These and other factors still present potential errors in recharge estimation especially for a fractured rock aquifer like the TMG. The results ranged from 0.2% to 12% of MAP. The upper range of values were derived from integrated approach such as water balance methods while the lower range of values were obtained from methods such as the CMB and CRD. For a given study area, the recharge rate is recharge-area dependent for the CMB mixing model and regression of Cumulative Flow (CF) methods, while the CRD method is dependent on the storativity of the aquifer. Errors would therefore depend on how accurate the recharge area and storativity values are obtained. Recharge rates are less than 5% of precipitation in contrast to the 15%-20% and over proposed by earlier researchers. The results indicate that the recharge rate varies from 0.24% to 7.56% of the MAP using a storativity of between 0.0001 and 0.001 with the CRD method. The average recharge rate was 5.38% of MAP or 48.67 mm, which equals to 3.88% of total precipitation of 1256 mm under storativity of 0.001 in considering impact of preceding rainfall. Most high recharge percentages are related to rainfall of 300 mm/a to 1100 mm/a. The recharge in terms of percentage of rainfall is lower if precipitation is greater than 1100 mm/a or less than 300 mm/a.

Recharge estimation methods have their uncertainties and inaccuracies arising from spatial and temporal variability in processes and parameter estimations, measurement errors and validity of assumptions. However, Xu *et al*. (2007) concluded that the following methods have been used in the study area with much certainty based on their reliability in space and time scales in the sub-region spanning a period of three decades: the Chloride Mass Balance (CMB), Cumulative Rainfall Departure (CRD), Rainfall Infiltration Breakthrough (RIB), Water Balance (WB) and Regression of Spring Flux.

Results from the several recharge studies conducted in the TMG area over the years by different individuals and groups of people using different methods indicated varying estimates in the range of 1% to 55% of MAP. Methods used included CMB, SVF, CRD, EARTH, Base Flow, Isotopes, Water Balance and GIS. Wide variations in estimates ranged between 165 and 2020 mm per annum from these methods however, it has been accepted that the scale of the recharge study often dictates the most appropriate methods to be used to determine aquifer recharge. Concerns were raised for review of recharge estimates in the Kammanassie area due to the continual decline of groundwater levels in the Vermaaks River Wellfield from 1994. The recharge estimate of 17% of MAP in the Wellfield was adjusted downwards several times to arrest the situation.

4.2. Climate trend in the study area

Temperature increases are worldwide however; precipitation decreases or increases are highly variable in time and space. The Mann-Kendall Trend test was applied on historical temperature and rainfall data records over several years. The Trend tests in the study area did show gradual increases in temperature over recent years while generally no significant trends have been observed with precipitation amounts in the TMG area generally. Using the Standard Precipitation Index (SPI) analysis variations in precipitation patterns were observed such as the intensity, duration and shifts in seasons. The SPI analysis clearly showed that there has been a persistent low rainfall in the KKRWSS area in particular since 2004. A particularly significant drought period was observed between 2004 and 2006 for three stations whiles in the fourth, Purification Works East, the drought is reflected between 2007 and 2010 period (figure 2). The low rainfall coupled with abstractions has greatly influenced the continual decline in water levels in the well fields in the KKRWSS area.

The results of the SPI analysis in this study have shown that there are wide variations in rainfall records in most of the stations which could be attributed to climate variability. It is still not very clear if the variations are increasing with time. With the results of the autocorrelation analysis the present trend cannot be used to predict the future trend of rainfall in the region. Higher temperatures would however, increase evapotranspiration which would in turn reduce direct recharge. In the catchment area there have been more drought effects in recent years resulting in reduced recharge which together with groundwater abstraction have resulted in massive groundwater level declines the area.

