Executive Summary

Introduction and scope of the investigation

A Governmental surveyor by the name H Ford proposed an irrigation scheme in the Harts Valley as early as 1875. The shortage of money and the unemployment due to the depression in the early 1930s led to the announcement by the Government, on 2 November 1933, that the scheme will be built. In 1934 Act 38 of 1934 was approved, giving permission to construct the Vaaldam and to develop the Vaalharts Irrigation Scheme. The water for the scheme was diverted from a weir in the Vaal river (24°55'30"E : 28°06'54"S) ± 6.5 km east of Warrenton.

The first farmers received their plots in 1938. Today there are 1200 plots that varies in size from 25 to 75 ha, covering a total area of 35 302 ha (31 732 ha in the Northern Cape and 3 570 ha in the North-West Province). Water logging and salinisation problems have been experienced in the area. To remedy the problem the installation of a main sub-surface drainage system began in 1972. The feeder canals were also lined with concrete. However, in 2000 it was discovered that approximately 50% of the plots did not have proper discharge points for the drained water although roughly 80% have installed internal subsurface drains.

Waterlogging and salinisation became a problem as the water table has risen from 24 mbgl at the inception of the scheme to an average of 1.6 mbgl at present. An earlier investigation furthermore indicated that the macro salt input and output of the scheme is not in balance, with the result that the salt arriving at Spitskop dam downstream of Vaalharts, is lower than expected. The quality of the groundwater is deteriorating as can be seen in samples and on site EC measurements. Therefore several studies had been carried out to explain the apparent macro-scale salt accumulation. In order to study the behaviour of groundwater in the saturated zone of the scheme, this study installed and monitored a network of piezometers on the scheme.

Project objectives

- To determine what influence the different irrigation methods, with and without drainage on different soil types have on the quality of groundwater in the upper zone (0-3 m) of the soil.
- To investigate the flow path of groundwater in the upper saturated zone. Also to determine the flow paths of the returning groundwater to the Harts River.
- Address some of the questions raised by previous investigations in this area. Reports from previous investigations include a long term salt balance and the investigation to determine if there is an accumulation of salts in the deeper aquifers.
- To determine the physical properties of the upper zone to construct a conceptual model for the groundwater flow.
- To conduct a water and salt mass balance to establish what effect does the irrigation and subsurface drainage have on the quality of groundwater in the upper zone (0-3 m) of the soil.

Methodology

This investigation covers the area from Jan Kempdorp in the south to Taung (Dry Hartz River) in the north, a total length of 40 km covering a total area of 34 400 ha (including the Vaalharts Water Users Association servitudes). Initially 197 locations (43 thereof in the Taung area) for piezometers were identified. Later another 51 piezometers were added (19 thereof Taung area) (see Figure 1 and 2). The groundwater levels and chemical parameters were monitored by installing a network of piezometers. Monitoring continued for one year in order to cover all seasons, planting, harvesting, rainy and dry periods. Measurements took place during August and November 2008 as well as February and May 2009. The hydraulic conductivity was also established and the existence of any stratification in the upper soils was determined to construct conceptual models.
The investigation consisted of the following steps:

- Literature Review and collection of background information of the existing scheme and previous studies conducted in the area
- Installation of a piezometer network
- Field work monitoring groundwater levels, piezometer electrical conductivity (EC) profiling

- Analysing groundwater levels and EC
- Monitoring drains at selected sites
- Testing of aquifer parameters
- Conceptual modelling to simulate drain flow
- Salt and Water balance
- Evaluation of options to ensure a sustainable irrigation system.

Although 200 piezometers were initially planned, a total of 247 piezometers were installed to be able to also monitor Taung and give the K block more coverage.

