The influence of Irrigation on Groundwater at the Vaalharts Irrigation Scheme – Preliminary Assessment

Report to the
Water Research Commission

by

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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.

Acknowledgements

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Although there was no Reference Group for this study, Mr HM du Plessis acted as the Water Research Commission research manager responsible for project management.

The following individuals and institutions are particularly acknowledged for their contributions in providing finance, access to the sites, numerous discussions and sharing of knowledge:

- The financing of the project by the organisations mentioned above are acknowledged gratefully.
- The Agricultural Engineering Services of DAFF in Silverton Pretoria for the funding and assistance of the drilling, and Mr AT van Coller for supporting the opportunity.
- Mr C van Niekerk and personal at the Northern Cape Department of Agriculture in Jan Kempdorp.
- Mr JMJ du Plessis of Department of Agriculture Forestry and Fisheries for all his help and assistance.
- Mr H Rossouw for the development of an electronic device to measure the recovering heights in the piezometers after pumping it to determine the K value.
- Eelco Lukas and Lore-Marie Cruywagen from the Institute for Groundwater Studies for assistance in Information Technology matters and laboratory analyses respectively.
- The farmers of the Vaalharts Irrigation Scheme for providing access to their land for research.
- There are many experts who contributed to the ideas and understanding in this report, especially personnel from the Dept of Soil Sciences at the University of the Free State.

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1. Introduction

1.1 Introduction and motivation for the investigation

The Vaalharts Irrigation Scheme is the largest and oldest irrigation scheme in the country. The scheme does not only provide food but also job opportunities. Therefore the sustainability of the scheme is very important.

A Governmental surveyor by the name, H Ford proposed an irrigation scheme in the Harts Valley as early as 1875. However it was the unemployment due to the depression in the early 1930s that led to a decision by Government and the announcement, on 2 November 1933, that the scheme will be built (De Jager and Marais, 1994).

Act 38 of 1934 approved the construction of Vaaldam and the development of 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 25-75 ha covering a total area of 35 302 ha which includes 31 732 ha in the Northern Cape and 3 570 ha in the North-West Province. Due to the use of flood irrigation on relatively permeable soils, water logging associated with salinisation problems have been experienced in the area since soon after its start. To remedy the problem irrigation application was improved, a switch to sprinkler irrigation took place and selected drains were installed. 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 ± 80% have got internal subsurface drains.

Several studies have been done in the Vaalharts Irrigation Scheme area to determine what the influence of the irrigation practises has on the groundwater. The findings of the study of Harold and Bailey (1996) postulated that salts are accumulating in the groundwater sources below the area by leaching through the upper soils. At some stage in future the sink will be exhausted and have severe effects. This postulate was triggered by the fact that the calculated macro salt input and output from the scheme is not in balance, with the result that the salt load arriving at Spitskop Dam, downstream of Vaalharts, is lower than expected.

A study conducted by Ellington, Usher and Van Tonder (2004) claimed that there is no accumulation of salt in a groundwater sink below Vaalharts, as the 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 separately. 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. The irrigation water added to the groundwater system is the greatest contributor in increasing the salt load even more so than fertilizers.

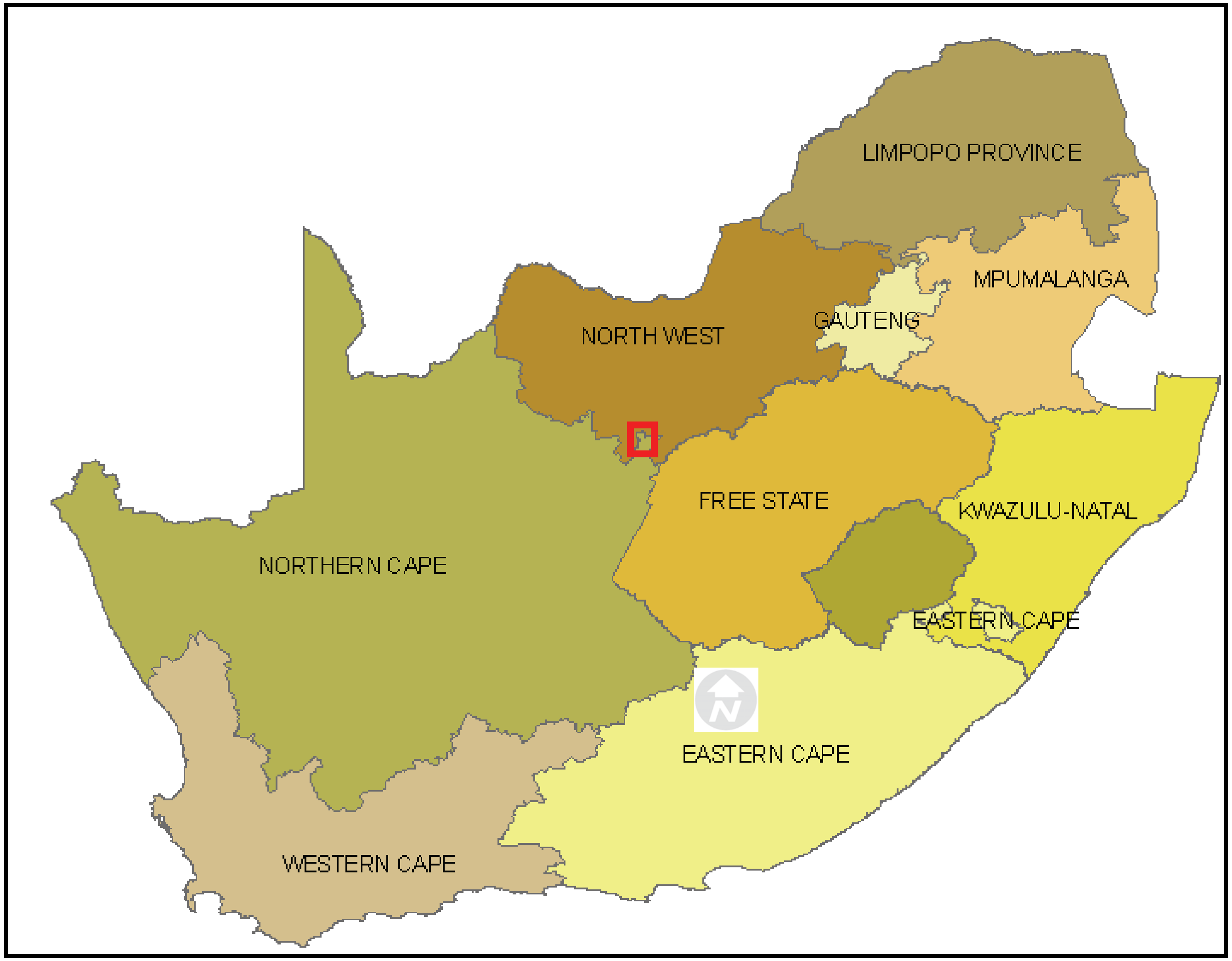


Figure 1: The red square indicates the location of the research area.

Figure 2: Map of the Study Area indicating Jan Kempdorp in the south.

1.2 Aims

The aim of the project was:

- 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.

Recommendations will be made to the relevant stakeholders based on the findings from the investigations to implement improvements to the Vaalharts Irrigation Scheme.

1.3 Approach to the Study

The 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 VHWUA 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 Figure 2).

The groundwater levels and chemical parameters were monitored in the network of installed piezometers over the period of August 2008 to May 2009. Monitoring was necessary to occur over at least one year to cover all seasons, planting, harvesting, rainy and dry periods. The hydraulic conductivity was also established and the existence of any stratification in the upper soils was determined to construct conceptual models.

In order to accomplish the above mentioned investigations the following tasks were carried out:

- Literature Review and 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 on selected sites
- Testing of aquifer parameters
- Conceptual modelling to simulate drain flow
- Salt and Water balance calculation
- Evaluation of options to ensure a sustainable irrigation system

2 Literature review and background information

Salinisation and waterlogging of irrigation schemes is a well researched field all over the world. Groundwater pollution due to increasing salinity of soils used for agricultural irrigation practises is very common. Several studies have been done with different proposals to rectify it, in some cases with success.

Salinisation is the build up of salt that is soluble by water, to such an extent that it influences agriculture, economy and livelihood especially in the top part of soil (including the A and B horizons). Soils are considered to be saline if the electrical conductivity reaches 400 mS/m. The effect of salinity may vary depending on plant types, soil – water relation and climate. The osmotic effect of salinity reduces the availability of water uptake by plants and consequently water in saline soils reduces plant growth. The plants then are not able to take up water and the plant cells are affected by the excess-ion. Salinated soils also induce nutritional imbalances in plants.

Salinisation due to sodium salts can enhance the formation of sodic soils which exhibit poor infiltration properties. Salt-affected soils are often waterlogged although only periodically in some cases. The interaction between hypoxia (lack of oxygen due to water logging) and salt has a powerful depressive effect on plant growth.

Inadequate drainage of irrigated soils leads to the built up of salts introduced by irrigation water in the root zone. Irrigation water of a poor quality, the lack of proper drainage, high evaporation, soils with low hydraulic conductivity (as in soils with a high clay content) and sodic soils enhance irrigation-induced salinity. Saline groundwater that rises into the root zone makes the problem even worse.

In dry-land cropping, a fresh water reserve in the subsoil is critical for crop production. The EC in soilwater of dry land soils are mostly low (ranging between 4 and 16 mS/m). When the soil becomes parched due to evapotranspiration it may cause an increasing osmotic effect. Low osmotic potential can reduce water uptake by plants thus affecting the produce. Plants can take up water in soil with moisture content as low as 5% when there are no salt present. In contrast with this an EC of 100 mS/m will restrain a plant to take up water only to a soil moisture content of 18% (Rengasamy, 2006).

In the nineteen seventies it became clear that the application of inorganic fertilisation to crops causes the leaching of ions and nitrates to groundwater in many types of soils. In the United States of America the increase of fertiliser use has doubled within 20 years from 20 to 40 million tons, and its nitrogen content increased 6 to 20%. The use of fertilizers in Europe has the same tendency. In upcoming and developing countries the use of fertilizers are also increasing. For example in India the demand for food are very high, thus the need for fertilization also. The use of fertilizers has increased three times since 1975 in developing countries (Chilton, 1996). Nitrate leaching is due to many reasons such as soil type, irrigation practises and crop types. In tropical areas groundwater are even more vulnerable.

About 2.5 million km^2 of land are irrigated in the world. Productivity due to salinisation is affected negatively on almost 50% of these lands. This makes it economically impossible to farm on these lands. Irrigation land decreases by about 40% of the amount of new developments. The salinisation of groundwater also has an effect on the suitability of water for drinking and industrial purposes (Sundquist, 2007).

Effective irrigation in combination with effective drainage is the only way to prevent salinisation of lands. A groundwater table of ±2.5 m below ground level must be obtained and managed.

There are several methods to drain soils for example, perforated pipes, open ditches and pumping wells.

Once collected saline drainage water must be disposed of in an environmental friendly way. Prevention of salinisation is however better than cure because it can take years to rehabilitate groundwater due to the slow movement thereof compared to surface water (Chilton, 1996).

2.1 Research world wide

2.1.1 Australia

Shepparton Region Irrigation, Northern Victoria.

In Australia, the planting of trees are promoted as a way of controlling the groundwater table. Due to the higher transpiration rate and the deeper root zone, the trees are more tolerant to salts. Trees also have a financial benefit. Unfortunately soil types play an important role in this application. Electrical conductivity measured on sites with heavy soils was much higher and the impact area/ cone much smaller than in sandy soils. In some cases the impact of the trees only stretched 50 meters into the irrigated land. If trees exclude salt in the uptake of water the salinity in the upper part of the soil increases due to the upward hydraulic gradient under the trees. It is however a good method to control seepage from channels (Heuperman et al., 2000).

Kununurra, Ord Stage 1, Irrigation Area, Western Australia

The rising groundwater levels posed a salinisation threat since the start of the irrigation in the 1960s. The water levels were monitored and the feeling was that it will never reach saturation and will settle at a safe level due to the runoff of the groundwater to the Ord River. It was discovered later that the groundwater system was not that well linked to the river and the reservoir was filling up. For four years, 1998 to 2001, the average rainfall was more than expected and the water table rose to the same level as the drain inlets. The danger of salinisation grew, as a water table of less than 2 m below ground occurred for an extended period. Due to drainage constraints the leaching of salts became insufficient.

The irrigation water must be able to move beyond the root zone to hinder the accumulation of salt in the zone. Therefore the groundwater level has to be controlled. There are several ways to do this, which includes improved farming management practises, improved irrigation water reservoirs, minimizing leakage from the supply channels, groundwater pumping and more sufficient drainage (Smith et al., 2006).

2.1.2 India

Channel seepage Indira Gandhi project, Rajasthan

The groundwater table in the area was at ±45 mbgl at the start of the project in 1952, but has risen with an average of about 0.9 m/a thereafter. Water logging took place along the supply channel. Although the channel was lined but the problem reoccurred. Trees were planted on both sides (some parts up to 260 m wide) of the cannel to protect it from sand deposits, for timber and to improve the environment.

As a result, draw down of the water table due to the plantations were up to 15 m. The drawdown did not only take place under the plantations but in some cases it had an effect of up to 500 m beyond the plantations borders. There were no substantial increases in salinity levels under the trees (Heuperman et al., 2000).

2.1.3 Israel

Yisreel Valley Northern Israel

A United States soil survey official classified the soil as 62% clay, 30% silt and 8% sand. Since 1921 a total of 20 000 ha in the western part was farmed as dry lands. Cotton became popular and to fulfil the demand irrigation was applied. The water table was shallow initially and soon it rose causing salinisation to occur. To remediate the salinisation, gravitational subsurface drainage and bio drainage using Eucalyptus were applied.

The subsurface drain had an immediate effect on the 3000 ha where it was installed. Eucalyptus trees were planted at five sites. The groundwater levels were monitored and dropped to 3 mbgl. (Heuperman et al., 2000).

2.1.4 North America

San Joaquin Valley Irrigation Scheme, in the southern half of California's Central Valley. The northern part is drained by the San Joaquin River but the southern part is in effect a closed basin and is only drained by the San Joaquin River in rare high floods.

Water flowing into the valley as well as water from boreholes is used for irrigation. Due to the evapotranspiration salts are left behind. The soil in the western part of the valley originated by sedimentation caused by the ocean and has a high salt content. Flushing (leaching) of the salt is difficult due to the geological structure, a shallow clay layer underlies the irrigation land in the area. Almost 285 000 ha of farmland are affected by the salt built up.

Drainage have been installed and water are conveyed elsewhere, but the problem remains, how to dispose of the salt. In 2001 almost 2 800 000 tons of salt came into the valley through water supply, and only 350 000 tons left it, therefore another 2 450 000 ton of salt had to be removed to achieve a salt balance.

As a solution, some growers switched to crops that can be irrigated with a blend of fresh and salt water. Others are discharging their drainage water in evaporation ponds, according to specifications set, or discharge it into the San Joaquin River at such a rate that it does not affect the quality of the stream water too much.

A long term solution was not found yet but the agricultural productivity of the lands is sustained by the measures in place (Alemi et al., 2001).

2.2 Previous research and findings regarding Vaalharts

A number of other research projects were undertaken in the Vaalharts area. Earlier studies were done to establish if the implementation of artificial drainage will remediate the problem. The suggestions were that the channels and soil overnight dams should be lined. Drains were installed and today ±65% of the plots has drains resulting in lowering the water table.

A study indicated that the possibility of constructing pumping wells to withdraw water from the water table in such a way that it overlaps, should be considered. It would mean that "old" water would also be replenished by "new" water. However the capital cost to implement the proposal, was too high and as a result it never got off the ground (Gombar & Erasmus, 1976).

Another concern raised was that the salt added to the subsurface water in the scheme does not return to the surface water. A water balance indicated that a volume of water flowing away in the Harts river is less than (irrigation water + percolation) – (evaporation + evapotranspiration + plant use). Therefore some of the irrigation water must drain to the groundwater (Herold and Bailey, 1996). A later study indicated that the salt migration from the irrigated soil to a lower level is less than expected. The *in situ* groundwater quality in the boreholes showed minor variation with depth, therefore it could not be stated that the geology is stratified (Ellington et al., 2004).

2.2.1 Arend Streutker 1971

Due to the salinisation and saturation of irrigation areas in the country research was carried out at Vaalharts. The research was not only to improve crops, groundwater levels and recover saturated soils but also to set a standard for the development of irrigation on similar soils. The study was conducted mainly on farms in the fifth row of the K block on the Vaalharts irrigation scheme.

The salt balance calculated at that stage, showed, that about 1200 kg/ha more salt was added to the lands than the amount drained. The leaching ability of the soils was 5% lower than the 9-15% needed and the possibility of salinisation was emphasised by soil samples tests. Comparing results of tests on soil of 1932 and 1970 taken on the same spot, the EC in the subsoil 30-180 mm were on average 52 mS/m higher although it dropped in the layer 0-30 mm.

The aim of the study was also to establish what influence artificial drainage would have on the area. Leakages from overnight dams and soil furrows in the system were about 45 million m^3 of water. This was much more than the natural drainage ability of the calcrete layer existing in the subsoil. The research suggested that soil dams and furrows should be lined with concrete. This could save up to 70% irrigation water.

2.2.2 Gombar Erasmus 1976

Due to the constant rise in the groundwater table at the Vaalharts Irrigation Scheme the Department of Agriculture Technical Services requested an investigation. In Vaalharts, the sandy soil layer in the area is between 0.5 and 8 meters thick. Beneath the sand a layer of calcinated gravel exist, that varies in thickness with the thicker layers east of blocks A to B as well as between H and I. There is also an alluvial gravel layer present in blocks E, F and H and most of the groundwater is transported in this layer. Deeper down is mainly tillite dolomite and weathered shale which has some clay in it. The Ventersdorp lava is mainly unweathered and thus no carrier of groundwater.

When the scheme started, the groundwater table was at 24 mbgl. In the seventies it became necessary to establish what the possibility is to lower the groundwater table, which was at that stage at 1 mbgl, by means of withdrawing groundwater using wells. A total of 87 boreholes for exploration, pump tests and monitoring were drilled during 1973 to 1975. For every hole drilled for pump tests 8 holes was drilled for monitoring. The depth of the holes varied between 8 and 80 m.

Step drawdown test were carried out on the boreholes and with Theis, Hantush and Jacob methods, transmissivity, storage capacity and hydraulic conductivity (K) were calculated. The average K values for Area 1 (blocks A-E) and Area 2 (blocks F-I) was 2.378 and 13.437 m/d respectively. Depressing cones due to extraction in Area 2 (as result of the higher K values) were larger.

At the time of the research the yearly usage of irrigation water was up to 180 million m^3/a. The average rainfall for the area is 431 mm/a. If 5% natural replenishing is considered, then another 1900 $m^3/ha/a$ of water is added to the system. The average storage capacity was 12.4%. Only 35% of the dams and 10% of the furrows were lined, in addition to this the un efficiencies introduced by flood irrigation, generated leaching of irrigation water to the groundwater. The total amount of water that reached the groundwater was in the order of 0.219 $m^3/m^2 \cdot a$ (219 mm/a). The thickness of the water carrier was constant and where it was thin it required a greater gradient to full fill its task. However, in reality it became saturated therefore the water table rose and water logging occurred. The TDS at that stage was between 513 and 1071 ppm.

The research determined that, construction of pumping wells to withdraw water from water tables 1 and 2, should be sited in such a way that they overlap implying that the “old” water would also be replenished by “new” water, thus managing the water table.

2.2.3 Herold & Bailey 1996

The effect of the drainage systems that are installed cannot be analysed fully, as farmers tend to plug the drains in dry cycles. The climate has more influence on the return flows than the climatic situations. A water balance indicated that the volume of water flowing in the Harts river is less than (irrigation water + percolation) – (evaporation + evapotranspiration + plant use). Therefore some of the irrigation water must drain to the groundwater.

They postulated that the permeability of the calcrete layer that is present in the area under the Kalahari sand, in combination with the capacity of the subsurface drains is enough to keep the groundwater level (GWL) at the average depth of 1.2 m with water logging only occurring in very wet seasons. This calcrete layer is not impermeable enough to have an effect on the percolation and salts. There is a deep groundwater table which has not yet been filled. This implies that the storage capacity is large enough for it not to be filled yet due to the net recharge rate.

A chloride load retention study showed that 40% of the chloride was retained, which was lower than the TDS retention. This could mean that some salts may have been retained faster due to precipitation of insoluble salts or the adsorption of it by soil particles. The accumulation of salts in the irrigation area by the soils should be minimised.

The study indicated that the "deep groundwater table" is unknown. As much as 100 000 t salt applied as part of irrigation water is not accounted for due to its loss to the water table. The influence of this deep groundwater table to the flow of the Harts River is small when compared to the drainage water inflow and the water from the perched water table above the calcrete layer.

2.2.4 GB Simpson 1999

This study investigated the manganese blockage of drainage pipes. Samples taken at the same spots showed that EC, TDS and total manganese values were much higher in drainage pipes than in irrigation water. The relative high pH (8.2) of irrigation water makes it corrosive and aggressive. Non liquid fertilizers contain sulphates which precipitated with the positive metal ions in the soil. Salts started to precipitate out of the saturated water was taken up in the solution moving through the soil, the metal salts become hard. This may lead to the manganese sulphate precipitates in the soil and drainage pipes causing blockages (Figure 3). Blockages are taking place within the drainage pipes and the filter material surrounding it. The reduced drainage capacity had a negative influence on height of the groundwater table.

The study also investigated a solution to prevent or minimise the blockages caused by the chemical precipitation on the scheme. After a trial period/experiment a proposal to use a Sea Quest concentration of 1.5% to improve the effectiveness of the drainage lines was recommended, but this proved to be too expensive

2.2.5 GHT Consulting (JJH Hough and DC Rudolph) 2003

The study determined that, the salinisation in the area is not mainly a spinoff of the irrigation. The Dwyka series, tillites and shales that exist in this area are mostly impermeable unless it has been fractured or weathered. Groundwater that is present in Dwyka series is of the most mineralised (salinised) in South Africa. The high mineral content of the Dwyka formation, the vertical circulation of groundwater (irrigation water), the sub calcrete layer water as well as fertilizing and high evaporation also influences the salinisation process negatively. At the time of the investigation in 2003 the groundwater level range was 1.5 to 6.2 mbgl with an average of 2.07 mbgl. This high level was attributed to over irrigation. TDS ranged between 1000 to 2000 mg/l.

Figure 3: Photo of a blockage recently (May 2009) removed.

2.2.6 Ellington, Usher & Van Tonder 2004

The study investigated the findings of Harold and Bailey (1996) that the deeper aquifer acts as a salt sink. Previous studies concluded that the salt added to the subsurface water in the scheme does not return to the surface water. They postulated that there is a salt sink present mainly due to a perched water table and that at some stage the water table will rise to a level where it decants into the Harts River. The salts will thus also end up in the Harts River having a severe effect on the ecology and other downstream activities including other irrigation schemes.

To conduct this study a total of 17 holes were drilled – three (3) on the river bank and the others on the plots to depths varying between 20 and 101 mbgl. Piezometers were installed in the same holes and all the casing and screens were slotted. This and the information from 22 other boreholes enabled the determination of the geohydrology and chemistry and a water-salt balance could be done. The piesos that were installed in three of the holes was to check the possibility of two aquifers as stated by Harold and Bailey.

Slug-, pumping- and tracer tests were carried out to obtain the hydraulic parameters. The groundwater was monitored at regular intervals in the holes over a period of one year. Numerical (Modflow) and Emperical methods were applied to simulate the aquifer system.

According to the monitoring results, the average TDS was 1350 mg/l, which increased by 350 mg/l since the Harold and Bailey report of 1996. The electrical conductivity was between 100 and 270 mS/m. The 2.2 mg/l nitrate value of the groundwater, is lower than expected for an irrigated area. This may indicate that the salt migration from the irrigated soil to a lower level is less than expected. The *in situ* groundwater quality in the boreholes showed minor variation with depth, therefore it could not be said that the geology is stratified. Water and salt balances indicated that approximately 98 000 t/a salts are added to groundwater. If the net storage of the aquifer remained constant, the TDS increase will be in the order of 14 mg/l. The irrigation water added to the groundwater system was the greatest factor in increasing the salt load even more than fertilizers.

Water quality has deteriorated over the years. The salt added to the system by the irrigation water from the Vaal River is more than double the quantity added by fertilizers thus it is the main contributor to the salt load. More effective irrigation practices should be applied to reduce the volume of water utilized thereby reducing the salt load.

2.3 Land type and Geology

The median annual simulated runoff in the area is in the range of 20 and 41 mm with a lowest 10 year recorded range of 4.8 to 9.3 mm (Schmidt et al., 1987). The altitude ranges from 1050 to 1175 mamsl (meters above mean sea level) decreasing towards the west (Harts River). The irrigation scheme is predominantly flat as 70% of the area comprises of slopes less than 1%.

The geology in the area forms part of the Ventersdorp Supergroup (Figure 4 and Figure 5). Lithostratigraphic classification of the area was done in 1965, 1976 and 1980, and the specific area of the study area was named the Bothaville formation. In 1975 it was classified again into the Rietgat sub formation (Schutte, 1994).

The geology consists of the Bothaville Formation overlying the Hartswater Group (comprising of the lower Mhole Formation and the upper Phokwane Formation). The area comprises of a Harts-Dry Harts Valley (stratum of calcrete) that runs in a north-south direction (Schutte, 1994).

The Rietgat formation in the Taung Jan Kempdorp area was known as the Phokwane Formation of the Hartswater group. The Phokwane formation consists mainly of porphyrite lava, volcanic tufa, tuffaceous sediments and chert (Schutte, 1994).

Since this research is focusing on the upper part of the geological structure the author gave more attention to the soils in this layer. The soil layer is more than 3 meters deep in this area.

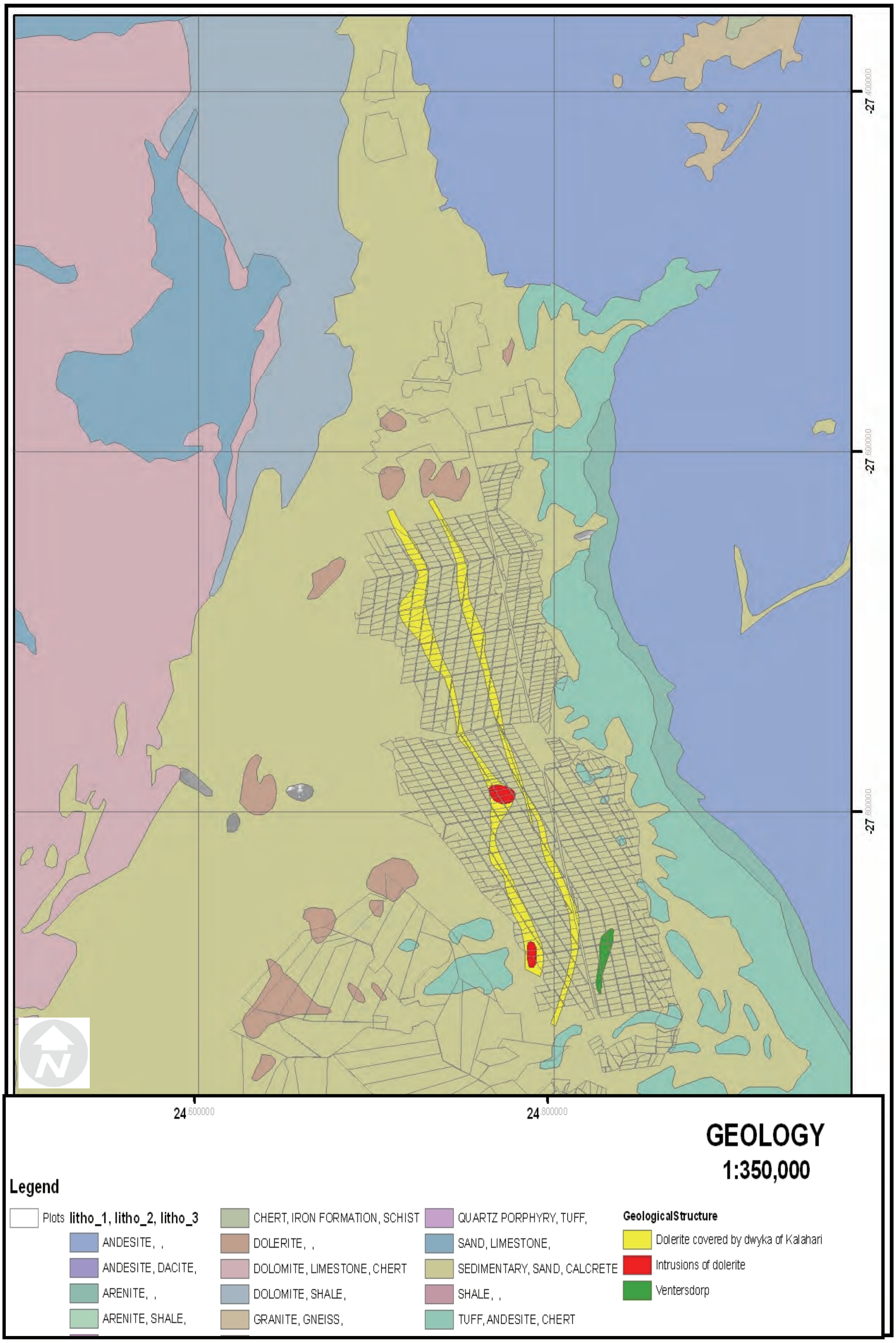


Figure 4: Geology of the study area (AGIS, 2009).

