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A case study using the SIMGRO model

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Abstract: For the Letaba basin situated in the South African part of the Limpopo basin, a hydrological study was carried out in order to quantify the effect of smallholder farming on river flows. Important was to study the consequences of improved agricultural systems on the river flows, in particular for the Kruger National Park situated in the lower part of the Letaba basin. The SIMGRO model was used in this study, which integrates groundwater and surface water. The model was calibrated, and furthermore a comparison of measured discharges and groundwater levels against calculated discharges and groundwater levels, revealed that the model is suiTable for practical analysis. For the smallholders farms different scenarios were defined with different levels of crop yield. An increase in crop yield has consequences on more water use as irrigation and crop water use. Because the area covering smallholder farming is only 0.5% of the basin, the effects of changes in water use are relatively small. In a scenario, the weather conditions for 2050 were analysed. This reveals that discharges will go down by 30% on average, which means a substantial reduction of the water resources.

Keywords: Letaba basin, SIMGRO model, smallholder farmers, irrigation, ground water, surface water

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Photo cover: Great Letaba River downstream of Tzaneen

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Summary

Within the European Union project EAU4Food, cooperative research is carried out to increase food production in irrigated farming systems in Africa. There are enormous challenges in African agriculture, as it is facing today, to increase agricultural productivity in order to keep up with the population growth. In the coming years irrigation will gain importance, but at the same time the availability of fresh water and the sustainable use of soil resources is under increasing pressure. Hence, new approaches are required to increase food production in irrigated areas in Africa, while ensuring healthy and resilient environments. Therefore, innovations are needed to reduce the water requirements for crop production. In order to test these innovations, hydrological models were used to estimate the effects of innovations on water quantity (water use). Many previous attempts to improve food production in irrigated areas did not live up to their expectations, because of limited involvement of stakeholders, ill-understood socio-economic structures and/or mono- disciplinary approaches. To overcome these potential pitfalls of successful adoption of innovations, the EAU4Food project utilizes a true trans-disciplinary approach, which involves the active participation of all stakeholders (Froebrich et al., 2013).

The aim of this project is to use the SIMGRO model to explore with this tool, innovations in agriculture. For feasible innovations in agriculture, it's needed to estimate the changes in water quantity within a river basin. In this study, the Letaba basin as a portion of the Limpopo basin in the northern part of South Africa is used to test the innovations. The water resources in the Letaba catchment are under pressure: there is a high demand on water and limited availability. Irrigation is one of the main water requirements within the catchment. Especially for the smallholder farms, little is known on the quantity of irrigation water use. Detailed information is also lacking on areal extend of the smallholder agricultural farms, the cattle farming and water use by rural communities.

For the SIMGRO model, the subsurface in the basin is built up of a number of layers. The first groundwater layer (aquitard) receives water from the unsaturated zone through percolation and loses of water to the unsaturated zone through capillary rise. This layer also drains to the surface water and might receive infiltration water. In the aquitard there is vertical flow, the aquifer with horizontal flow is overlying the hydrological base.

The Letaba basin is divided into several hydrogeological regions characterized by fractured aquifers formed mainly by metamorphic basement rocks. The main regions are the Escarpment zone with fractured rooks which are highly permeable although the storage in these aquifers is very limited and the plains which cover 50% of the catchment and are characterised by fractured rocks. Further regions are the Drakensberg Foothills and Valleys, the Giyani-Gravelotte region dominated by local fractured materials as a result of the intense folding and associated fracturing. Boreholes yield varies between 0.5 and 5 l/s (~43-430 m^3/d). Along most of the main rivers, an alluvium layer exists, composed of unconsolidated clayey silts to coarse gravels and boulders. The aquifer properties are highly variable within short distance. For the aquifer we used the hydrogeological data of SADC and transmissivities reported by Holland (2011).

Based on the main streams considered for the surface water modelling, the basin was divided into 190 sub catchments. For the headwaters the width of the streams is < 10 m, the width of the middle reaches is from 10-50 m and the main river is between 50-100 m wide. All these water courses are used to simulate the interaction between surface water and groundwater. For each node a drainage resistance and the difference in level between the simulated groundwater and pre-defined surface water are used to calculate the water flow (either drainage or infiltration). Within the Letaba basin there are 22 major dams (DWAF, 2003). The 14 largest 14 dams are included in the SIMGRO model.

In the Letaba basin water for irrigation of commercial farms is mainly extracted from the major dams. In other areas groundwater is used where surface water is not available. It has been assumed that the

land use cultivated dry land (semi commercial) are the farmers, which use mainly supplementary groundwater to irrigate their crops, or when located next to a river they use surface water.

We use in SIMGRO crop factors to estimate the potential reference evapotranspiration of the crops. The crop production and thus water use is differentiated between the two farming systems, being the large-scale commercial farms and the smallholder agriculture. For the present situation (base line), we used crop factors to give estimates of the potential evapotranspiration (Annandale et al, 1999). For the different scenarios, when more water and/or nutrients are applied, the water use by the crops increases. Since our study concerns only changes in the smallholder farming we only changed the production levels for these farms. It is expected that increase in crop yields will be substantial for the smallholder farms. They will apply more water in order to increase the crop production and thus income.

The Nash-Sutcliffe modelling efficiency was used to present the differences between measured and calculated discharge. The efficiency Figure shows how reliable the model simulates the real situation. The closer the model efficiency is to one, the more accurate the model is. Using daily discharges, gauge B8H018 (Charles Engelhard dam) has a low modelling efficiency of 0.09. Gauge B8H034 and B8H010 show the best comparison of measured and calculated discharges. If we take the monthly average discharges and compare these, then the model efficiency becomes much higher.

Scenario analysis
Model result as the change in river flow, at the Charles Engelhard dam, were analysed. For the present situation the smallholder farm use about 34 mln m3/a of water. The majority of the water comes from groundwater, since a few smallholder farms are located next to a stream. When more water is applied representing more crop yield the water use increases by 7 mln/a. For environmental crop yield, which uses more water and more nutrients, it shows an increase of 11 mln m^3 of water, as compared to the present situation. Using the maximum amount of nutrients and thus the maximum yield is obtained, that scenario uses 19 mln m3/a more water. If the area of smallholders is increased by 50% this requires in total 51 mln or an increase of 17 mln m3/a.

Because the area of smallholder farms in the basin is only 0.5% of the basin area, this means as well that changes in crops or changes in varieties with a larger evapotranspiration has a very small influence on hydrology of the basin and thus on downstream river flows.

Climate change
The Letaba basin consists of high mountains in the western part and in the eastern part, it is as low as about 300m+MSL. Measured rainfall varies from approx. 1400 mm in the western part to 300 mm in the eastern part. The climate models were not able to predict these drastic changes in precipitation. We used the predicted changes of the climate data between 2000 and 2050 and superimposed that on the measured precipitation and evapotranspiration data to derive at values for 2050. Using these values in the model resulted in discharges for 2050 of about 70% of the river flows at present. Thus, climate change has an enormous effect on the water resources of the Letaba basin.

The main conclusions of this study can be summarized as follows:
- Water resources in the Letaba basin are limited;
- Increased production by smallholders farmers has some effect on the river flows downstream, because the area of smallholder farm is only 0.5% of the basin;
- Climate change (2050) will result in river flow of about 70% of the present flows, thus climate change has an enormous effect on the water resources.

1 Introduction

Within the European Union project EAU4Food, cooperative research is carried out to increase food production in irrigated farming systems in Africa. There are enormous challenges in African agriculture, as it is facing today, to increase agricultural productivity in order to keep up with the population growth. In the coming years irrigation will gain importance, but at the same time the availability of fresh water and the sustainable use of soil resources is under increasing pressure. Hence, new approaches are required to increase food production in irrigated areas in Africa, while ensuring healthy and resilient environments. Therefore, innovations are needed to reduce the water requirements for crop production. In order to test these innovations, hydrological models will be used to estimate the effects of innovations on water quantity (water use). Many previous attempts to improve food production in irrigated areas did not live up to their expectations, because of limited involvement of stakeholders, ill-understood socio-economic structures and/or mono- disciplinary approaches. To overcome these potential pitfalls of successful adoption of innovations, the EAU4Food project utilizes a true trans-disciplinary approach, which involves the active participation of all stakeholders (Froebrich et al., 2013).

In Southern Africa, many rivers are temporarily. During the short rainy season, they carry water, but in the remaining dry periods, the water flow ceases. The lack of enough water during the dry season is a huge problem, and especially farmers suffer from this water shortage. Such conditions also prevail in the Limpopo basin in Southern Africa. The water resources are limited and irrigation is essential for agriculture. Therefore, the conditions in such a basin are suited to test innovations in soil and water management.

For effective integrated water resources management, as taken up in the EAU4FOOD project, state-of-art models are needed that can cover the entire land and water system, including plant-atmosphere interactions, soil water, groundwater and surface water. Alterra has developed the simulation package SIMGRO (Querner & Povilaitis, 2006) for this purpose. One of its strong points is the integrated simulation of saturated and unsaturated flow, and the interaction between ground- and surface water. Its capabilities are, partly restrained by the often non-systematically documented soil physical characteristics. Currently a systematic and ready-to-use (GIS) database is being composed by ISRIC for a major part of Africa, which can be used for local and regional assessments (ISRIC, 2013). In this way water quantity issues can be dealt with at the river basin scale.

1.1 Aim of the modelling study

The aim of this project is to use the SIMGRO model to explore with this tool innovations in agriculture. For feasible innovations in agriculture, it’s needed to estimate the changes in water quantity within a river basin. In this study, the Letaba basin in the northern part of South Africa is used to test the innovations. The Letaba basin is situated within the Limpopo basin as shown in Fig. 1.1. The Limpopo basin was considered too large with considerable regional differences in elevation, landscape, land use, farmers practises, etc.

The model application for the Letaba basin gives on a (sub) basin scale the effects in terms of changes in river flow and changes in water balances. Any agricultural innovations should not affect downstream users. For the Letaba basin, the Kruger National Park is an important water user requiring an ecological flow for the vegetation and animals in the park.

1.2 The Limpopo River basin

The Limpopo river basin is situated in Mozambique and upstream parts in Zambia, Botswana and South Africa (Fig. 1.1). For the Limpopo basin, the water resources are under pressure. In a study carried out some 30 years ago, the recession of the stream flow during successive dry seasons over a number of years was analysed (NDW, 1989). In that study, it was found that a significant increase in water abstractions from the river in upstream countries had taken place. This situation was partly masked because of droughts that affected the whole region. However, it is clear that the Limpopo in Mozambique virtually has no flowing water in the dry season, even in years with normal rainfall. Such situations did not happen before 1975. In the Limpopo basin there are 138 major dams (Limpoporak, 2011). At present there are 13 large dams with a storage capacity exceeding 100 mln m^3; one in Mozambique; eight in South Africa; three in Zimbabwe and one in Botswana. The largest one is Massingir dam in Mozambique (capacity of 1200 mln m^3). Apparently, in Zimbabwe the river has been developed nearly to its full potential and the remaining runoff makes very little contribution to the flow in the Limpopo River. There is no information in Mozambique regarding the present water uses in Mozambique and information on planned future developments in the upstream countries is largely lacking, besides sparse information that is presented in various reports. Both Botswana and South Africa are separately planning new water developments and the construction of new storage dams. Rainfall in the Limpopo basin is seasonal and unreliable. In dry years, the upper parts of the river flow for 40 days or less. The upper part of the drainage basin is arid, in the Kalahari Desert, but becomes less arid further downstream. The middle reaches drain the Waterberg massif, a region with semi-deciduous forest and low density human population. The lower reaches are fertile and heavily populated. Floods after the rainy season are an occasional problem in the lower reaches, most notably was the catastrophic floods in February 2000 and recently in February 2013.

