Application on Groundwater/Surface water Interaction Modeling in the Schoonspruit Catchment

H. G.Maré[1], J.I. Rademeyer[2], K Sami[3]

[1] WRP Consulting Engineers (Pty)Ltd, HG. Maré
[2] WSM Leshika Consulting (Pty)Ltd, K. Sami
[3] Department of Water Affairs and Forestry, Directorate: Water Resource Planning Systems, JI. Rademeyer

Abstract

Under natural conditions approximately 50% of all the flow in the Schoonspruit catchment, comes from the Schoonspruit Eye, emphasizing the importance of the correct simulation of the eye flows. The aim was to develop a refined water resource model, based on existing information and data, which is capable of simulating the groundwater / surface water interaction. The K Sami groundwater surface water interaction model (still in its testing stage) was used to model the flow from the Schoonspruit Eye. Results were fed into the WRYM, to model the combined effect of ground and surface water on water availability in the catchment. The experience gained by using the Sami model for the Schoonspruit Eye simulations, contributed to several changes and improvements to the model. This resulted in acceptable calibrations on observed flow under natural and developed conditions which could not be achieved by earlier models.

Keywords: *Schoonspruit groundwater/surface water interaction*

1 Introduction

As part of the Middle Vaal Internal Strategic Perspective (ISP) workshops, cursory analysis of the Schoonspruit Sub-system was carried out, which indicated that the users receiving water from Johan Neser Dam may be experiencing shortages in water supply.. Although the course resolution of the existing water resources network model is acceptable to simulate the larger Vaal River System, it has been identified that to be able to undertake allocation decisions within the Schoonspruit System, it is necessary to refine the existing model configuration. A further important characteristic of the Schoonspruit System, which has not been explicitly simulated in the existing system model, is the strong interaction between groundwater and surface water resources due to dolomitic compartments that are located in the upper portion of the Schoonspruit Catchment.

There are significant pressures on the water resource of the sub-system from users abstracting water from both the groundwater and surface water resources and judicious planning and management is required to ensure equitable allocation of the available water resources

The Department of Water Affairs and Forestry has appointed PD Naidoo & Associates (PDNA) to carry out a situation assessment study for the Schoonspruit System and adjacent catchments. The purpose of the study is to describe the situation in the catchment, which will form the basis to compile strategies for the management of the water resources. The study also includes a groundwater assessment component that will provide more clarity on the availability and level of utilisation of the groundwater resources.

The purpose of this sub-component of the study is to develop a refined water resource model, based on existing information and data, which is capable of simulating the groundwater / surface water interaction by catering specifically for the dolomitic compartments in the catchment. This model will be used to support the determination of the Reserve and the development of catchment management strategies, which are both the subject of the current study undertaken by PDNA for the DWAF.

2 Hydrology

The observed flow from the Schoonspruit Eye was not available when the hydrology for the Vaal River Analysis Update (VRSAU) study was created. Observed flows from the eye indicated an average flow of in excess of 50 million m³/a, which is far more than the 28 million m³/a assumed in the VRSAU study. The hydrology for the Schoonspruit catchment was therefore re-calibrated and the recently developed groundwater surface water interaction model by Sami was used to model the flow from the Schoonspruit Eye. An improved calibration was obtained and the outflow from the Schoonspruit under natural conditions was estimated at 105 million m³/a in comparison with the 96 million m³/a from the VRSAU study. Under natural conditions approximately 50% of all the flow generated in the Schoonspruit catchment, comes from the Schoonspruit Eye, which emphasizes the importance of the correct simulation of the eye flows. The updated hydrology is therefore definitely an improvement on the VRSAU hydrology and can be used with more confidence.

3 Groundwater

3.1 Cumulative Rainfall Departure (CRD) method

Previous work on the modeling of the flow from the Schoonspruit Eye was done by S Veltman and the cumulative rainfall departure (CRD) method was used for this purpose. The main drawback of this method was that it could not model the effect of large abstractions for irrigation purposes via boreholes from the dolomitic aquifers. This is clearly evident from Figure 1, showing the large discrepancy in observed and modeled flows since 1986, when severe increases in groundwater abstraction from the dolomites took place.