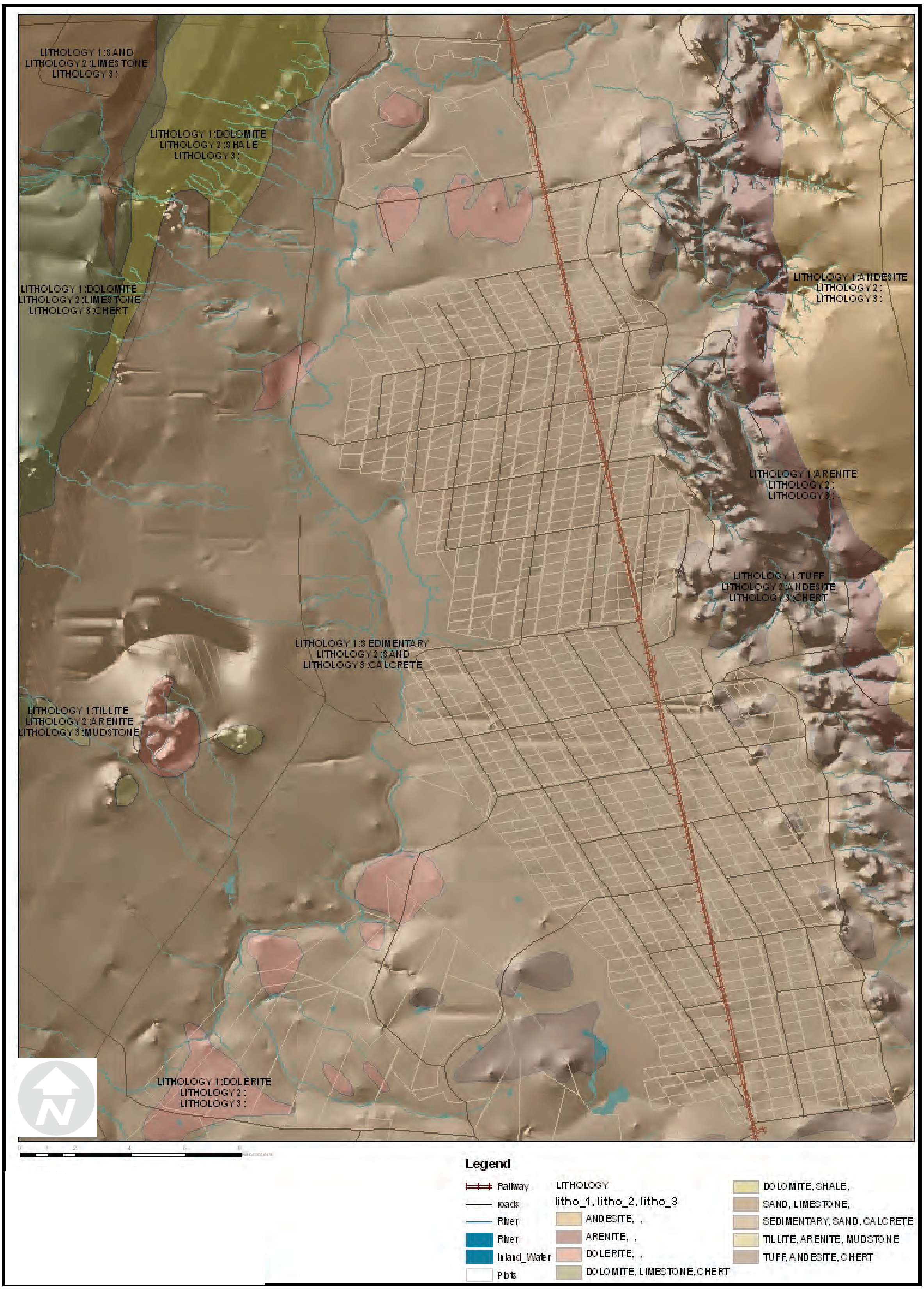


Figure 5: Lithology of the study area (AGIS, 2009).

2.4 Surface runoff

The proportion of the precipitation water that finds its way back to the river the sea and lake as surface flow is called surface runoff.

Many factors, like the length and density of a storm, influence the quantity of surface water. A lengthy storm with a high density will cause most of the rainfall to flow away. On the other hand, during a rainfall with a short duration and low density, more water will filtrate into the soil, thus less surface flow. The surface water is also influenced by the length of the path the surface flow follows to a water body. Topography with a steep gradient, the lack of vegetation or other plant cover causes higher flow rates.

The irrigation scheme is predominantly flat as 70% of the area comprises of slopes less than 1%. The median annual simulated runoff in the area is in the range of 20 and 41 mm with the lowest 10 year recording of 4.8 to 9.3 mm (Schmidt et al., 1987).

2.5 Rainfall

The rain season for the area is usually from October to March. In the winter months almost no rainfall occurs. The data obtained from ARC and reworked by AGIS (AGIS, 2009), for the period January 2008 to April 2009 that is relevant for this study proves this (Figure 6).

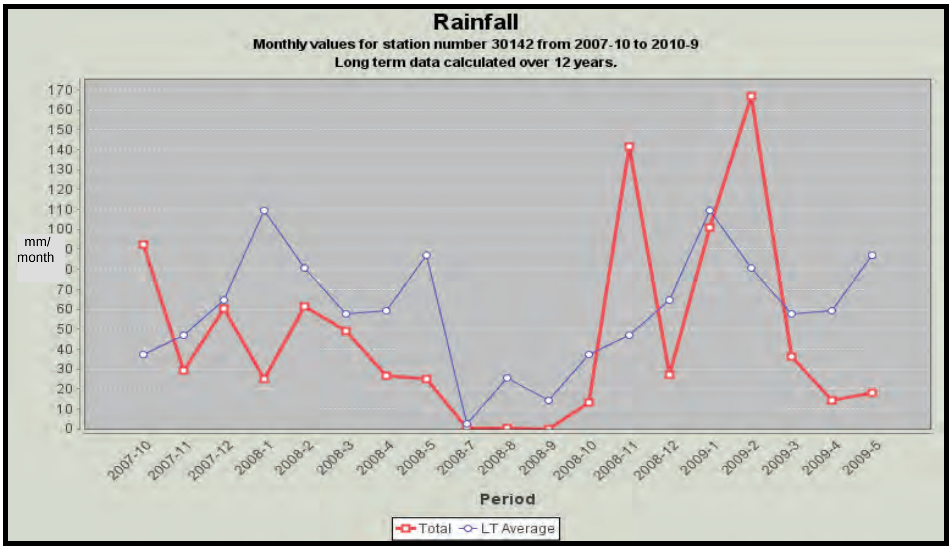


Figure 6: Rainfall figures October 2007 to May 2009 for Jan Kempdorp.

The average rainfall of the area is 477 mm in Hartswater and 450 mm in Jan Kempdorp. Recent data is only available for Jan Kempdorp since the Hartswater station is out of order and the rainfall for the monitoring period was 530 mm.

2.6 Temperature and Evapotranspiration

2.6.1 Temperature

The average temperature of the spring and summer months are above 30˚C (Figure 7). Temperatures in the area are the highest in February. Evapotranspiration due to the application of irrigation water, rainfall and plant growth in this month are then high (AGIS, 2009).

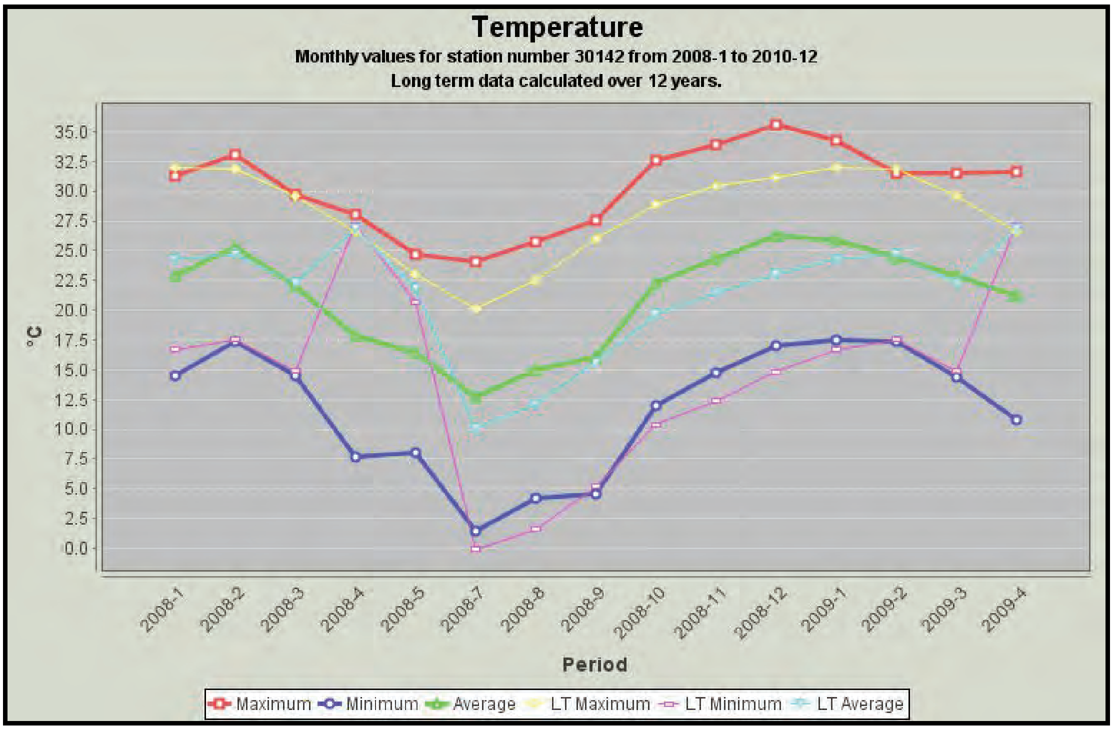


Figure 7: Average temperatures for the period October 2007 to May 2009.

2.6.2 Evapotranspiration

Evapotranspiration is the loss of water from a surface during a specific period due to evaporation and the transpiration by plants.

ET = E + T (mm/period) eq 2.6.2.1

Where E = Evaporation of the surface (mm/period)

T = Transpiration by a growing plant (mm/period) eq 2.6.2.2 (Lategan et al., 2003)

Evapotranspiration is the highest during the midday period band during the part of the season when the plants start producing the harvest. It is also influenced by climate, soilwater availability, irrigation practices, soil texture, plant types and soil salinity. Climate (wind temperature and radiant energy) has the largest influence. The importance and relevance of evapotranspiration is to calculate the use of water by a plant during a season. This also known as the C factor and by multiplying it with the A pan evaporation an estimate of ET is obtained. No recent A-pan data for the area is available (Fritz, 2009).

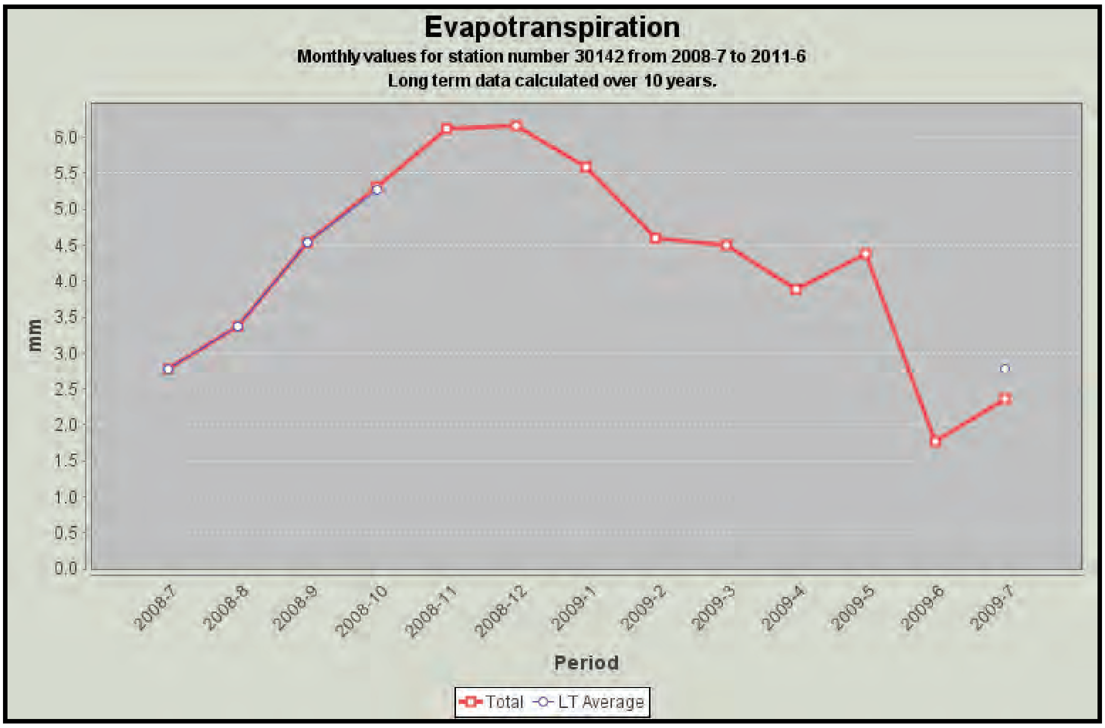


Figure 8: Average evaporation July 2007 to July 2009 measured at the Jan Kempdorp station in mm/d.

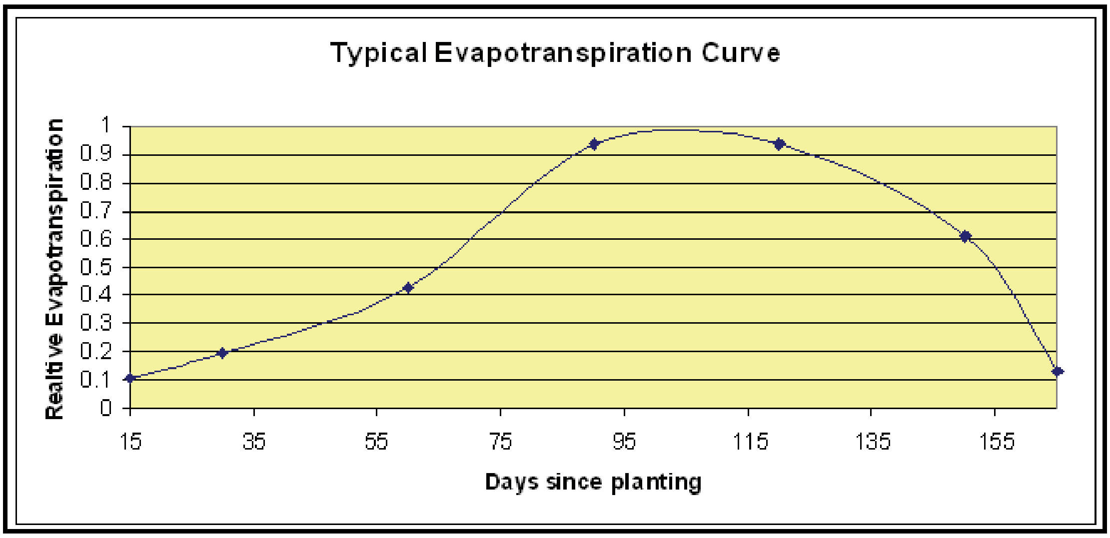


Figure 9: Typical seasonal evapotranspiration curve of a plant.

Table 1: Total Evapotranspiration for Wheat and Maize during the monitoring period.

Evapotranspiration figures for Maize and Wheat two typical summer and winter crops in the Vaalharts Irrigation Scheme													
	Aug-08	Sep-08	Oct-08	Nov-08	Dec-08	Jan-09	Feb-09	Mar-09	Apr-09	May-09	Jun-09	Jul-09	total/a
days	31	30.0	31	30	31	31	28	31	30	31	30	31	365
ET/d mm	3.3	4.5	5.2	6.1	6.1	5.5	4.5	3.9	3.8	4.3	1.6	2.2	51.0
ET/month mm	102.3	135.0	161.2	183.0	189.1	170.5	126.0	120.9	114.0	133.3	48.0	68.2	1551.5
Rain	0.0	23.0	142.0	27.0	102.0	168.0	37.0	13.0	18.0	0.0	0.0	0.0	530.0
Maize season				X	X	X	X	X					
plant use %	0.0	0.0	0.0	0.2	0.4	1.0	1.0	0.6	0.0	0.0	0.0	0.0	
ET in mm	0.0	0.0	0.0	35.7	80.7	162.2	126.0	73.7	0.0	0.0	0.0	0.0	478.3
Wheat season	X	X								X	X	X	
plant use %	1.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.4	1.0	
ET in mm	102.3	82.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	26.0	20.5	64.9	296.0
												total	774.3

Cash crops, mainly maize and wheat presents more than 50% of the crops planted in the area (Table 1) therefore ET were calculated to using factors for these two crops. The total Evapotranspiration to be used in the salt and water balance calculations is 774 mm per annum.

2.7 Topography

The irrigation scheme is situated on the flood plain of the Harts River, it was a glazier valley. The elevations in the study area vary between 1065 and 1170 mamsl. The gradients are in the order of 1:150 from east to west and 1:1030 from north to south.

A topographic map was generated using the RSA DTM20m, obtained from ESRI, and interpolated using ArcMap 7.1 and the IDW method (see paragraph 1.12 and Figure 10).

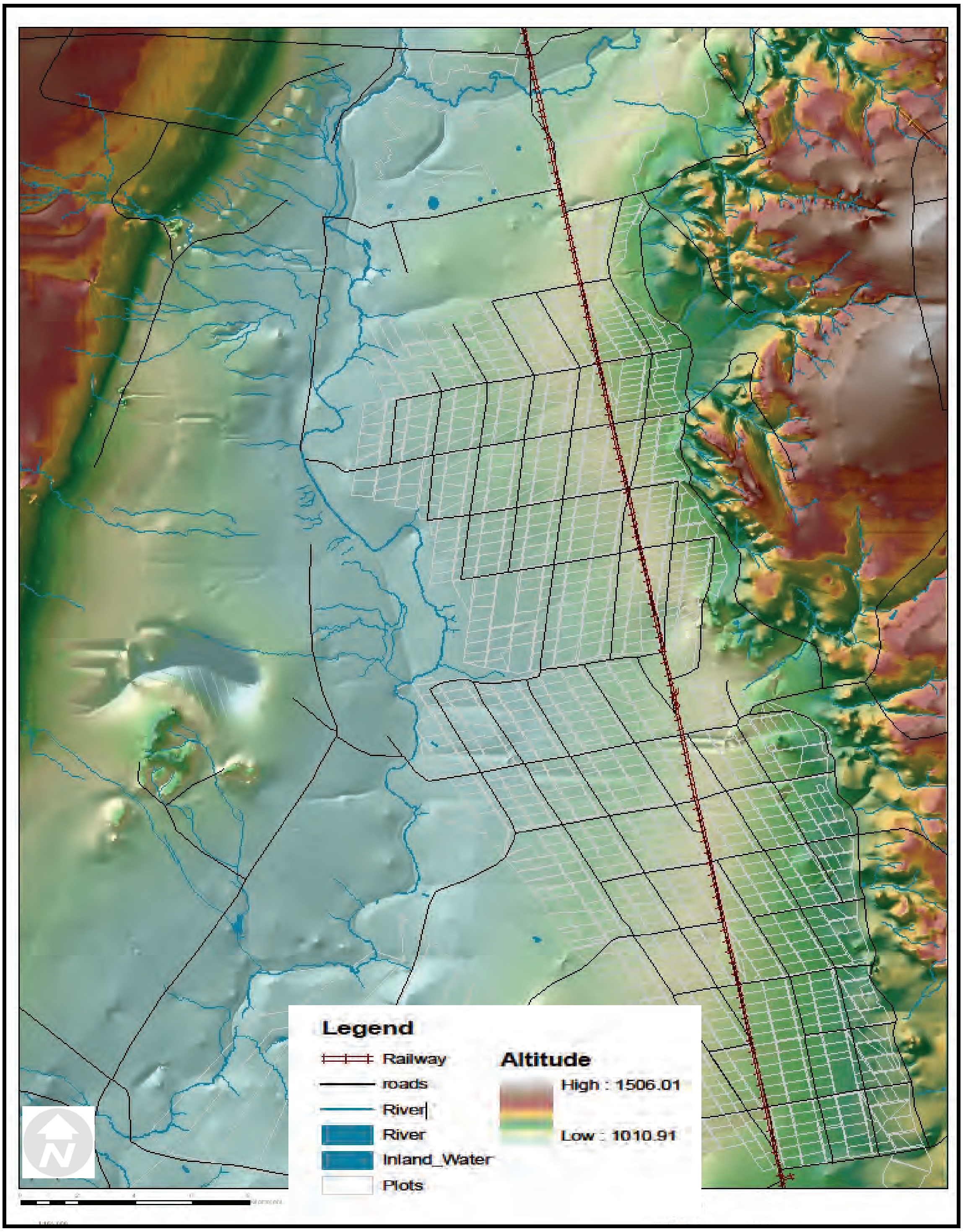


Figure 10: Topographic map of the study area (AGIS, 2009).

2.8 Soils

The soils of the area are alluvial and are described as Kalahari Sand (Hough and Rudolph, 2003). The soil consists mainly of sand, silt and clay (on average 75% sand, 15% clay and 10% silt). The irrigation area is situated in an old glazier valley that is drained by the Hartz River. Underlying the red

Kalahari Sand is the Dwyka shale and tillite, calcrete and Ventersdorp lava. There are areas where the calcrete is impermeable. The map in Figure 11 depicts the soil types.

Salts decrease the amount of water held by soil that is available to plants (Rengasamy, 2006). Plants can take up water in soil with moisture content as low as 5% when there are no salts present. In contrast with this an EC of 100 mS/m will restrain a plant to take up water only to a soil moisture content of 18%.

Three characteristics of soil that are important for irrigation are the ability of the soil to absorb water to release some of the water held to plants. Sandy soils have coarse particles with a small area surface, thus holds back only a little water compared to clay. Sands drain easily and only a little water is available at field capacity. Irrigation can replenish soil moisture but this depends on the infiltration capability and permeability (its ability to absorb water) of the soil. These properties influence the rate at which water need to be applied, for example, sprinkling must be slow to allow time for infiltration while flooding need to be fast to prevent exclusive uptake at the top of the irrigation bed, causing uneven water application. Irrigation applications should be scheduled to insure that the soil moisture content does not drop below the wilting point, this is the point; this is the point where water becomes unavailable for uptake by plants. Soil properties therefore dictate a fine balance in the application of irrigation water.

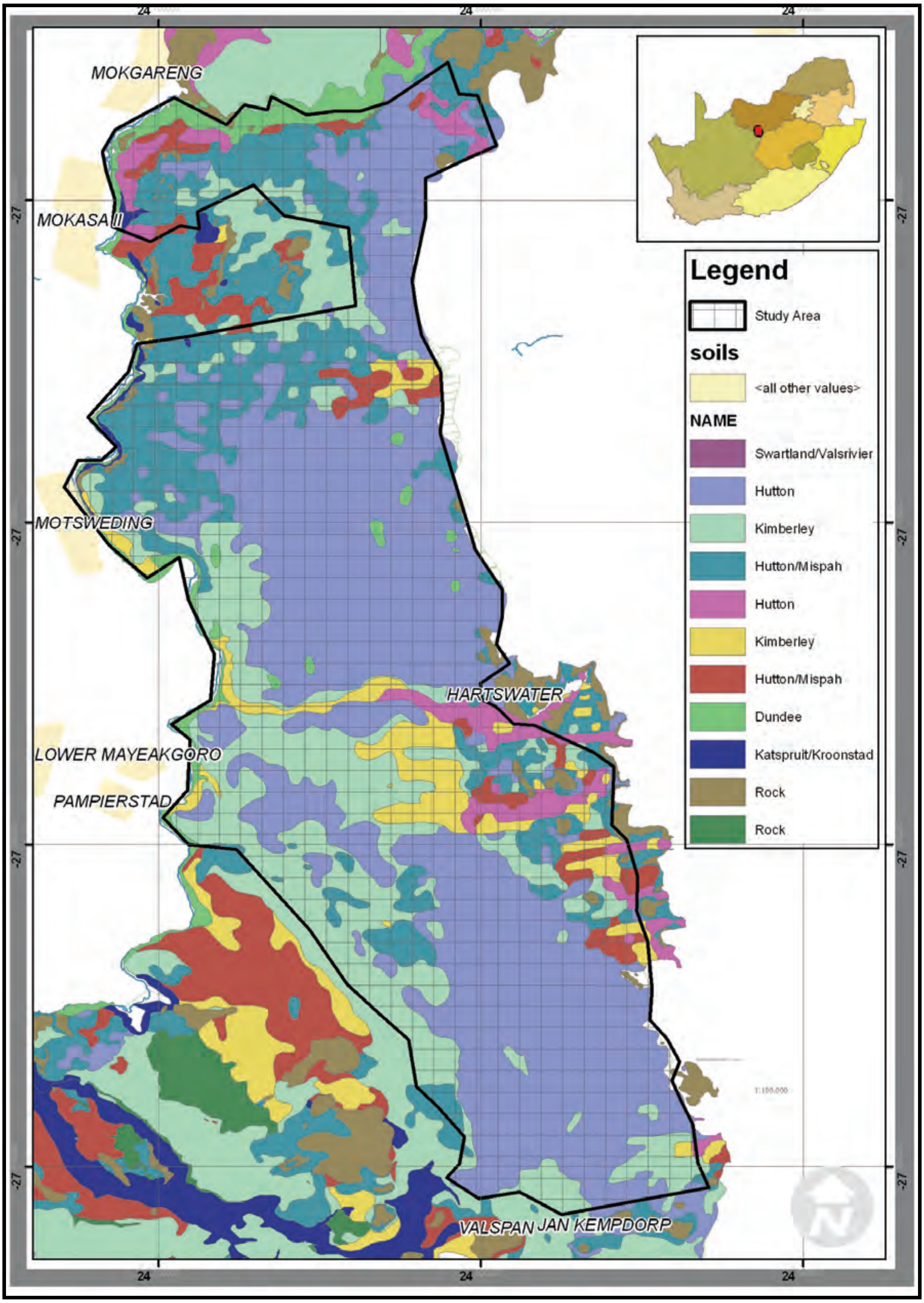


Figure 11: Soil map of the area (Barnard, 2008).

Clay content data obtained from the Institute of Soil Climate and Water were used and interpolated to create contour maps of the clay percentages found between 1.0 and 2.0 meter below surface. This soil investigation took place during the 1980s. Figure 12 is a contour map that represents the clay content as a percentage.