4.3. Effects of abstraction rate on groundwater levels

The major concern in the area has been the decline of water levels. It has been reported that groundwater levels of the production boreholes have been falling since 1984 in the Vermaaks catchment. Even though the Vermaaks River wellfield had a fairly good recharge, by 1999 the water level decline was approximately 20 m. By 2002 the decline had reached about 30 m and again approximately 40 m by 2006. Current records obtained from GEOSS (with permission from the Oudtshoorn Municipality) in 2010 showed that the water levels in boreholes VR6, VR7, VR8 and VR11 have declined by 70 m, 109 m, 134 m and 160 m respectively. Abstraction rates in the production boreholes have been reset a number of times since the scheme began its operations as the scheme managers battled the high demand for water and low recharge. In February 1993, after evaluating the step-drawdown and 72 hr constant discharge tests conducted upon the production boreholes in 1990-91, Mulder estimated the 24 hr production potential of the wellfield at 72 *l*/s – with a peak supply potential of 110 *l*/s.

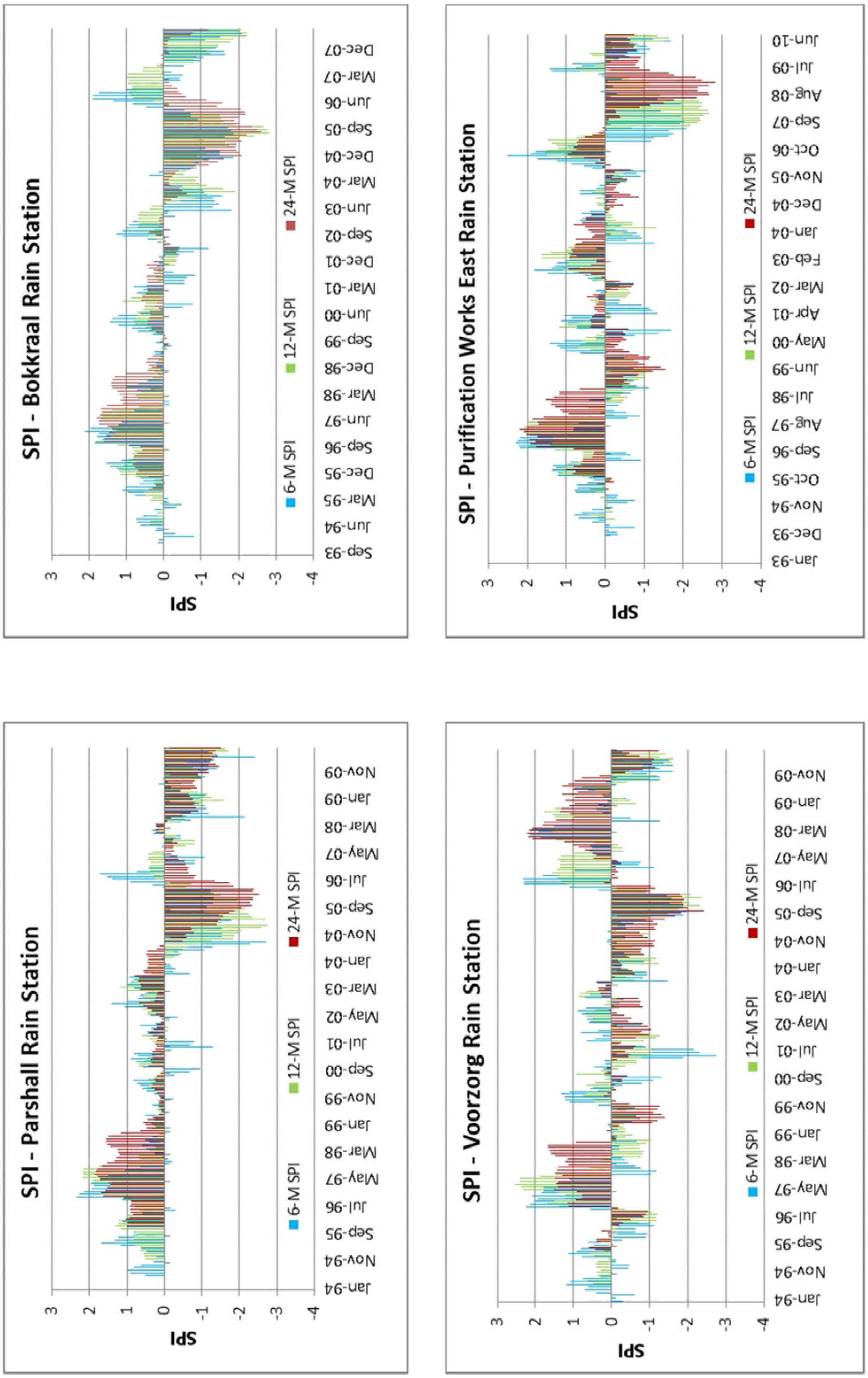

Figure 2. Comparative variations of 6-, 12- and 24-month SPIs for rainfall stations in the KKRWSS project area.

Costly, high-yielding pumps were installed in the production boreholes to meet this expected yield. In November 1993, after only eight months of production, Mulder re-evaluated the pump-test data in conjunction with the abstraction and water level monitoring data and down-scaled the long-term production