The rainfall record used for the previous calibration carried out by S Veltman only cover the period 1954 to 2001 and was obtained from a rain gauge located in Ventersdorp. For the purpose of the hydrology calibration for the Schoonspruit system a record period from 1920 to 1994 is however required. The Ventersdorp rainfall record unfortunately does not have data available for the period prior to 1954 and is also located on the southern perimeter of the aquifer. Rainfall records that were available from the VRSAU study which were previously used to generate the surface runoff from the Schoonspruit catchment as part of the VRSAU hydrology task, were utilized to produce a longer and more representative rainfall record. These rainfall records include the whole Schoonspruit Dolomitic Aquifer recharge area and cover a record period from 1911 to 1994, which was sufficient for the re-calibration of the Schoonspruit Catchment hydrology. These rainfall records were already, as part of the hydrology process in the VRSAU study, checked, verified and patched. The rainfall records were then used to create a single rainfall record that represents the rainfall on the total aquifer recharge area for the period 1911 to 1994. Due to the fact that the calibrated equation obtained from the work done by S Veldtman (CRD Method) is sensitive to the rainfall data used, the equation was re-calibrated using the new rainfall data set. Similar to the initial calibration done by S Veldtman, the new calibration also showed a very good fit over the period 1970 to 1985. By using the new calibration and rainfall records, it was now possible to produce a long record of the monthly outflow from the eye covering the period 1920 to 1994. This record represents the outflow from the eye under natural conditions as the CRD method can not deal effectively with the borehole abstractions.

The new calibration of the CRD method was based on:

$$Q = \left(\operatorname{Re} N * \frac{48P}{108P} * (96P - ThN) * \frac{1585km^2}{1000} \right) + \left(\operatorname{Re} F * (108P - ThF) * \frac{1585km^2}{1000} \right)$$

Where:

P	moving average length of monthly rainfall
ReN	0.05
ThN	30 mm
ReF	0.373
ThF	43 mm

The new calibrated equation (CRD Method) was used as the basis for the initial ground water flow modeling. From Figure 1 it is clear that the two different rainfall data sets produced very similar results over the calibration period. The main advantage of the second rainfall data set is that it covers a much longer record period, which was required for the WRSM2000 model calibration.

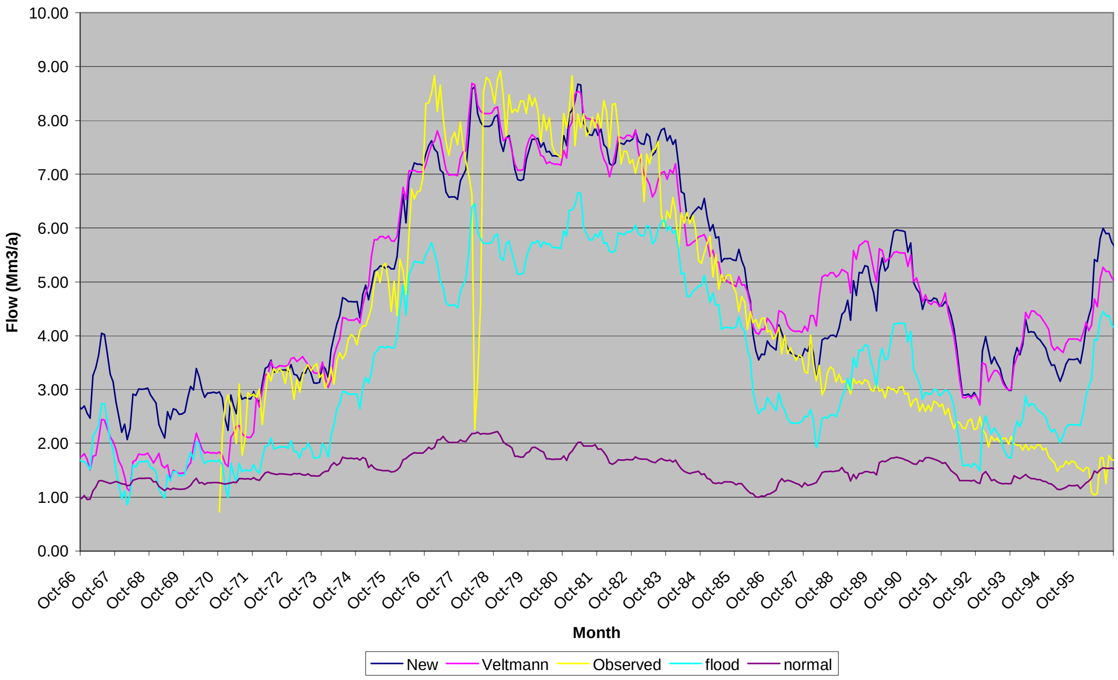

Figure1: Calculated spring discharge used in this study (new) compared to the Veltman study, as well as flood (ReF) and normal recharge (ReN).