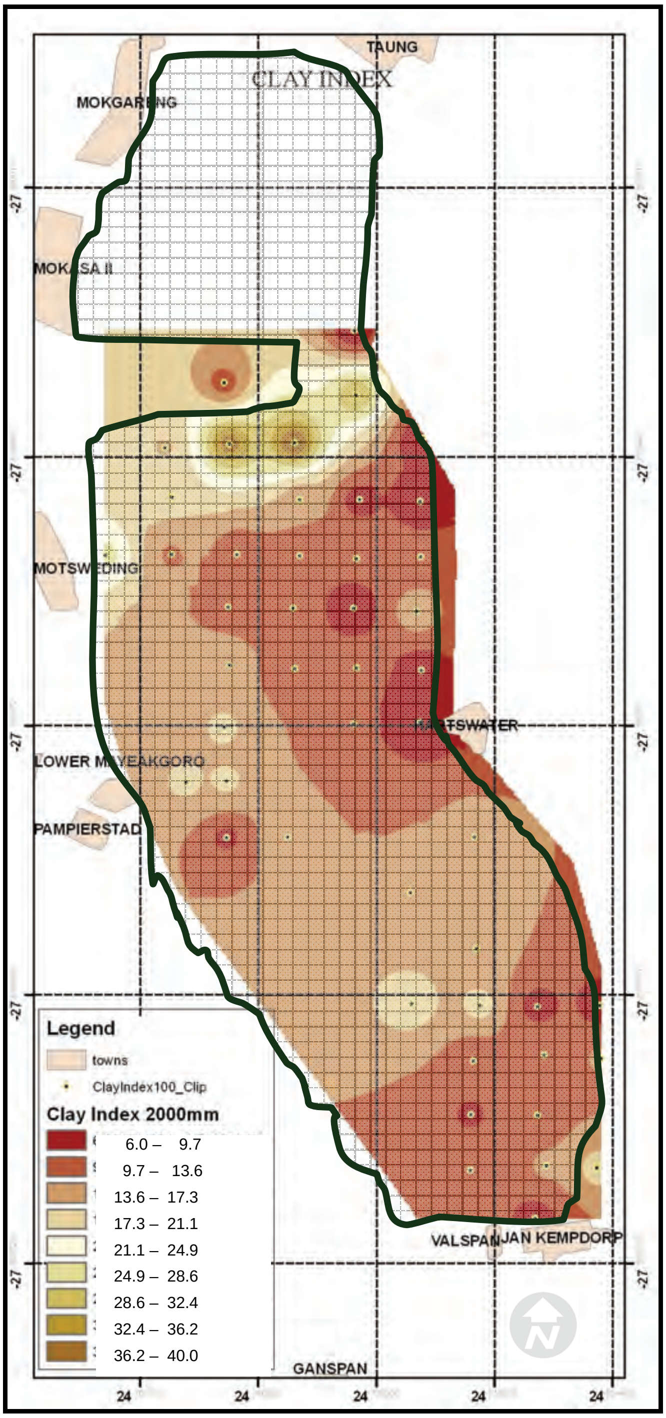


Figure 12: Interpolated contour map of clay percentage at 1-2 m depth, also indicated are sampling points (Nell, 2008).

Soil sample results from sampling points in block K, F and M (Figure 13), extracted and tested by Department of Soil Crop and Climate Sciences, UFS, Bloemfontein, are presented in Table 2.

Table 2: Soil textural analyses of samples collected during the current investigation, see Figure 13 for sampling points.

Vaalharts						
Block	**Sampling site**	**Soil depth (mm)**	**Total Sand (%)**	**Total silt (%)**	**Clay (%)**	**Silt-plus-clay**
K6	**V2**	2400	74.0	10.0	16.0	26
	V3	2100	87.0	6.0	7.0	13
	V4	2100	87.0	5.5	7.5	13
	V5	1800	84.0	6.5	9.5	16
K13	**V6**	2100	86.0	7.0	7.0	14
	V7	1500	90.0	4.0	6.0	10
	V8	1500	87.0	6.0	7.0	13
	V9	1800	88.0	4.0	8.0	12
F8	**V11**	1800	89.0	3.5	6.5	11
	V12	1800	89.0	3.0	8.0	11
M5	**V13**	1200	90.0	4.5	5.5	10

The soil in the area has the following water constants and infiltration capacities (Table 3) (Barnard, 2008).

Table 3: Soil water constants and infiltration capacities (Bennie, 2008).

Vaalharts						
Block	**Sampling site**	**Silt-plus-clay %**	**Field capacity mm/m**	**Wilting point mm/m**	**Available water mm/m**	**Infiltration capacity mm/m**
K6	**V2**	26	220	84	136	12
	V3	13	156	50	106	24
	V4	13	156	50	106	24
	V5	16	164	52	112	19
K13	**V6**	14	158	50	108	22
	V7	10	150	50	100	25
	V8	13	156	50	106	24
	V9	12	154	50	104	26
F8	**V11**	11	152	50	102	28
	V12	11	152	50	102	28
M5	**V13**	10	150	50	100	30

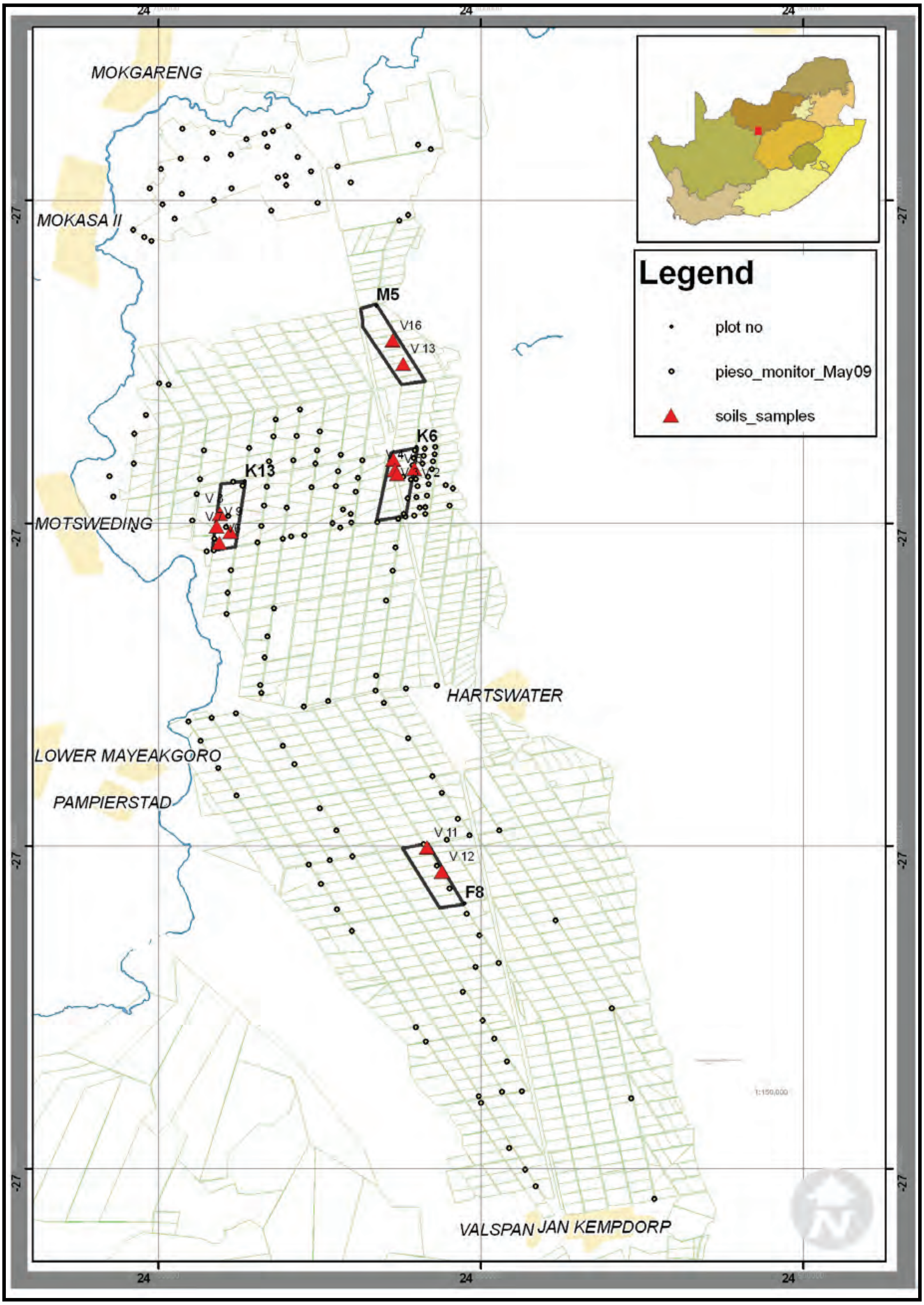


Figure 13: Map of the soil sampling points during the current investigation (Barnard, 2008).

2.9 Infrastructure

Irrigation water is relayed to the plots on the Vaalharts and Taung irrigation schemes through an extensive network of open channels, siphons and pipes. The main canal is 18.4 km long, where after it splits into the north canal, 82 km long serving 33 400 ha and the western canal, 22 km long serving 4 800 ha respectively. The water reaches the plots by means of feeder (45 km) and tertiary canals (580 km). There are five balancing dams on the scheme. Farmers also make use of overnight dams to enable them to irrigate when the canal is dry and to assist with scheduling. The average size of an overnight dam is 3600 m^3 (Momberg VHWA, 2007).

2.10 Crops

2.10.1 Types of crops

A large variety of fruits, nuts and crops are planted in the area right through the year. Pecan nuts, groundnuts, citrus and olives are exported to the USA, Europe and Japan. Other cash crops that form part of the farming are wheat, maize, cotton, grapes, potatoes, oats and lucerne. This is illustrated by the chart in Figure 14. The data was obtained from the Vaalharts Water User Association (Momberg VHWA, 2007).

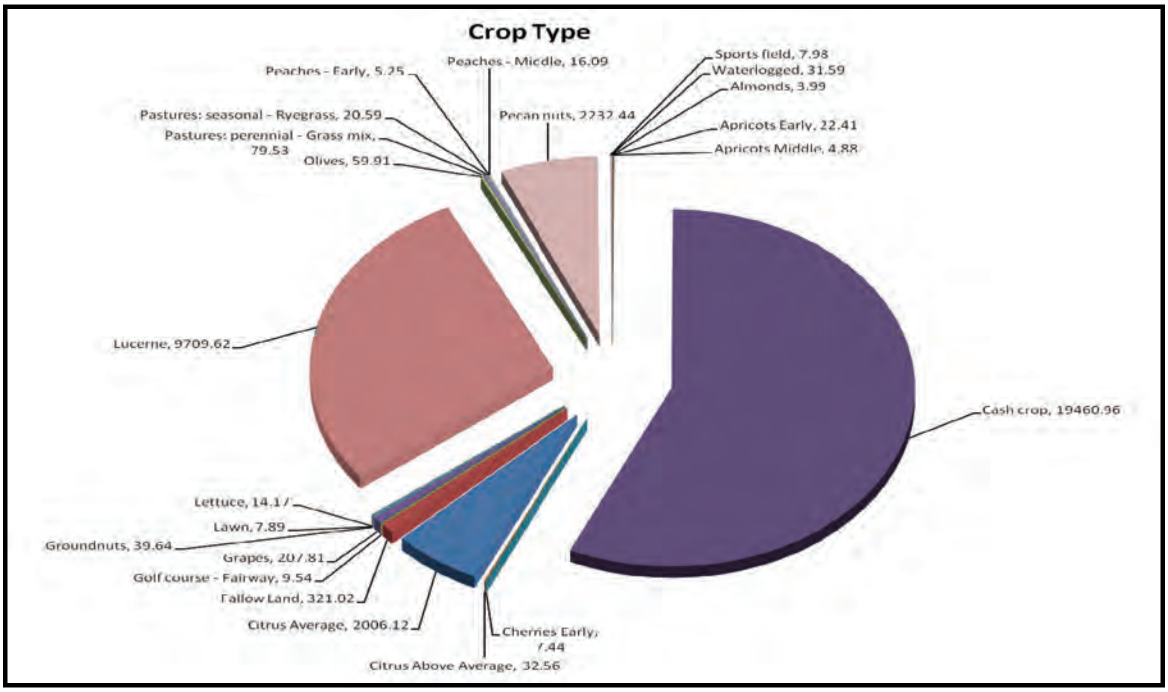


Figure 14: Pie diagram of crops planted on the Irrigation scheme (all values in tons) (Potgieter, 2008).

2.10.2 EC tolerance of Crops

Different crops have different EC tolerant levels. Table 4 provides an indication of the threshold level (EC) for various crops that must be adhered to ensure minimum yield loss. Maize, wheat and lucerne are crops that most farmers plant in Vaalharts. The tolerances for these crops are respectively 170, 200 and 600 mS/m. The EC of groundwater that were measured is effectively the same as that of a soil saturation extract. The EC values reported in Table 4 can thus be used to determine if a piezometer EC reading would cause yield loss as a result of salinity.

Table 4: Threshold EC (saturation Extract) tolerance for Crops to avoid yield loss Crops (Bennie, 2008)

Crop	mS/m	Crop	mS/s
Cotton	770	Sugarcane	170
Sugarbeet	700	Potato	170
Wheat	600	Flax	170
Soyabean	500	Maize	170
Date	400	Orange	170
Beetroot	400	Peach	170
Groundnuts	320	Apricot	160
Rice	300	Grape	150
Brussels sprouts	280	Sweet potato	150
Sweet corn	270	Plum	150
Tomato	250	Lettuce	130
Cucumber	250	Onion	120
Spinach	200	Bean	100
Lucerne	200	Strawberry	100
Grapefruit	180	Carrot	100
Cabbage	180	Almond	15

2.11 Irrigation Practices

Vaalharts is the oldest irrigation scheme in the country and some of the farmers still use the initial system of flood irrigation. Many farmers have switched over to other systems like pivots and drip due to the effectiveness of these systems. These systems make scheduling easier and have other advantages, some discussed beneath.

Drip Irrigation: – good adaptation to water and fertilizer doses, no foliage wetting thus reduces diseases, not affected by wind, more energy effective than sprinklers and limited evaporation loss.

Pivot Irrigation: – fertilization possible through the system, not labour intensive and the uniformity coefficient is high (Brown, 2008).

Sprinkler: – a fixed system does not damage crops, fertilizing through irrigation possible.

The pie bar chart (Figure 15) represents the relative importance of current irrigation methods in use on the Vaalharts Irrigation Scheme, (data obtained from Momberg, VHWUA, 2007). Figure 16 provides a map of the different irrigation systems in use on Vaalharts at present.

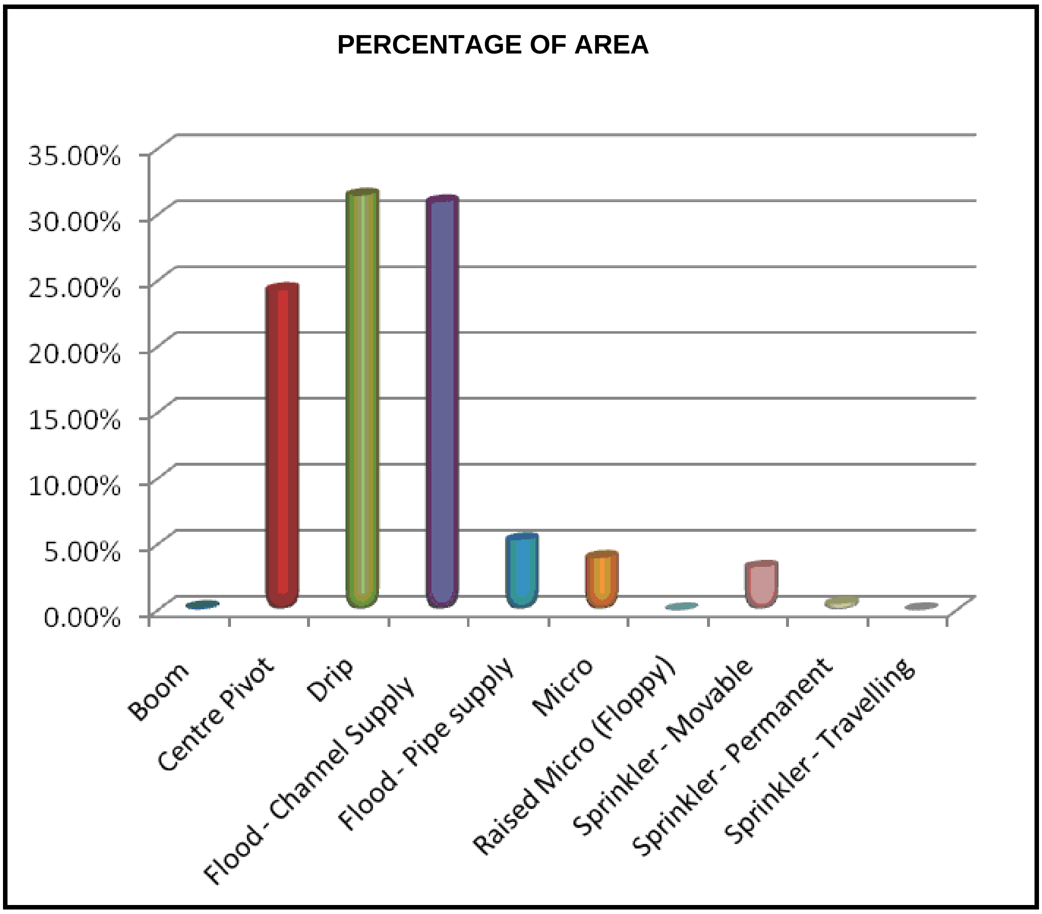


Figure 15: Diagram comparing the use of different irrigation systems as a percentage of area currently in use on Vaalharts (Momberg, VHWUA, 2007).

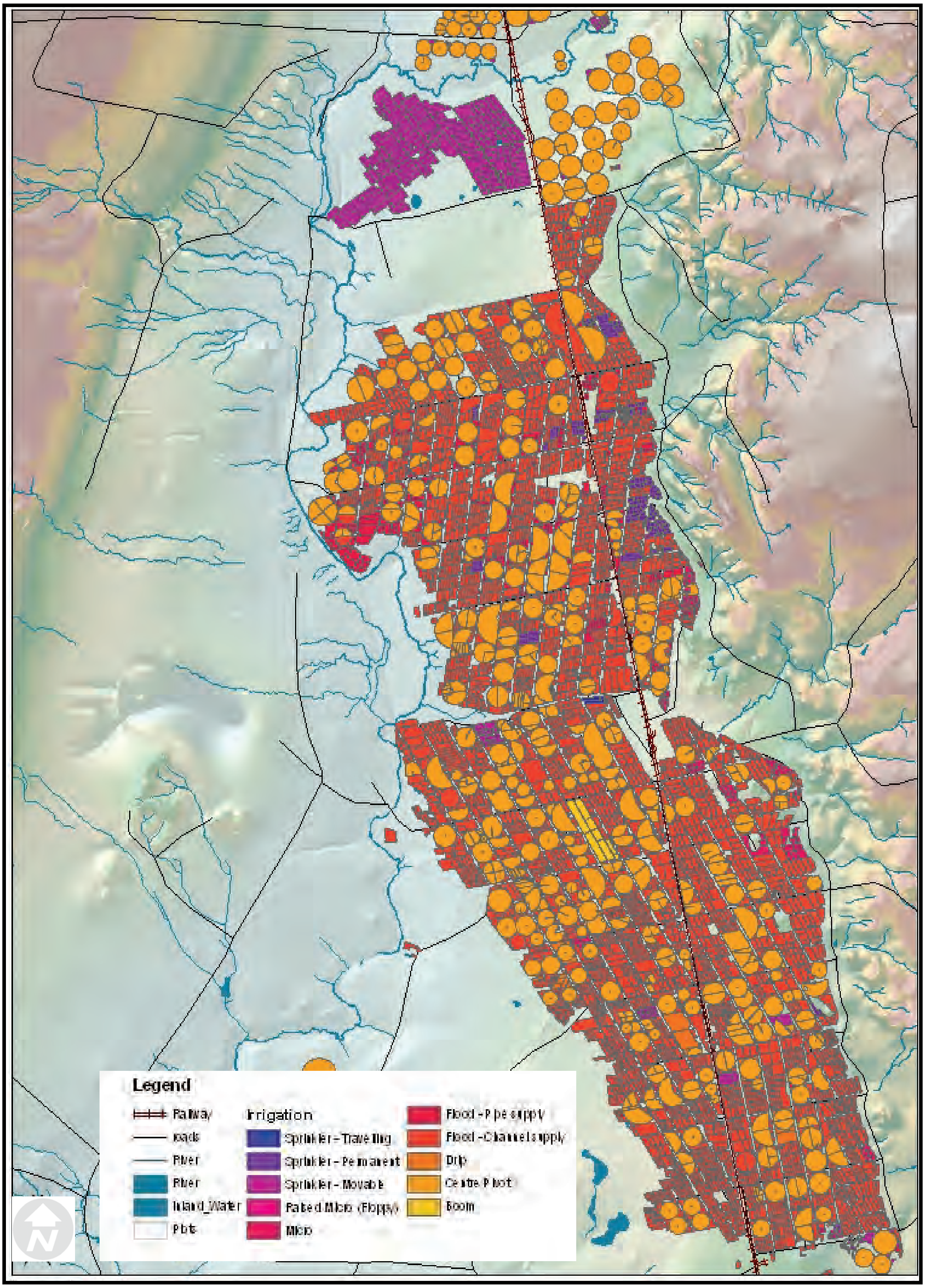


Figure 16: Map of irrigation systems in use on Vaalharts (AGIS, 2008).

2.12 Inverse Distant Weight (IDW) Interpolation Method

The IDW method was used to carry out interpolations and develop topography, K-value and clay content contour maps.

How does this IDW method works? It is based on the assumption that things that are closer to one another are most likely more alike and hereby predict values for unknown points by using values surrounding the known. The values closer to the point will then have more influence than those further away. In other words closer values bear more weight, therefore the name inverse distance weight.

The dots inside the circle in Figure 17 are the positions linked to values that will be used to predict the value at the dot in the centre of the circle. The dots closest to the centre will carry the most weight therefore the dot at half past two. The dots at four and ten o' clock will carry ± 50% of this weight and the ones at one and seven o'clock 5-10%.

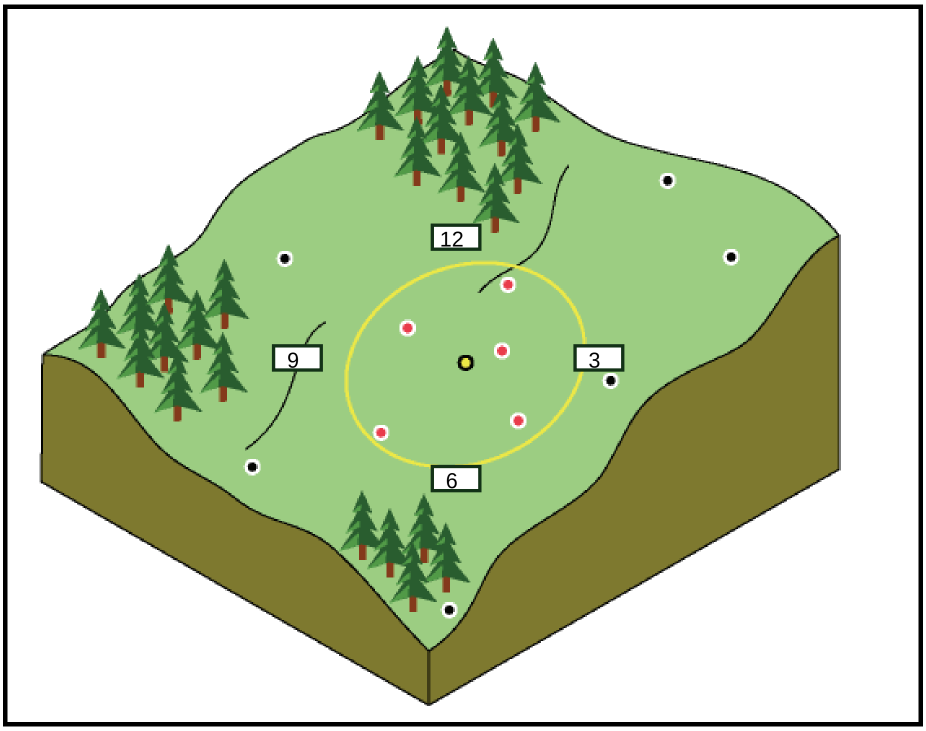


Figure 17: Understanding the IDW interpolation method (ESRI, 2009).

The IDW method gives the user the power to control the significance of a known position. By defining a higher power to closer points, they have more influence but this causes the creation of unsmooth contour lines. The opposite is also true if the power is low and points further away, it will bear more weight and contours will be smoother; the most common use power is 2 and it is the default of the program.

Furthermore you can control the weight a point carries by reducing or enlarging the search radius from the unknown position. Reducing the radius will also reduce the points that will have influence and the process will be faster.

By limiting the number of points that will be taken in consideration, points that are far away and have no spatial correlation will not influence the calculations. If the radius and the minimum number of points to use is specified the program will extend the radius to find the given number of positions. It is prudent to use a smaller number of points to consider when they are far apart and differ much.

A polyline or polygon that indicates a cliff can be used to act as a barrier to prevent the search over this line when it may cause confusion and incorrect assumptions (ESRI GIS software, 2009).

3 Field study and Geohydrology data collection

3.1 Introduction

In order to monitor and measure the parameters of groundwater in the top layer of the soil a network of piezometers had to be installed across the area between Jan Kempdorp and Taung. The existing boreholes in the area are very few and could not be used for the research to conduct a thorough investigation on the scale required for the study. Most of the existing boreholes are inadequately equipped, damaged or for some or other reason not suitable.

3.2 Installing piezometers

A piezometer is a pipe with open ends, fitted in a borehole of a certain diameter, drilled to a specific depth in the ground/soil (Freeze and Cherry, 1995). In this case the entire pipe was slotted to monitor groundwater from zero (0) mbgl to a depth of 3 mbgl.

3.2.1 Procurement and labour

At the start of the project the National Department of Agriculture Forestry and Fisheries in cooperation with the Northern Cape Provincial Department of Agriculture conducted surveys for a baseline study on the revitalisation of the irrigation scheme. The benefit of this research to the revitalisation of the project could not be overseen. Leakages of the canals, overnight dams and other infrastructure have an influence on the groundwater flow. If the path of the flow can be calculated, the starting point can also be determined. This study would therefore assist with the identification of the problem areas. The Departments agreed to assist with the material, labour and drilling rigs to construct the holes and install the piezometers.

3.2.2 Positioning of the Piezometers

On a meeting held at the VWUA offices in Jan Kempdorp in June 2006 a decision was taken to install a network of 200 piezometers on the irrigation plots between Jan Kempdorp in south and Taung in the north.

Various factors had to be considered to decide on the exact position of every piezometer. It was decided that the research will concentrate on the plots in block K. A total of 74 piezometers were planned for Block K, 43 for Taung and the rest (83) to create a network over the remainder of the research area (Figure 18). The purpose of the piezometer grid was to collect as much data as possible, covering an area as big as possible. An area of 29 400 ha was covered of which 3 400 ha was in Taung.

In determining the positions of the piezometers the following was taken into consideration;

- Irrigation type
- Land usage (cash or annual crops)
- Drainage
- Soil type
- Interpolation possibilities
- Previous research

Before any piezometers could be installed a permission letter was send to every plot owner. In this letter permission was requested to implement such an installation on the plot. Those who did not respond were contacted during the installation to obtain permission. All the piezometers were installed only after permission from the plot owner was obtained.

Figure 18: Map indicating positions where piezometers were planned to be installed.

3.2.3 Piezometer construction

Piezometers with a diameter of 63 mm had to be used to enable pumping for EC measurements and sampling (Figure 19). Therefore holes with a diameter of 110 mm had to be drilled to ensure space for installing a gravel filter around the pipe. An auger drill was used to drill most of the holes but about 20% were drilled by hand in the softer soils. Special augers had to be built since the available augers had standard diameters of 76 mm.