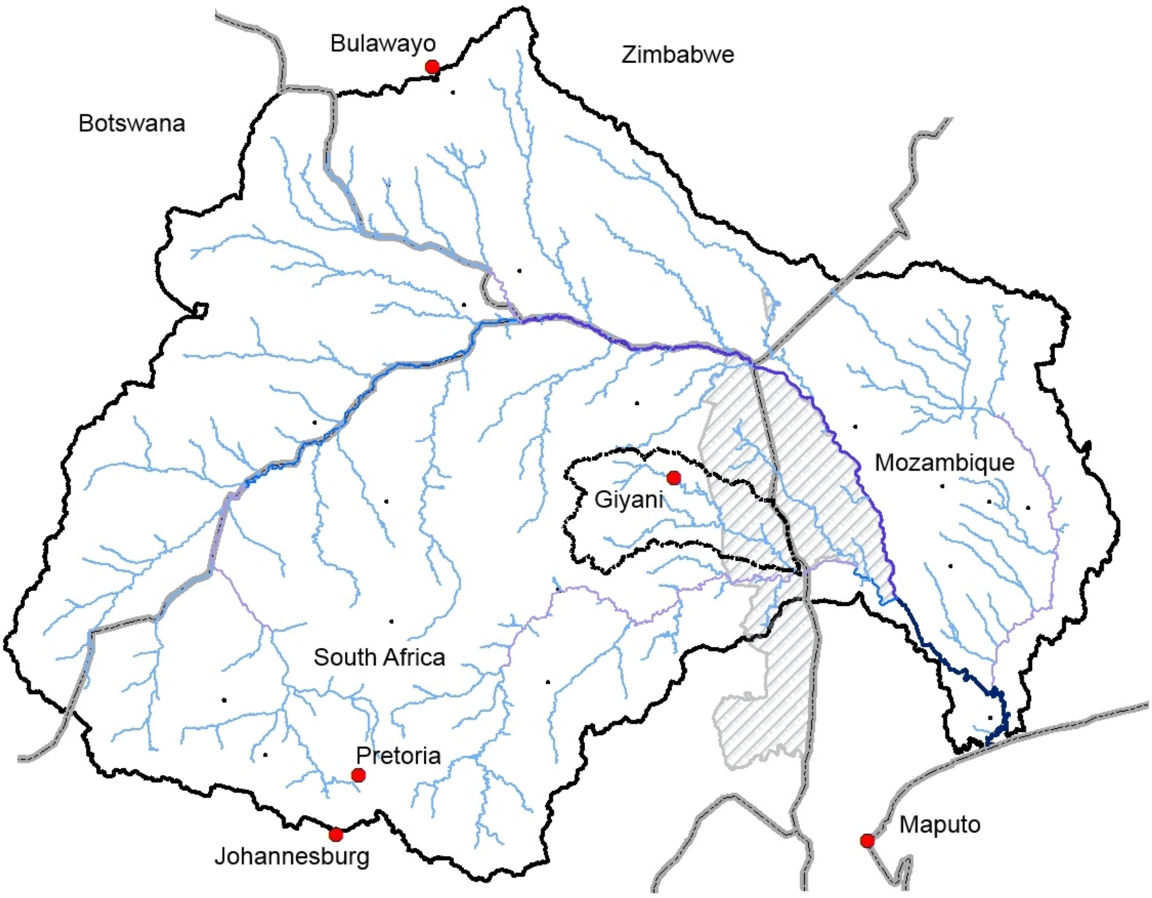


Figure 1.1 *The Limpopo basin as situated in Mozambique, South Africa, Zimbabwe and Botswana. The Letaba basin is shown as well together with the large nature parks situated on both side of the border between South Africa and Mozambique.*

1.3 The Letaba River basin

The Limpopo river basin, as shown in Figure 1.1, has a main tributary which is the Elephants River and from this river the Letaba River is again a tributary. Figure 1.1 also shows the Letaba basin and the city of Giyani.

The water resources in the Letaba catchment are under pressure: there is a high demand on water and limited availability. Irrigation is one of the main water requirements within the catchment. Especially for the smallholder farms, little is known on the quantity of irrigation water use (Wichern, 2013). Detailed information is also lacking on areal extend of the smallholder agricultural farms, the cattle farming and water use by rural communities.

Together with CSIR and Stellenbosch University a detailed application of the SIMGRO model for the Letaba basin has been developed. This model application should support the stakeholder discussions on innovations for the pilot area around Giyani (see Fig. 1.1) on water issues and analyses the feasibility of proposed measures. The soil data, land-use and water requirements of crops has been implemented in the model, an inventory of irrigated areas and storage dams has been carried out, using literature and Google Earth observations. For the local weather conditions data is available. In the EAU4FOOD project, pilot sites have been selected to test the innovation.

1.4 Outline of report

In Chapter 2 a description of the Letaba basin and an outline of the SIMGRO model is given. Chapter 3 describes the model application of the Letaba basin, the model schematisation, input data and the comparison of model results with field measurements. Chapter 4 gives the modelling scenario's and the results. In Chapter 5 the conclusion and recommendations are given.

2 Hydrological modelling of the Letaba basin

2.1 Description of the Letaba basin

The Letaba River basin, being part of the Limpopo River basin, covers a total area of 14 086 km² (see Fig. 1.1). The Letaba River has three main branches: The Klein Letaba River in the northwest, the Middle Letaba and the Groot Letaba River in the southwest of the catchment (Figure 2.1). Some major tributaries are further the Nsama, Letsitele and Molototsi rivers (Fig. 2.1). Originating in the mountain area in the western part of the catchment, the rivers flow to the east and have their confluence on the western boundary of the Kruger National Park. The Letaba River drains into the Olifants River near the Mozambican border, which then drains into the Limpopo River before it reaches the Indian Ocean.

The topography of the Letaba varies from a zone of high mountains in the west through low mountains and foothills to the low lying plains in the east. The mountainous zone or Great Escarpment includes the northern portion of the Drakensberg mountain range and the eastern Soutpansberg (Fig. 2.1), which both extend to the western parts of the Letaba basin. The highest peaks have an elevation of more than 2 000 m above mean sea level. This zone is deeply incised by the major tributaries. To the east of the escarpment, the characteristic of the region is a wide expanse of the Lowveld. The low-lying plains cover most of the area and has gentle to flat slopes.

The Groot Letaba streams originate in the Drakensberg Escarpment, descending in long runs with an occasional riffle or pool. Bank sides are of gentle slope. Riparian vegetation is sparse. The natural grasslands have been replaced by commercial forestry and irrigated agriculture. The Klein Letaba, Nsama and Molototsi Rivers are typical sandy lowveld rivers, with deeply incised river channels. Wide sandy stretches are interspersed with occasional gravel riffles. Bedrock dykes cross these rivers at infrequent intervals, occasionally causing deep pools on their upstream sides. River flows vary considerably during a year.

Agriculture is a key economic sector in the Limpopo Province. There are two distinct agricultural production systems in the province, smallholder agriculture and large-scale commercial farming (CSIR, 2012). Large-scale commercial agriculture is characterized by large farms, it is mainly situated on prime agricultural land and mainly uses surface water irrigation. Smallholder agriculture is located mostly in the former homeland areas and covers about 20% of the provincial land surface area. Smallholder agriculture is characterized by a low level of production technology and covers approximately 1.5 ha per farm. The smallholder sector production is primarily for subsistence and small surpluses are marketed.

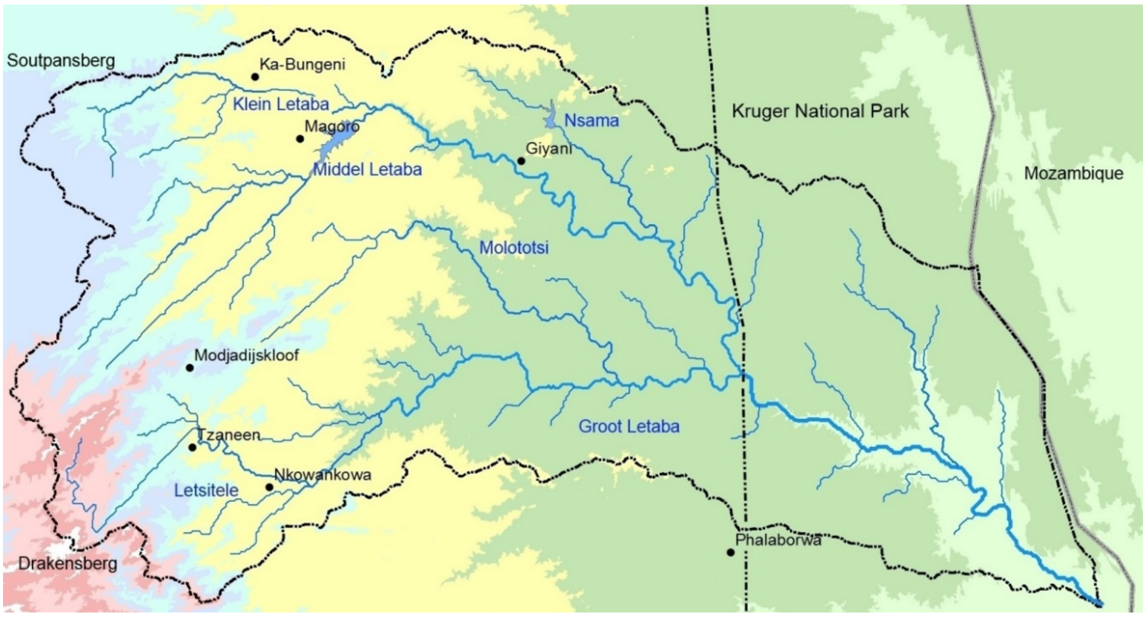


Figure 2.1 *Major cities and streams in the Letaba basin (elevation background colour from light green: low, to purple: high)*

2.2 Characteristics of the basin

Rainfall and temperature

Mean annual temperatures within the Letaba basin range from 18 °C in the mountains to more than 28 °C in the lowlands with maximum and minimum temperatures in January and July, respectively (State of the River, 2001). The area belongs to the summer rainfall sub-tropical area with the rainy season commonly starting in October and lasting until March (Wichern, 2013). Precipitation is influenced by the topography resulting in less than 300 mm/a in the lowlands and more than 1200 mm/a in the mountains. This results in large water availability along the Groot Letaba River, whereas water resources in the Klein Letaba and lower Letaba catchment are scarce (DWAF, 2003). The area of Greater Giyani has a mean annual rainfall of 300 to 400 mm/a. Average potential reference evapotranspiration ranges between 1100 and 1300 mm/a.