potential of the wellfield to 40 *l*/s (peak 80 *l*/s). This indicated Mulder overestimated the production potential of the wellfield by at least 36% when using only aquifer-test information. In 1995, Kotze again re-adjusted the supply potential of the wellfield downwards to 20 *l*/s due to continual declines in water levels in the wellfield, representing a 72% downscaling of Mulder's original yield estimates. Jolly in 1998 conducted further step-drawdown tests on boreholes VR6, VR7, VR8 and VR11, as well as 72 hr constant-discharge tests on boreholes VR6 and VR7 and recommended that only boreholes VR7 and VR11 should be continuously pumped at a rate of 11 and 6 *l*/s, respectively, as boreholes VR6, VR7 and VR8 are interconnected with one another. Jolly added that this combined yield of 17 *l*/s is a conservative estimate upon the current water demand only. He also stated that boreholes VR7 and VR11 were capable of yielding up to 25 and 10 *l*/s respectively, on a continual basis, which could add an additional 18 *l*/s to the supply but added that accurate estimates of the volumes of rainfall recharge and a water-balance calculation were required in order to obtain the long-term sustainable yield of the Vermaaks River aquifer. Kotze in 2000 conducted such recharge and water-balance studies using 74 months of hydrological monitoring data, as well as a re-evaluation of the 1990 and 1997 aquifer-test data. Kotze estimated that the long-term supply potential of the wellfield is in the order of 8.5 *l*/s. Figure 3 is a plot of water levels in the Vermaaks wellfield.