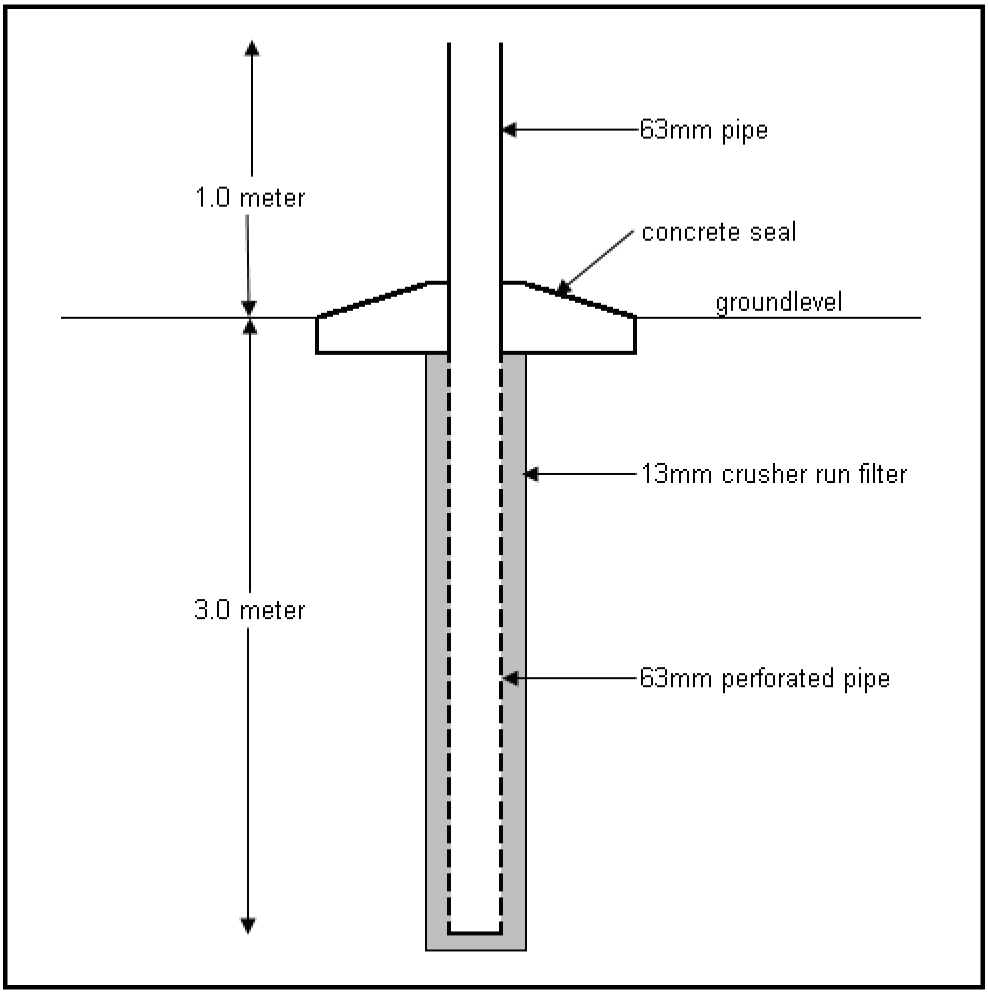


Figure 19: Illustration of piezometer installation.

The piezometers consisted of a 2.9 m X 63 mm Ø, upvc pipe. The pipe was perforated at 10 mm intervals, from 120 mm from the bottom to 120 mm from the top. To enable measurements up to 3.0 mbgl and to make it visible, a standpipe was screwed on top. These standpipes made field work and finding the piezometers easier. They also enabled the farmers to identify and/or remove them when working the land (Refer to Figure 20 and Figure 21).

Figure 20: Drilling of the holes.

A hole was drilled into the soil by means of a 110 mm Ø auger drill. The pipe was then placed in the hole. The 19 mm gap between the soil and the pipe was used for the filter material and filled with 6.7 mm crusher stone. A concrete collar was casted at the top to seal the piezometer and prevent irrigation and other surface water from entering. Each piezometer was fitted with a cap to keep foreign objects out.

Figure 21: Add filter material and seal the piezometer.

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

3.2.4 Survey

A survey was done to determine the exact position of each piezometer X, Y and Z coordinates were measured with the assistance of the Provincial Department of Agriculture (PDA) Northern Cape.

A sub centimetre global positioning system (GPS) was used to conduct the survey. Firstly, the GPS was calibrated by using 4 trigonometric beacons that is in the area. The best results are obtained if the area of the survey is within the circumference of the beacons. The calibration was necessary to position it on the correct ellipsoid reference. This survey was performed using the real time post processing method. The North South direction is X, the East West direction is Y and the height above sea level is Z.

Figure 22: Map of installed piezometers.

Unfortunately some of the piezometers were demolished and some could not been found. 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 (Figure 22).

3.3 Water Level Monitoring

An electronic TLC (temperature, level and conductivity) meter was used to monitor the EC and water levels in the piezometers. A TLC can measure temperature, electrical conductivity and the depth (millimetre accuracy) of the water level. This instrument also enables conductivity profiling of the piezometers.

3.3.1 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 the piezometers. All the measurements were performed more than 24 hours after the holes were drilled and the 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 of 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.

3.3.2 Water Level and Surface Correlation

In order to establish if the Bayesian interpolation method could be used to interpolate groundwater contours, the correlation between the surface and water levels must be 80% or above. The data of the installed piezometers were used as reference groundwater heights. The correlation for the data for all four monitoring periods was above 99% (Refer to Figure 23-Figure 26).

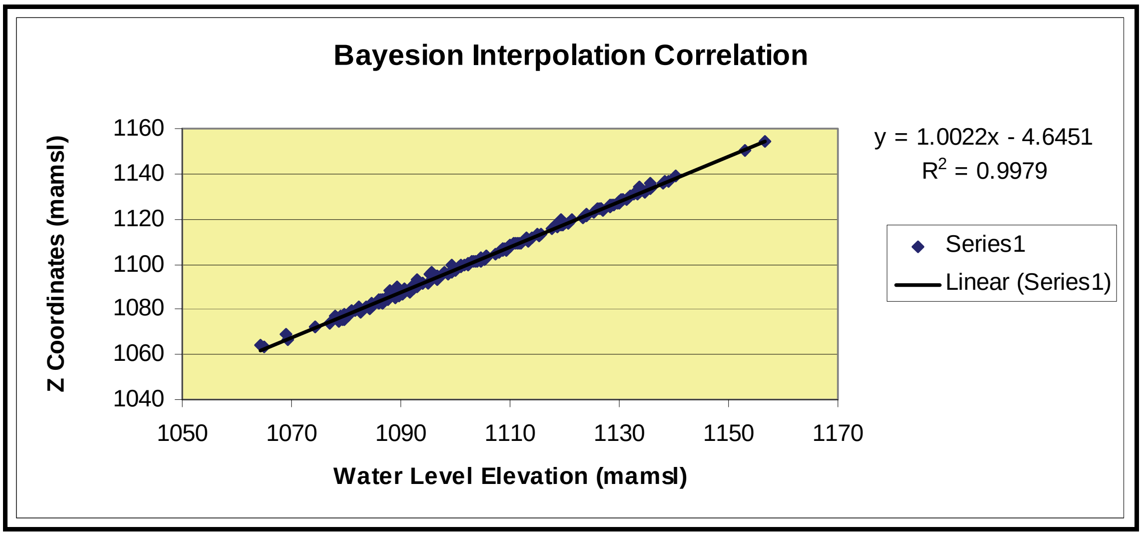


Figure 23: Groundwater and surface level correlation August 2008.

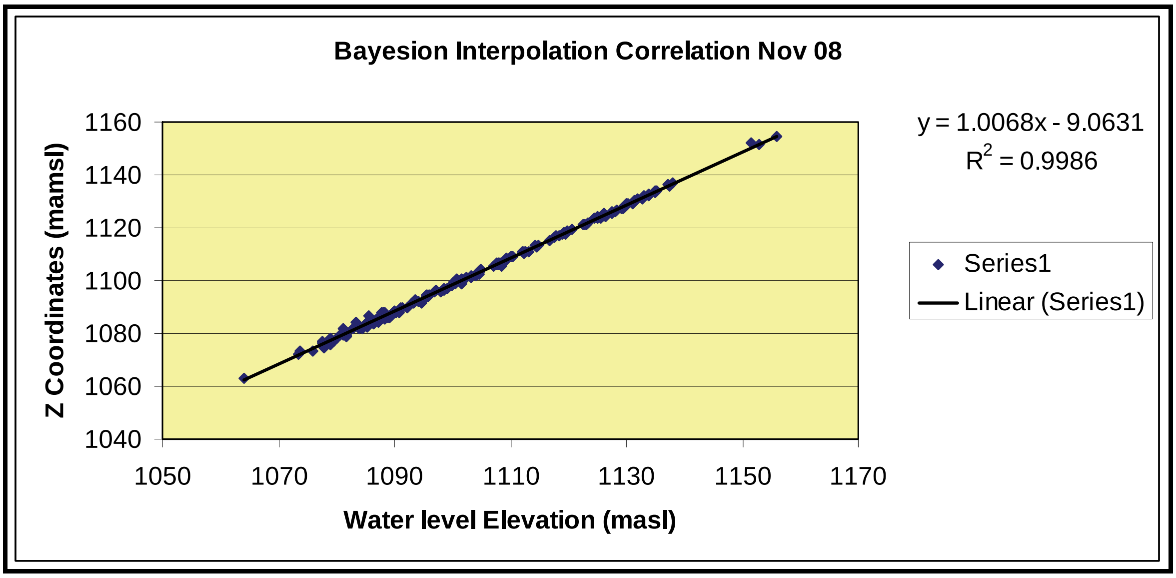


Figure 24: Groundwater and surface level correlation November 2008.

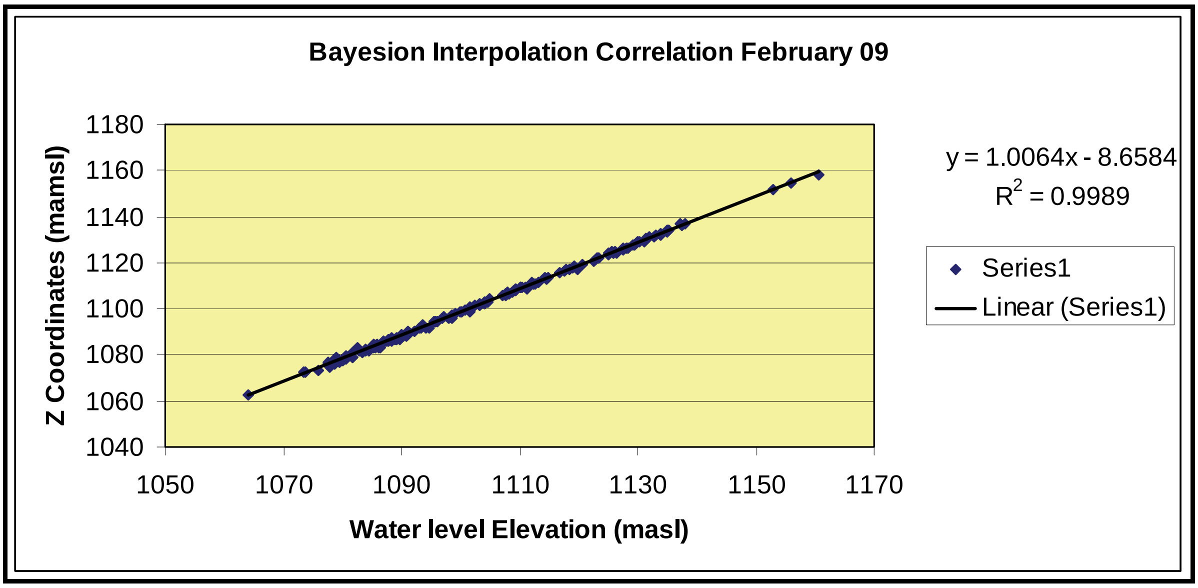


Figure 25: Groundwater and surface level correlation February 2009.

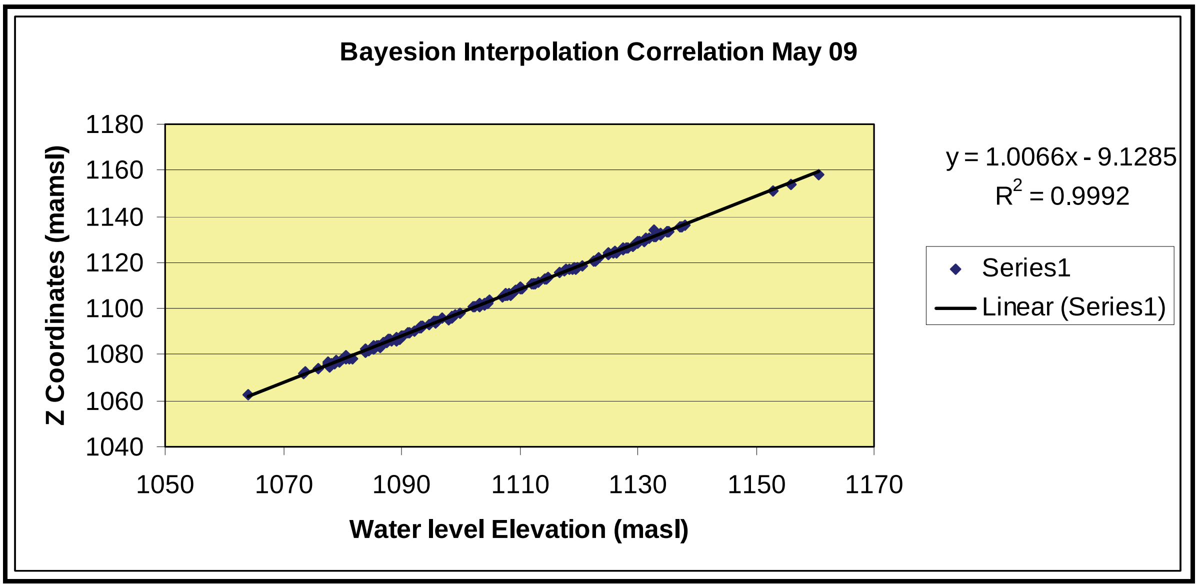


Figure 26: Groundwater and surface level correlation May 2009.

3.3.4 Water Level contour maps

As shown previously the correlation between surface and groundwater levels are well within the range qualifying them for use in contour generating. Groundwater levels were interpolated, contours and flow lines were generated (Refer to Figure 27 to 30).

Both surface and sub surface water flows perpendicular to the contour, in other words it crosses contour lines perpendicular. The correlation coefficients between groundwater and surface elevation were in excess of 0.99, all four sampling times (Refer to Figures 23 to 26). Both surface and sub surface (ground) water thus follows the same flow direction. The irrigation water therefore must drain towards the Harts River (as with groundwater).

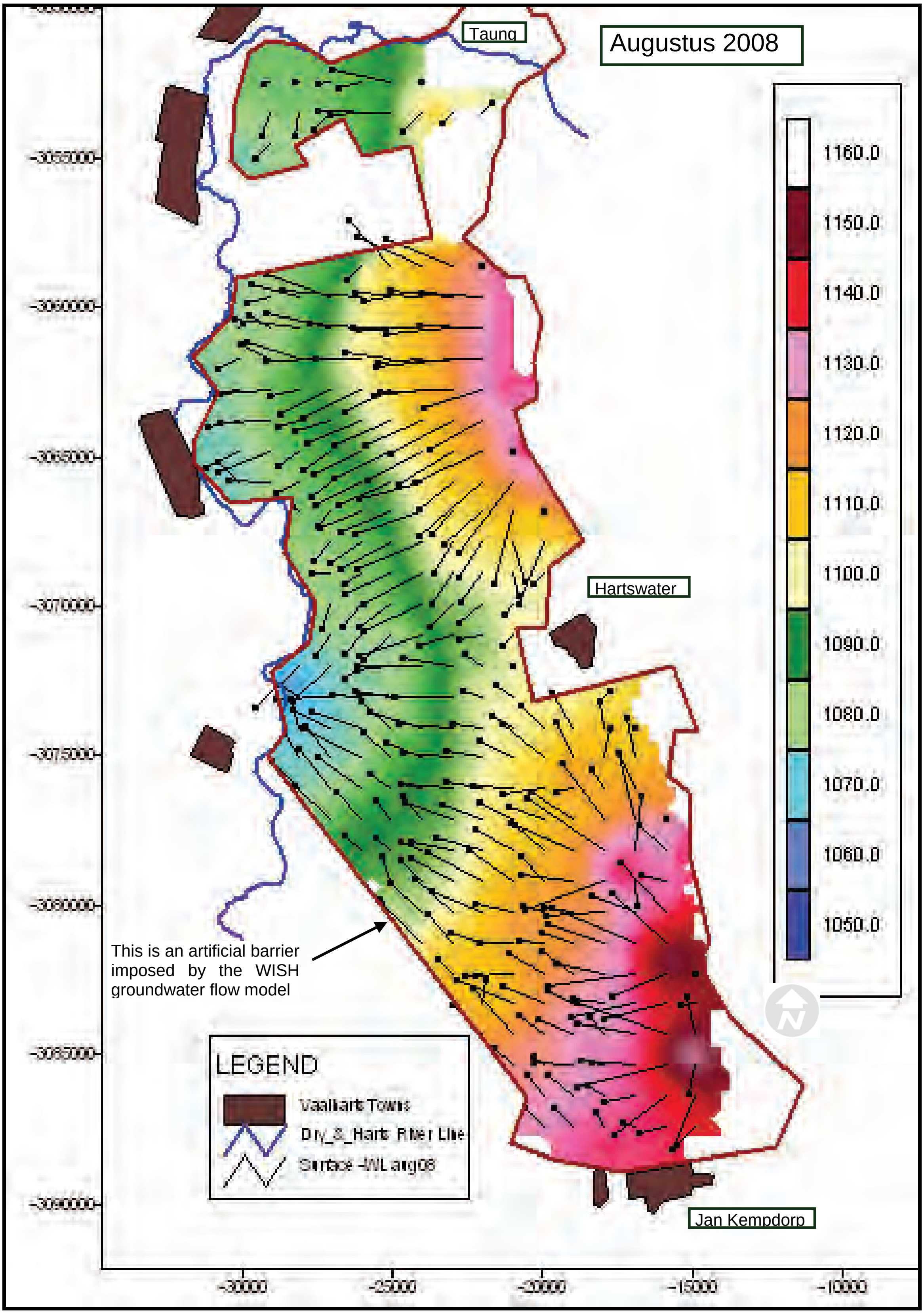


Figure 27: Piezometer water levels and groundwater flow lines August 2008.

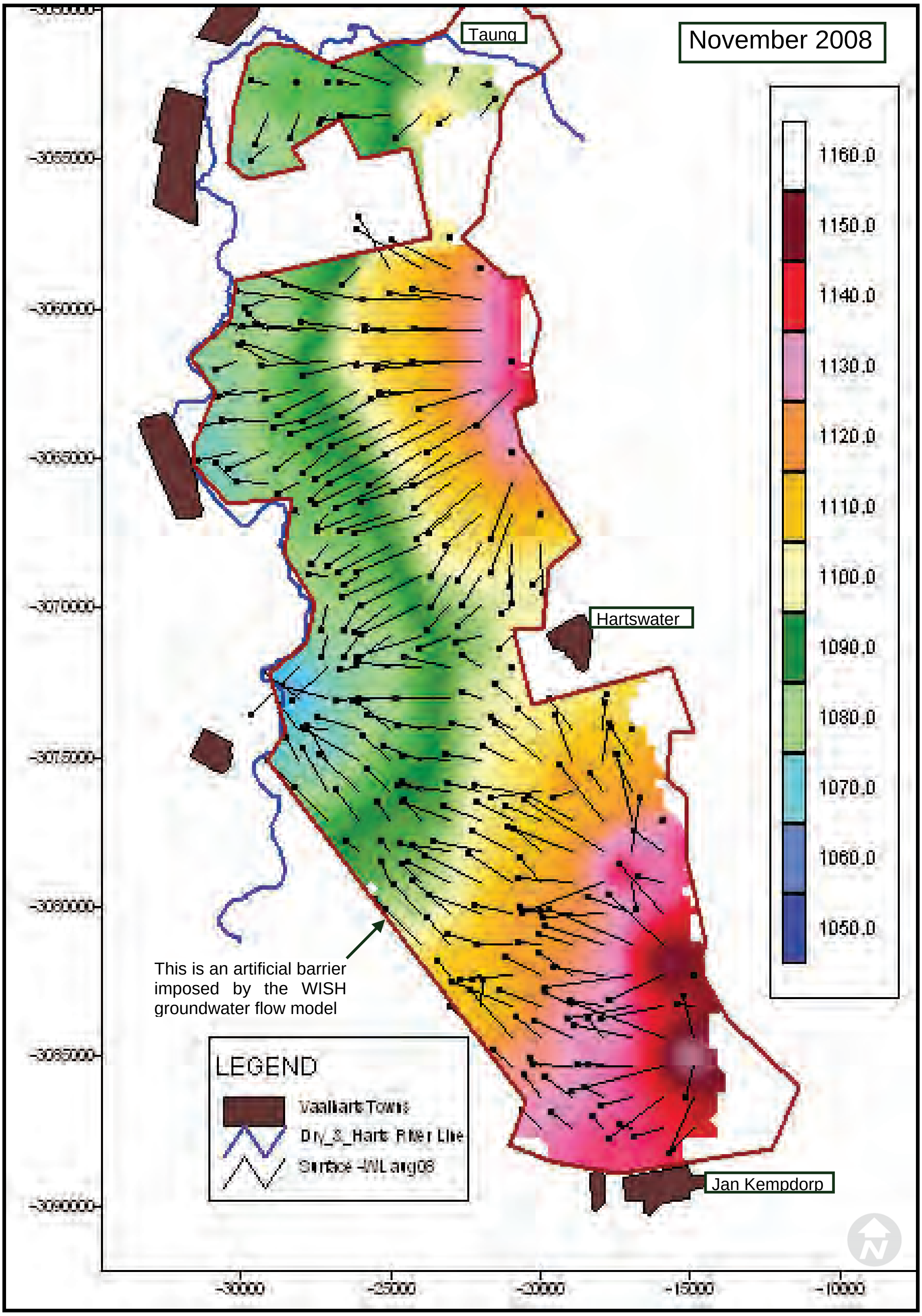


Figure 28: Piezometer water levels and groundwater flow lines November 2008.

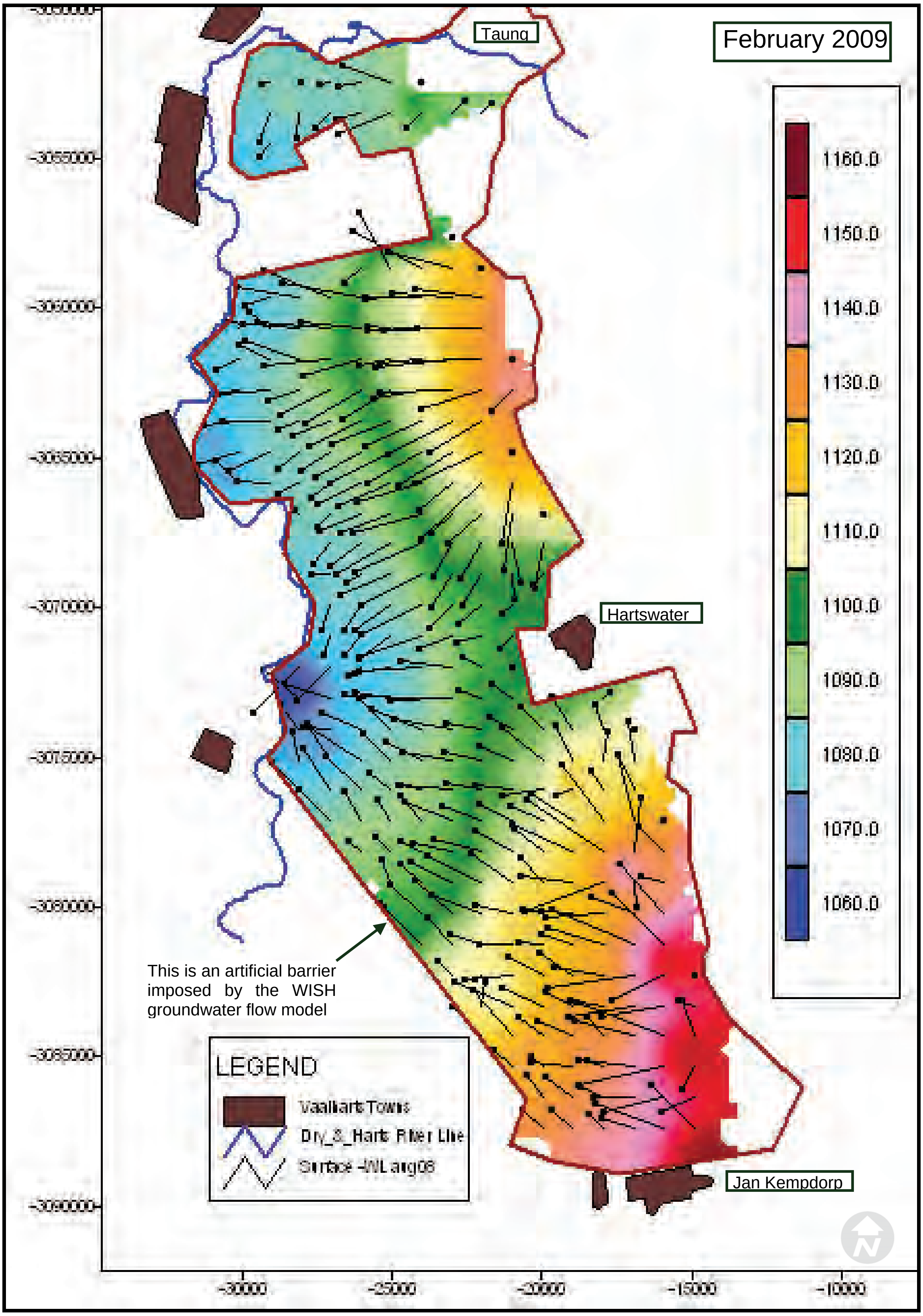


Figure 29: Piezometer water levels and groundwater flow lines February 2009.

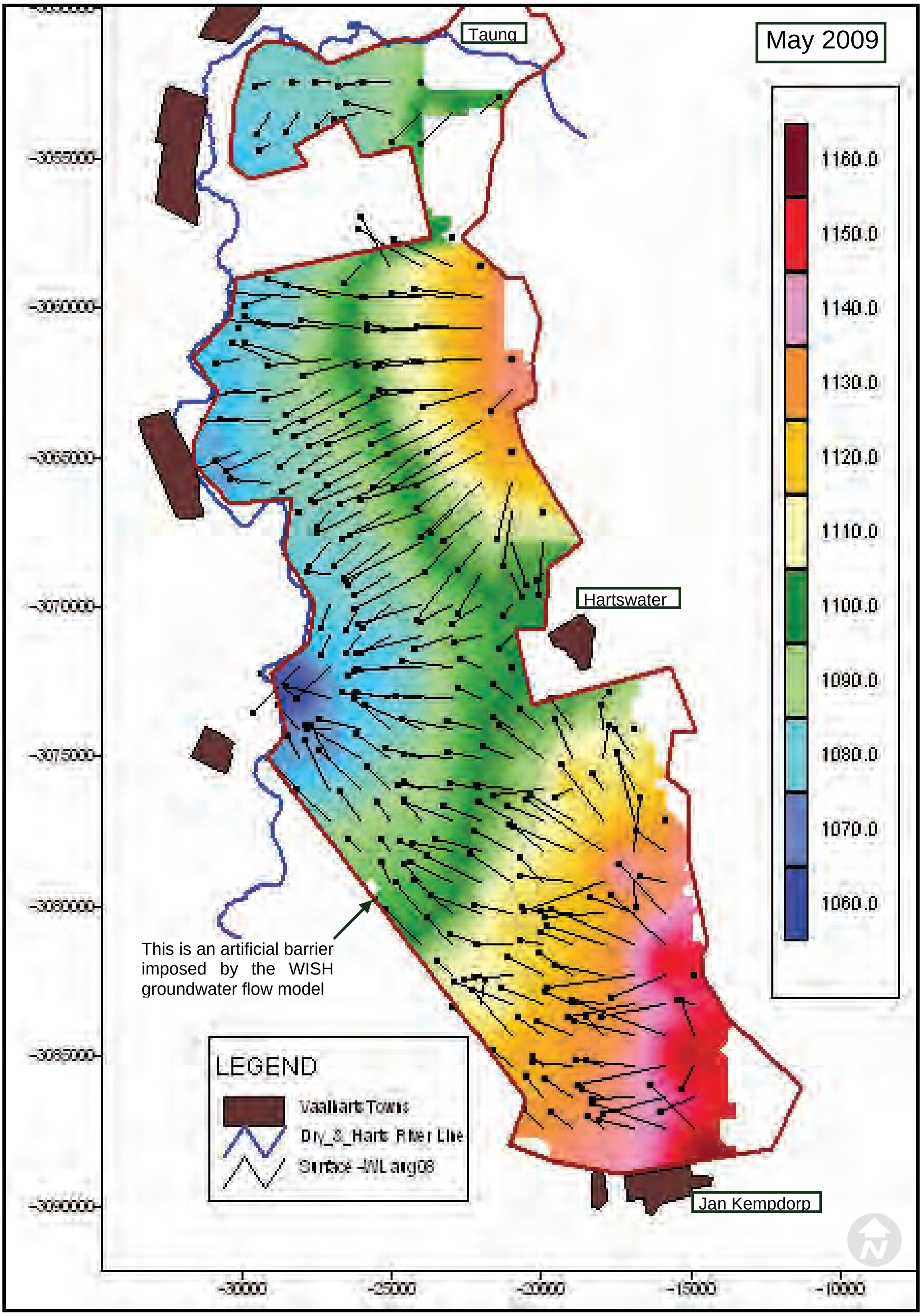


Figure 30: Piezometer water levels and groundwater flow lines May 2009.