Land use

Land use in the basin is mainly grassland, savannah and shrub land (68%). Cropland covers about 26%, of which approx. 1.75% is irrigated. The remaining area is woodland and urban. Agriculture in the Letaba River basin is typically extensive with low input levels and utilises the natural resources. However, irrigation of agriculture accounts for more than 50% of the total water demand in the Letaba basin (LBPTC, 2010).

In the Letaba basin there is around 245 km^2 irrigated and a further 484 km^2 is commercial forested (pine and blue gum), mainly in the upper reaches of the Groot Letaba River catchment (DWAF, 2004). Particularly the Groot Letaba sub-basin is a highly productive agricultural area with mixed farming including cattle ranching, game farming, dry land crop production and irrigated cropping. Intensive irrigation farming is also practised in the upper parts of the Klein Letaba River catchment and near the Middle Letaba Dam. Agriculture, with the irrigation sector in particular, is the main base of the economy of the region. Crops are mainly citrus fruits and vegetables. Other fruits are bananas, mangoes, avocados and nuts. There are large tomato plantations.

In the Lowveld extensive areas are under rain, fed cultivation (smallholder/semi-commercial farming) situated around rural villages. These farmers use mainly surface water, if situated along a stream, otherwise supplementary groundwater is used.

Hydrology
Agriculture and domestic use are the major demand sectors of the water resources in the system. The decline in present day flow, when compared to the natural flow, is mainly attributed to the large demand of irrigation in the Groot Letaba Catchment and Middle and Klein Letaba sub-catchments (Fig. 2.2). According to the Letaba Reserve Determination Study (DWAF, 2006), water is allocated from Tzaneen Dam for downstream domestic use, but also for the Kruger National Park (DWAF, 2010a). For the Kruger National Park, it is essential to have natural rivers flowing into the park. These natural rivers can contribute substantially to the conservation of the river system in the park and important for the water use by the animals (Rogers and Bestbier, 1997). Upstream river regulation in the Letaba and other rivers had large impacts on the river flow in the KNP. In the 1950's, the Letaba River changed from a perennial to a seasonal river, mainly contributed to the construction of the storage dams and subsequent water use for drinking water and irrigation.

Mean annual runoff (MAR) of the Letaba catchment is 574 mln m^3 (range from 100 to 2 700 mln m^3) (DWAF 2003) The MAR is defined as the long-term mean annul flow calculated for a specified period, at a particular point along a river and for a particular catchment and catchment development condition. In the reports of DWAF the MARs are based on the 70-year period Oct. 1920 to Sept. 1990 (DWAF, 2004). The MAR varies from more than 10% of the mean annual precipitation (MAP) in the wet mountainous zone to less than 2% in the drier parts of the catchment.

More than 20 major dams have been constructed in the Letaba River basin (Fig 2.2). The Middle Letaba dam has a capacity of 172 mln m^3 and build in 1984. The Tzaneen Dam is the second largest dam and dates from 1977 (Wikipedia, 2013a). The Middle Letaba dam feeds a 60 km long irrigation canal, which flows into the Nsama Dam. See Fig. 2.3 for an impression of both dams and irrigation canal.

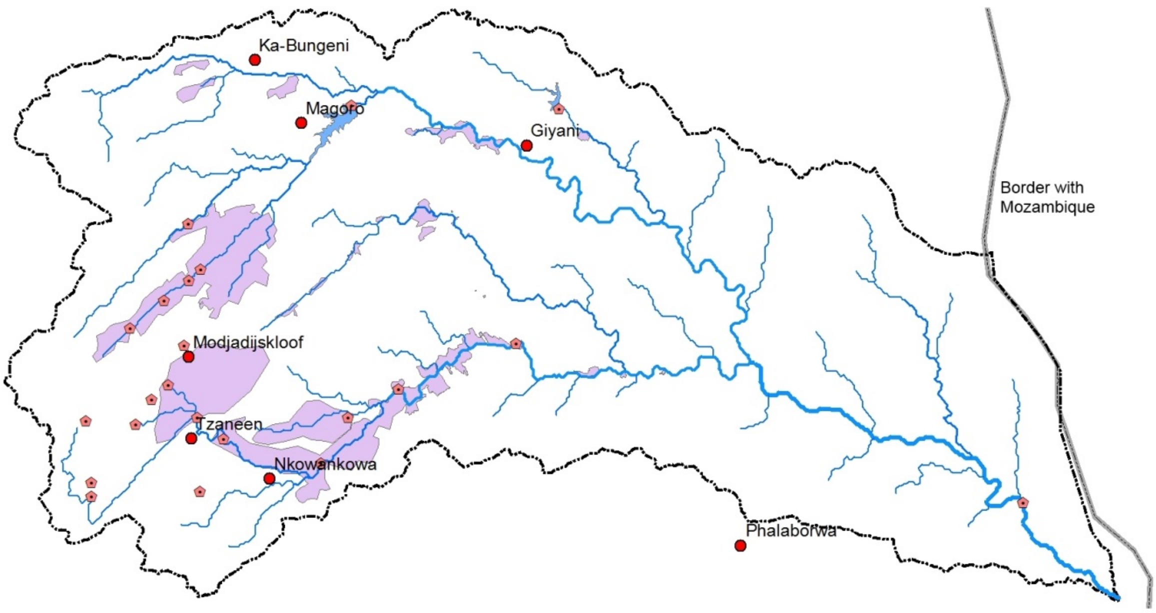


Figure 2.2 *Overview of the Letaba basin together with the major dams and irrigated areas (purple)*

Figure 2.3 *Impressions of dams and irrigation canal.*
a) Tzaneen Dam; b) Middle Letaba Dam; c) Irrigation canal from Middle Letaba Dam to Nsami Dam (capacity 4 m^3/s).

The total water requirements for the Groot Letaba and Klein Letaba are estimated 181 mln m^3/a and 37 mln m^3/a respectively. In the Letaba basin it has been estimated that around 40 mln m^3/a of groundwater is extracted: for urban water use around 11 mln m^3/a and for irrigation around 29 mln m^3 (Aurecon, 2010).
Irrigation schemes extract around 170 mln m^3/a from the large dams and directly from the river.

Geohydrology and soils
The geology is varied and complex and consists mainly of sedimentary rocks in the north and rocks in the south (Holland, 2011). The formations are of relatively low water-bearing capacity. A wide spectrum of soils occur in the Letaba basin, with sandy soils most common.
Mostly composite and deep fractured aquifers occur in the relatively impermeable bedrock in the mountainous areas. Considerable rainfall recharge to groundwater occurs in the Groot Letaba sub-catchment with declining intensity from west to east. A large potential on groundwater use is assumed for this sub-catchment (DWAF, 2010a). Groundwater availability in the Klein Letaba sub-basin seems to be lower. Alluvial deposits along the river have some sedimentary aquifers. However, detailed information on the entire groundwater characteristics and faults are limited (DWAF, 2003).

Smallholder farming
Until a few years back the irrigation near Giyani was supported by several larger dams providing water to irrigation schemes and individual farmers. However, the water supply was cut down because of the increasing water use by the villages. Since 2007 many irrigation schemes around Giyani are no longer supplied with water and were nearly all closed down. Individual farmers searched for alternative water sources or changed to dry land farming (CSIR, 2012).

Wichern (2013) studied the water use by smallholder farms in the Letaba catchment by on-site data collection from interviews and measurements for 18 farms within near Giyani. Standardized farm types where distinguished according to its source of water supply, being: groundwater irrigation (borehole); surface water irrigation; water pumped from the pools or alluvium of riverbeds; rainwater harvesting and dry land farming. Cattle farming using quite some space around the rural villages was not considered. Spatial aggregation and up scaling of water use to the catchment scale was based on the distribution of farms throughout the catchment as derived from the NLC2000 land use map and data from the local Department of Agriculture. It was estimated that the water use by the smallholder farms is in the order of 29 to 43 mln m^3/a (Wichern, 2013). This may be an over-estimation, since the water use only considered agricultural farms and cattle farming was left out. The influence of agricultural smallholders on the catchment's water balance seems to be considerable and there is a need to integrate their water requirements in regional water resources management plans.

Ecological reserve

The quantity and quality of water required as ecological reserve is defined to satisfy basic human needs by securing a basic water supply, as prescribed under the Water Services Act, 1997, now and in the near future (DWAF, 2004). It reserve is also to protect aquatic ecosystems in order to secure ecologically sustainable development and use of the relevant water resource as indicated in the National Water Act, 1998.

The ecological reserve is recommended to be 12% of the total river flow (Aurecon, 2010). For the Kruger National Park it has reported that 8 mln m^3/a should be reserved (DWAF, 2006).

Experimental farms near Giyani

The 4 experimental farms selected in the EAU4FOOD project are situated in the middle part of the Letaba basin (Figure 2.4). Two farms use groundwater and 2 farms use surface water to irrigate their crops. Further details on soils and EC are presented by the CSIR (2012).

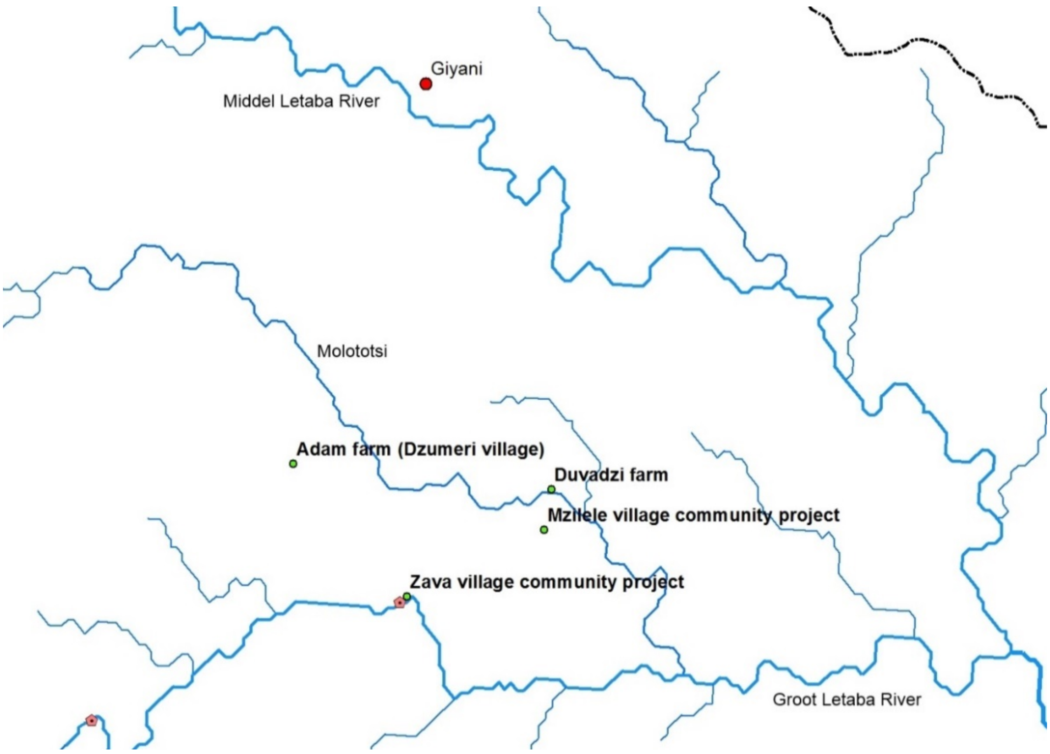


Figure 2.4 *Experimental farms as situated in the Letaba basin around the city of Giyani.*

2.3 Description of the SIMGRO model

To predict the effect of measures on a complex river basin like the Lethaba, it is necessary to use a combined groundwater and surface water model. SIMGRO (SIMulation of GROundwater and surface water levels) is a distributed parameter model that simulates regional transient saturated groundwater flow, unsaturated flow, actual evapotranspiration, sprinkler irrigation, stream flow, and groundwater and surface water levels as a response to rainfall, reference evapotranspiration, and groundwater abstraction (Figure 2.5). To model regional groundwater flow, as in SIMGRO, the system has to be schematized geographically, both horizontally and vertically. The horizontal schematization allows different land uses and soils to be input per node, to make it possible to model spatial differences in evapotranspiration and moisture content in the unsaturated zone. For the saturated zone, various spatially distributed subsurface layers are considered; for the surface water, the streams are simplified into one reservoir per sub catchment. For a comprehensive description of SIMGRO, including all model parameters, see Querner (1997) or Povilaitis and Querner (2006).