Water level measurements

Groundwater levels were measured a total of six times. The first measurements/readings took place over a period of four months from July 2007 till October 2007, coinciding with the installation of piezometers. All measurements were performed more than 24 hours after holes were drilled and piezometer installation to ensure recovering of the groundwater level. The second reading took place in November 2007, followed by a series of four readings over a period of one year to cover all seasons and irrigation periods. Although 210 piezometers had to be measured, all readings were taken within a period of three days every season to ensure comparability.
Water levels were measured to establish the effect that precipitation, drainage and irrigation has on the groundwater level. These levels were also used to create groundwater contour maps and to determine the direction of groundwater flow.
The average groundwater level of the piezometers monitored in August 2008 was 1.65 mbgl, in November 2008 1.57 mbgl, in February 2009 1.56 mbgl, and in May 2009 1.76 mbgl. Although there are differences the trends are much the same with an average of 1.63 mbgl.
Both surface and sub surface water flows perpendicular to the contour. The contours developed with the data of the subsurface water levels showed that the groundwater therefore must drain towards the Harts River.

EC measurements

An EC and temperature log taken at intervals down a piezometer can be interpreted to determine if there is cross flow, aquifer heterogeneities and groundwater movement in the piezometer (Michalski, 1989).

In August 2008 piezometer profiling was performed. The EC values of all the piezometers were determined at intervals of 200 mm from the water level to the bottom of the hole. The EC readings of the water in each piezometer were all within the same range. From this it can be determined that there is no stratification or layering of groundwater within the top 3.0 m of the soil in the study area. Of the 209 piezometers measured in August 2008, 158 had water wit an average EC of 160 mS/m (1231 mg/l). In November 2008, 156 had water the average EC was 232 mS/m. During February 2009, 159 had water with an average EC of 190.8 mS/m and in May 2009 138 had water with an average EC of 183 mS/m. The average EC was 192 mS/m which is lower than most plants can tolerate. Although it is much higher than the 66 mS/m of the irrigation water, it indicates a macro leaching fraction as high as 30%.

EC values of Harts River Water

Electrical conductivities were measured at various positions in the Harts River during December 2009. The river was dry and the first measurements were only possible at a position 1.2 km north of the junction of the Harts and Dry Harts Rivers. Measurements were taken at four positions up to the Espagsdrift gauging station, to cover the influence of the entire research area. Flow measurements were also obtained from Vaalharts Water User Association. The average flow for the period January 2008 to December 2008 was 8227 m^3/hour, i.e. 2906 m^3/ha·a. The EC measured at Espags Drif was 105 mS/m. This indicates that the river system at this point drains 1,47 t/ha·a of salts.

Saturated Hydraulic Conductivity (K Value) measurements

A total of 26 piezometers were selected for determining K values. The following criteria were used:
- The sites should have a column of water that is at least 800 mm in depth from the

groundwater level to the bottom of the piezometer.
- The sites should be at good representative locations of the entire study area.
- The soil map was studied to cover as many different soils as possible.
- Preferably the same sites used for sampling should be used to ensure consistency.

The K values were found to vary between 0.013 and 5.4 m/d.

Comparing Hydraulic Conductivity (K) and Electrical Conductivity (EC)

The K values at 25 piezometers were compared to the EC values measured during the monitoring period. A correlation coefficient of only 25.9% was found, which indicate no correlation between these two parameters. Electrical Conductivity was found to be influenced by the position of the piezometer and the following trends were noticed:
- EC measured on the highest elevation of a land was lower than the rest of the land
- EC measured in the middle of a land is higher
- If a piezometer was on the opposite side of a drainage line than the land, the EC is lower
- Piezometers close to an open channel drainage were lower which could be caused by leaching into the drains.

EC monitoring in drains

A decision was taken to monitor the flow and the EC of the drains in the K block to estimate how effective the existing systems are and what the influence of the drainage is on the EC of the soil and groundwater. Monitoring took place simultaneously with the regular monitoring of the piezometers. The average EC of the drainage water measured at the same four drains in Block K during August 2008, November 2008, February 2009 and May 2009 was 201, 182, 152 and 162 mS/m respectively. The EC of the groundwater measured in the piezometers in Block K during the same time frame was 142, 172, 155 and 151 mS/m respectively.
Comparing the EC values of the drainage water at the outlets and the average ECs of the piezometers (that delivers through the specific outlet) showed that on average the EC of drainage water are 20% higher. Where good drainage exists and no over irrigation are taking place the EC values of the drainage water tends to be lower; this mean that the salts are drained and do not accumulate, emphasising the importance of subsurface drainage that is in a good working condition. Salt accumulation in soil is a function of over or under irrigation. Low soil EC indicates over irrigation (poor irrigation). The water table level is an indication of the effectiveness of drains and the degree of over irrigation.