3.2 GRA II Groundwater-Surface Water interaction model

During the execution of the Schoonspruit Sub-system Analysis Study, it was identified that a short coming of the groundwater-surface water interaction model, as was developed for the Groundwater Resource Assessment Phase 2 study (GRA II), (*Groundwater-Surface Water Interactions: Report compiled by K Sami of WSM Leshika (Pty) Ltd, as part of the Phase II Groundwater Resource Assessment programme for the Department of Water Affairs and Forestry, Directorate: Information Programmes Systems Analysis*), was, that it was based on hydrograph separations of the Pitman model to calculate baseflow. Since no simulated results were available for the dolomites, the moving average of rainfall was initially used as a simulated hydrograph. This was not considered an independent test of the model, hence it was decided to revise the model and utilize Pitman subsurface storage as the input to the model from which to calculate baseflow. To account for the extensive time lag that exists between rainfall events and when the effect thereof is reflected in the outflow from the Schoonspruit Eye, it was identified that an additional process need to be added to the GRA II groundwater algorithm to incorporate this lag effect. Conceptually this time lag is thought to be as a result of the percolation of water and the time it takes for rainfall to travel from the catchment surface to the discharge point at the eye. Known lag algorithms were then tested to find a suitable solution, and eventually a second percolation storage layer was added to the model.

The Pitman model was run to generate a Pitman S time series for the revised model. The parameters used to generate the Pitman S values are shown in Table 1.

Table 1: Parameters used for the Pitman model

Parameter	Value	Parameter	Value
Rain Zone	C2F	ST	600
Zonevap	10A	FT	8.5
Ann.Evap	1750	zmin	100
Area	1585	zmax	900
eff_area	1585	GW	7
MAP	587	PI	1.5
Afor	0	TL	0.5
POW	1	GL	6
SL	0	R	0.5

Two scenarios were simulated using the final improved Groundwater-Surface Water Interaction Model:

1. *Scenario 1: Based on 1 compartment*

   -Based on SW-GW model using Pitman S time series as input

   -T=3000 m2/d, S=0.027 (Polivka, 1987)

   -Irrigation from entire compartment (1585 km2) was applied

   -calibration undertaken until 1994 and verification from 1994-2002

2. *Scenario 2: Based on 1 compartment*

   Based on SW-GW model using Pitman S time series as input

   -T=3000 m2/d, S=0.027 (Polivka, 1987)

   -Irrigation from entire compartment (1585 km2) was applied but mean distance of irrigation was shifted away from the spring from 20 to 32 km in 2000, as suggest by Veltman

   -calibration undertaken until 1994 and verification from 1994-2002

Simulation results are shown in Figures 2 & 3.