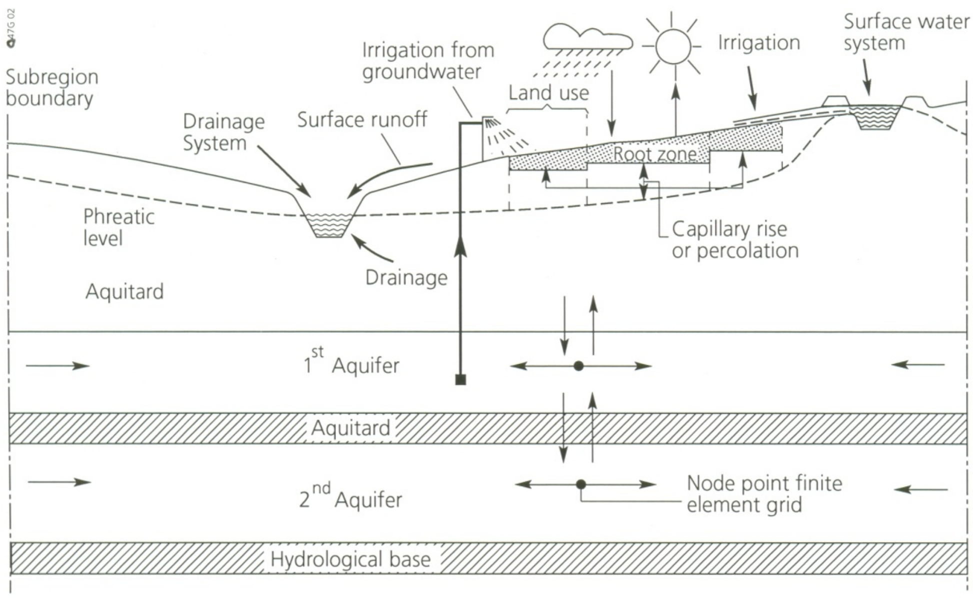


Figure 2.5 *Schematization of the hydrological system modelled with SIMGRO (adapted from Querner, 1997)*

The model is used within the GIS environment ArcView. A user interface, AlterrAqua, serves to convert digital geographical information (soil map, land use, watercourses, etc.) into input data for the model. The results of the modelling are visualised and analysed together with specific input parameters. AlterrAqua was built according to Dutch environmental conditions, which have to be adjusted when modelling a catchment with a different climate, land use and subsurface.

In SIMGRO the finite element procedure is applied to approach the flow equation which describes transient groundwater flow in the saturated zone. A transmissivity is allocated to each nodal point and aquifer to account for the regional hydrogeology. The unsaturated zone is represented by means of two reservoirs, one for the root zone and one for the subsoil (Figure 2.5). The calculation procedure is based on a pseudo-steady state approach. If the equilibrium moisture storage for the root zone is exceeded, the excess water will percolate towards the saturated zone. If the moisture storage is less than the equilibrium moisture storage, then water will flow upwards from the saturated zone (capillary rise). The height of the phreatic surface is calculated from the water balance of the subsoil below the root zone and the saturated flow equation, using a storage coefficient. The equilibrium moisture storage, capillary rise and storage coefficient are required as input data and are given for different depths to the groundwater.

Actual evapotranspiration is a function of the reference evaporation, the crop and moisture content in the root zone. To calculate the actual evapotranspiration, it is necessary to input the measured values for net precipitation, and the potential evapotranspiration for a reference crop (grass) and woodland. The model derives the potential evapotranspiration for other crops or vegetation types from the values for the reference crop, by converting it with known crop factors.

The surface water system usually consists of a natural river and a network of small watercourses, lakes and pools. It is not feasible to explicitly account for all these watercourses in a regional simulation model, yet the water levels in the smaller watercourses are important for estimating the amount of drainage and the water flow in the major watercourses is important for the flow routing. The solution chosen in SIMGRO is to model the surface water system as a network of reservoirs. The inflow into one reservoir may be the discharge from the various watercourses, ditches and surface runoff. The outflow from one reservoir is the inflow to the next reservoir. For each reservoir, input data are required on two relationships: 'stage versus storage' and 'stage versus discharge'. For the interaction between surface water and groundwater, there are four different categories of watercourses (related to its size) to simulate the drainage. It is assumed that three of the subsystems - ditches, tertiary watercourses and secondary watercourses - are primarily involved in the interaction between surface water and groundwater. A fourth system includes surface drainage to local depressions.

The time step of the groundwater model is one day. However, the surface water sub-model performs several computational time steps during one time step of the groundwater sub-model. The dynamics of surface water movement are much faster than those of groundwater movement. Therefore, both sub models have their own time step. The time step of the surface water sub-model is 0.05 days, and the time step of the groundwater sub model is one day. Groundwater levels remain constant during the time steps of the surface water sub-model. After one day, the groundwater sub model updates the groundwater levels using the state of the unsaturated zone and the surface water zone at that point in time.

Irrigation scheduling
In the SIMGRO model, the irrigation gifts can be assigned automatically, based on the moisture content in the root zone (automatic). Each crop can be assigned a particular threshold value at which irrigation should start. This method is used in situations where farmers use sprinkler irrigation and individually abstract the water from surface water and/or groundwater. In irrigated areas, it is necessary to specify the irrigation for each node and crop, based on a specific rotational scheme (prescribed). The way the water is distributed is derived for each command area, based on field measurements of the water distribution. The IRRIG module was developed for such situations: it transforms the available information into input data for SIMGRO (Querner et al., 2008). This module requires the monthly water volumes (surface water and groundwater) for each management unit and the application depth, the duration of a gift, and the number of applications per month. Information on the variation of the application depth over the growing season must also be input. Using this information, IRRIG calculates the water allocation to each crop and region in time. The module can also assign certain crops more water, if water is available, or reduce the water allocation if less water is available. For instance, if more water is available, then the application depth for some crops is increased. Crops are selected for the adjusted treatment in accordance with the priority assigned to them. In this way, crops very sensitive to a water shortage, such as vegetables, can be given more water. This enables the irrigation gifts to be specified as closely as possible to what is common practice in the irrigation area, but using the SIMGRO model it is also possible to define different water allocation strategies and evaluate them.

Surface runoff
We used an approach for surface runoff as used in a study on water scarcity in Africa (Conijn et al, 2011). Based on the soil texture class, ground slope and rainfall intensity the surface runoff is estimated.

2.4 Water use by crops and woodland

Below an outline is given on the methodology of the water use by crop and woodland. In par 3.2.3, the method for woodland is applied to calculate the water use of woodland in the Letaba basin.

2.4.1 Crop water use

SIMGRO requires the potential evapotranspiration of a reference vegetation as input data. The potential evapotranspiration for other vegetation types is calculated using crop factors (Feddes, 1987; Allen et al., 1998). The potential evapotranspiration of the reference vegetation is computed from meteorological data using the Makkink equation for grass (De Bruin, 1987).

The bare soil evaporation is computed when reading the meteorological data, since it involves the precipitation history. It is a process involving the thin upper soil layer. When this layer dries out, it limits the loss of moisture. The method of Boesten and Stroosnijder (1986) is used to estimate this reduction. The method reduces soil evaporation as a function of precipitation and the reference evapotranspiration, expressing the result as a ‘crop’ factor.

The potential evapotranspiration for woodland is calculated as the sum of transpiration and interception. For deciduous forest, the change in leaf area over the year is considered for including soil evaporation as well (Querner, 1993). The approach has been developed in different projects abroad (Argentina, Poland, Lithuania, Brazil and Southern Africa) and is outlined in par 2.4.2.

2.4.2 Concept for estimating water use by woodland

Water use of woodland can range in general quite drastic, as it depends on the transpiration by the trees, the interception and the under growth. The forest is differentiated in pine and deciduous forest. For both types, the procedure is identical as described below. The procedure is developed to cover different types, like a dense forest, but also a savannah in which there is a grass cover or a combination of a grass cover and fallow soil. The representation of the water use by woodland is given in Figure 2.6.

The equation to estimate the total evapotranspiration of an area with trees, but also open spaces with either a fallow soil or a grass cover is given by:

$$E_p = A_{trees} * (E_{tr} + E_{int}) + (1\text{-}A_{soil}) * E_{ref} * C_{grass} + A_{soil} * E_{ref} * f_{c.\ fact\ soil} * C_{soil} \qquad (1)$$

where:

E_p	=	Potential evapotranspiration for an area with trees, partly open spaces and partly an undercover of grass
A_{trees}	=	Area with trees
E_{tr}	=	Transpiration ($E_{ref} * f_{c.\ factor\ trees}$)
E_{int}	=	Interception, estimated using interception reservoir, rainfall data and estimated reference evapotranspiration.
A_{soil}	=	Area with fallow soil
E_{ref}	=	Reference evapotranspiration
C_{grass}	=	a constant to convert the ref. evapotranspiration of a dense grass cover (ref crop) to the evapotr. of the natural vegetation (variable from 0.3 to 1.0 as a function of forest cover)
$f_{c.\ fact\ soil}$	=	crop factor for fallow soil
C_{soil}	=	a constant to convert the bare soil crop factor for a situation under the trees (variable from 0.1 to 1.0 as a function of forest cover)

The default values for Cgrass and Csoil are given in Table 2.1

For the input of the meteorological data, two options can be considered, being:

1. Basic input data of precipitation, temperature, relative humidity and short wave radiation
2. Precipitation and reference evapotranspiration

Using the data in the first option, the reference evapotranspiration is calculated using the Makkink equation (De Bruin, 1987). The potential evapotranspiration of the trees is calculated using the MUST concept. The surface resistance Rc is a function of solar radiation. The solar radiation required for this relation are daily values and therefore the short wave radiation (24 hour value) is multiplied with a factor three to use the relation.