3.4 EC Monitoring

Electrical Conductivity (EC) is obtained by measuring the electrical resistance between two parallel electrodes. Clear or pure water is a poor conductor of electrical current. Water that contains salt on the other hand has the ability to conduct a current that is a close resemblance of the salt content of the water (Shainberg and Oster, 1978).

The perforated piezometers make it possible to measure ECs at different levels in order to do an EC profiling for each piezometer. The results are then used to determine if more than one source contributes to the groundwater level. The EC values enable the determination of the general piezometer (well) conditions and temporal changes in the groundwater conditions.

3.4.1 EC a tool for stratification determination

Interpretation of an EC and temperature log taken at vertical intervals of a piezometer can be used to determine if there is cross flow, aquifer heterogeneities and groundwater movement in the piezometer (Michalski, 1989).

In August 2008 this 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 of layers in the top 3.0 m of the soil in the study area.

3.4.2 EC measuring

Figure 31: Measuring EC and Water Levels using a TLC meter.

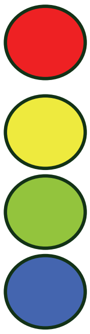
For the purpose of this study monitoring of the EC took place during August and November 2008 as well as February and May 2009 to cover all seasons as well as the planting, growing and harvest periods of the agricultural cycle.

Of the 209 piezometers measured in August 2008, 158 had water, the average EC was 160 mS/m (1231 mg/l). In November 2008, 156 had water and the average EC was 232 mS/m. During February 2009, 159 had water and the average EC was 190.8 mS/m and in May 2009 138 had water with an average EC of 183 mS/m. The average was for the total period 192 mS/m which is lower than most plants can tolerate, but it is much higher than the 66 mS/m of the irrigation water.

3.4.3 Electrical conductivity (EC) mapping

The data were used to generate maps to visualise the EC values and differences of the area (Refer to Figure 32-Figure 35).

The classifications as in South African National Standards 241:2006 where used to differentiate the EC values as measured in the study area (the bigger the dot the higher the value)



⇒ EC > 370 mS/m

⇒ EC 150-370 mS/m

⇒ EC 70-150 mS/m

⇒ EC < 70 mS/m

As can be seen in Table 4 crops can on average only tolerate an EC of 243 mS/m compared to the average measured in the area over a year of 192 mS/m. The crops most farmers plant in the Vaalharts area is cash crops (wheat, maize barley and lucerne) (Refer to Figure 14). The salinity threshold EC of lucerne and maize are respectively 200 and 170 mS/m. Therefore as can be seen in Figure 32 to Figure 35 there are many areas with yellow and red dots indicating that the salinity threshold of these crops has been exceeded and that salinity induced yield reductions can be expected.

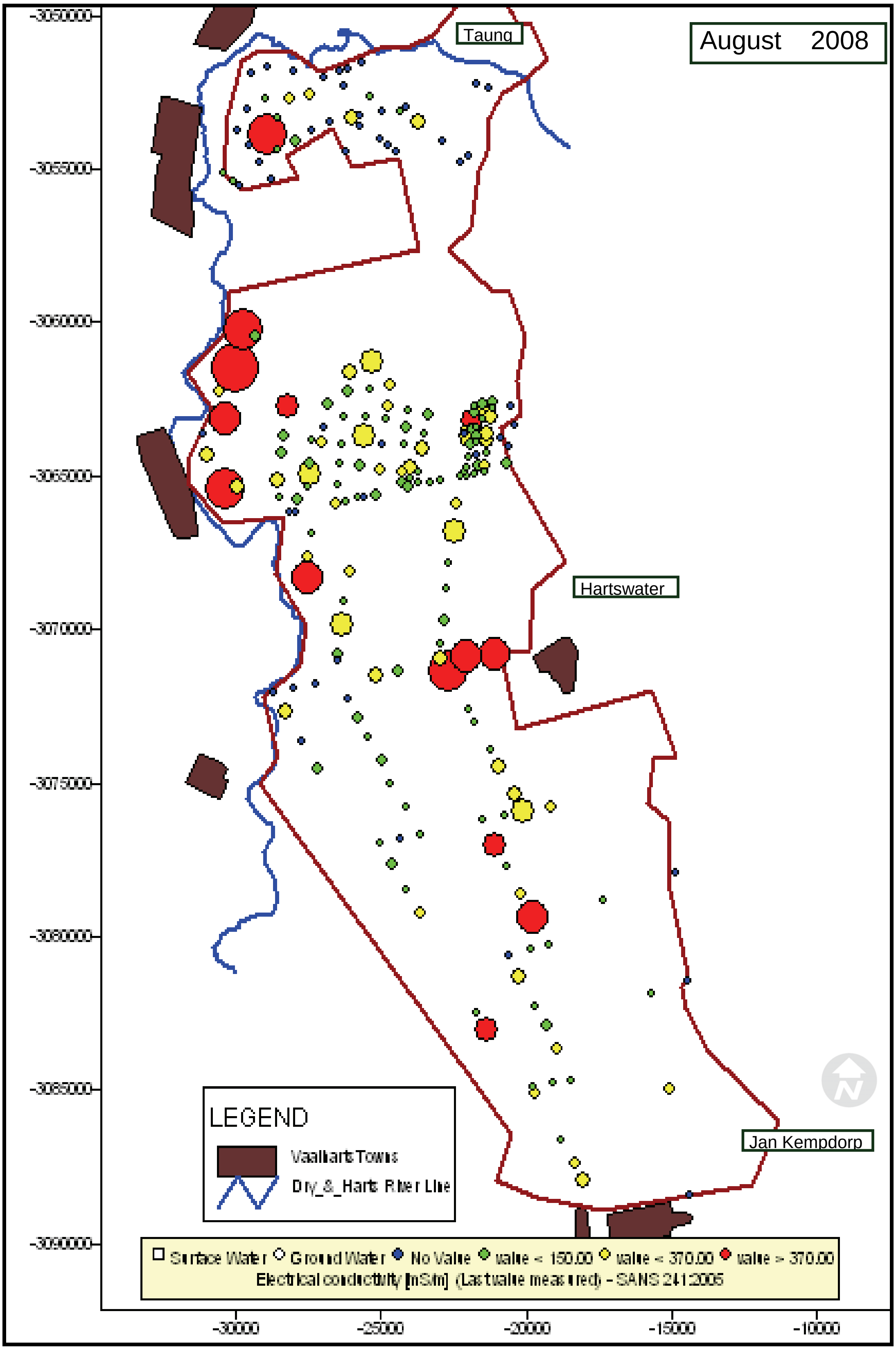


Figure 32: EC monitoring values for August 2008.

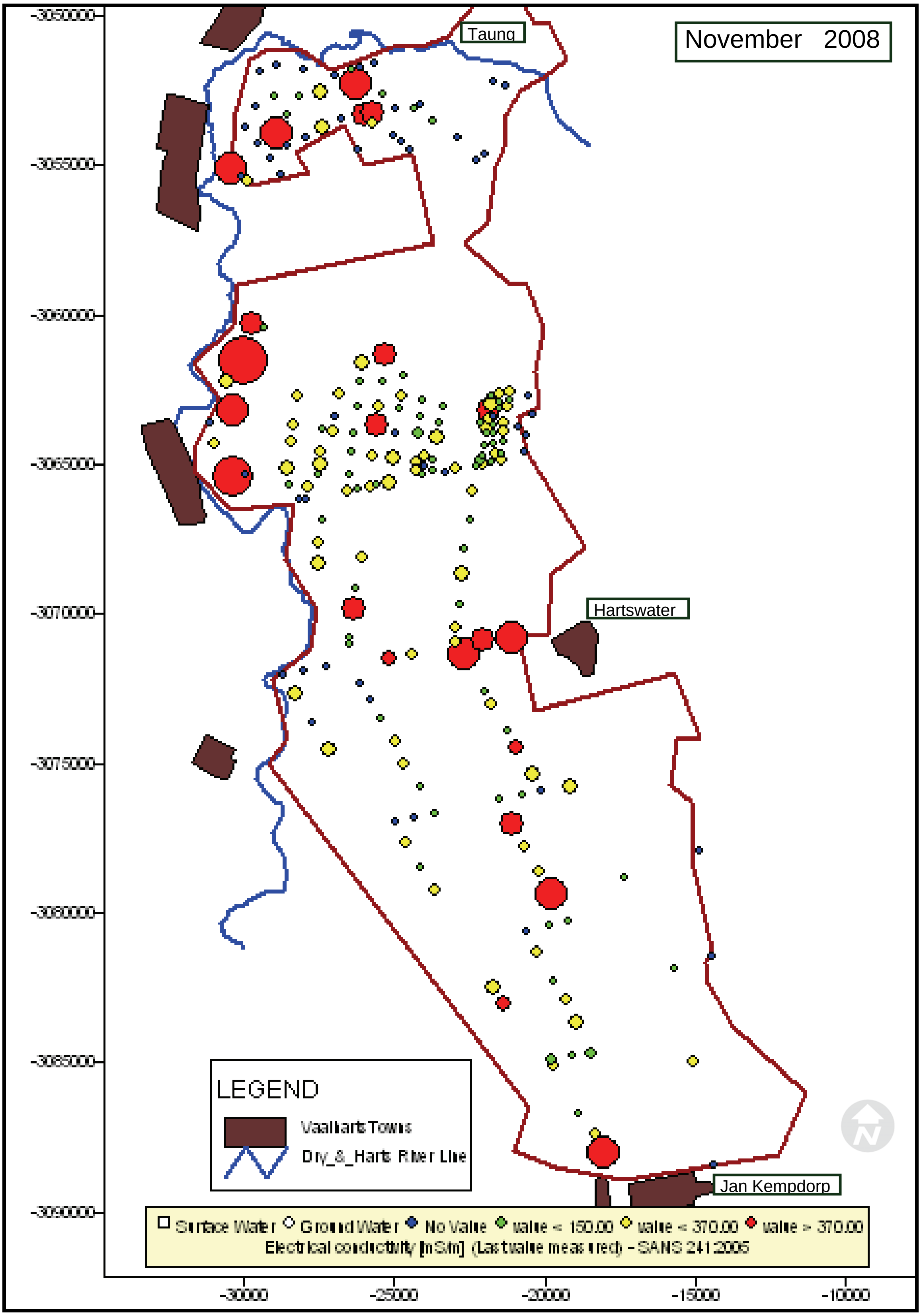


Figure 33: EC monitoring values for November 2008.

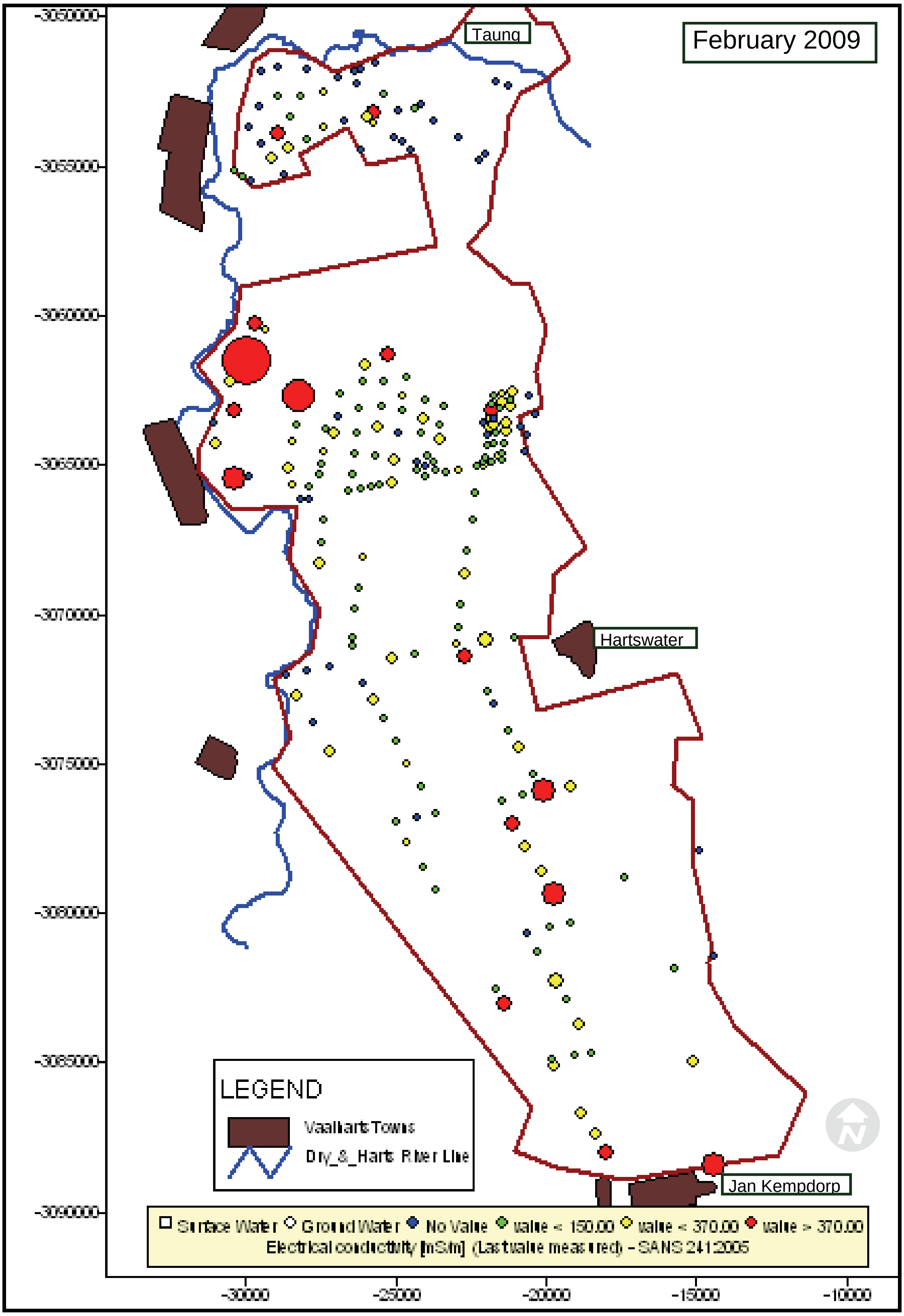


Figure 34: EC monitoring values for February 2009.

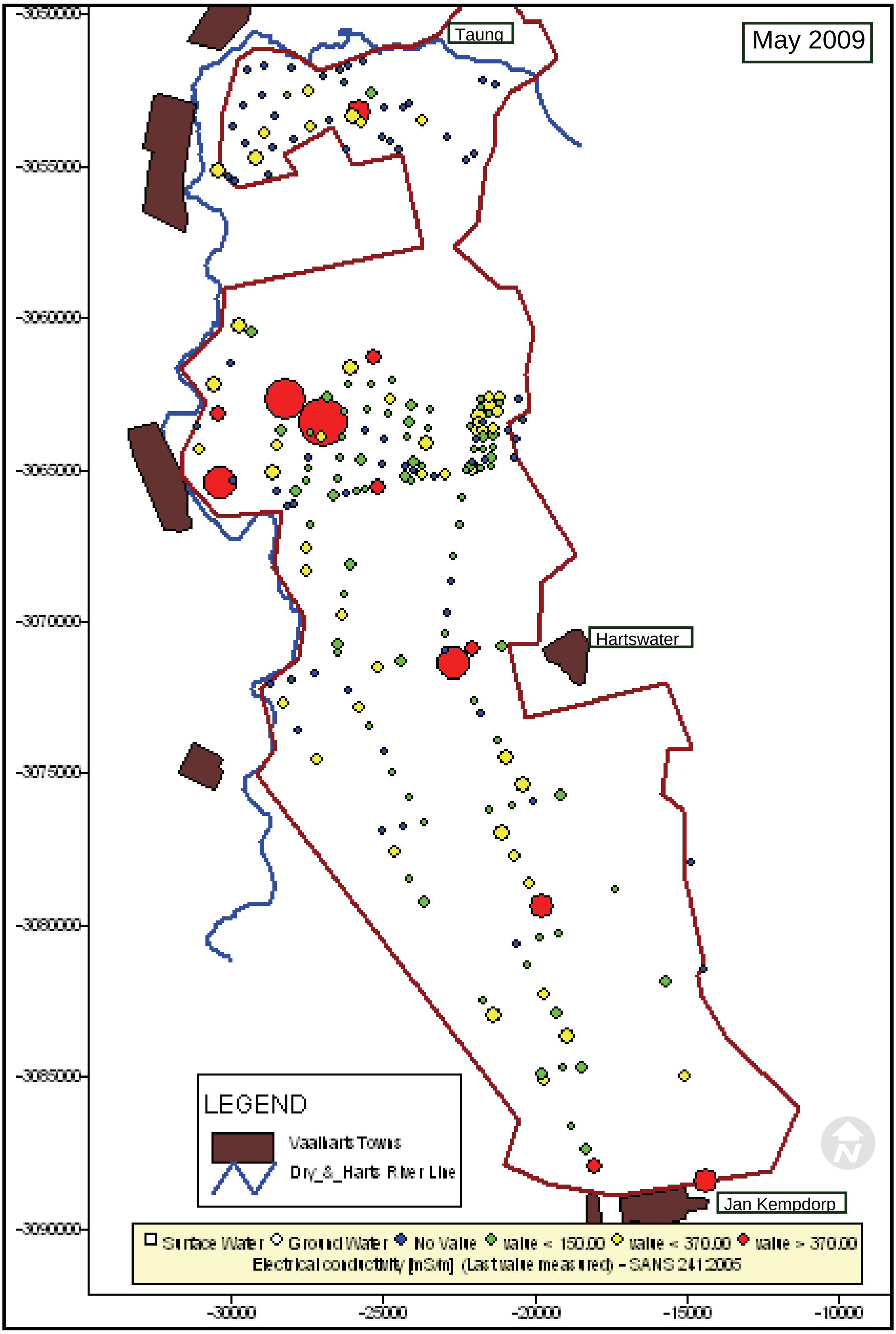


Figure 35: EC monitoring values for May 2009.

3.4.4 EC Values of Harts River Water

Electrical conductivities were measured at various positions in the Harts River during December 2009 (Figure 37). 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 Espags Drif gauging station, to cover the influence of the entire research area. Flow measurement was also obtained from Vaalharts Water User Association (Harbron, 2009) (Figure 36) There are a correlation between this flow measurements and the rain measurements (Figure 6).

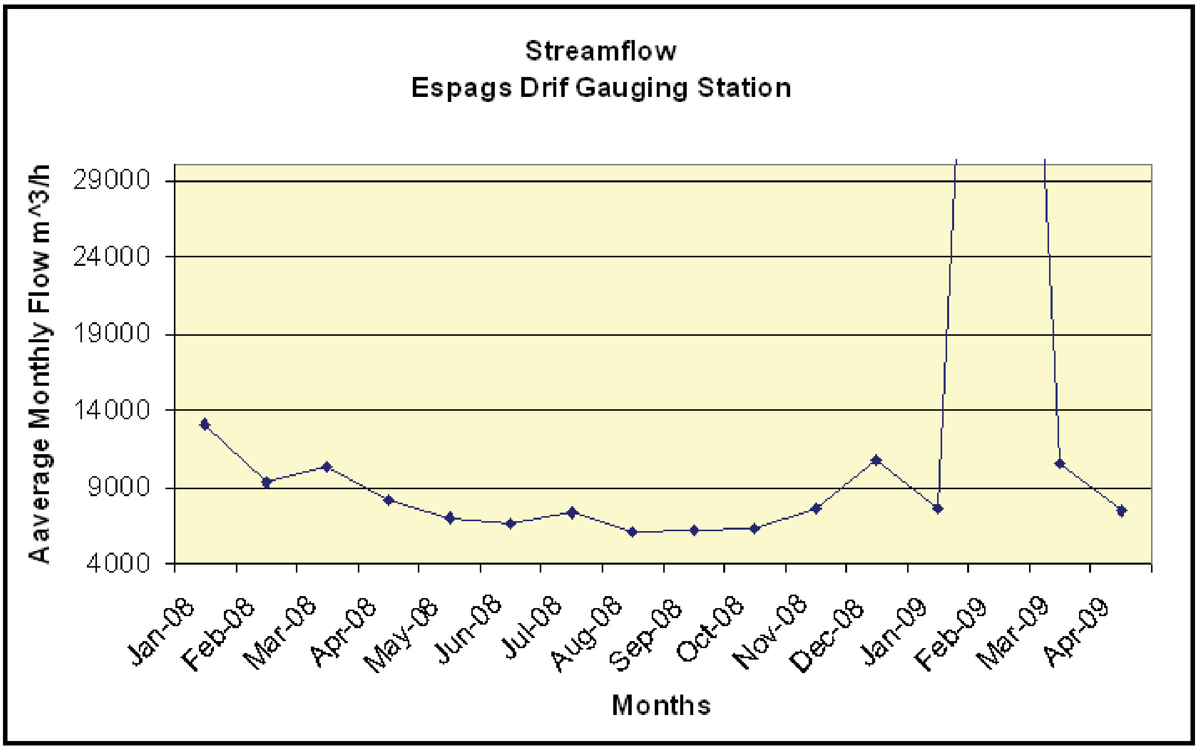


Figure 36: Flow measurements at the Espags Drif Gauging Station.

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.

Figure 37: Positions of electrical conductivity measurements in the Harts River.

3.5 Saturated Hydraulic Conductivity of water logged soils (K)

Hydraulic conductivity, is the velocity that the seepage water reaches and is influenced by the unit pressure gradient. The saturated Hydraulic Conductivity values of the water logged soils were used to:

- Investigate the resemblance with the EC values and clay content on the scheme. Where the clay content is high K should be low and the EC high due to the low flow rate.
- As a parameter in the setting up a numerical model.
- Compile salt and water balances, where it was applied in the formula to estimate flow.

3.5.1 The effect of soil properties

The porosity of the medium has an effect on the flow direction and space which affects the conductivity. Most mediums in the groundwater regime are either heterogeneous or anisotropic and very seldom heterogeneous and anisotropic. In soils, the K value changes with the change in soil characteristics. The K value is closely related to the macro porosity also known as effective porosity (Φ_e) and is defined as total porosity Φ –water content at 33 kPa (Ahuja et al., 1984). K_s and Φ_e are then related as.

$$K_s = B(\Phi_e)^n$$

Where B and n are two parameters obtained for the relative soil (Bruandt et al., 2005).

However it should be noted that when soils are cultivated and irrigated the water causes the collapsing of the macro porosity, the measurement of K thus becomes difficult.

3.5.2 Site selection

A total of 26 piezometers were selected for K value determination (Figure 38), 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 (Refer to Figure 11) was studied to cover as many different soils as possible.

⇒ Preferably the same sites used for sampling should be used to ensure consistency.

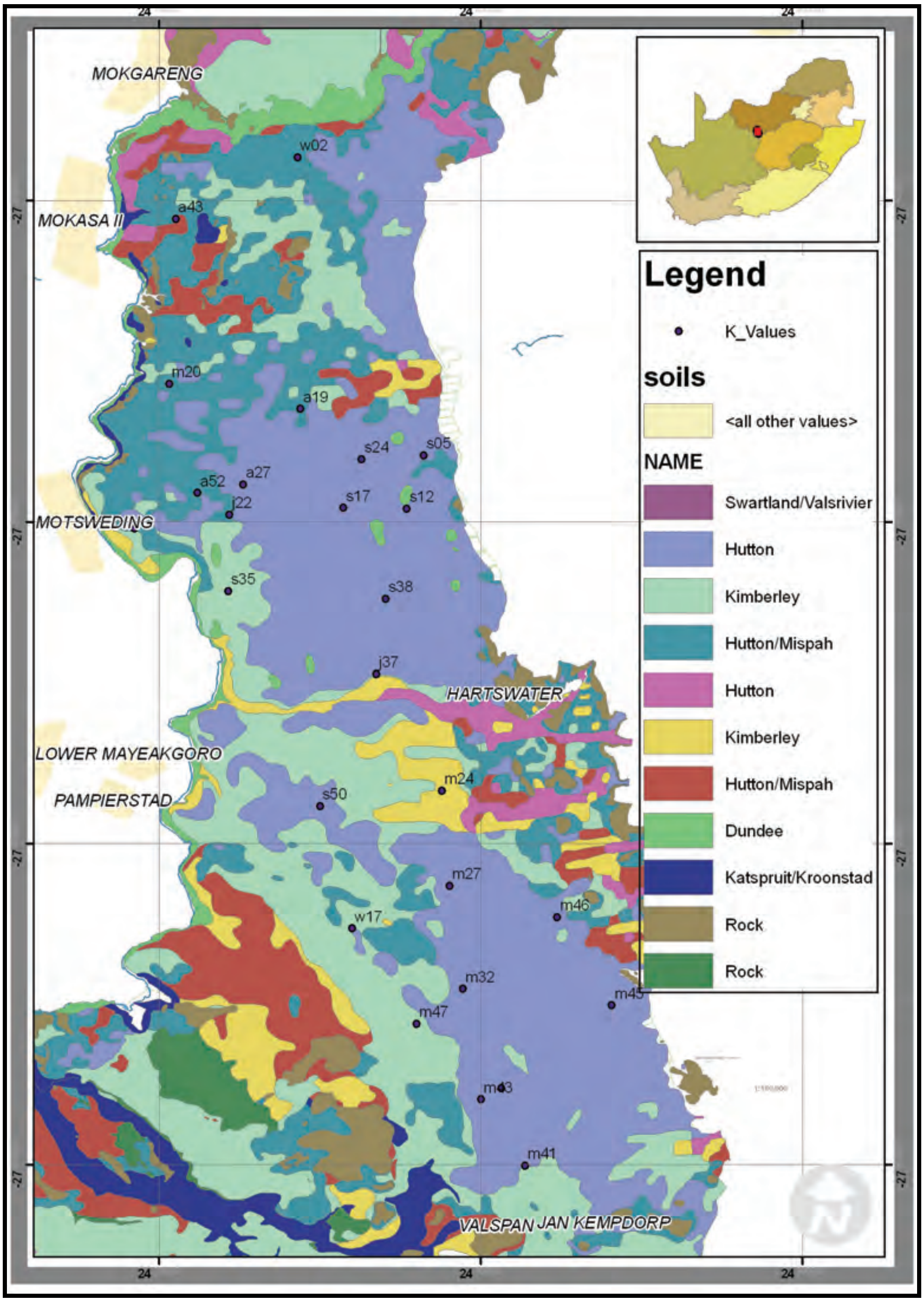


Figure 38: Sites where the K values were determined.

3.5.3 On site tests

The K value was determined using field tests. The groundwater was pumped or bailed out of the piezometers. The recovery of the groundwater was measured with an electronic device that stores the time of recovery every 50 mm. To enable the use of Hooghoudt's method at least five readings were necessary. The top and bottom quarter of the recovery should not be used in the calculations, only the middle half (Van Beers, 1983).

Therefore a recovery of at least 400 mm was necessary. The device used could take readings for 500 mm.