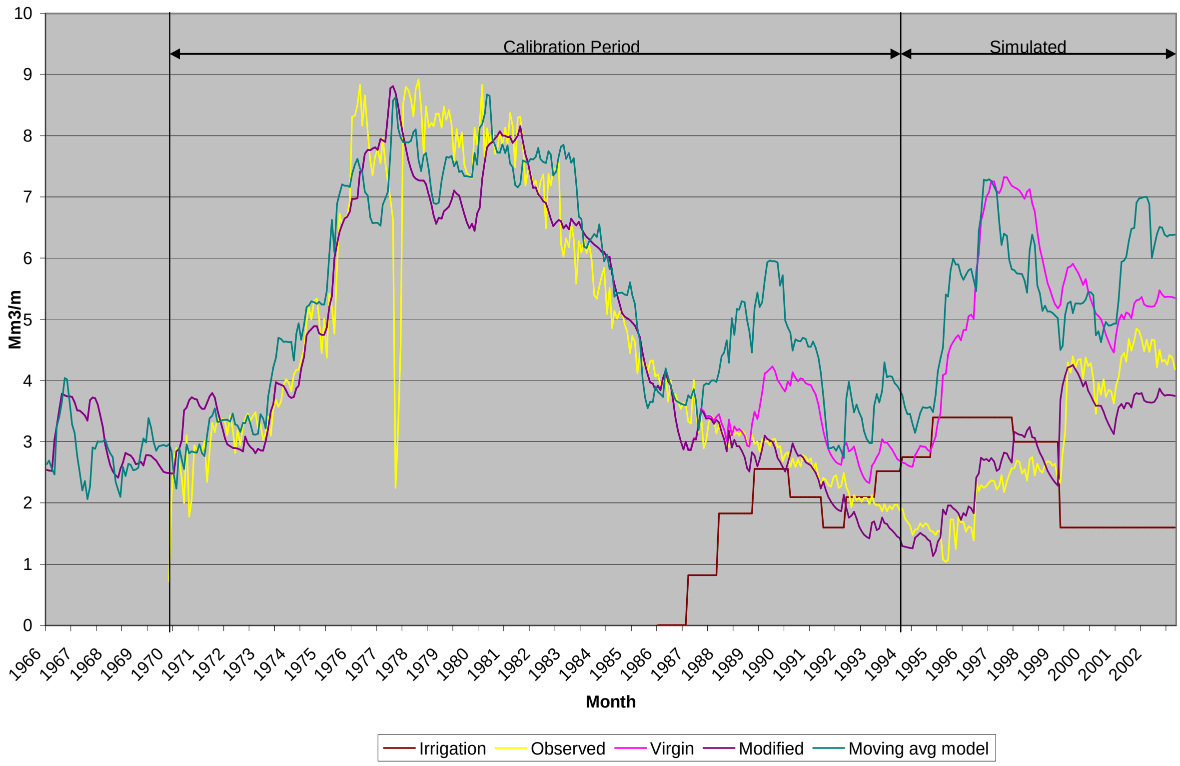

Figure 2: Scenario 1 Simulation results

From Figure 2 it is evident that the model could not reproduce the impacts of abstraction when fixed irrigation was assumed from 1999/2000 onwards (Scenario 1). To be able to obtain a reasonable fit between the simulated and observed flow from the Schoonspruit eye from 1999/2000 onwards, it was necessary to reduce the borehole abstractions for irrigation purposes significantly. This however does not agree with what happened in practice.

Acceptable results where however obtained (Scenario 2) after a modification was included to allow the weighted mean distance of irrigation to be shifted (See Figure 3). It is important to note that the ground water model was only calibrated on the period 1970 to 1994. Rainfall and irrigation abstraction data were the added to the model to extend the simulation period by an additional 8 years to 2002. The additional 8 years were simulated purely by using the already calibrated model with no further calibration. The 8 year simulated eye flow still compared fairly well with the observed flow at the eye, which increases the confidence level in the simulated flows.