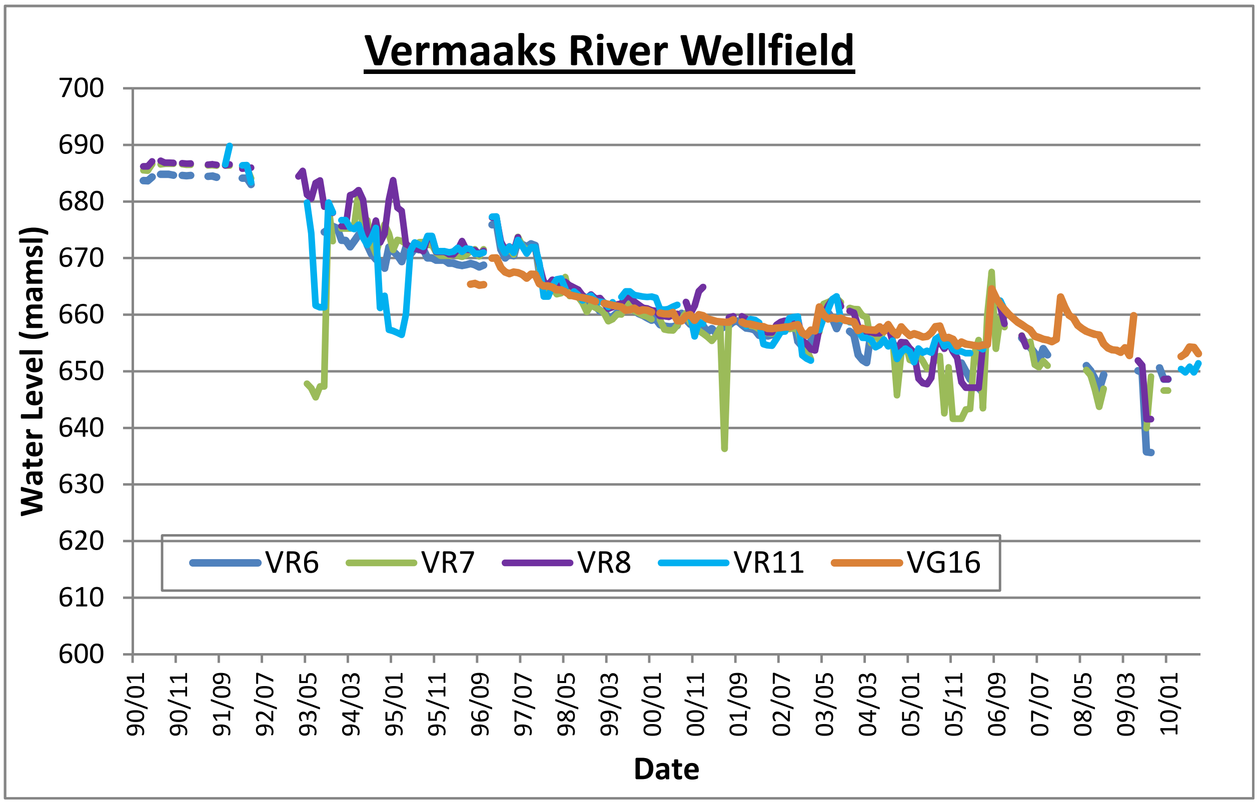

Figure 3. Decline of water levels in the production boreholes in the Vermaaks Wellfield

VG16 is the only observation borehole which reflects the decline of the production boreholes. With the continued adjustment in abstraction rates the decline of the production boreholes slowed down considerably from about 2001 except for the seasonal increases in abstraction rates at high demand periods (summer) as can be seen from figure 6.4. The wells are currently being pumped on the average at 5.5, 15, 4.5 and 5 *l*/s for VR6, VR7, VR8 and VR11 respectively on a 24 hour basis.

4.4. Effects of abstraction on hydrological and environmental resources

There are several springs in the KKRWSS catchment. Even though some of these springs are ephemeral their existences however have been affected by groundwater abstractions in the catchment. In a report to the Department of Water Affairs, Xu *et al*. (2002) recorded a number of springs that have dried up as a result of borehole construction in the vicinity of those springs. A spring G46083, 2 km downstream of borehole VG16 and located near the Cedarberg shale outcrop in the Vermaaks valley dried up after the construction of borehole G40175A in the vicinity in September 1999. Further downstream the spring G46084 was affected when a borehole G46077 was drilled through the Cedarberg shale into the Peninsula formation nearby in November 2001. The initial high pressure in the borehole was lost eventually. It has also been reported by Xu *et al*., (2007) that a hot spring which used to flow at a regional discharge area in Dysselsdorp has dried up. The hot spring was located at the intersection of two faults between the TMG and the Bokkeveld group. The drying up of the hot spring has been attributed to earthquakes (Tulbagh in 1969, magnitude 6.5 and Oudtshoorn in 2001, magnitude 3.6) and the large abstractions from the wellfield near the site (Jia, 2007). There were reported losses of many springs in 2001 and a few before, in 1999 and 2000 as a result of low rainfall and borehole constructions. Investigations by Xu *et al*. (2002) also established that flow in the Vermaaks River had abruptly dipped since the onset of the Water Supply Scheme in the catchment even though rainfall is the major contributory factor to the continual flow of the river.