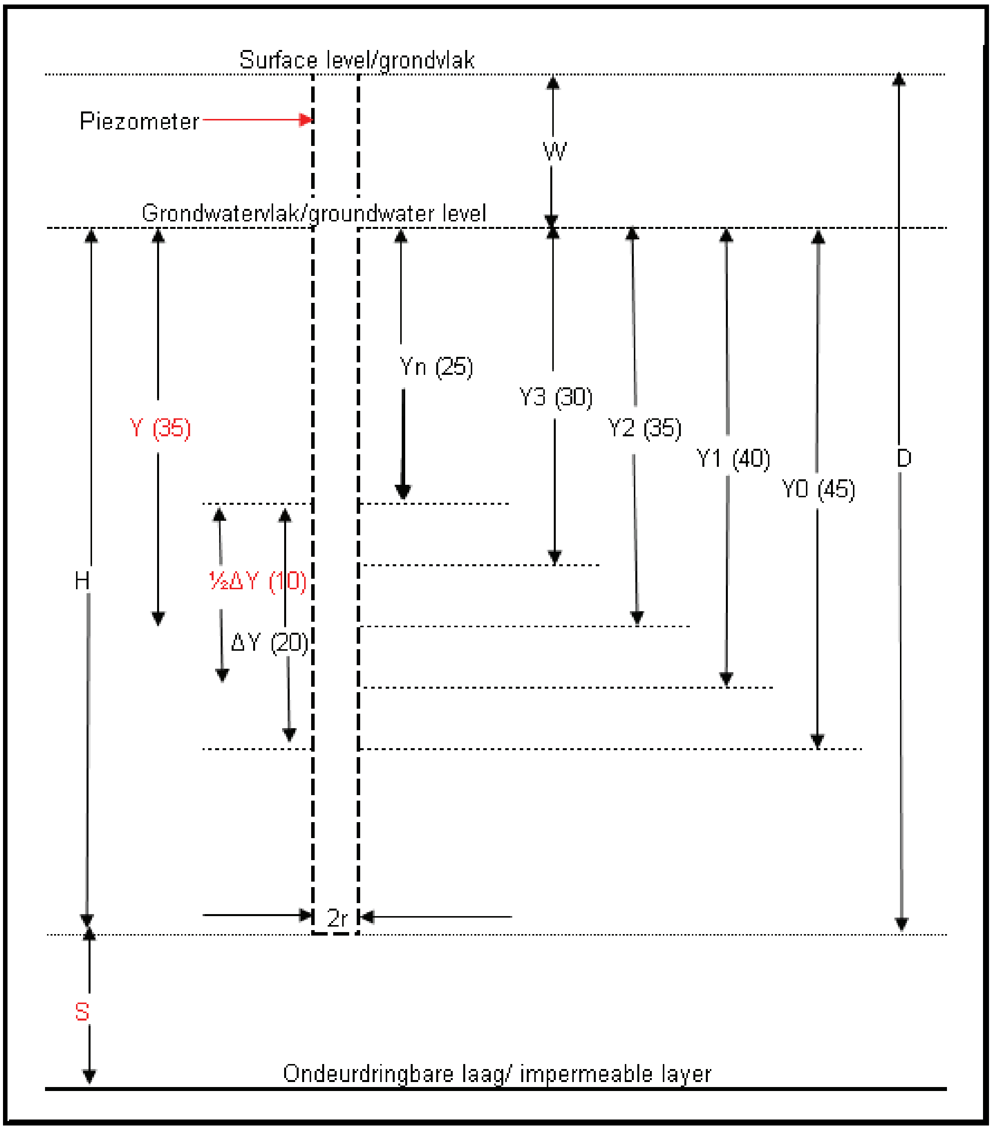


Figure 39: Diagram showing K value calculation measurements (Van Beers 1983).

3.5.4 Conversion of site readings

The readings from the field work were converted to Hydraulic Conductivity (K) in m/day using Hooghoudt's method (Van Beers, 1983) as reported in Table 6.

Table 5: Example of calculations used to determine the K Value (Van Beers, 1983).

Voorbeeld / Example (S > H)
value in seconds and centimeters answer in m/day

	input
D =	250
W =	60
3 < r < 7cm =	2.5
Y (> 0.2H) =	35
ΔY =	0
$\Delta Y_t \leq 0.25 Y_0$	20.0
Δt =	127.25
20 < H < 200cm	190

Data			
t(s)	Y	Y_t	Δyt(cm)
0	Y_0	25.0	
0	Y_1	25.0	0.0
6.25	Y_2	20.0	5.0
18.3	Y_3	15.0	5.0
37.85	Y_4	10.0	5.0
64.85	Y_5	5.0	5.0
127.25		ΔYt	20.0

$K=((4000r^2) / ((H+20r)(2-Y/H)(Y)) \times (\Delta Y/\Delta t)=$ 0.2576128 m/day 0.1572

If S ≤ ½H then use the following formula / as S ≤ ½H gebruik die volgende vergelyking

$K=((3600r^2) / ((H+10r)(2-Y/H)(Y)) \times (\Delta Y/\Delta t)=$ 0.258811 m/dag

Pieso_no	water_leve	withdraw	EC	depth	date			
w17	1.80	60.0	117	2.40	07/07/2009			
recovery	a	b	c	a	b	c	average	
mm							seconds	
50								
100				0.000	0.000			
150	0.000	0.000		0.000	0.000			
200	0.300	0.200		0.300	0.200			
250	7.000	6.000		6.700	5.800		6.250	Y_2
300	25.800	23.800		18.800	17.800		18.300	Y_3
350	65.200	60.100		39.400	36.300		37.850	Y_4
400	132.300	122.700		67.100	62.600		64.850	Y_5
450								

Table 6: Hydraulic Conductivities of the soil at the tested piezometers.

Piezometer number	Water level m	EC mS/m	Withdraw m	Depth m	Date	Hydraulic conductivity (K)
m24	1.80	300	1.1	2.70	07/07/2009	0.013m/d
b12	1.85	1000	0.9	2.50	27/01/2009	0.018m/d
a43	2.20	326	0.8	2.80	07/07/2009	0.023m/d
a24	1.30	55	1.0	2.10	27/01/2009	0.033m/d
m41	1.60	121	1.2	2.60	09/07/2009	0.054m/d
m27	1.45	130	1.2	2.45	08/07/2009	0.064m/d
m43	1.45	208	1.5	3.10	08/07/2009	0.068m/d
a52	1.50	232	1.5	2.90	27/01/2009	0.07m/d
m38	1.30	69	1.2	2.30	08/07/2009	0.131m/d
w02	0.80	202	1.4	2.00	07/07/2009	0.165m/d
s35	1.40	206	1.4	2.60	28/01/2009	0.174m/d
a19	1.10	580	1.5	3.00	28/01/2009	0.231m/d
w17	1.80	117	0.8	2.40	09/07/2009	0.258m/d
s38	0.60	173	1.5	2.20	28/01/2009	0.321m/d
m32	1.40	58	1.3	2.50	08/07/2009	0.408m/d
m46	1.45	50	1.3	2.50	08/07/2009	0.429m/d
s50	1.85	105	1.2	2.80	08/07/2009	0.675m/d
s12	1.00	169	1.5	2.70	27/01/2009	0.678m/d
s24	0.90	89	1.5	2.45	27/01/2009	0.729m/d
s17	1.20	220	1.5	2.50	27/01/2009	0.9m/d
m20	1.07	254	1.3	2.20	28/01/2009	1.072m/d
j22	1.25	100	0.8	1.80	27/01/2009	1.488m/d
m45	1.55	74	1.2	2.50	09/07/2009	1.49m/d
m47	1.00	63	1.5	3.00	09/07/2009	2.21m/d
j37	1.30	65	1.4	2.50	07/07/2009	5.217m/d
s05	1.30	122	1.5	3.00	27/01/2009	5.405m/d

The K values varied between 0.013 and 5.4 m/d.

3.5.5 Comparing Hydraulic Conductivity and Electrical Conductivity

The K values calculated for the soil at 25 piezometers were compared to the EC values measured for the monitoring period. The correlation coefficient was 25.9% (Figure 40), indicating a poor correlation. Electrical Conductivity was influenced by the placing of the piezometer and the following trends were noticed by observing the actual data:

- EC measured on the elevation point of a land was lower than in the land
- EC measured in the middle of a land is higher on the outer borders
- If a piezometer was on the opposite side of a drainage line than the land the EC is low, indicating that salinisation are prohibited to spread where drainage is in place
- Piezometers close to open channel drainage were lower than those close to subsurface drains which could be explained by leaching into the drains.

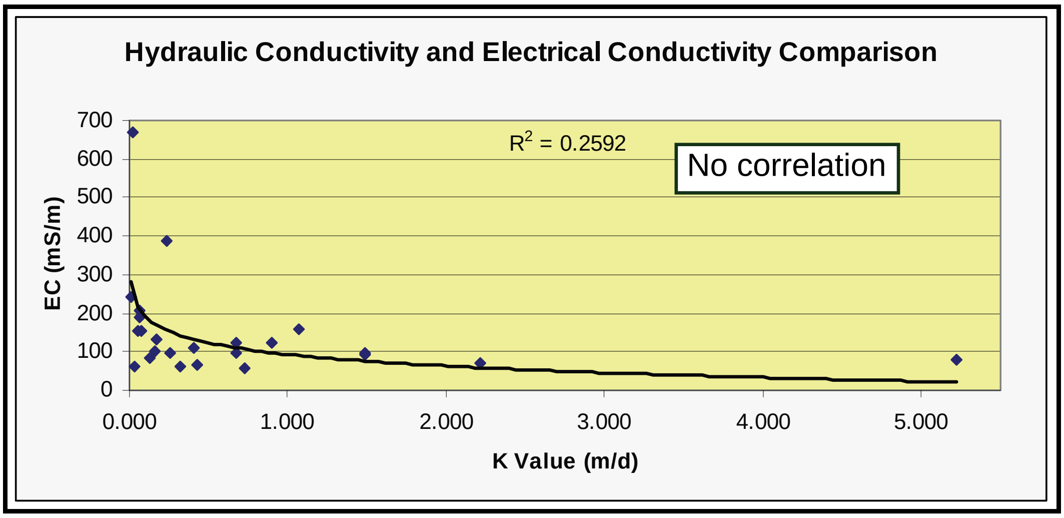


Figure 40: Hydraulic Conductivity and Electrical Conductivity Comparison.

3.5.6 Generating a contour map of the K Values

The IDW (inverse distance weight) interpolation method (see 2.11) was used to generate values for the development of contour lines to represent the K-values (Figure 41).

3.5.7 Comparing K Values with clay content and EC

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

Site	EC (mS/m)	K (m/d)	Clay content (%)
A	149 - 284	K > 4.60	low 9.7 - 13.6
B	> 700	K < 0.58	high > 24
C	285 - 419	K < 0.58	medium 17 - 21
D	0 – 150	1.7 < K < 2.3	medium 17.3
E	149 – 284	1.16 < K < 1.75	medium 13.5

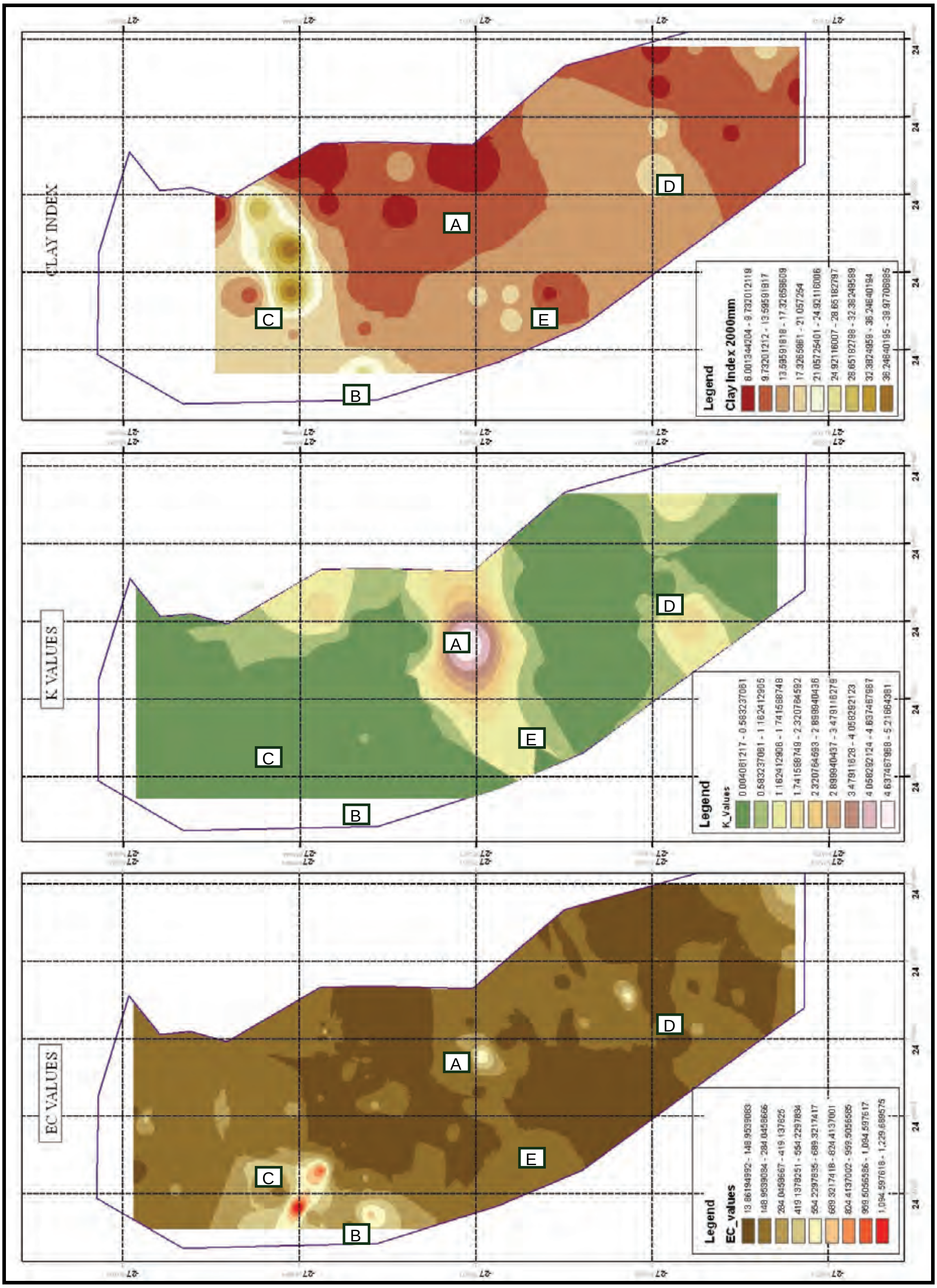


Figure 41: Comparison between K values, Clay content and EC values.

3.6 Drainage

The rising of the water table due to the irrigation in the Vaalharts area had to be controlled and subsurface drainage systems were introduced to the scheme in the 1970s. A drainage network consisting of open drainage canals and subsurface drainage pipes were and still are being installed. The perforated subsurface drainage pipes are installed beneath the root zone to drain excess water from the root area thereby ensuring oxic conditions conducive to optimal growth. A lack of drainage furthermore leads to an accumulation of salt and the development saline conditions in the soil. This further affects plant growth.

The effectiveness of the drainage system was evaluated by monitoring EC and the flow of drains.

3.6.1 EC Monitoring

A decision was taken to monitor the flow and the EC of the drains in the K block (Figure 42) to estimate how productive the existing systems are and what the influence of the drainage is on the electrical conductivity of the soil and the groundwater. Monitoring took place simultaneously with the monitoring of the piezometers to check and compare the values to see if there are any correlations.

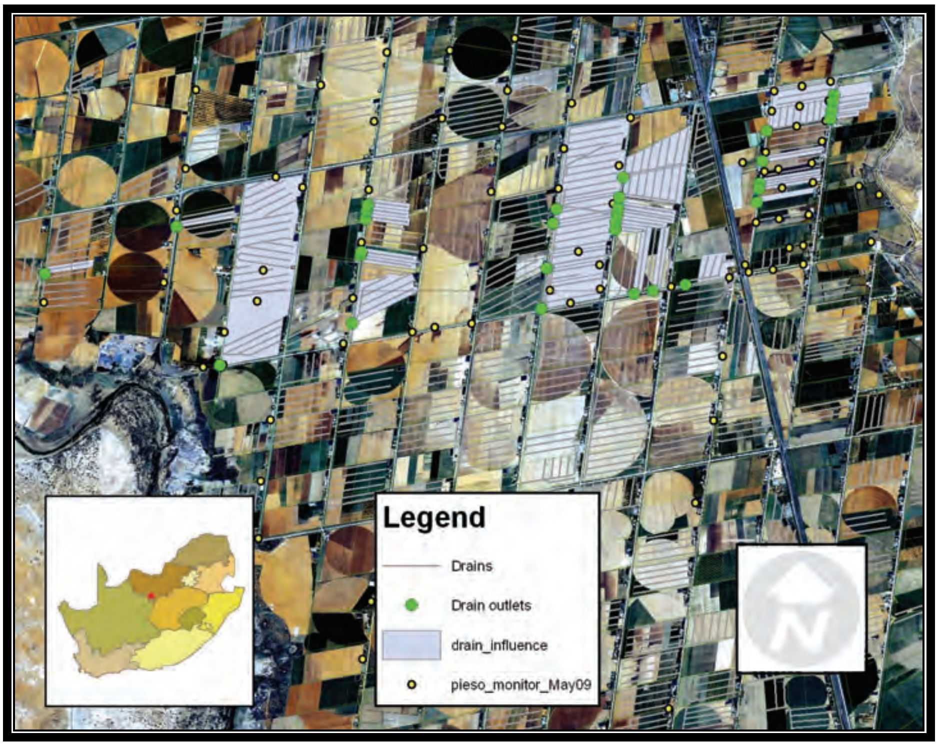


Figure 42: Drain outlet flows monitored in the K Block during the study.

The average EC of the drained water measured at the same drains each time 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 served by that specific outlet, indicated that on average the EC of drainage water is 20% higher than that of the piezometers. This indicates that a salt built are taking place, higher average EC values of the groundwater measured during this research period than that of previous investigations also proves that (Table 7).

Table 7: Diagram, comparison of EC values for the drainage and piezometer water.

drain	Piezo	Aug-08		Nov-08		Feb-09		May-09		Area Drained
outlet	number	liter/s	EC	liter/s	EC	liter/s	EC	liter/s	EC	(Hectares)
dr05		1.10	203	1.25	226	1.5	171	0.66	165	16.5
	s06		156		114		172		72	
	s05		116		104		352		365	
	j06		71		300		130		105	
	j04		66		110		85		104	
	j03		250		247		198		181	
	j05		387		525		500		350	
average			174		233		240		196	
dr20		15.00	178	8	171	15	174	15	178	149.8
	ji6		109		80		65		108	
	ji5		118		160		120		131	
	j18		56		85		137		165	
	s16		69		93		76		66	
	s17		220		203		132		111	
	s23		229		270		225		265	
	s25		72		150		86		108	
	j24		134		112		128		138	
	s24		110		112		57		62	
average			124		141		114		128	
dr39		7.00	248	10	221	14.3	188	10.00	147	147.0
	s19		126		182		132		134.0	
	j19		63		84		82		66	
	j22		338		352		125		130	
	s21		129		230		161		173	
	a27		165		225		174		172	
	s22		157		70		67		71	
average			163		191		124		124	
The	orange	blocks represents an average of the measured values since no measurements were possible								

3.6.2 Drainage water flows

The drainage flows were also measured at the drain outlets to determine how effective the drainage system still is. The area served by each outlet was determined and the average flow recalculated to cubic meters per annum. Dividing the m^3/a by the area in m^2 and multiplying it by 1000 gave an answer in millimeters, a depth of water drained which was compared to the drainage need. The maximum design value of the area used per day is 3 mm (Van Niekerk, 2009) per day which is 1095 mm/a if it drains this water constantly over a period of a year. These subsurface drains was installed at double spacing and therefore designed to be able to drain 547 mm/a constantly.

Table 8: Indicating the depth and average depth of water drained by 31 different drains in Block K as monitored over four seasons.

drain	Aug-08			Nov-08			Feb-09			May-09			average	average	Area	Depth
outlet	l/s	m^3/day	EC	l/s	m^3/day	EC	l/s	m^3/day	EC	l/s	m^3/day	EC	liters/s	m^3/annum	drained (ha)	drained (mm)
dr01	0.07	0.101	252	0.01	0.014	251	0.12	0.173	313	0.07	0.101	231	0.07	2129	5.6	38.3
dr02	0.18	0.259	243	0.2	0.288	201	0.13	0.187	250	0.20	0.288	219	0.18	5598	4.5	125.0
dr03	0.19	0.274	116	0.05	0.072	187	0.13	0.187	126	0.40	0.576	151	0.19	6071	2.9	207.4
dr04	0.07	0.101	119	0.02	0.029	187	0.1	0.144	127	0.10	0.144	155	0.07	2286	2.1	107.9
dr05	1.10	1.584	203	1.25	1.800	226	1.5	2.160	171	0.66	0.950	165	1.13	35557	30.0	118.5
dr06	0.10	0.144	193	0.02	0.029	270	0.25	0.360	192	0.01	0.007	209	0.09	2957	5.4	54.3
dr07	0.32	0.461	175	0.3	0.432	224	0.4	0.576	182	0.25	0.360	176	0.32	10013	5.0	200.4
dr08	0.83	1.195	189	0.5	0.720	217	1	1.440	182	1.00	1.440	173	0.83	26254	4.8	542.2
dr09	0.45	0.648	139	0.4	0.576	158	0.55	0.792	132	0.40	0.576	141	0.45	14191	4.1	348.9
dr10	1.05	1.512	284	0.8	1.152	246	0.9	1.296		0.9	1.296		0.91	28777	10.9	263.6
dr11	4.00	5.760	211	2.5	3.600	195	5	7.200	166	3.8	5.472		3.83	120625	24.8	485.5
dr12	1.80	2.592	227	2.5	3.600	230	4.36	6.278	166	2.3	3.312		2.74	86409	25.0	346.3
dr13	1.10	1.584	257	0.6	0.864	227	0.56	0.806	177	0.50	0.720	168	0.69	21760	5.6	386.4
dr14	0.10	0.144	315	0.1	0.144		0.1	0.144		0.1	0.144		0.10	3154	5.0	63.2
dr15	0.30	0.432	252	0.4	0.576	230	0.24	0.346	173	0.38	0.547		0.33	10407	4.8	217.3
dr16	0.14	0.202	238	0.2	0.288	190	0.16	0.230	158	0.05	0.076	161	0.14	4360	2.7	162.6
dr18	0.66	0.950	236	1.1	1.584	224	1.1	1.584		1.1	1.584		0.99	31221	8.4	372.4
dr19	0.28	0.403	228	0.35	0.504	205	0.21	0.302		0.35	0.504		0.30	9382	7.8	120.7
dr20	15.00	21.600	178	13	18.720	171	15	21.600		15	21.600		14.50	457272	149.8	305.3
dr21b	4.00	5.760	194	1.9	2.736	169	3	4.320		0.60	0.864	120	2.38	74898	11.2	670.4
dr23	1.00	1.440	155	0.7	1.008	170	0.57	0.821		0.50	0.720	103	0.69	21839	7.2	303.9
dr24	1.00	1.440	172	0.7	1.008	186	0.56	0.806		0.5	0.720		0.69	21760	10.6	205.9
dr33b	0.34	0.490	201	0.3	0.432	125	0.34	0.490	88	0.3	0.432		0.32	10092	4.0	251.5
dr34	0.50	0.720	195	0.4	0.576	138	0.6	0.864	90	0.5	0.720		0.50	15768	4.1	380.4
dr35	0.50	0.720	190	0.5	0.720	108	0.65	0.936	88	0.65	0.936		0.58	18133	4.3	421.1
dr37	1.20	1.728	222	1.2	1.728	111	1.2	1.728	93	1.2	1.728		1.20	37843	5.6	675.2
dr38a	0.50	0.720	217	0.6	0.864	118	1.5	2.160	92	1.6	2.304		1.05	33113	5.1	644.1
dr38b	0.10	0.144	267	1	1.440	154	1.6	2.304	116	1.3	1.872		1.00	31536	25.3	124.6
dr39	7.00	10.080	248	10	14.400	221	14.3	20.592	188	10.00	14.400	147	10.33	325609	147.0	221.4
dr40	0.50	0.720	342	0.2	0.288		0.17	0.245	223	0.21	0.302		0.27	8515	5.2	164.1
dr42	0.42	0.605	1646	0.2	0.288	159	0.75	1.080	330	0.30	0.432	124	0.42	13166	4.8	274.3
															total	8803.0
															average	284.0

The best result was found to be of drain outlet dr37 which was 675.2 mm/a in depth with an average EC of 147 mS/m which can be interpreted as a good drain (Table 8). In contrast with this dr01 only drain 38 mm/a in depth with an average EC of 250 mS/m. Where good drainage exists 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.

3.7 Groundwater Chemistry

Samples for chemistry analyses were taken at 22 sites (Figure 43). The sites are a representation of all types of sites where monitoring took place, including drainage outlets piezometers and boreholes to compare the quality of the aquifer at a deeper level with the top layer and of the canal water.

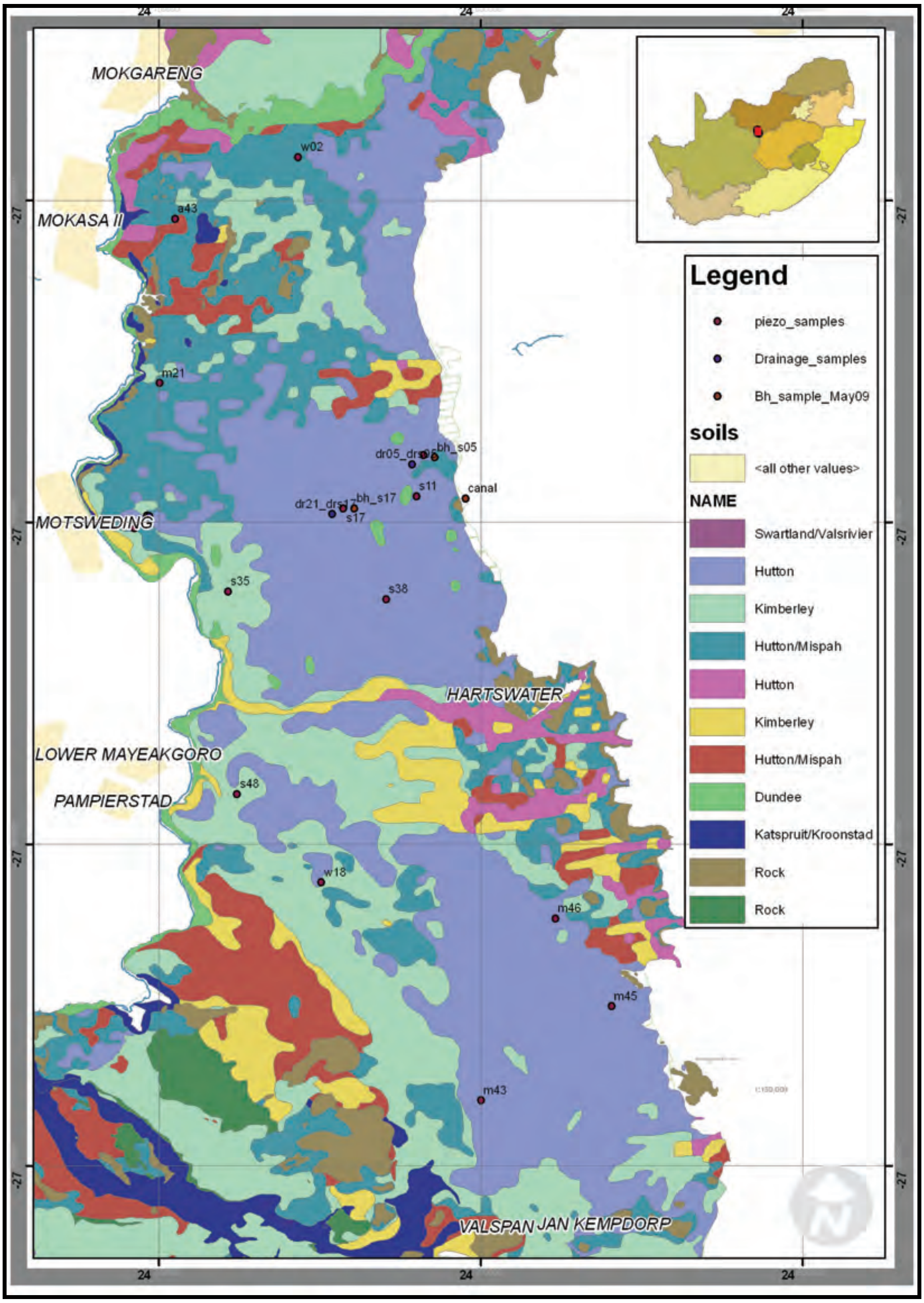


Figure 43: Chemistry sampling positions.