Option 2 uses the reference evapotranspiration as a basis and calculates the potential evapotranspiration of pine and deciduous forest, as done in the study.

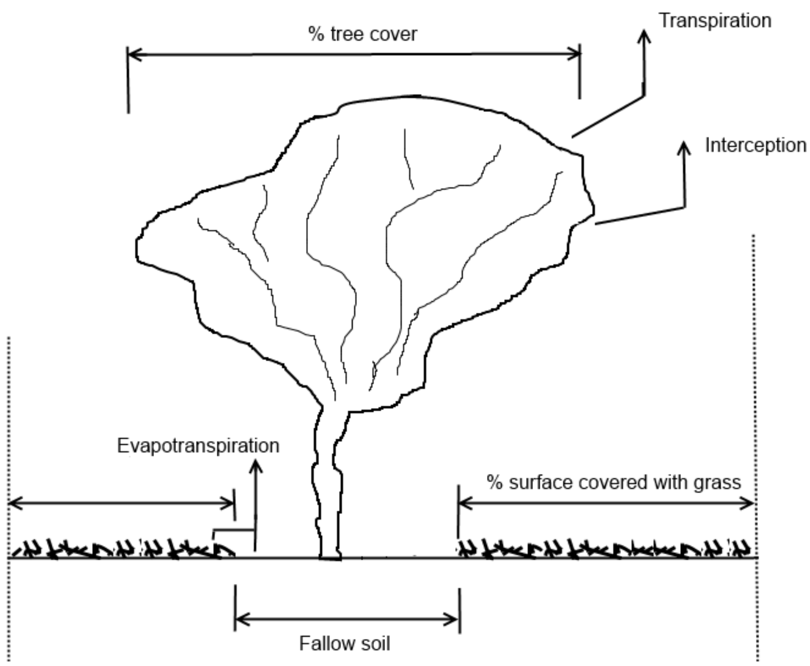


Figure 2.6 *Schematic representation of an area with trees and an undercover of grass and bare soil.*

Table 2.1

Typical values of Cgrass and Csoil required in Eq. 1 to estimate the potential evapotranspiration of woodland.

Woodland (%)	Cgrass	Woodland cover (%)	Csoil
< 20	1.0	< 40	1.0
20 – 40	0.9	40 – 60	0.95
40 – 60	0.75	60 – 80	0.7
60 – 80	0.55	80 – 95	0.35
80 – 95	0.35	> 95	0.1
> 95	0.3		

For the Letaba basin in paragraph 3.2.4, the potential evapotranspiration of woodland is estimated and given as monthly crop factors in order for a comparison with other land uses.

3 SIMGRO model application Letaba basin

3.1 Schematisation basin and elevation

Nodes depict the spatial schematisation of the SIMGRO model. A network of 7365 nodes in which each node represents a part of the groundwater system covers the basin. Nodes are spaced about 1500 m apart.

For the elevation of the ground level a 95*95 m grid DEM was used (SRTM, 2013; Far et. al., 2007). The Shuttle Radar Topography Mission (SRTM) obtained elevation data on a near-global scale to generate a high-resolution digital topographic database. SRTM consisted of a specially modified radar system that flew on board of the Space Shuttle Endeavour during an 11-day mission in February of 2000. Figure 3.1 shows the DEM with the elevation from 175 to 1800 m+MSL (light to dark colour). We used the HydroSHEDS data (Hydrological data and maps based on SHuttle Elevation Derivatives at multiple Scales), which provides hydrographical information in a consistent format for regional applications (USGS, 2013). Stream networks and sub-basins are identified and can be used for the flow routing thru the streams and rivers. Using the DEM of the Letaba, the major sub basins of the Letaba were delineated. In the SIMGRO model application the sub basins are further subdivided into sub catchments per stream section.

The western part of the catchment is covered by the Drakensberg Mountain Range and the eastern Soutpansberg with elevations up to 2000 m+MSL in the southwest (Figure 3.1). Moving towards the east the landscape changes to low mountains (yellow colour) and foothills until reaching the lowlands in the eastern part of the catchment with elevations of 300-500 m (CSIR, 2012). The area of Greater Giyani is located within the lowlands.

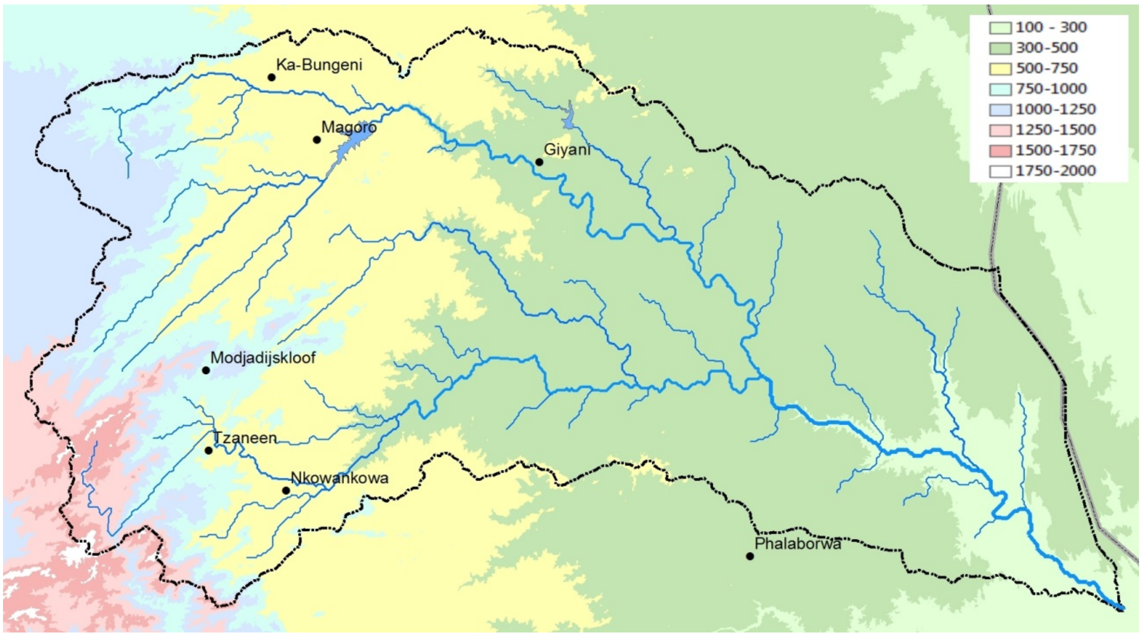


Figure 3.1 *Ground level elevation of the Letaba basin, from 175 to 1800 m+MSL.*

3.2 Input data

The preliminary SIMGRO model was developed for the Letaba basin based on available data. In this paragraph, the main input data used for the model are discussed. The main input data concerns information on groundwater, surface water, land use, soil properties, irrigation and meteorological data.

3.2.1 Input data for groundwater and surface water

The subsurface in the basin is built up of a number of layers. Little information is available; therefore we assumed an aquitard on top of an aquifer (Pers. com. Nebo Jovanovic). The first layer (aquitard) receives water from the unsaturated zone through percolation and loses water to the unsaturated zone through capillary rise. This layer also drains water to the surface water and might receive infiltrated water from the rivers. In the aquitard there is vertical flow, in the aquifer there is horizontal flow and it is overlying the hydrological base.

The catchment can divided into several hydrogeology regions (see also Figure 3.2) characterized by fractured aquifers formed mainly by metamorphic basement rocks. Inter-granular aquifers with unconsolidated to semi consolidated materials, with primary porosity occur on the Letaba River (DWAF, 2004). The main regions are the Escarpment zone with fractured rooks which are highly permeable although the storage in these aquifers is very limited and the plains which cover 50% of the catchment and are characterised by fractured rocks. Further regions are the Drakensberg Foothills and Valleys, the Giyani-Gravelotte region dominated by local fractured materials as a result of the intense folding and associated fracturing. Boreholes yield varies between 0.5 and 5 l/s (~43-430 m^3/d). Along most of the main rivers, an alluvium layer exists, composed of unconsolidated clayey silts to coarse gravels and boulders. The aquifer properties are highly variable within short distance.

For the aquifer we used the hydrogeological data of SADC (SADC, 2010). Transmissivities have been reported by Holland (2011) and shown in Figure 3.2. It has been found that in the Letaba basin the transmissivity (kD) varies between 7 and 42 m^2/d. In the mountains around Tzaneen the Granite has a kD of 7 m^2/d. For the Giyani Belt its 37 m^2/d. For the Lowveld and part in the Kruger National Park the transmissivity of the Gneiss is 24 m^2/d.

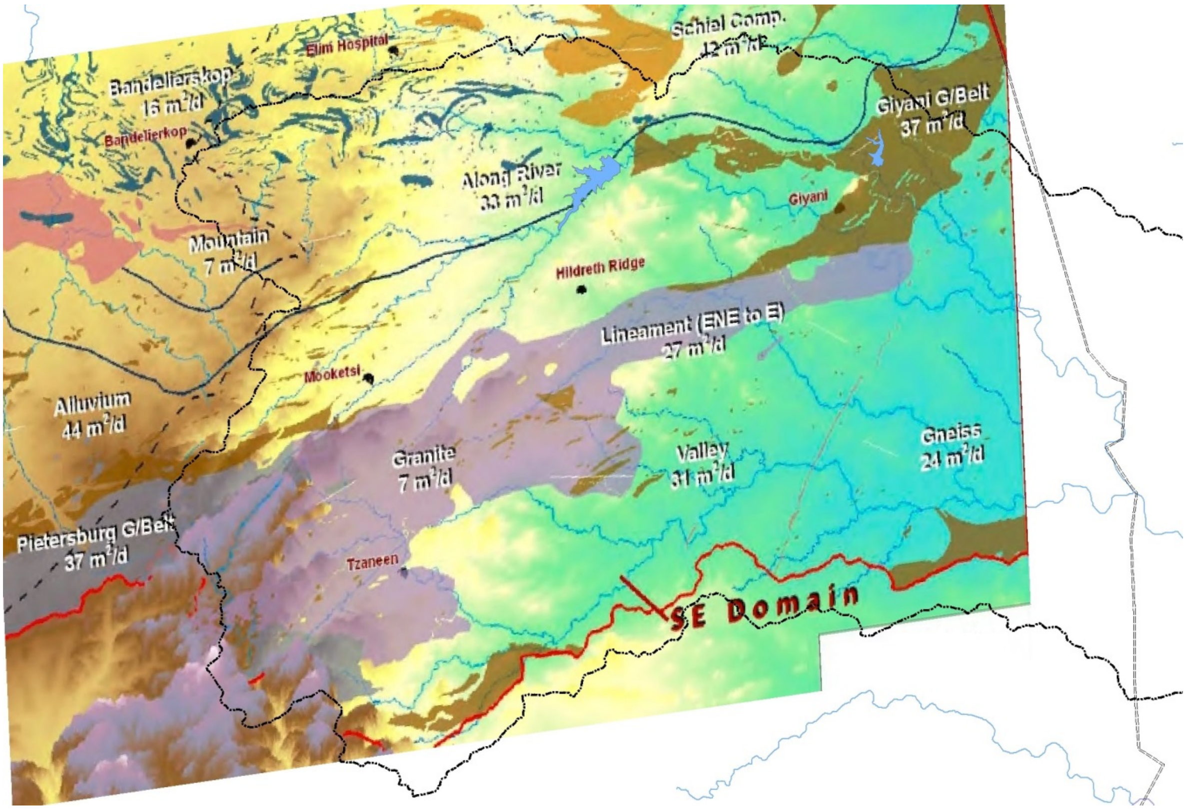


Figure 3.2 *Transmissivity values and faults for the Letaba basin (Holland, 2011)*

Based on the main streams considered for the surface water modelling, the basin was divided into 190 sub catchments. These sub catchments consist of the reservoirs mentioned in Par. 2.3 and shown in Fig. 2.5. The size of the sub catchments are shown in Figure 3.3. Due to lack of information but based on a limited number of photos, the width of the river is based on the upstream size of the catchment. For the headwaters the width ranges < 10 m, the width of the middle reaches is from 10-50 m and the main river is from 50-100 m (Figure 3.1). The network of rivers, streams, channels and ditches is dense. All these water courses are used to simulate the interaction between surface water and groundwater. For each node a drainage resistance and the difference in level between the simulated groundwater and pre-defined surface water are used to calculate the water flow (either drainage or infiltration).