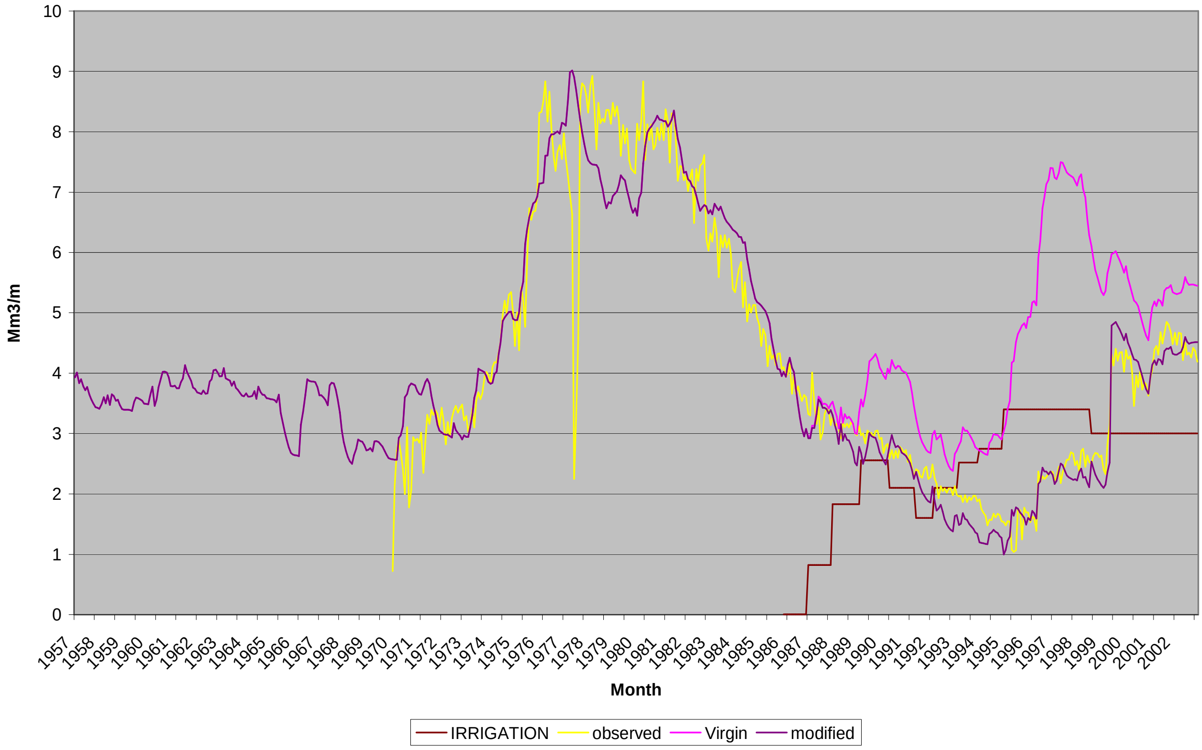

Figure 3: Scenario 2 Simulation results

3.3 Schoonspruit Eye simulated flows to be used in the WRSM2000 and WRYM.

To be able to calibrate the WRSM2000 model on the observed flow (1922 to 1950) at Johan Neser Dam it very important to obtain the flows from the Schoonspruit Eye over this period, as the eye flow contributes to approximately 50% of the total natural flow generated upstream of Johan Neser Dam. The final calibrated groundwater model was therefore used to be able to obtain this flow record. For this scenario it was assumed that no significant abstractions took place from the dolomite compartments prior to 1988 when the large irrigation abstractions started. For the period 1922 to 1950 the flows from the Schoonspruit Eye therefore represented natural conditions. Results from this simulation are given in Figure 4. The simulation started at 1911 to allow for a warming up period before 1922 when flow data is require for WRS2000 calibration purposes. The natural flow as obtained from the CRD method which was used for the initial WRSM2000 calibration is also shown on Figure 4 and compares in general fairly well with the natural flow as simulated with the final Groundwater-Surface Water Interaction Model.

For the purpose of the WRYM two flow records were required. These are the flow from the Schoonspruit Eye under natural conditions and the flow from the eye under current development conditions. The flow under natural conditions was obtained from the same simulation as shown in **Figure 4** as the natural or virgin flows are the same as the modified eye flow for most of the simulation period. The virgin flow started to differ from the modified eye flow only from 1987 onwards when irrigation abstractions from the dolomite aquifers started to take place and the monthly flow values from the purple line where then used as natural flow for the rest of the simulation period.

The modified outflow from the eye for current development level is shown on Figure 5 in comparison with the current development flows, as obtained when using the CDR method. The current development flows from the CRD method seem to be in general significantly lower than those simulated with the final Groundwater-Surface Water Interaction Model.

The bulk of the irrigation developments are located relatively far from the eye (see Figure 6) and are therefore not impacting directly on the flow from the eye as would be reflected by the CRD method.