Chemical analyses

The samples taken at 22 sites, representing boreholes, piezometers, drainage water and canal water, were chemically analysed by the laboratory of the IGS.
The EC values were mostly within the range 60-250 mS/m. The two highest values were from piezometers positioned in an area where the clay content is >20%. The reduction in natural and installed subsurface drainage associated with a lower hydraulic conductivity (as a result of the higher clay content) may be responsible for the salt built up.
Measurements indicate that rainfall preceding measurements had a decreasing effect on almost all EC values.

• Chloride sampling and analyses

During October 2009 samples were taken from 14 piezometers to determine the chloride concentration in the groundwater. Three samples were taken where possible: at the groundwater level, at the level of the subsurface drains and beneath the subsurface drains at the bottom of the piezometers. (The reason for the sampling was to determine if the irrigation water was bypassing the subsurface drainage system and if the soil type, influence the drainage).
The following conclusions were made:
- All positions where sampling was done beneath the subsurface have higher chloride concentrations than above the drains indicating that drains are having an effect.
- Where the drainage and irrigation application are effective the increase of chloride content of the water is minimal.

• At the sampling position where the clay index was 28%, the water table were also high indicating that drainage are not very effective, this influences the leaching of chloride in the area, and chloride is accumulating due to the slow drainage tempo.

Water budget

Zones, representing the effective drainage influence around drains, were assigned to 57 areas to model drain outflow using the zone input method. The water budget was determined for the 57 zones and compared to the drainage outflows that were measured at four occasions during the monitoring period. The values of 13 of the drainage outflow measuring positions and 21 of the drain zones were used for the comparison
On average the measured drainage outflows was 67.4% of the modelled average of 583.7 mm/a.

Salt and water balance

Salt Balance and water balance calculations were done to establish if the salts that enter the irrigation area are leaving it, or whether it leads to a salt build up. If there is a salt built up, it should be estimated where the salt build up takes place. A previous study by Herold and Bailey (1996) indicated that almost 100 000 t of salt is not being accounted for. A study done by Gombar and Erasmus (1976) measured a groundwater TDS average of 1005 mg/l. Another study conducted by Ellington et al. (2004) indicated that the groundwater TDS is 1350 mg/l, an average increase of 13 mg/l.
This study found the average EC of piezometers to be 191 mS/m which represents a TDS of (191 X 7.699 + 5.4) 1476 mg/l. This indicated an increase of 96 mg/l in 5 years, an average increase of 19.25 mg/l/a, an indication that the salt content in the upper 3.0 m layer is increasing.
In order to balance (flush) the salt deposits in the upper layer of soil that are generated by the accumulating effect of the salt content of the irrigation water and the additional salt that stays behind in the soil after the fertilizing process, leaching must take place. The application of a well maintained and functional drainage system is essential. The salt content is not yet at a level requiring removal; salinity may increase with minimal effect but can also be reduced by reducing irrigation or scheduling. This would also result in the reduction of drainage volume and the need for additional drains.
The bulk drainage system is in place and drainage on the plots are still being installed, to date almost 60% of the plots have internal drainage and ± 350 applications are receiving attention (Van Niekerk, 2009). The leaching requirement was calculated by using the formula using the average EC of the drainage water of block K. The measured drainage average was 284 mm/a.

Findings

• In 1971 salinisation became a problem as the water table has risen from 24 mbgl to 1.2 mbgl. Leakages from overnight dams and soil furrows in the system were about 45 million m^3 of water a year. These dams and furrows had to be lined to reduce its contribution into a rising water table.