The most comprehensive study on the impact of abstractions on spring flow in the Kammanassie area was done by Cleaver *et al*. (2003). The study grouped 53 springs in the area into 3 categories, 9 were considered most vulnerable to abstractions from the wellfield; 10 were considered as intermediate to vulnerability while the remaining 34 were considered least vulnerable. The study also confirmed that groundwater abstraction by the KKRWSS has impacted on the low-flow discharge in the Vermaaks River. On the impact of abstraction on vegetation, the study concluded that groundwater abstraction has a significant negative impact on plant water stress at the experimental sites in the Vermaaks River valley and recommended that changes in the water abstraction management could improve the situation. Spring losses caused localized impact on spring vegetation and ecosystems. Spring losses were also linked directly and indirectly to the death of four Cape Mountain Zebra on the Kammanassie Mountain between November 2000 and August 2001 as a result of inaccessibility to natural flowing water sources. Two artificial watering points were installed to protect the endangered species from extinction (Cleaver *et al*., 2003).

4.5. Sustainable management concept

The problems associated with the sustainable management of the KKRWSS are common to most abstraction schemes of such nature. There are a lot of positive impacts that such schemes bring to the beneficiaries and the general economy of the municipality and the nation as a whole. It is a laudable project that has brought a lot of improvements in the life of several communities, the right to access safe drinking water. Another positive indication from the project is the fact that the TMG has proven to be a good source of bulk water supply for many purposes. However, the challenges faced by the scheme need to be addressed not only to curb the negative impacts on the environment but also to ensure the long term survival of the scheme itself. In order to deal with the challenges facing the scheme there is a need to categorize them into what can be referred to as reversible and irreversible problems. The reversible problems are those that can be rectified or reversed because no permanent damage has been caused. On the other hand, an irreversible problem is that which causes permanent damage that cannot be reversed, life of species may be lost. Sometimes the full impact of a problem may not be immediately known until a thorough investigation has been done. There have been suggestions and remedies provided in the past to arrest the critical problems of the scheme but they have been on ad-hoc basis and it is important that a comprehensive approach is taken to maintain a sustainable project that will continue to improve the quality of life to humans and other forms of life. Some key goals related to groundwater sustainability in the United Kingdom are listed in figure 6.12. These goals must apply equally well in South Africa especially in the KKRWSS.

The most important attribute of the concept of groundwater sustainability is that it fosters a long-term perspective to management of groundwater resources. Several factors reinforce the need for a long-term perspective. First, groundwater is not a non-renewable resource, such as a mineral or petroleum deposit, nor is it completely renewable in the same manner and timeframe as solar energy. Recharge to groundwater from precipitation continually replenishes the groundwater resource but may do so at much smaller rates than the rates of groundwater withdrawals. Second, groundwater development may take place over many years; thus, the effects of both current and future development must be considered in any water management strategy. Third, the effects of groundwater pumping tend to manifest themselves slowly over time. For example, the full effects of pumping on surface water resources may not be evident for many years after pumping begins. Finally, losses from groundwater storage must be placed in the context of the period over which sustainability needs to be achieved. Groundwater withdrawals and replenishment by recharge usually are variable both seasonally and from year to year. Viewing the groundwater system through time, a long-term approach to sustainability may involve frequent temporary withdrawals from groundwater storage that are balanced by intervening additions to groundwater storage. The consequence of pumping should be assessed for each level of development; developments such as water-level declines, reduced streamflow, degradation of water quality and loss of dependent ecosystems through vegetation loss or spring loss.