Within the Letaba basin there are 22 major dams (DWAF, 2003). In Figure 3.4 the 14 dams are shown, which are included in the SIMGRO model (green) and some others not considered (red). Table 3.1 gives the volume of the considered dams. There are 4 major dams in the basin with a volume ranging from 29 to 184 mln m^3. Besides those dams shown in Fig. 3.4 there are numerous smaller dams from local communities or farmers. Table 3.2 gives the extractions of water for urban use from dams, with a total of 41.7 mln m^3/year.

Table 3.1

Dams includes in the SIMGRO model.

Name of dam	Volume (mln m^3)	Remark
Charles Engelhard	3.7	Gauge weir
Nsami	29.5	Storage dam
Prieka	0.5	
Jasi	1.1	Storage dam
Junction	0.8	Junction dam
Yamorna	1.0	
Tzaneen	157.3	Storage dam
Magoebaskloof	4.9	
Ebenezer	70.0	Storage dam
Neldoret	1.8	
Altenzur	0.9	
Lorna Dawn	11.7	
Middle Letaba	184.2	Storage dam

Table 3.2

Extractions from dams for urban water use.

City	mil m^3/year
Tzaneen	3.2
Letsitele	0.3
Bolobedu	0.2
Giyani (from Middle Letaba dam)	3.0
Giyani (from Nsama dam)	0.7
Magoro	0.0
Ka-Bungeni	0.0
Namakgale (Phalaborwa)	0.8
Ritavi 1	1.9
Ritavi 2	8.2
Polokwane (from Ebenezer dam)	18.8
Polokwane (from Dap Naude)	4.6

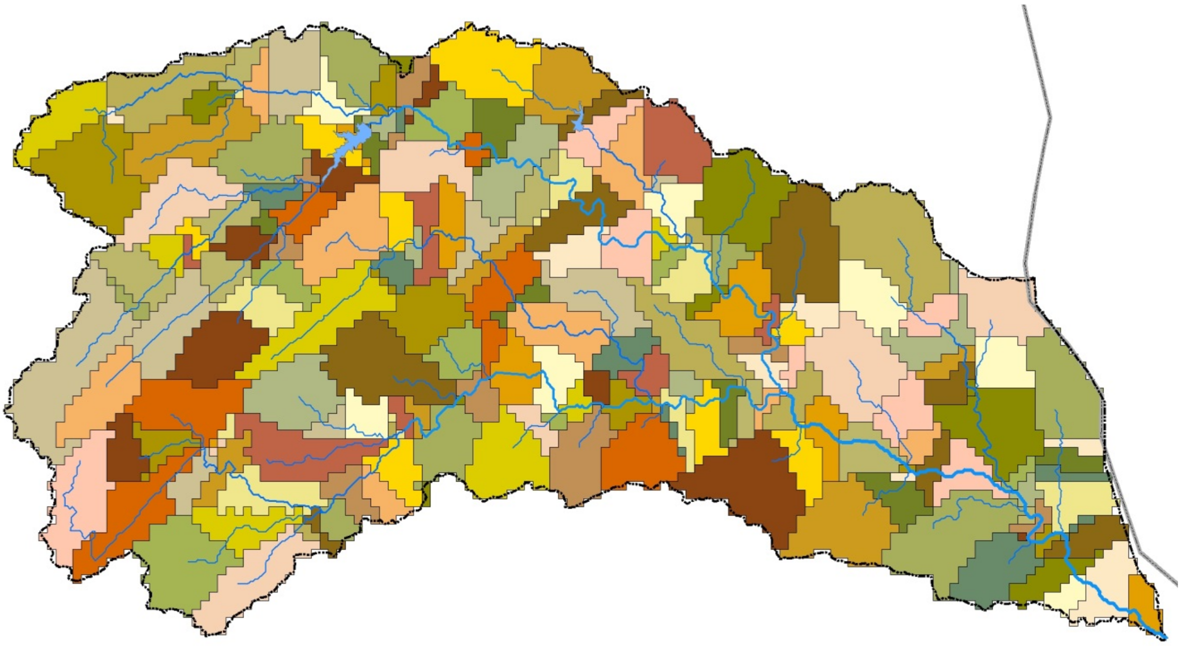


Figure 3.3 *Sub basins identified in the Letaba basin, based on the streams with an upstream catchment size of approx. 200 km^2.*

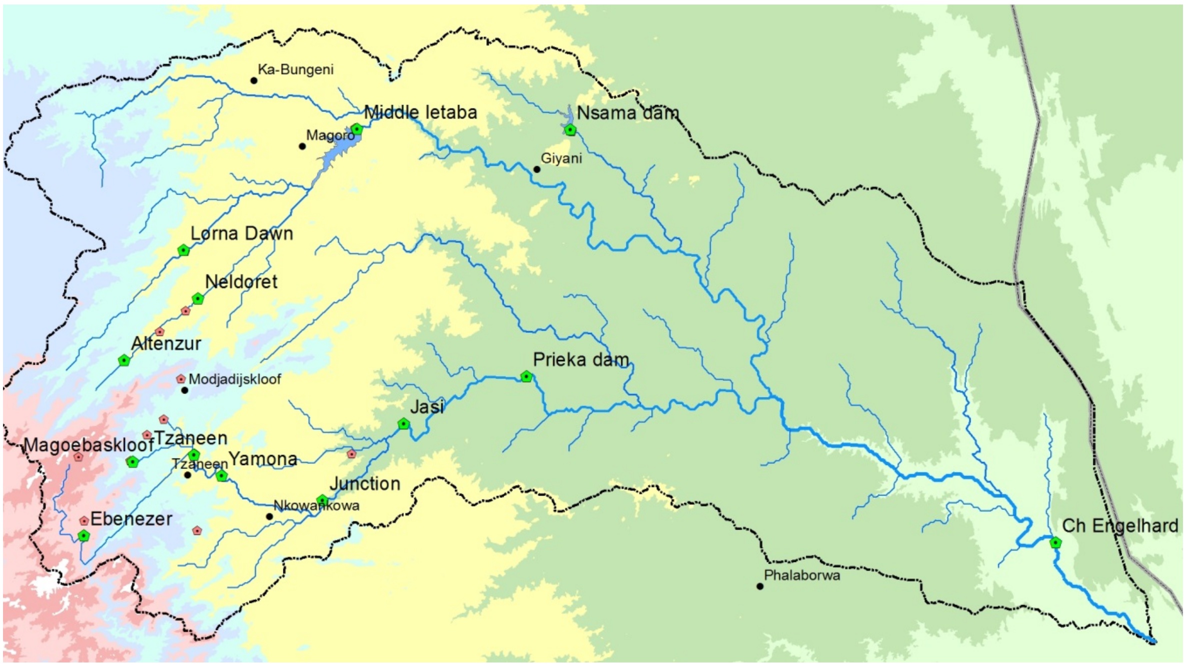


Figure 3.4 *Major dams in the Letaba River basin as schematised in the SIMGRO model (green), other dams are coloured in red.*

Land use and soils

The NLC2000 land use map was created as an up-to-date digital raster land-cover map for South-Africa, Swaziland and Lesotho. The map distinguishes 49 mapping units. For this study the 49 legend units were brought down to 12 units as given in Table 3.3 and shown in Fig. 3.5. NLC2000 defines commercial cultivation as characterized by large, uniform and well-managed fields supplying regional, national and export markets, and often being highly mechanized (GLCN-LCTC, 2000). In contrast, semi-commercial cultivation is understood to consist of several small fields in the proximity of rural settlements supplying food for the local market and individual households. Natural areas, predominantly wood- and bushland, dominate the eastern part of the catchment, which lies within the territory of the Kruger National Park (Fig. 3.5).

Also shown in Fig. 3.5 is the schematisation of the groundwater system in the SIMGRO model. There are just more than 7000 grid cells (nodes) and each cell is 1500 m square.

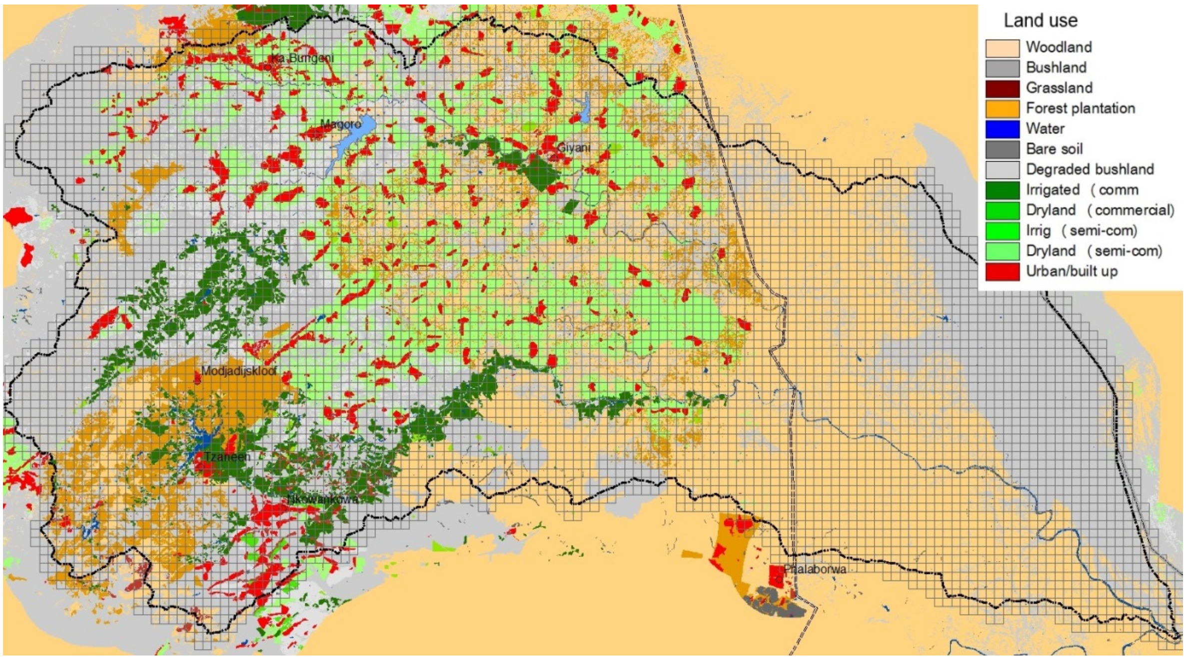


Figure 3.5 *Schematisation of the Letaba basin in the SIMGRO model, together with the land use map (NLC2000). Land use was simplified from originally 49 classes to 12 classes.*

The characteristics of the unsaturated zone has been based on the SOTER data base (Wosten et al., 2012). From the data base 15 units were distinguished in the Limpopo basin, to be important for the water bearing characteristics of the unsaturated zone. In the Letaba basin, only 10 map units are present.