• In 1972 installation of the main drainage canals and lining of the feeder canals to limit the leaching to the groundwater started.

• In 1976 a proposal was made to lower the water table by installing and pumping boreholes, at the same time water would be replenished by fresh water, this was too expensive.
• In the 1980s the construction of subsurface drainage started.

• Another concern raised was that the salt added to the subsurface water in the scheme does not return to the surface water. The quality of the water in the Spitskop Dam, where the irrigation water drained to, does not deteriorate at the same rate as the groundwater in the irrigation area.

• In 1996 Harold and Bailey claimed that the salts are accumulating in the groundwater sources below the area by leaching through the upper soils, that there is a salt sink present due to a perched water table and that at some stage the sink will be exhausted and have severe effects.

• In 1999 another problem arose as the internal subsurface drainage pipes got blocked due to magnesium sulphate precipitation, and the remedy was too expensive.

• A study conducted by Ellington, Usher and Van Tonder (2004) claimed that there is no perched water table. Water levels do not differ more than a few centimetres in deep and shallow water systems. Water quality as profiled in piezometers indicated no major stratification of groundwater. The deep lying aquifer does not perform separate and if the net storage of the aquifer remains the same the total dissolved solids (TDS) increase, will be in the order of 14 mg/l per annum.

• Soils are considered to be saline if the electrical conductivity reaches 400 mS/m. This may vary depending on plant and crop types but salt-affected soils are often waterlogged and that has more severe effects.

• A possible remedy for the rising table is the planting of eucalyptus trees. But it excludes salt in the uptake which then accumulates in the root area of the trees, the salinity of the water in the upper part of the soil increases.

• Trees were planted on both sides of the canal can use the water leaching from it, this is not a good idea keeping in mind that RSA is a water scares country and the unused water from Vaalharts is supposed to go to the Taung Irrigation Area.

• Vaalharts is in a glacier valley, therefore the topographic gradient of the scheme is predominantly flat, 70% of the area comprises of slopes less than 1%. This minimises the surface runoff and maximises the effectiveness of irrigation in the area. The median annual simulated runoff in the area is in the range of 20 and 41 mm.

• The soils in the area are alluvial and are described as Kalahari Sand and consist on average of 75% sand, 15% clay and 10% silt.

• Although there is a dolerite dyke present it would not have an influence on the subsurface water flow. The maximum water flow depth was calculated at 8 mbgl and thus should flow over the dyke. This does not necessarily happen, a plot owner in the L block between the dykes are pumping water from a borehole for irrigation constantly at a range of more than 4l/s to replenish the irrigation quota.

• Drip, centre pivot and flood irrigation accumulates to more than 85% of the irrigation practises its effectiveness is over 80%.

• More than 90% of the piezometers were constructed to depth of 3.0 mbgl and 100% deeper than 2.0 mbgl.

• Wheat, maize and lucerne are crops that most farmers plant in Vaalharts. The tolerances for these crops are 170, 200 and 600 mS/m and the average measured in the piezometers 191 mS/m thus emphasising the salinity thread.

• A total of 210 piezometers (43 in Taung, 74 in block K and 91 in the rest of the research area) were surveyed and georeferenced and used for the monitoring.

• The interpretation of an EC log taken at 200 mm intervals in all the piezometers showed that there are no cross flow thus no stratification.

• The EC of the groundwater in the top 3.0 m for the four seasons were 160, 232, 190, and 183 mS/m. The average of 191 mS/m is lower than most plants can tolerate, but it is much higher than the 66 mS/m of the irrigation water.

• The average groundwater level of the piezometers monitored 1.65, 1.57, 1.56 and 1.76 mbgl. Although there were differences the trends were much the same with an average of 1.63 mbgl.

- The K values varied between 0.013 and 5.4 m/d, which could be related to the clay content which ranged between 6 and 40%.

- Contour maps that were developed for the K values, the clay content and the EC readings showed that there are resemblances.