The KKRWSS supplies water to meet demand from a population of 15,000 in addition to stock watering. The latter is estimated to account for about 20% of the water supplied from the scheme. A sustainable groundwater yield which will lead to a sustainable utilization should be expressed in the form of an extraction regime, not just an extraction volume. A regime in this context means a set of management practices that are defined within a specified time and place. Abstraction limits may be set in volumetric quantity terms or rates of extraction over a given period and/or impact, water level or quality trigger rules. In exceptional cases where draw beyond the rate of recharge may be acceptable, it may be only for a specified period, after which time the rate may be less than the rate of recharge to compensate for the loss. Also under specified circumstances (for example, high or low rainfall years) the amount of water that may be abstracted may be greater or less than the longer-term value. It has already been stated above that records from the KKRWSS site indicate less than average rainfall for the past few years and one would have expected that abstraction levels would be much less than normal. From figure 3, it appears that the Vermaaks wellfield is still experiencing water level decline. The four production boreholes in the Vermaaks wellfield are functioning well and appear to be producing the bulk of the water supply to the scheme. The following analysis is centered on the Vermaaks wellfield as the main area of concern. As has been stated elsewhere human activities such as groundwater withdrawals change the natural flow patterns and these changes must be accounted for in the calculation of the water budget. Because any water that is withdrawn must come from somewhere, human activities affect the amount and rate of movement of water in the system, entering the system, and leaving the system. For a sustainable utilization to occur, a sustainable pumping rate is defined by *Eqn. 1* as:

$$P_s \leq R_o + \Delta R_o - D_R \tag{1}$$

and

$$D_R = D_o - \Delta D_o \tag{2}$$

where R_o is natural recharge, ΔR_o is induced recharge, D_R is residual discharge, D_o is natural discharge and ΔD_o reduced discharge. Unless the borehole is drilled close to a reservoir, the induced recharge usually does not occur and reduced discharge dominates. Hence a sustainable pumping rate is given by:

$$P_s \leq R_o - D_R \tag{3}$$

In the case of over-pumping the residual discharge could be reduced to nothing and pumping will be drawing on storage setting up a long-term decline in groundwater level. The yield of the groundwater system is at the expense of the groundwater discharge and storage components. This is the situation in the Vermaaks River wellfield where borehole levels have seen a long-term decline as shown above. The long-term decline of local groundwater level is an indication of unsustainable groundwater resource depletion. Table 1 is the results of groundwater budget analysis in the Vermaaks wellfield.between July 2009 and June 2010.

The average rainfall records for three stations (Parshall, Wildebeesvlakte and V-notch) from 2000 to 2010 were computed for the Vermaaks wellfield. The Peninsula formation window at the Vermaaks wellfield was used as the area of recharge given as 48 km^2. The recharge is taken as 3% of rainfall based on the most recent studies. The abstraction volume is the actual records obtained from the KKRWSS management for the period of July 2009 to June 2010. The water demand volume is obtained from a population of 15000 plus a 20% demand from stock watering. The legal provision of 25 litres per person per day is the basic human need requirement. The same quota was assumed for stock watering. The population figure was obtained from the scheme management. The historical recharge (Hist Rech) is based on 3% of long-term MAP for the area which is 50% more than the records for the period of analysis.

Date	Rainfall (mm)	Rech (3%)	Recharge (m^3)	Abstraction (m^3)	Popn & Stock Dmd (m^3)	Historical Recharge (m^3)	Storage Depletion (m^3)
Jul-09	26.24	0.7872	37785.6	73275	11475	56678.4	-35489.4
Aug-09	29.13	0.8739	41947.2	71936	11475	62920.8	-29988.8
Sep-09	26.43	0.7929	38059.2	158025	11475	57088.8	-119965.8
Oct-09	32.08	0.9624	46195.2	12041	11475	69292.8	**-34154.2**
Nov-09	37.35	1.1205	53784	158630	11475	80676	-104846
Dec-09	21.11	0.6333	30398.4	81958	11475	45597.6	-51559.6
Jan-10	19.93	0.5979	28699.2	82494	11475	43048.8	-53794.8
Feb-10	24.93	0.7479	35899.2	47428	11475	53848.8	-11528.8
Mar-10	30.8	0.924	44352	39307	11475	66528	**-5045**
Apr-10	18.76	0.5628	27014.4	62774	11475	40521.6	-35759.6
May-10	28.75	0.8625	41400	35292	11475	62100	**-6108**
Jun-10	36.35	1.0905	52344	59501	11475	78516	-7157
Total	**331.86**	**9.9558**	**477878.4**	**882661**	**137700**	**716817.6**	**-404782.6**