3.7.1 Chemical properties

The samples taken at 22 sites, representing boreholes, piezometers, drainage water and canal water, were chemically analysed by the laboratory of the IGS and the results are shown in Table 9.

Table 9: Chemical analyses results.

Field no	Lab no	pH	EC mS/m	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	PAlk mg/L	MAlk mg/L	F mg/L	Cl mg/L	NO3(N) mg/L	SO4 mg/L	Al mg/L	Fe mg/L	Mn mg/L	B mg/L	Mo mg/L	Zn mg/L	Br mg/L
Canal	21	8.12	66.6	44	22	51	10.91		112	0.28	56	0.04	134	0.029	0.045	0.006	0.131	0.004	0.023	0.17
BHB12	3	7.74	143	131.0	75.1	83.5	8.01	0	247	0.74	136.0	4.84	331	0.005	0.021	0.002	0.206	<0.003	0.010	0.71
BHS05	4	7.39	85	89.7	48.9	22.5	4.73	0	344	0.45	43.4	1.23	62	0.006	0.033	0.002	0.116	<0.003	0.017	0.29
BHS17	5	7.28	188	168.2	105.4	112.8	13.94	0	220	0.34	319.6	9.13	333	0.006	0.052	2.244	0.169	<0.003	0.014	2.10
A43	1	7.51	299	315.3	286.1	256.7	14.77	0	601	0.15	200.0	0.04	1428	0.004	0.038	2.629	0.239	<0.003	0.010	0.97
B12	2	7.30	708	997.9	542.0	274.7	6.68	0	198	0.98	3108.0	0.02	745	0.007	0.020	0.365	0.356	<0.003	0.021	15.63
M21	9	8.23	356	28.4	98.4	995.9	8.30	0	1207	16.82	409.0	0.03	732	0.060	0.051	0.004	1.339	0.027	0.008	2.28
M43	10	7.80	191	226.7	153.2	167.5	12.70	0	288	0.34	233.5	0.54	821	0.004	0.019	0.017	0.202	<0.003	0.009	1.17
M45	11	7.35	117	98.8	39.2	96.7	10.04	0	187	0.07	113.0	3.28	295	0.045	0.043	0.431	0.246	<0.003	0.016	0.43
M46	12	7.66	85.3	63.8	29.2	69.6	10.43	0	153	0.52	68.0	0.08	187	0.060	0.036	0.042	0.249	<0.003	0.007	0.22
S05	13	7.58	303	364.7	141.8	387.1	18.21	0	278	0.28	493.6	23.66	1258	0.052	0.060	0.959	0.201	<0.003	0.009	1.84
S11	14	7.63	75	72.2	19.9	61.2	7.76	0	118	0.40	66.0	1.82	156	0.068	0.188	0.007	0.127	<0.003	0.007	0.21
S17	15	7.68	144	88.6	34.5	191.9	17.94	0	309	0.11	152.0	3.47	242	0.009	0.025	0.039	0.217	<0.003	0.009	0.70
S35	16	7.75	177	123.9	89.9	157.5	7.13	0	273	1.71	200.0	10.14	358	0.061	0.097	0.034	0.238	<0.003	0.010	1.14
S38	17	7.79	80	59.4	24.3	67.5	9.81	0	138	0.44	69.0	0.04	161	0.062	0.098	0.024	0.135	0.003	0.009	0.21
S48	18	7.69	187	115.1	155.9	238.6	12.89	0	464	3.10	204.1	10.79	569	0.021	0.028	0.009	0.517	0.004	0.008	1.20
W02	19	7.87	132	82.2	72.2	106.5	5.69	0	246	2.81	134.0	6.84	228	0.011	0.022	0.195	0.204	0.006	0.014	0.54
W18	20	7.85	179	64.4	88.9	243.6	12.18	0	497	0.19	150.7	0.13	276	0.068	0.066	0.842	0.161	<0.003	0.009	0.32
DRB12	6	7.63	159	159.7	76.1	107.3	4.81	0	252	0.16	156.0	9.92	351	0.001	0.030	0.014	0.156	<0.003	0.014	0.61
DRS05	7	7.70	189	131.7	124.4	211.0	10.58	0	394	1.33	201.6	5.17	554	0.002	0.020	0.015	0.576	0.006	0.007	0.76
DRS17	8	7.39	155	131.1	67.6	127.6	10.55	0	226	0.22	149.0	<0.045	341	0.010	0.030	2.512	0.171	<0.003	0.027	55.85

3.7.1.1 Aluminium (Al)

Aluminium is no threat at the moment the Target Guideline is 0-5 mg/l (DWAF, 1993).

3.7.1.2 Boron (B)

The target Boron content is 0-0.2 mg/l. The sites with a Boron content of 0.2 to .9 mg/l can maintain crop yields of up to 95%. For moderately Boron sensitive crops when a 0.1 leaching fraction is maintained. For sites higher than 0.9 the decline in yields can be as much as 10% for moderately B tolerant crops. Irrigate to achieve a 0.15 leaching fraction with a low frequency irrigation application (DWAF, 1993).

3.7.1.3 Chloride (Cl)

The Chloride content of 56 mg/l (canal water) does not impose any danger to leaf damage to crops. The Chloride content in the groundwater of higher than 350 mg/l may have an effect when deciding which irrigation practices and what crop types should be planted (Cruywagen, 2001).

3.7.1.4 Iron (Fe)

Iron is an important plant nutrient. Contents in the plant of up to 5 mg/l is allowable, but high concentrations in the irrigation water can have an aesthetic affect on plants if applied by sprinklers (DWAF, 1993)

3.7.1.5 Manganese (Mn)

It is an important plant nutrient, but can be toxic if the levels reach more than 0.2 mg/l in acidic soils (DWAF, 1993).

3.7.1.6 Molybdenum (Mo)

At the levels recorded the Molybdenum is an important nutrient to the plant (DWAF, 1993).

3.7.1.7 Zinc (Zn)

At levels less than 1 mg/l Zinc is not toxic to plants and a very important nutrient (DWAF, 1993).

3.7.2 Hardness and sodium adsorption ratio

Hardness is calculated using the concentration of Ca^{2+} and Mg^{2+} of a water sample using the following formula (Weight, 2008).

Hardness in mg/l of $CaCO_3$ = (Ca in mg/l) X 2.5 + (Mg mg/l) X 4.1 (eq 3.7.2.1)

The term hard water is the tendency of water to precipitate calcium carbonate scale during evapotranspiration therefore it is given in $CaCO_3$ equivalents. It is possible for a sample of water to have a high Ca and Mg content (thus high Hardness) but low dissolved carbonate contents (Weight, 2008)

SAR or Sodium Adsorption Ratio is an indication of the sodium toxicity of irrigation water. The formula to calculate it is as follows.

SAR = Na/[$\sqrt{}${(Ca+Mg)/2}] (Garcia, 2008) (eq 3.7.2.2)

Na, Mg and Ca values must be in millimole per litre which is the mg/l divided by the molar mass. If you irrigate continuously with water containing a SAR value >10 it has detrimental effects on the crops. The same applies for crops that are continuously subjected to groundwater or water table with a SAR >10.

<u>For example:</u> SAR for sample of piezometer m21

Na = 995.9 mg/l

Ca = 28.4 mg/l

Mg = 98.4 mg/l

SAR = Na / [√ {(Ca+Mg) ÷ 2}]

SAR = (995.9 mg/l ÷ 22.99 mg/meq) ÷ √ [(28.4÷20.04 + 98.4÷12.16) ÷ 2]

SAR = 43.32 ÷ √ [(1.42 + 8.09) ÷ 2]

SAR = 43.32 ÷ 2.18

SAR = 19.87 (therefore too high for irrigation practices)

In a similar way the SAR values for all 22 samples were calculated (Table 10).

Table 10: SAR values for the 22 sample points.

Field no	Lab no	EC mS/m	Ca mg/L	Mg mg/L	Na mg/L	SAR	TDS mg/l
Canal	21	66.6	44	22	51	1.56767	
BHB12	3	143	131.0	75.1	83.5	1.439942	
BHS05	4	85	89.7	48.9	22.5	0.475129	
BHS17	5	188	168.2	105.4	112.8	1.679219	
A43	1	299	315.3	286.1	256.7	2.520411	2310
B12	2	**708**	**997.9**	**542.0**	274.7	1.739502	5740
M21	9	356	28.4	98.4	**995.9**	**19.86109**	2940
M43	10	191	226.7	153.2	167.5	2.107684	1520
M45	11	117	98.8	39.2	96.7	2.082068	830
M46	12	85.3	63.8	29.2	69.6	1.811272	
S05	13	303	364.7	141.8	387.1	4.357854	2595
S11	14	75	72.2	19.9	61.2	1.643271	565
S17	15	144	88.6	34.5	191.9	4.381528	971
S35	16	177	123.9	89.9	157.5	2.629839	
S38	17	80	59.4	24.3	67.5	1.864796	553
S48	18	187	115.1	155.9	238.6	3.406233	
W02	19	132	82.2	72.2	106.5	2.068254	848
W18	20	179	64.4	88.9	243.6	4.620506	1170
DRB12	6	159	159.7	76.1	107.3	1.749188	
DRS05	7	189	131.7	124.4	211.0	3.166784	
DRS17	8	155	131.1	67.6	127.6	2.256201	

These values were plotted on the US Salinity Laboratory irrigation water quality diagram (Figure 44) to establish if the soil is still suitable for irrigation farming. All the examples have a salinity index of high to very high but only one, m21 has a SAR of more than 10. This piezometer however is not in an irrigation land but on the edge of a wetland about 460 m away from the nearest cultivation. This is however on the edge of a wetland area which is a concern. There are no irrigation and farming taking place at this position but salt are still accumulating and has a negative influence on natural plant growth.

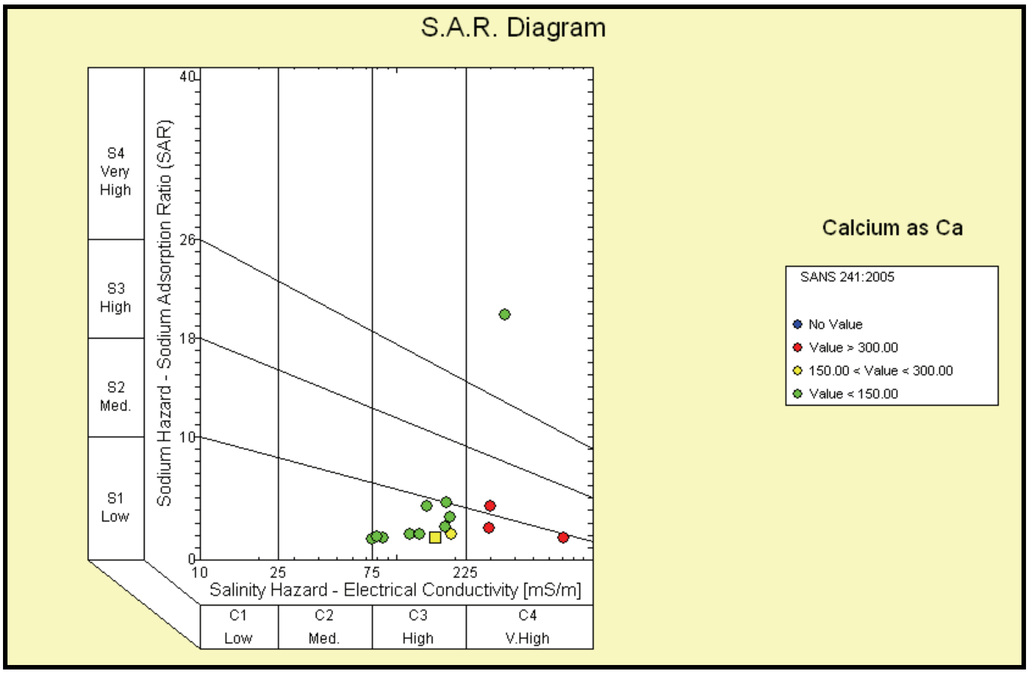


Figure 44: Plot a variety of water samples on the US Salinity Laboratory irrigation water quality classification diagram (1954).

The electrical conductivities as shown in Table 10, is mostly within the range 60-250 mS/m. The two highest values are those of two piezometers b12 and m21. With b12, the highest, positioned in an area were the clay content is >20%, certainly has an effect of natural and installed subsurface drainage and the hydraulic conductivity causing a salt built up.

Figure 45: Photo of crystallised salts on the surface near Piezometer m21.

Piezometer m21 is installed on the edge of a wetland were salt crystals can be seen on the surface and drainage and infiltration are low. Salts therefore do not wash out easily although a drop can be seen in the EC values. This was mainly caused by rainfall figures higher than the norm, almost twice the normal in November 2008 and February 2009 (Refer to Figure 45). The rainfall had a decreasing effect on almost all EC values on the diagram and in the scheme (Figure 46).

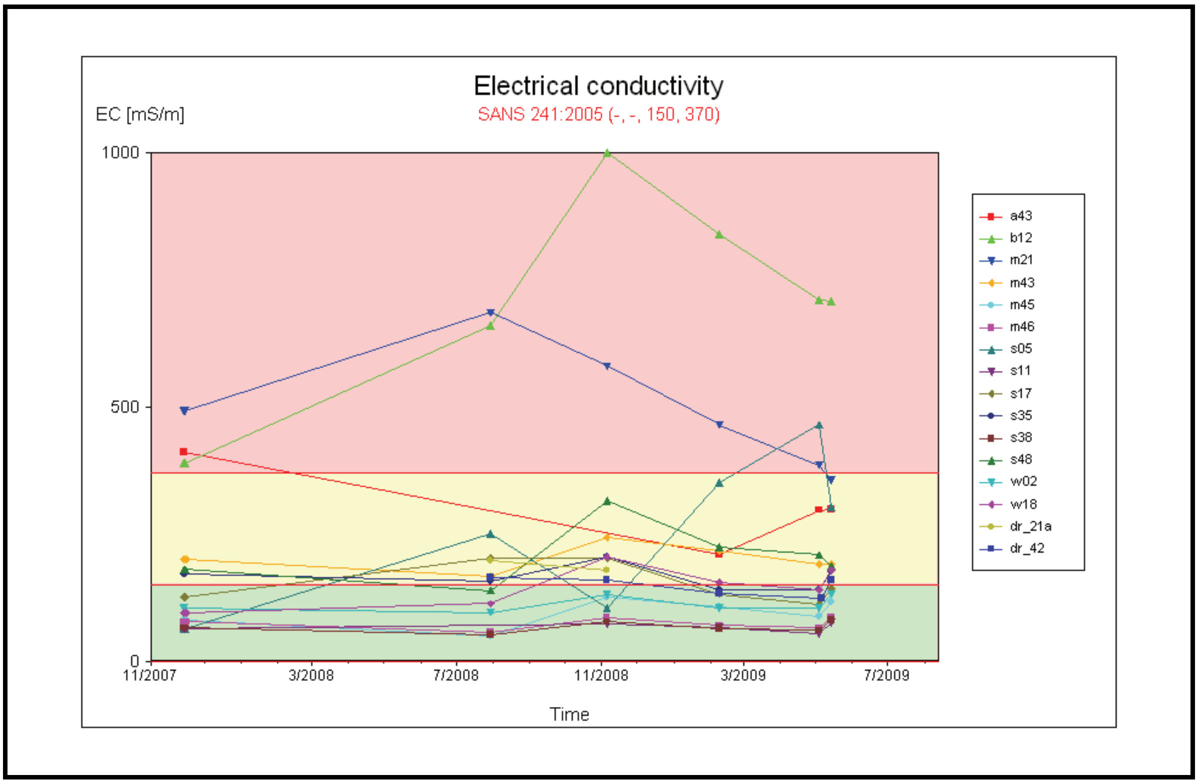


Figure 46: Electrical conductivity of piezometers and drains water samples taken at the selected sites.

Water with a low salinity in the order of 0.005 mS/m can also cause infiltration problems. It leaches salts from the soil and may cause clay particles to dispense, blocking soil pores or forming surface seals. The result is that less water can infiltrate into the soil column. Soil crusting makes it difficult for crops to emerge (Ayres and Westcott, 1985).

3.7.3 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, on the level of the subsurface drains and beneath the subsurface drains at the bottom of the piezometers.

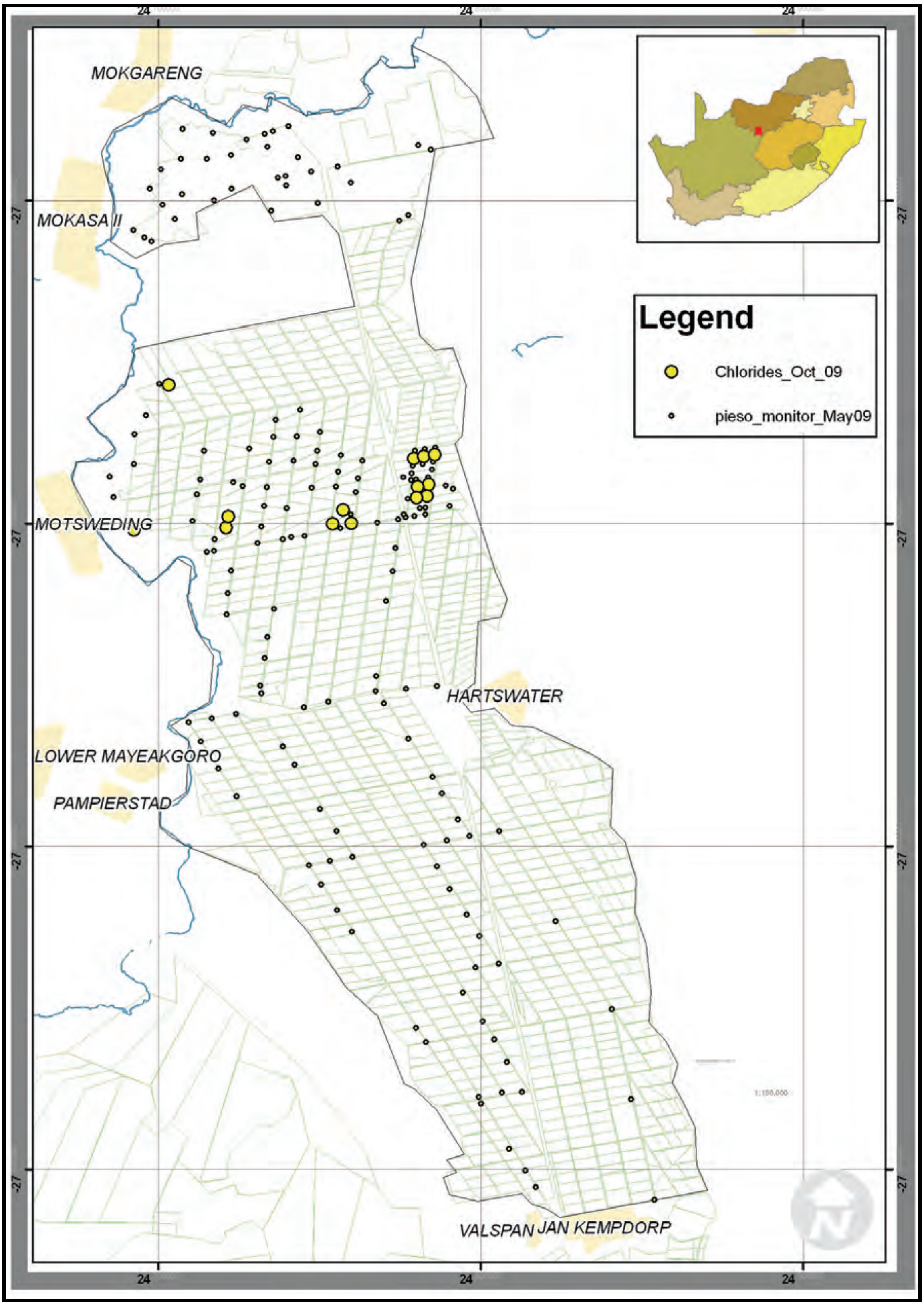


Figure 47: Sites where samples for chloride analyses were taken.

The reason for the sampling was to determine if the irrigation water are passing the subsurface drainage system and if the soil type influence the drainage the result however did not give any indication.

Table 11: Chloride analyses data.

Position	EC mS/m	Groundwater Level Cl mg/l	Drainage Level Cl mg/l	Beneath Subsurface Drains Cl mg/l
B12	835	3230	3300	3315
J06	173		190	200
J08	89	159	160	
J09	236	245	272	
J10	57	57	59	
J15	144	117	149	
J17	98	229	230	
J19	59	59	62	66
J22	91	115	116	
M20	173	104	208	
S05	98	558	554	584
S06	65	64	70	
S11	49	54	55	57
S17	124	151	146	148
Canal	66	56		

The following conclusions were made from the data in Table 11:

- All five positions where sampling was done beneath the subsurface have higher chloride concentrations than above the drains indicating, water are draining pass the installed subsurface drains.

- The drainage at J19, J10, S11 and S06 is functioning well there are only minimal chloride build up.

- Chloride at S05 is building up; this was a reflection of the EC measurements in the piezometer. Piezometer S05 is the centre piezometer of nine in a macadamia orchard and the EC at this position were usually higher than the other eight during the monitoring period. This may indicate that the site is stratified but was not obvious when the measurement for the determination of stratification was done.

- At B12 the clay index was 28% this affects the leaching of chloride in the area. The water table were only 200 mm bgl during a measurement period, chloride are accumulating due to the slow drainage tempo.

- M20 is on the border of a wetland with no subsurface drains, the reason for the chloride concentration being lower at the groundwater level than at the bottom of the Piezometer can be the existence of a clay layer on top of what can be a silt or surface evaporation.

3.7.4 Total Dissolved Solids

The EC and TDS values of the samples taken (Refer to Table 10), were used to determine what was the TDS conversion factor to convert EC to TDS (Figure 48). This conversion factor (TDS = 7.669 + 5.37 X EC) will be used to determine the salt load when calculating the Salt Balance.

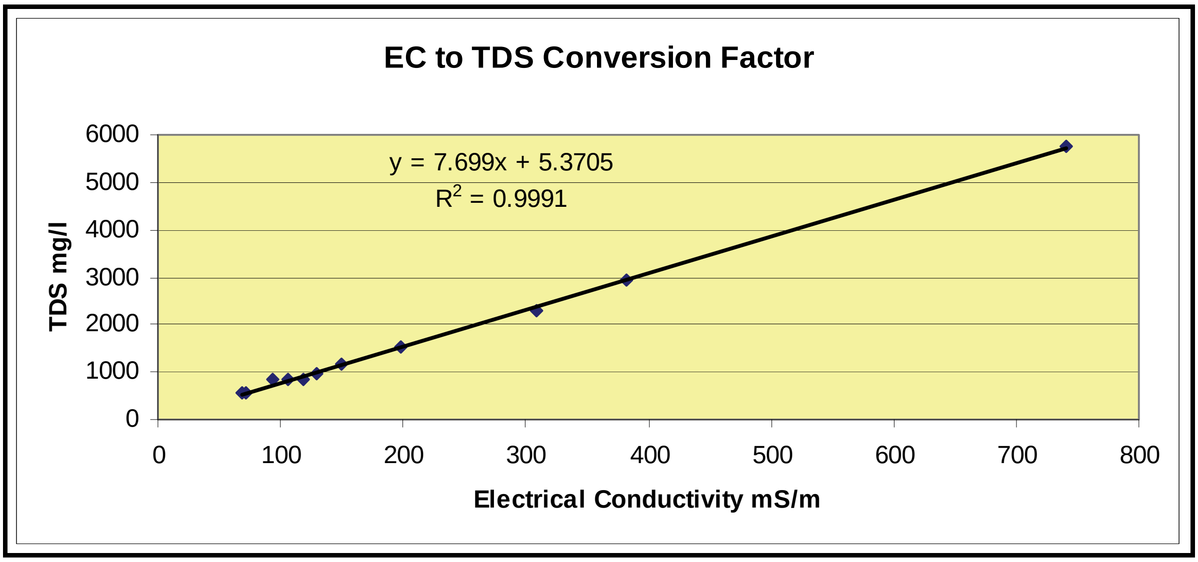


Figure 48: Conversion factor Electrical Conductivity to Total Dissolved Solids.

4 Numerical Modeling

To develop a better understanding of the groundwater flows and reactions to different property inputs a model can be set up.

Under the heading “background information:”, data were presented on;-runoff, rainfall, temperature, evapotranspiration, topography, soils, crops and irrigation types all of which are factors that form part of the input required to set up a numerical model.

“There is no such thing as a perfect model. The application of numerical simulation models to groundwater problems involves both an art and a science” (Middlemis, 2000).

4.1 What is a Model

The complexity of groundwater systems makes it almost impossible to evaluate it in a comprehensive way. Data forms an integral part of a model and the less known the more untrue the outcome of the modelling process will be. Data are almost always not adequate and assumptions are made to get to workable solution to determine the character of a groundwater system. The model assists in the development of a tool to predict the groundwater reactions but is limited by the assumptions and limited data input.

Using the software it is only possible to represent a hydrogeological scenario using two components namely a conceptual model and mathematical model. A conceptual model is often a graphical representation of the way the hydrogeological flows in the system is understood. A mathematical model uses one’s inputs and with assumptions and a set of equations that calculates the physical processes in the groundwater system. In other words it is a scientific method to synthesise collected data and create a numerical groundwater system. This model then acts as a prediction tool to quantify pumping and irrigation stresses and other effects. This can be helpful to determine and or forecast impacts of certain interventions to develop a management plan to counter negative outcomes. This is not the alpha and omega but a tool to assist in decision making (Middlemis, 2000).

4.1 Model Development

To set up a groundwater model the following steps can be followed:

⇒ Model objectives, i.e. the purpose of using the groundwater model. This will have an effect on the impact on the modeling attempt.

⇒ Hydrogeological Characterization, to understand the importance of hydrogeological conditions at a site in order to set the model up correctly and to be appropriate.

⇒ Model Conceptualization, i.e. the collection of field condition data that will help to explain the groundwater flow and possible contaminations at a specific site. (Kumar, 2009)

⇒ Setting up a model using flow model software

⇒ Calibrating the model by adjusting the initial values in order to get the output of the model as close as possible to observed data

⇒ Comparing in this case the drain flows to that of what was measured, as a comparison / check.

The modelling program used is MODFLOW and it uses a finite calculation process. The finite difference equation states that the sum of all in flows into a cell + the outflows must be equal to the rate of change in storage in the cell.

Numerical models go through a process of iteration to solve the finite difference equations. A solution is determined for every time step of the finite difference equation. It would be ideal to stop the process the moment the calculated initial heads are close to those measured. Since this is not possible another method is used to shorten the process.

Commonly the method is to stop by specifying the required iteration difference of subsequent calculations. This ensures that when the change in head reaches the minimum specified the iteration process is complete. The value for this minimum difference is usually 1-10 mm.

4.2 Conceptual inputs

To enable the compiling of a conceptual model various field test were done and information gathered during the background study. Information was gathered from data of the weather services, previous WRC reports, Department of Agriculture Forestry and Fisheries (AGIS network), the Department of Water Environmental Affairs and the University of the Free State. Information also included the fieldwork and monitoring of ECs and water levels of 248 piezometers.

The geology, run off, temperature, topography, surface runoff and rainfall were discussed in chapter 2. The hydraulic conductivity and drainage values were determined on site (See chapter 3.5 and 3.6).

4.3 Numerical model

A hypothesis was made to determine how much of the irrigation and rainfall water are being drained by the installed drainage system in place. This was done by making use of the MODFLOW modelling package. The model was set up as a steady state model the drain zones was applied and the water levels, generated by the model, were compared to what was measured. The water levels were the elevation simulated by the model in a single cell. The model is a grid of 100 m X 100 m cells, divided in columns and rows. These cells are small enough to obtain a good representation of water levels. The piezometers were all 300 m and further apart.

- Model size: The initial model was built up by 210 columns X 390 rows (Figure 49) to run and compare the initial hydraulic heads simulated to those measured. The model was compressed to focus on the K block to conduct drain simulation in zones for the area where drainage monitoring took place.
- The K block model was 210 columns X 40 rows.
- Single layer, thickness of 5.0 m (piezometers installed 3.0 mbgl at the deepest) was imposed as a sand layer.
- Recharge = 0.00198 m/day (precipitation only).
- Saturated hydraulic conductivity between 0.013 and 5.4 m/day as were determined in chapter 3.5 and visualised in Figure 41.
- Porosity = 25%.
- Evapotranspiration (chapter 2.6.2) = 0.002 m/day.
- Initial Hydraulic heads = heights determined during May 2009 monitoring.