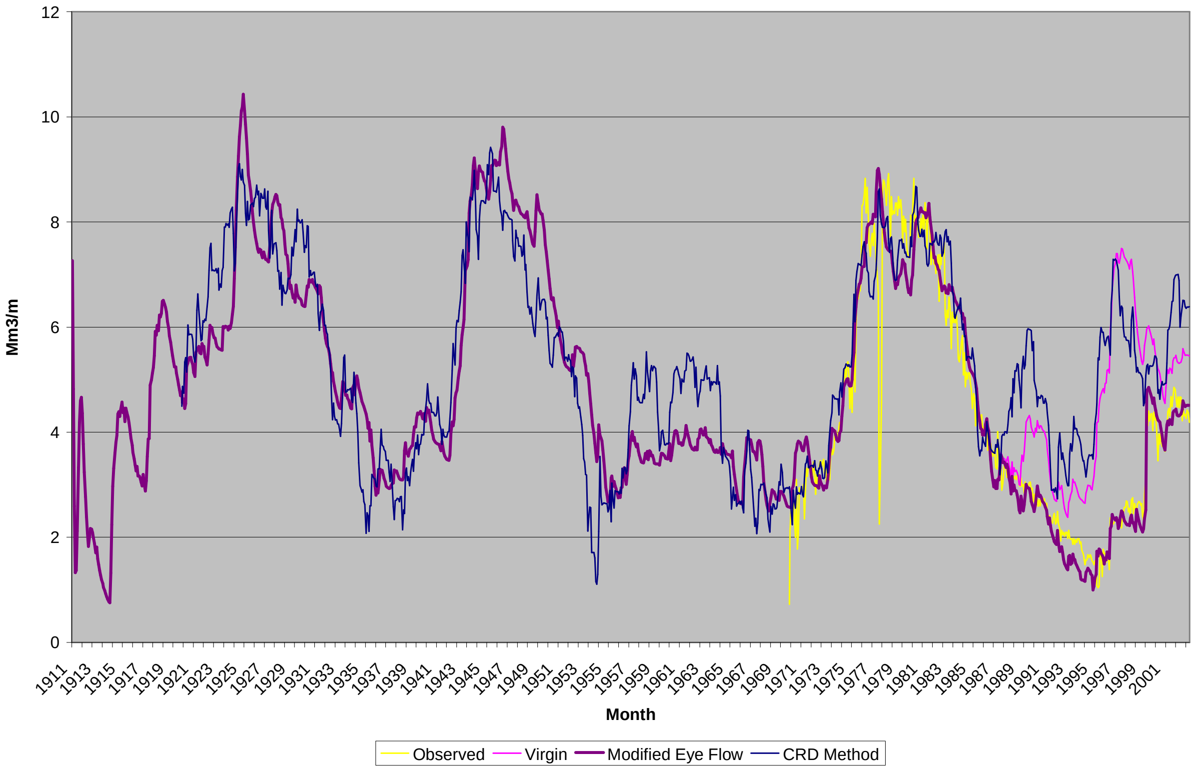

Figure 4: Simulated Schoonspruit Eye flow to be used in WRSM2000 model

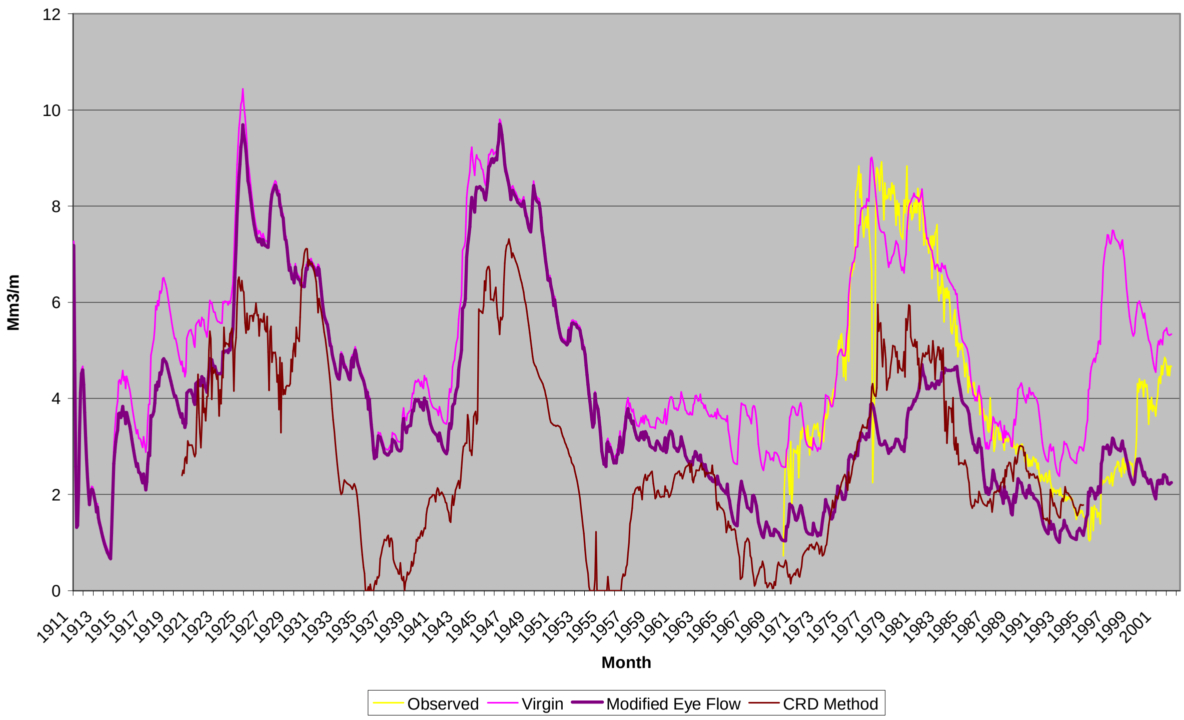

Figure 5: Simulated Schoonspruit Eye flow at current development level

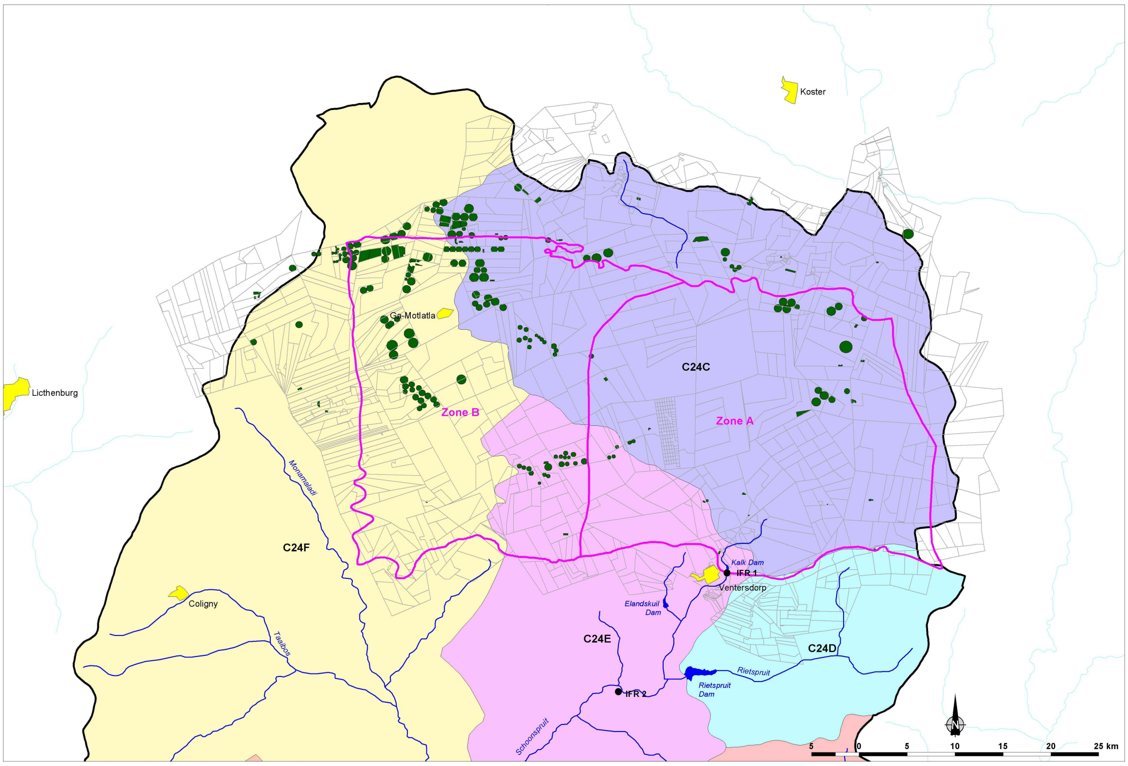

Figure 6: 2002 Irrigation Development on the dolomitic aquifer recharge area

4 Conclusions and Recommendations

At the time of this study the groundwater – surface water interaction module developed by K Sami was still in the testing stages. It was never the less used and the experience gained by using it for the Schoonspruit Eye modeling, contributed to several changes and improvements to the groundwater – surface water interaction model. One of the main improvements was to take into account the location of irrigation abstractions on the dolomitic aquifer, as abstractions far from the eye did not impact on the outflow to the same extent as those close to the eye, due to lag times and available storage in the aquifer.

For the period before borehole abstractions started from the aquifer, the two models provided very similar results as these outflows represent flows under natural conditions. As soon as abstractions started, the modeled flows from the CRD method deviated considerable from the observed flows, while the simulated flows from the new model followed the observed flows reasonably well. For the purpose of the WRYM analyses it was required to have a natural outflow record from the eye (flow as it will be under natural conditions for the total simulation period) and a record of the outflow when the current development level of borehole abstractions were in place for the total simulation period from 1920 to 1995. It was possible to derive these outflow records by using the final improved groundwater – surface water interaction module developed by K Sami.

The groundwater model did provide acceptable calibrations on the observed flow under natural and developed conditions which is an improvement on the earlier model used. It is therefore recommended to use these modeled results in the WRSM2000 and WRYM analysis and to keep on improving the model based on the experienced gained from further analysis.

References

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