Table 1. Results of Vermaaks groundwater budget

Results from the table are plotted in figure 4. The following conclusions may be drawn from the results:

- The water demand is more than the requirements for basic human needs
- The recharge in the last decade has been less than average due to low rainfall
- The abstractions from the wellfield exceed the recharge leading to decline in water levels
- There has been depletion of groundwater storage due to over-abstraction
- The over-abstraction has the potential to capture natural discharge to surface water bodies
- The over-abstraction leaves no provision for discharge to cater for environmental flows

In figure 4 the abstraction line is well over the recharge line. For the sustainable utilization of the groundwater resource, the abstraction level should be less than or at least equal to the recharge line as indicated in Eqn, (1). The graph shows a situation of unsustainable utilization of the resource.

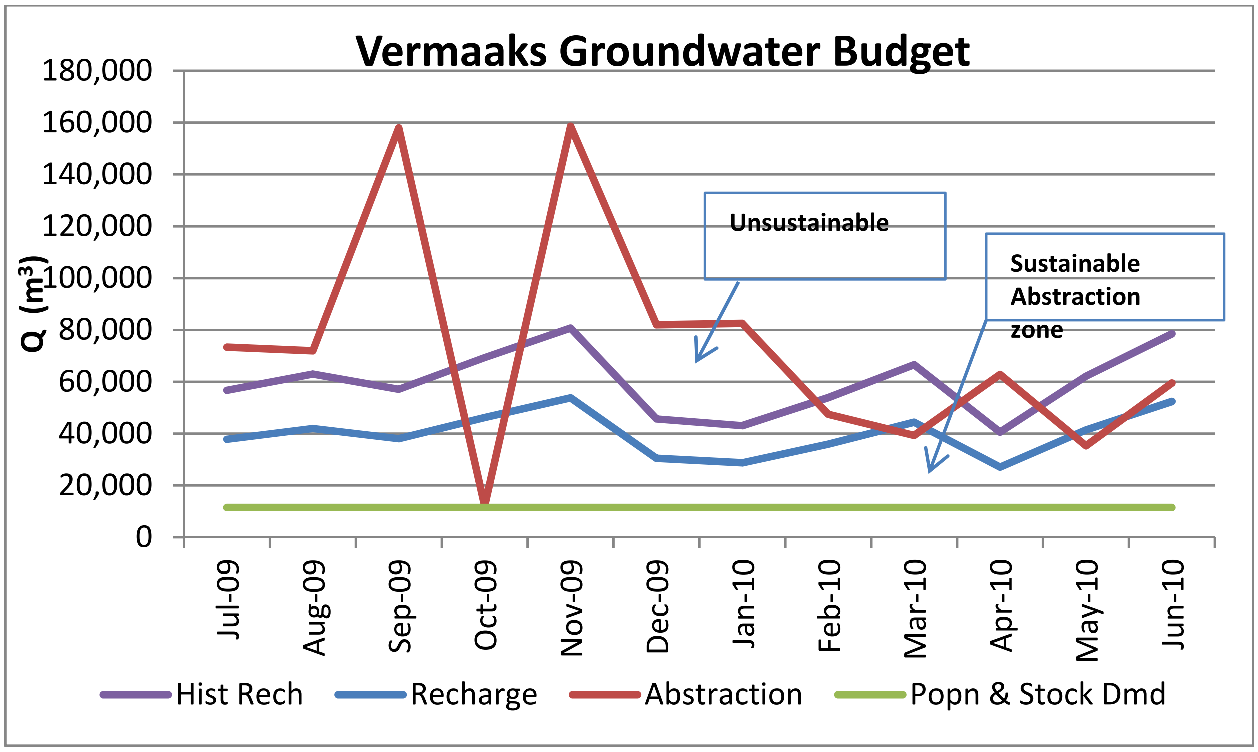

Figure 4. Vermaaks Wellfield groundwater budget

There are abstractions from the other wellfields notably Varkieskloof, Bokkraal and Calitzdorp to augment the total groundwater supply from the scheme. In addition surface water is drawn from the Olifants River to augment the scheme's supply. Between July 2009 and June 2010 a total of 1,518,425 m^3 of water was supplied from the scheme made up of 1,275,920 m^3 of groundwater and the rest from surface water sources.

5. Conclusion

From the above study it has been established that recharge to the TMG aquifers, and in particular to the Vermaaks Wellfield is much lower (about 3% of MAP) than has been estimated in the past. Climate trends generally have shown that temperature is gradually increasing everywhere while rainfall shows minor increases and decreases over different areas. In the KKRWSS region rainfall has generally declined in recent years. Rainfall variability also remains high with potential for causing droughts and floods. Recommendations on abstraction rates based on higher recharge estimates have resulted in serious decline in water levels in the wellfields posing serious threat to the water supply scheme itself. The water demand has risen far and above the basic human requirements and stock demand over the years and with abstraction rates based on demand requirements, the decline in water levels has persisted over a decade. The production wells in the Verimaaks wellfield do not have time to recover. Decline in water levels has resulted in decline in natural discharges from the aquifer to streams, springs and other wetlands with negative impacts on the hydro-ecological environment. The reduction in low-flows in the Vermaaks River, the loss of spring flows and the resultant loss of certain vegetation types as well as threat to local ecosystems have led to temporal and permanent damage to the hydro-ecological environment.