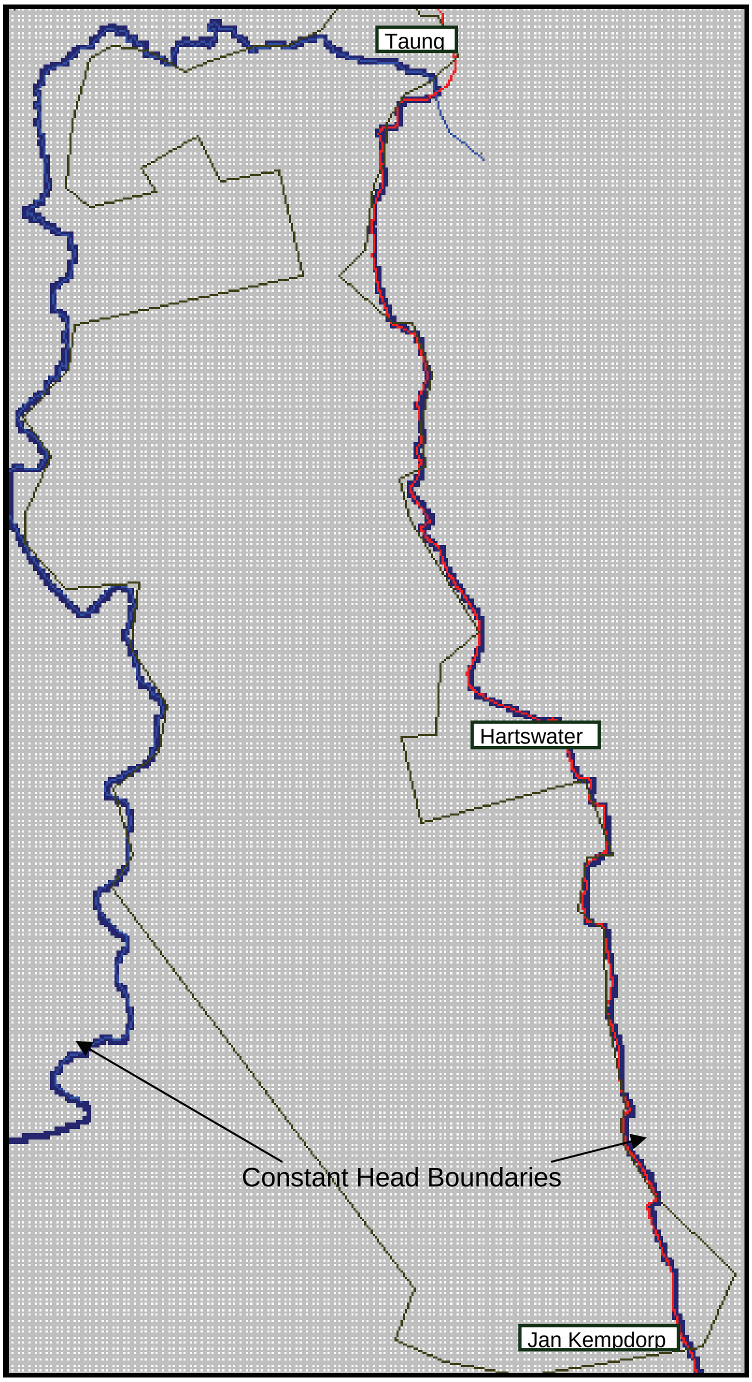


Figure 49: Research area as a grid in MODFLOW.

The data from RSA DTM20m was interpolated and used as the top layer of the model. The bottom layer was interpolated using the water level measurements of the May 2009 monitoring. The Bayesian method of interpolation could be used to determine initial hydraulic head contours since the correlation between water levels measured and the topographic height is over 80% (Refer to section 3.3.2). The model indicated that water flowing perpendicular to the contours will end up in the Harts River (Figure 50).

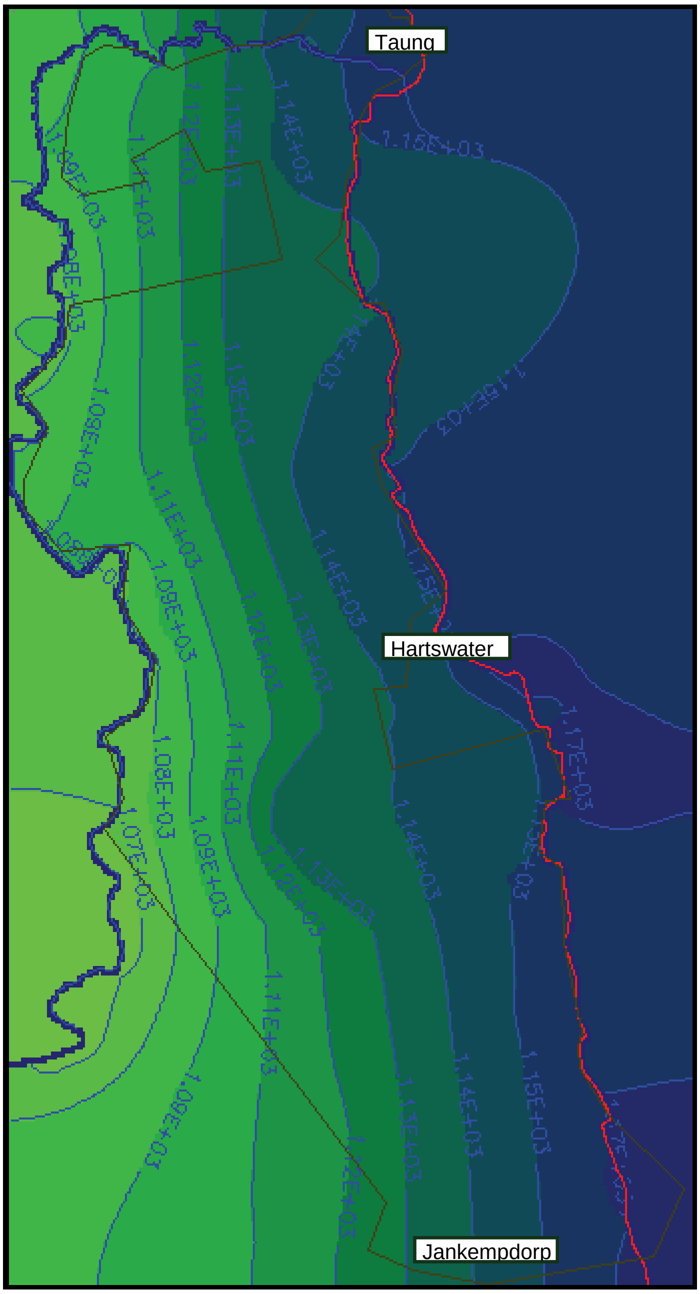


Figure 50: Contour map of water levels (Hydraulic Heads) as developed by MODFLOW.

4.4 Drain Modelling

The way the drainage package of MODFLOW function can be described as follows. The hydraulic head of the cell simulated is compared to the drain that cell represents. If the initial head is greater, the water "flows" into the drain to obtain the same level as that of the drain.

A total of 57 drains had to be simulated by zones to be able to cover all the drains in the K Block. However the MODFLOW program allows only 20 drain zones. This was not enough for the K block due to the elevation difference of 80 m from east to west and the simulation layer being 5.0 m thick.

The effect of a non-zoned area on the water levels in the zone next to it made it difficult to draw the water level down to the measured values. This necessitated to the splitting of the K block into three areas (Figure 51).

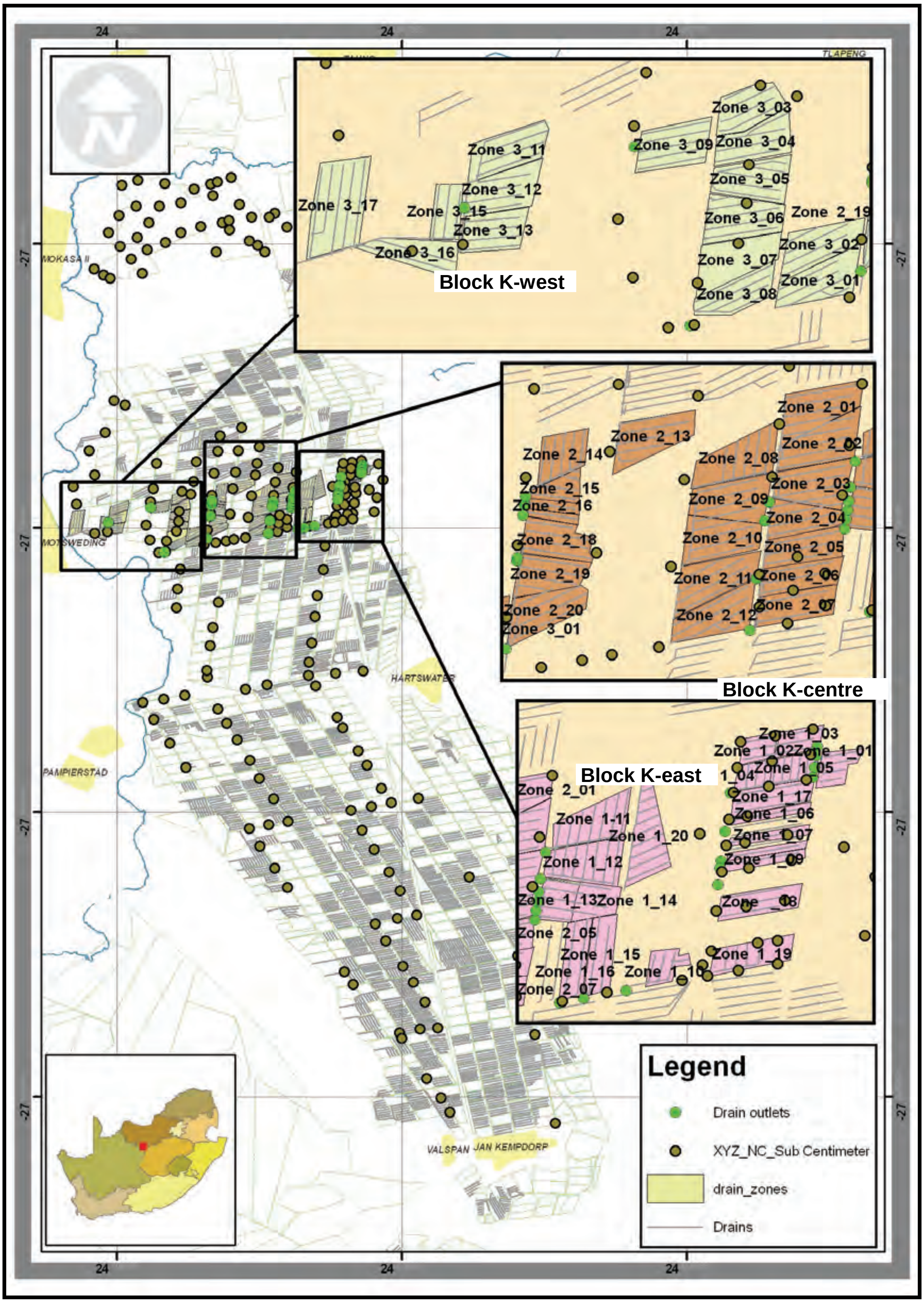


Figure 51: Map indicating three drain zone sections.

4.5 Water Budget

Zones were assigned to 57 areas to simulate the drains by using the zone input method. Different zone numbers, hydraulic conductance and height of the particular drain above the sea level were assigned to each zone. And the values were determined as the drain results representing the sub surface drains in the K block.

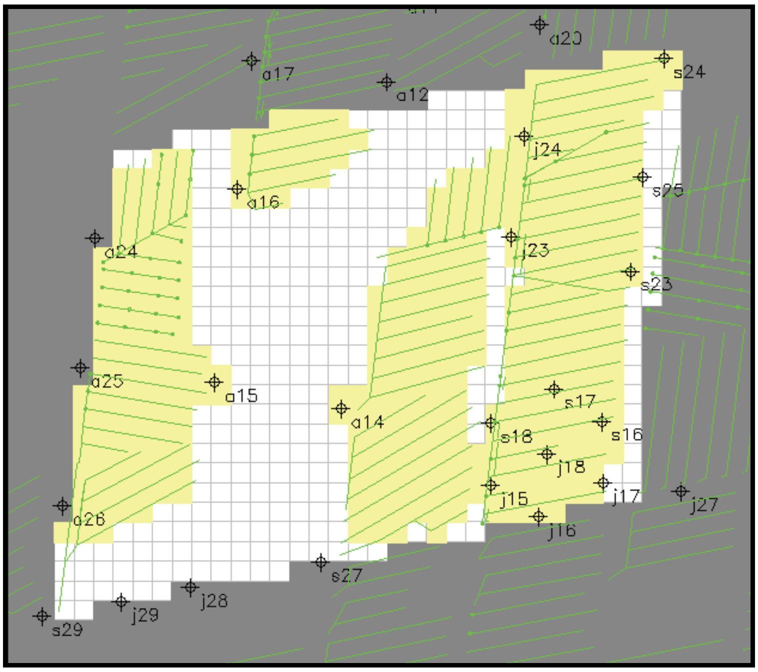


Figure 52: Zones, Block K-Centre as modelled.

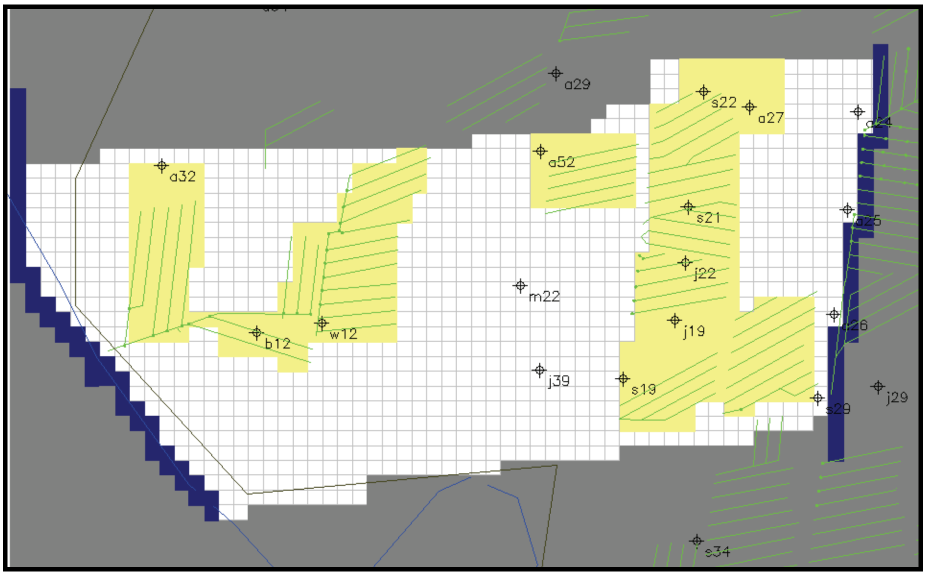


Figure 53: Zones, Block K-West as modelled.

The water budget was determined for the 57 zones and compared to the drainage outflows that were measured on 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 (Refer to Table 12).

Table 12: Comparison of Drainage measured and Zone outflows as modeled.

		Drainage Modelled	Drainage Measured	Area Drained	depth drained measured	depth drained modelled
drain nunmber	zone number	m^3/day	m^3/day	Ha	mm	mm
dr20	2_01	108.5	1252	149.8	305.13	335.86
	2_02	96.7				
	2_03	406.6				
	2_04	190.1				
	2_05	76.2				
	2_06	189.99				
	2_07	310				
	Total	1378.09				
dr21b	2_05	72.75	205.2	7.0	1069.97	379.34
dr23	2_04	55.95	59.83	3.6	606.61	567.28
dr24	2_03	203.3	59.62	10.6	205.89	702.07
dr33b	2_14	119.91	27.648	4.0	251.53	1090.89
dr34	2_15	44.22	43.2	4.1	380.37	389.35
dr35	2_17	45.57	49.68	4.3	421.07	386.24
dr37	2_18	109.49	136.08	11.2	443.48	356.82
dr38a	2_19	135.69	90.72	5.1	644.13	963.43
dr38b	2_20	535.14	86.4	25.3	124.58	771.64
dr39	3_03	457.32	892.08	147.0	221.44	493.97
	3_04	113.74				
	3_05	465.98				
	3_06	256.9				
	3_07	341.05				
	3_08	355.02				
	total	1990.01				
dr40	3_09	116.28	23.328	5.2	163.74	816.20
dr42	3_12	44.04	36.072	4.8	274.30	334.89
				average	393.25	583.69

The best correlation is at drain outlet dr20 serving zones 2_1 to 2_7. The difference was only 30.7 mm for a period of a year but only 52.3 and 57.6% of the modelled drainage need of 584 mm/a. The largest difference is 839 mm and the measured value was 23% that of the 1090 mm/a modelled. On average the drainage outflows measured was 67.4% of the modelled average of 583.7 mm/a.

5 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. Furthermore it must be estimated were the salt build up is taking place. A previous studies by Herold and Bailey (1996) indicated that almost 100 000 t of salt are not being accounted for. A study done by Gombar and Erasmus (1976) measured a TDS average of 1005 mg/l. Another study conducted by Ellington et al. (2004) indicated that the TDS is 1350 mg/l, an average increase of 13 mg/l per year.

This study found the average EC 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 some of the salts accumulated in the upper 3.0 m layer.

5.1 Salt balance

All soils contain salts as a result of the weathering of rocks, and are eventually leached and dissolved and transported to the sea. Frequent salinisation of soils causes the reverse of the leaching process and can be seen as a secondary salinity (Smededa and Rycrofft, 1983).

5.1.1 Leaching Requirement

Leaching requirement is a calculation of the leaching that is required to keep soil salinity at a level that crops can tolerate. Leaching fraction is the degree (fraction) of water that is actually leached.

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 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).

Leaching requirements can be calculated with the formula:

$Dp = (Di \div Ci) \div Cp$ Eq 5.1.1.1

Where $Di = (ET - Dr) \div [1 - (Ci \div Cp)]$ Eq 5.1.1.2

Ci = EC of the irrigation water

Cp = EC of the Drainage water

Dr = Effective rain

ET = Evapotranspiration

Dp = Leaching requirement

Table 13: Leaching requirement calculations.

EC values at drainage outlets in block K						
			Aug-08	Nov-08	Feb-09	May-09
		drain	EC mS/m	EC mS/m	EC mS/m	EC mS/m
		dr01	252	251	313	231
		dr02	243	201	250	219
		dr03	116	187	126	151
		dr04	119	187	127	155
		dr05	203	226	171	165
		dr06	193	270	192	209
		dr07	175	224	182	176
		dr08	189	217	182	173
		dr09	139	158	132	141
		dr13	257	227	177	168
		dr16	238	190	158	161
		dr39	248	221	188	147
		dr42	164	159	330	124
		Total	2536	2718	2528	2220
		Average	195.06	209.08	194.46	170.77
Leaching requirement Calculations						
Effective rain depth	mm/d	Dr =	1.18	1.18	1.18	1.18
EC of Irrigation water	mS/m	Ci =	66	66	66	66
EC drainage water	mS/m	Cp =	195	209	194	170
Evapotranspiration	mm/d	ET =	4.34	4.34	4.34	4.34
Di = (ET-Dr)/(1-Ci/Cp)	mm/d	Di =	4.77	4.61	4.78	5.16
Dp = (Di X Ci)/Cp	mm/d	Dp =	1.61	1.46	1.63	2.00
Leaching requirement Dp	mm/a		589.4	531.7	594.0	731.1
Total						2446.2
Average requirement	mm/a					611.5
Average requirement	mm/d					1.67

The leaching fraction was calculated by using the formula using the average EC of the drainage water of block K. The EC of drainage water, where monitoring was performed where possible for all four seasons, was considered and the leaching requirement was determined to be 611.5 mm/a (Refer to Table 13). The 583.7 mm/a drainage needs that was modelled (Refer to Table 12) compares well with the leaching fraction of 611.5 mm/a. The measured drainage average was 284 mm/a (Refer to Table 8) which imply that the drainage is not effective.

5.1.2 Flow beneath subsurface drains

Another method that can be used to compare the flows is by using the Darcy equation:

$Q = KiA$

Therefore $P \times C_p + I \times C_i - Et \times C_{et} - Dr \times C_{dr} = KiA \times C_{gw}$

Q = all the inflows – the outflows (m^3/d)

K = Hydraulic Conductivity (m/d)

i = the gradient 0.7

A = (depth of flow beneath the saturated level) X length of the irrigated area (perpendicular to the flow direction) (m^2)

P = Precipitation (m^3/d)

C_p = EC (mS/m) of the precipitation

I = Irrigation (m^3/d)

C_i = EC (mS/m) of the Irrigation water

ET = Evapotranspiration

C_{et} = EC of Evapotranspiration (m^3/d)

Dr = Drainage (m^3/d)

C_{dr} = EC (mS/m) of the drainage water

C_{gw} = EC (mS/m) Groundwater (in the boreholes)

(See results in Table 14).

Table 14: Calculations for the confirmation of salt balances using the K values.

											Zone Area				
	Method	Area	Irrigation	C_i	Precipitation	C_p	ET	C_{ET}	Drainage	C_{dr}	length	depth	Gradient	C_{gw}	K
Site	used	ha	m^3/d	mS/m	m^3/d	mS/m	m^3/d	mS/m	m^3/d	mS/m	m	m	i	mS/m	m/d
s17dr20	measured	149.8	3751.0	66.00	1768.00	1.00	3176.00	1.00	1252.00	126.00	2400	0.30	0.70	188.00	0.93
s17/dr20	modelled	149.8	3751.0	66.00	1768.00	1.00	3176.00	1.00	1378.00	126.00	2400	0.25	0.70	188.00	0.92
s05/drs05	measured	30.0	751.0	66.00	354.00	1.00	636.00	1.00	97.00	210.00	506	0.19	0.70	85.00	5.19
s05/drs05	modelled	30.0	751.0	66.00	354.00	1.00	636.00	1.00	179.00	210.00	506	0.08	0.70	85.00	5.18
b12/dr42	measured	4.8	125.0	66.00	86.40	1.00	104.00	1.00	36.10	151.00	90	6.00	0.70	143.00	0.05
b12/dr42	modelled	4.8	125.0	66.00	86.40	1.00	104.00	1.00	44.00	151.00	90	3.50	0.70	143.00	0.05

This method could be used for these three drains because samples were taken at boreholes in the proximity of these subsurface drain outlets to determine the EC of the groundwater. Not one of these drains is effective.

The calculations were used to investigate if the hydraulic conductivity that was determined in field investigations (section 3.5) can be used to estimate the depth of the subsurface groundwater flow in the soil is beneath the subsurface drainage in place.

The highest value for the depth is 6 m at b12. This is in an area were the EC of the water in the piezometers were high during the monitoring period, values of 660, 1000, 841 and 711 mS/m were measured. The clay content was high 28% (Figure 12). All these facts emphasize why a salt build up is taking place in the area and will build up in similar scenarios.

5.2 Water balance

The average EC for the piezometers is 191 mS/m and that of the irrigation water 66 mS/m for the period monitored. The evapotranspiration for the 2008/2009 season is 4.3 mm/d. These values are reduced when considering the water demand of a plant at different stages (Figure 9). The estimated evapotranspiration on an area where wheat and maize are planted is 743 mm/a. The effective rainfall is 431/365 = 1.18 mm/d. The recharge is 5% (Vegter, 1995) of rainfall + irrigation equalling 6.9 mm. Tailends are 49 mm and runoff 5.7 mm/a (Ellington et al., 2004).

Table 15: Water balance values for the Research area.

	Inflows (mm/a)	Outflows (mm/a)
Irrigation	980	
Rainfall	431	
Tailend		49
Recharge @ 5%		21
Drainage		?
Run-off		5.7
Evapotranspiration		774
Total	1411	849.7
Therefore drainage (1411-849.7) / 365 = 1.54 mm/d = 562.1 mm/a		

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 (Refer to Table 15).

5.2.1 Water loss estimation

To balance the inflows and outflows the following calculation should be true:

Irrigation (I) + Precipitation (P) – Drainage (D) – ET = 0 (Refer Table 16)

This is definitely not the case here therefore the water table should rise. The water table had risen from 24 mbgl at the start of the irrigation, but it settled after the installation of the subsurface drainage implying that some of the water has been lost from the irrigation and drainage system (Herold and Bailey 1996).

Table 16: Water balance values and loss determination.

Losses per drainage area								
Drain	Area	Drainage	Irrigation	Precipitation	Drainage	ET	Q	
nr	ha	m^3/d	$m^3/ha/d$	$m^3/ha/d$	$m^3/ha/d$	$m^3/ha/d$	m^3/d	mm loss/a
			I	**P**	**D**	**ET**	**Q**	
dr20	149.8	1252	25.00	11.80	8.36	21.10	7.34	267.99
dr21b	21.0	205.2	25.00	11.80	9.77	21.10	5.93	216.39
dr23	10.8	59.83	25.00	11.80	5.54	21.10	10.16	370.85
dr24	10.6	59.62	25.00	11.80	5.64	21.10	10.06	367.16
dr33b	4.0	27.648	25.00	11.80	6.89	21.10	8.81	321.52
dr34	4.1	43.2	25.00	11.80	10.42	21.10	5.28	192.68
dr35	4.3	49.68	25.00	11.80	11.54	21.10	4.16	151.98
dr37	11.2	103.68	25.00	11.80	9.26	21.10	6.44	235.16
dr38a	8.0	90.72	25.00	11.80	11.34	21.10	4.36	159.14
dr38b	18.1	86.4	25.00	11.80	4.77	21.10	10.93	398.82
dr39	147.0	892	25.00	11.80	6.07	21.10	9.63	351.57
dr40	5.2	23.328	25.00	11.80	4.49	21.10	11.21	408.98
dr42	10.0	36.072	25.00	11.80	3.61	21.10	12.09	441.39
							Total	3883.63
							Average	298.74

This "loss" can be determined from the Inflows and outflows balance.

5.2.2 Inflow, outflow and leaching requirement balance

The drainage values measured + the losses determined in section 5.1.2 should be equal to the leaching requirements calculated in section 5.1.1. If this is true the Inflow and outflow is in balance.

Table 17: Comparison of the water balance values.

Water balance = Measured Drainage values + Loss					
Drain	Loss	Drainage water	total	Leaching Requirement	Balance
nr	mm/a	mm/a	mm/a	mm/a	%
	a	**b**	**a + b**	**Dp (Table 12)**	**(a + b)/Dp**
dr20	268.0	305.3	573.29	611.50	93.75%
dr21b	216.4	303.3	519.69	611.50	84.99%
dr23	370.8	303.3	674.15	611.50	110.24%
dr24	367.2	205.9	573.06	611.50	93.71%
dr33b	321.5	251.5	573.02	611.50	93.71%
dr34	192.7	380.4	573.08	611.50	93.72%
dr35	152.0	421.1	573.08	611.50	93.72%
dr37	235.0	675	910.00	611.50	148.81%
dr38a	159.1	644.1	803.24	611.50	131.36%
dr38b	398.8	124.6	523.42	611.50	85.60%
dr39	351.6	221.4	572.97	611.50	93.70%
dr40	409.0	164.1	573.08	611.50	93.72%
dr42	441.4	274.3	715.69	611.50	117.04%
				Total	1334.06%
				average	102.62%
		Total if losses at dr37 and dr38a is zero			1253.00%
		Average if losses at dr37 and dr38a is zero			96.39%

A correlation of 102.6% is reached by the calculation. Drains dr37 and dr38b are effective. The losses from these two drains will be due to malfunctioning drains adjacent to it. If the losses at these two drains are left out of the equation the balance is 96.4%.

6 Findings and Recommendations

6.1 Findings

- The Vaalharts Irrigation scheme was initiated by a Mr Ford in 1875 but was only approved by the Government in 1933. The first farmers started farming and constructing the weir and open ditch soil canals.

- In 1938 farmers were able to make a living of a plot of 25 ha these days a farmer need 3 plots.

- 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.

- 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 to drain the water with 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 manganese 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 rainfall for the monitoring period of a year to cover all seasons was 530 mm.

- The total evapotranspiration for the area that is predominantly planted with cash crops was 774 mm for the research period.

- 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 threat.

- 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 (implying a leaching fraction of ~ 0.3).

- 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, m21 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.

6.2 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.

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