Table 3.3
Description of land use, areal size and percentage.

No	Land use description	Area (km^2)	Area (%)
1	Woodland	4120.1	29.3
2	Bush land & high fynbos	5035.6	35.7
3	Grassland	40.0	0.3
4	Forest plantations	1112.1	7.9
5	Water, wetlands	109.8	0.8
6	Bare rock & soil	53.7	0.4
7	Degraded bush land & high fynbos	901.1	6.4
8	Cultivated and irrigated (commercial)	244.8	1.7
9	Cultivated dry land (commercial)	30.2	0.2
10	Cultivated and irrigated (semi-commercial)	13.9	0.1
11	Cultivated dry land (semi-commercial)	1828.4	13.0
12	Urban, built up	596.3	4.2
	Total	**14086.0**	

Groundwater
A large proportion of the rural domestic and stock watering requirements are supplied from groundwater for most of the rural settlements and villages. Groundwater is also used for game watering in the Kruger National Park and other game reserves. Substantial quantities of groundwater are abstracted for irrigation purposes in the upstream part of the Middle Letaba Dam. In total, some 15% of all available yield from water resources is from groundwater.

Groundwater resources are available throughout the catchments, but in varying quantities depending upon the hydrogeological characteristics of the underlying aquifer. Parts of the Letaba catchment are heavily populated and widespread rural communities are a feature of the area. Many communities rely on groundwater although conjunctive use schemes are also widespread.

Boreholes

Data on boreholes in the Letaba basin has been obtained from the GRIP database (GRIP Limpopo, 2013). The boreholes from the database are shown in Figure 3.6. There are 3003 boreholes which are operational and another 631 are blocked/abandoned or have another function. It was found that 1345 boreholes are situated within urban areas. The database does not show any boreholes situated in the Kruger National Park, but they are present for game watering when surface water is not available.

Boreholes are generally 50 – 100 m deep and yields tend to be between 0.5 – 5 l/s (DWAF, 2004). Yields of larger than 5 l/s are locally present in major structural features and zones of extensive weathering. Static groundwater levels are between 15 and 30 m-ss.
Estimated daily extractions are partly known. From 1554 boreholes with known capacity, the average capacity is 67 m^3/d. Urban boreholes have an average capacity of 62 m^3/d (total no. 548) and for 1006 boreholes situated in agricultural areas the average capacity is 70 m^3/d. From 1573 boreholes, the depth ranges between 10 and 201 m.

Based on the above information the amount of extractions from groundwater can be estimated. For urban boreholes (no. 1345), they have a total extraction in the order of 13 mln m^3/year, assuming 10 hours of pumping per day and the average capacity of 62 m^3/d (GRIP Limpopo, 2013). For agricultural boreholes (no. 1658), the extraction is estimated in the order of 15 mln m^3/year, based on 5 days a week pumping for 12 hours. It is known that there are also quite a number of unregistered boreholes, but how many is not quantified (LDA, 2014).

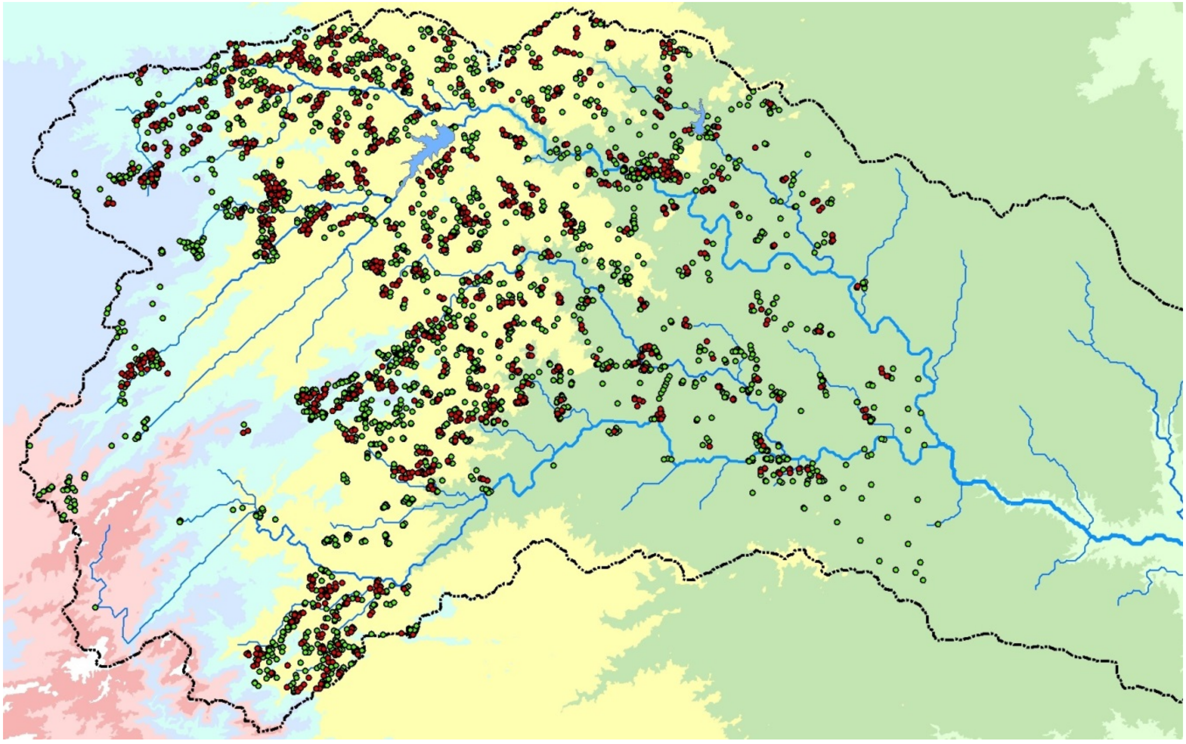


Figure 3.6 *Boreholes within urban areas (red) and boreholes for agricultural water use (green).*

Irrigation

In the Letaba basin water for irrigation of commercial farming is mainly extracted from the major dams as shown in Fig. 3.4. The irrigated areas were shown in Fig. 2.2 and they correspond more or less with the land use map cultivated and irrigated (commercial).

Groundwater is used in other areas where surface water is not available. It has been assumed that the land use cultivated dry land (semi commercial) are the farmers, which use mainly supplementary groundwater to irrigate their crops, or when located next to a river they use surface water. Further analysis of water use by the smallholder farms is given in Par. 3.2.5. and Annex 1.

Transfer of water
A number of schemes were constructed for the transfer of water to neighbouring water management areas. The largest transfers are from Ebenezer Dam and Dap Naudé Dam to Polokwane. There are small transfers from the Groot Letaba catchment for mining near Gravelotte and to rural villages in the Olifants River basin.

3.2.2 Meteorological data

In the Letaba basin and its surrounding there are 9 stations with precipitation data and the reference evapotranspiration available. It was necessary to fill in missing data from the nearby stations. The location of the stations is given in Figure 3.7. Using thiessen polygons the data from each of the stations was assigned to a set of nodal points (grid cells) as present in Fig. 3.5. From the 9 meteorological stations data on evaporation was often available from an evaporation pan. Conversion of E pan values to the reference evapotranspiration (ETref) is:

$$ETref = Kpan \times Epan$$

ETref	Reference crop evapotranspiration
Kpan	Pan coefficient
Epan	Pan evaporation

For the Class A evaporation pan, the Kpan values varies between 0.35 and 0.85. Average Kpan = 0.70. For the Sunken Colorado pan, the Kpan values varies between 0.45 and 1.10. Average K pan = 0.80 (Wikipedia, 2013b).

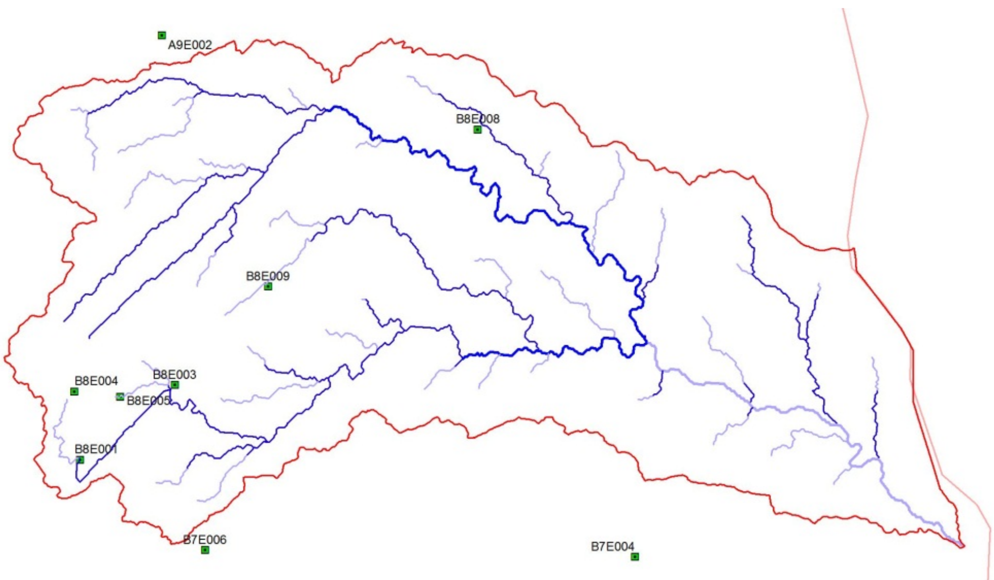


Figure 3.7 *Location of meteorological stations in and around the Letaba basin.*

SIMGRO uses the reference evapotranspiration (ET0) to calculate the actual evapotranspiration through the following steps. The potential evapotranspiration for a particular crop is derived from the reference crop evapotranspiration using crop factors. A crop factor is a correction factor containing all variation of evapotranspiration with crop type, growth stage or management practice (Allen et al., 1998; Annandale et al., 1999). Then the actual evapotranspiration of each crop is determined in the model depending on the moisture content in the root zone.

For a quick analysis of potential evapotranspiration and water requirements for irrigation, we used data from the meteorological station B8E008 (Fig. 3.7). Irrigation requirements are presented in Annex 1, based on the FAO guidelines (FAO, 1986) and analysis reported by Meijer *et al.* (2012). For the period 1995-2011, the average annual precipitation was 323 mm and the average reference evapotranspiration was 1227 mm. The average net irrigation requirements is 1078 mm/year (Annex 1).