Temperature increases in the atmosphere is likely to cause droughts during the summer whiles in the winter the atmosphere can absorb more moisture and cause floods. The implications of these changes on freshwater resources either directly or indirectly are of much concern to water resources managers. Responses to climate variations by surface water resources are fast and intense however groundwater response is much delayed even though it is likely to be affected indirectly by the absence of fresh surface water resources. Semi-arid and arid regions of developing countries are particularly vulnerable to impacts of climate variations and there is an urgent call for mitigation and adaptation measures to sustainably utilize our freshwater resources particularly the groundwater. The high groundwater storage depletion due to over-abstraction needs to be reversed to restore the hydro-ecological environment.

5.1. Recommendations

The long-term sustainability of the groundwater resources in the study area is dependent on the time-management approach, a form of an adaptive management in which abstraction rates are adjusted according to the recharge patterns and not driven by demand as currently pertains in the area. Generally, abstraction rates have been higher than sustainable levels in almost all year round. If the abstraction rates are not reduced, unless there is a major increase in the rainfall pattern, the scheme is bound to fail in the near future.

The priorities for groundwater management should be:

- Sustainable long-term yield from aquifers;
- Effective use of the large volume of water stored in aquifers in critical periods,
- Preservation of groundwater quality;
- Preservation of the aquatic environment by prudent abstraction of groundwater and
- Integration of groundwater and surface water into a comprehensive water and environmental management system.

The trade-off between water for consumption and the effects of withdrawals on the environment often become the driving force in determining a good management scheme. The concept of adaptive management which treats management policies and actions as experiments, not fixed policies has been recommended. Management continually improves by learning from experiences. Changing technology and increasing knowledge and understanding change the perception of risk and priorities with regard to the acceptability of trade-offs, hence water resource management must be adaptive and flexible.

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