- The average EC of drainage in the K block were 201, 182, 152 and 162 mS/m with an average of 174 mS/m. The EC in the piezometers in Block K during the same time frame had an average of 155 mS/m. This difference of 11% indicates a salt build up and non-effective drainage.

- Continuous irrigation with water containing a SAR value >10 has detrimental effects on the crops. Samples took in the area have salinity index of high to very high but only one has a SAR of more than 10.

- Drainage canals need cleaning up, the sand deposits in it leads to a build up of drainage water that leads to the submerging of drainage outlets prohibiting outflows.

- On average the drainage outflows measured was 67.4% of the modelled average of 583.7 mm/a.

- The finding of this research is that the EC in the upper 3.0 m of soil averages 191 mS/m thus representing a TDS of (191 X 7.699+5.4) 1476 mg/l. This indicates an increase of 96 mg/l in 5 years, an average increase of 19.25 mg/l/a, an indication that some of the salts remains in the upper 3.0 m layer.

- Incoming salts through irrigation = 4.65 t/ha/a, irrigation salt not drained = 0.8 t/ha/a.

- The leaching requirement to maintain salt balance was 611.5 mm/a. This compared well with 583.7 mm/a modelled. The measured drainage average was 284 mm/a indicating that the drainage is not effective.

- A subsurface flow depth of 8 m was calculated at the piezometer b12 position. The EC of the groundwater in this area was high during the entire monitoring period. Values of 660, 1000, 841 and 711 mS/m were measured. The clay content was 28%, these facts emphasize why a salt built up is taking place in the area and will built up in similar scenarios.

- The leaching requirement is 1.67 mm/d which is only 0.13 mm/d more than the 1.54 mm/d calculated in the water balance.

- Considering the measured drainage and average leaching requirements there are 298 mm/a subsurface water passing the subsurface drainage system.

Recommendations

- Effective irrigation in combination with effective drainage is the only way to prevent salinisation of lands.

- The overnight dams, feeder canals, community furrows and open drains have to be cleaned, plants generates cracks in panels, this leads to water loss.

- Panels of open drains, overnight dams, feeder canals and community furrows that are cracked have to be replaced to prevent leaching of water to the groundwater.

- Trees can be planted as an intermediate remedy for waterlogging, timber can be used but this is no long term solution. The water is necessary in Taung and RSA is a water scares country.

- Scheduling irrigation will lead to a more effective use of irrigation water and less water would have to be drained.

- Effective use of irrigation water will cause less water to pass the subsurface drainage system.

- Replacing Flood Irrigation Systems with Centre Pivots will ensure more effective use of irrigation water, all plants cannot be irrigated from above, keep in mind plant needs.

- Cleaning and or replacing of internal subsurface drainage.

- Reducing of the internal sub surface drainage spacing.

- Repair, maintenance and replacement of default irrigation equipment, including pumps, pipes, nozzles, standpipes, sprinkler nozzles, hydrants, valves, etc.

Achieving the goals of the investigation

All goals and objectives of the study have been met. The groundwater contour maps for the different seasons were created, the influence the different irrigation methods was determined, as well as the flow paths of the groundwater. Some of the questions raised by previous investigations in this area have been addressed. A water and salt mass balance was established and it was determined what effect the irrigation and subsurface drainage have on the quality of groundwater in the upper zone of the soil.

Technology transfer

All information generated during the investigation has been transferred electronically to the WRC. Publishing this information through the WRC will make it available to a wide spectrum of individuals and stakeholders. These findings were also presented at the biannual Groundwater Division Conference in 2009, and two papers will be published in accredited journals.

Participation and upliftment

In 2009 Mr Flip Verwey submitted this work as fulfilment towards a Master's degree in Geohydrology to the University of the Free State.
Four B.Sc. (Hons) students completed tasks on this project. They are Stephen Fonkem, Corneli Hogan, Kevin Vermaak and Morne Burger. All of them have gone on to complete their Masters degrees in Geohydrology as well (or are in the process of completing the degree) and are currently employed as geohydrologists.