3.2.3 Aridity index Letaba basin

Since rainfall conditions vary quite drastic over the basin, information on yearly precipitation and potential evapotranspiration is presented in Table 3.5 for the 9 stations. Rainfall ranges between 300 and 1450 mm per year and potential reference evapotranspiration ranges between 1000 and 1300 mm/year. To express the stations in terms of aridity we used the UNEP (1992) classification. The index of aridity is defined as:

$$AI = P / PET$$

where AI is the aridity index, PET is the potential evapotranspiration and P is the average annual precipitation (UNEP, 1992). PET and P must be expressed in the same units. To define the various degrees of aridity in terms of this aridity index is given by the classification as shown in Table 3.4.

Table 3.4
Classification of aridity based on the UNEP methodology.

Classification	Aridity Index
Hyper arid	< 0.05
Arid	0.05 - 0.20
Semi-arid	0.20 - 0.50
Dry sub-humid	0.50 - 0.65

For the meteorological stations in the Letaba basin, the estimated aridity index is presented in Table 3.5. From 2 stations (B7E004 and B8E008) the aridity classification is semi-arid and for station B8E009 it is classified as dry sub-humid. The station B8E008 at the Nsama dam near Giyani is nearly classified as arid. Table 3.5 shows clearly that there is a large variation of meteorological conditions across the basin on more or less 100 km apart between station B8E003 and B8E008 or B7E004.

Table 3.5
Average annual precipitation and potential evapotranspiration (1995 – 2011) given the aridity index for the meteorological station as shown in Fig. 3.7.

Stat no.	Precipitation (mm)	Pot. ref. evapotranspiration (mm)	Aridity index (-)
B7E004	464	1203	0.39
B7E006	966	1266	0.76
B8E001	1272	1002	1.27
B8E003	1136	1132	1.00
B8E004	1437	1064	1.35
B8E005	1443	1084	1.33
B8E008	291	1219	0.24
B8E009	798	1281	0.62
A9E002	935	1125	0.83

3.2.4 Water use for woodland and forest in the Letaba basin

The annual evapotranspiration from natural vegetation into a forestry regions ranges from 700 to 900 mm. By contrast, evapotranspiration from established forest plantations is commonly in the range of

1100–1200 mm, and is limited by the rainfall available on the site (Dye and Versfeld, 2007). The difference in evapotranspiration is also contributed to the seasonal differences in green leaf area, interception and water use by the undergrowth.

From the theoretical outline on how to derive at water use in the Letaba basin as presented in Par. 3.2.3 we now give the practical application to the Letaba basin. Both woodland and forest water use is considered. We used the local meteorological station B8E008, as shown in Fig. 3.7, for the Lowveld area. In Table 3.6 gives some of the characteristics used to estimate the water use by woodland and forest.

The analysis we adopted a pragmatic approach: a range of grass cover vegetation was assumed as undergrowth for the different tree covers. Table 3.6 gives the data. The potential water use by the woodland was converted to a crop factor in order to compare it with the water use of agricultural crops. Figure 3.8 shows the crop factors as a function of tree cover and under growth of a grass cover.

Table 3.6
Parameters assumed for the Letaba basin.

	Pine trees	Deciduous			
Interception reservoir winter period (mm)	1.3	0.4			
Interception reservoir summer period (mm)	1.8	3.0			
Crop factor winter (-)	0.85	1.0			
Crop factor summer (-)	0.95	1.05			
Pine or deciduous forest:					
Tree cover (%)	10	25	50	75	90
Soil covered with (grass) vegetation (%)	100	100	80	50	25

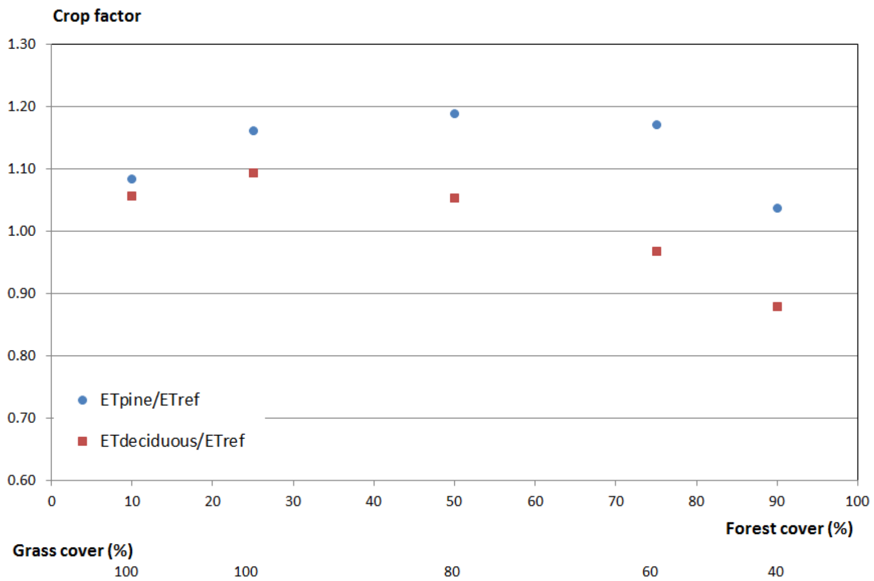


Figure 3.8 *Crop factors for pine and deciduous forests as a function of tree cover, and under growth (grass cover and bare soil).*

3.2.5 Farming and crop water use

We use in SIMGRO crop factors to estimate the potential reference evapotranspiration of the crops. The crop production and thus water use is differentiated between the two farming systems, being the large-scale commercial farms and the smallholder agriculture. For the present situation (base line), we used crop factors to give estimates of the potential evapotranspiration (Annandale et al, 1999). For the different scenarios, when more water or nutrients are applied (Table 3.7), the water use by the crops increases. Since our study concerns only changes in the smallholder farming we only changed the production levels for these farms. It is expected that increase in crop yields will be substantial for the smallholder farms. They will apply more water in order to increase the crop production and thus income. Table 3.7 gives the change in crop factors for a set of defined projections of the crop production. In Chapter 4 the scenario-analysis uses these projections of increase in evapotranspiration.

Table 3.7
Estimated increase in potential evapotranspiration for the agricultural land uses in the Letaba basin.

Scenario	Land use number from Table 3.3	
	10	11
Baseline	1.00	1.00
More water	1.05	1.10
Optimum water + small increase in nutrients	1.10	1.25
Water and nutrients optimal	1.15	1.30

In Simgro, we apply for the baseline scenario a fixed rotational scheme as outlined in Par. 2.3. In Table 3.8, the information is given on the irrigation depth, duration and the source of the water. The irrigation applications are given 4 times a month (Table 3.8), indicated by the day number of the month. In such a way, the reality has been captured in the model. It remains a strong simplification, but sufficient for a regional model like the Letaba basin (Querner et al., 2008).

Table 3.8
Details of the irrigation parameters considered in the SIMGRO model for the baseline scenario.

Land use	Description	Applic. depth (mm)	Extraction sw/gw	Application day in month			
8	commercial (irr)	30	sw	1	9	17	24
9	commercial dryland						
10	semi-comm (irrig)	20	sw	3	11	19	26
11	semi-comm	15	gw/sw	3	11	19	26
12	urban	4	gw	5	15	25	

In the Letaba basin the land use dry land (semi-commercial) as classified by NLC2000 was presented in Table 3.3, being a total area of 1828 km^2. A fraction of that area covers actually agricultural smallholder farms. Cattle farming is another activity and the remaining area is in general degraded bush land. Some uncertainty exists on how much agricultural farmers are actually present. In the Greater Giyani municipality it has been recorded that around 900 agricultural smallholder farmers are present (data retrieved from database of Prov. of Limpopo, Dep. of Agric., Mopani Distr.). These farmers grow mainly maize, but other crops grown are mixed vegetables, tomatoes and cabbage. We assume that these 900 agricultural smallholder farms have each on average 4 ha cropped, then in Greater Giyani municipality there is around 3600 ha of smallholder agricultural land. Further assuming that in the other municipalities in the Letaba basin there is also such an area, it means there is around 7500 ha of agricultural land classified as smallholder crop farming. Such an area of agriculture represent 4.1% of the total land of semi-commercial in the Letaba basin.

Table 3.5 shows that the rainfall around Giyani is not enough to have rainwater agriculture and additionally irrigation water is needed. If we assume that 450-500 mm per year is required as an additional water source (Pienaar, 2014), then this means that around 38 mln m^3 of water is used annually. Such a water use to supplement the crops means an average water flow of 1.2 m^3/s. This required amount of irrigation will be extracted from surface water and groundwater. The extraction from groundwater will eventually influence the drainage downstream in the basin, so the surface water flow will be reduced by 1.2 m^3/s.

From the data on agricultural boreholes in Par. 3.2.1, the amount of extraction was estimated in the order of 15 mln m^3/year. Compared to the water use estimated above of 38 mln m^3/year from surface water and groundwater, the extraction from borehole data is probably an underestimation, since quite a number of boreholes are not registered and probably are operational more hours a week. In addition, the amount extracted from surface water is uncertain. Information is then needed how much farmers are situated within, say 250-500 m distance, along a stream with running water.

3.2.6 Cropping patterns for the smallholder farms in the model

In reality each farmer has his own cropping pattern depending on numerous local conditions, among others: farming area, soil type, different crops and water availability (groundwater and/or surface water). For the modelling at the river basin scale all the local cropping and management aspects cannot be taken into consideration. The land use, irrigation practise and management needs to be simplified and robust, that it can be used in the scenario analysis.

Farmers grow different crops like tomatoes, green pepper, spinach, cabbage, beetroot, carrots, maize, butternuts, okra, watermelon, mangoes, baby marrows, chillies, lettuce and onion under irrigation using water from the Greater Letaba River or groundwater (CSIR, 2012). Such a variety of crops cannot be considered in the regional model. We consider all the smallholder farmers to be represented by growing two different (representative) crops. These two crops have an annual cycle of representative winter and summer crops. The first representative cropping cycle is maize in summer and in winter vegetables (on a smaller area). Crops grown are mainly maize, wheat and barley. The winter vegetables are particular groundnut and soya bean. The second crop represent vegetables grown all year round, like tomatoes, beans, cabbage and cauliflower. The typical arrangement of both groups in a farm is a 50-50% division.

3.3 Calibration

Discharges
Measured river flows were obtained from the website of the Dep. of Water Affairs and Forestry (DWAF, 2013). In Figure 3.9 the locations of the 5 gauging stations are shown. The discharge data from these stations are used to compare these against model output.

Measured and calculated discharges for 3 gauging stations are shown in Figure 3.10. Calculated discharges are sometimes higher, which is probably partly contributed to the higher surface runoff estimated then occurs in reality. The surface runoff in the model is based on the simple approach (Par. 2.3) based on input data of daily precipitation. The input of daily rainfall data is generally too course to indicate surface runoff by a rainfall event of short duration and high intensity during a day. In addition, the storage dams are included in the model, but operational rules are lacking, thus dam releases or spillway overflows may be in the model far from the reality.

In the year 2000 an extreme flood occurred. To a lesser extend as well in 2004.

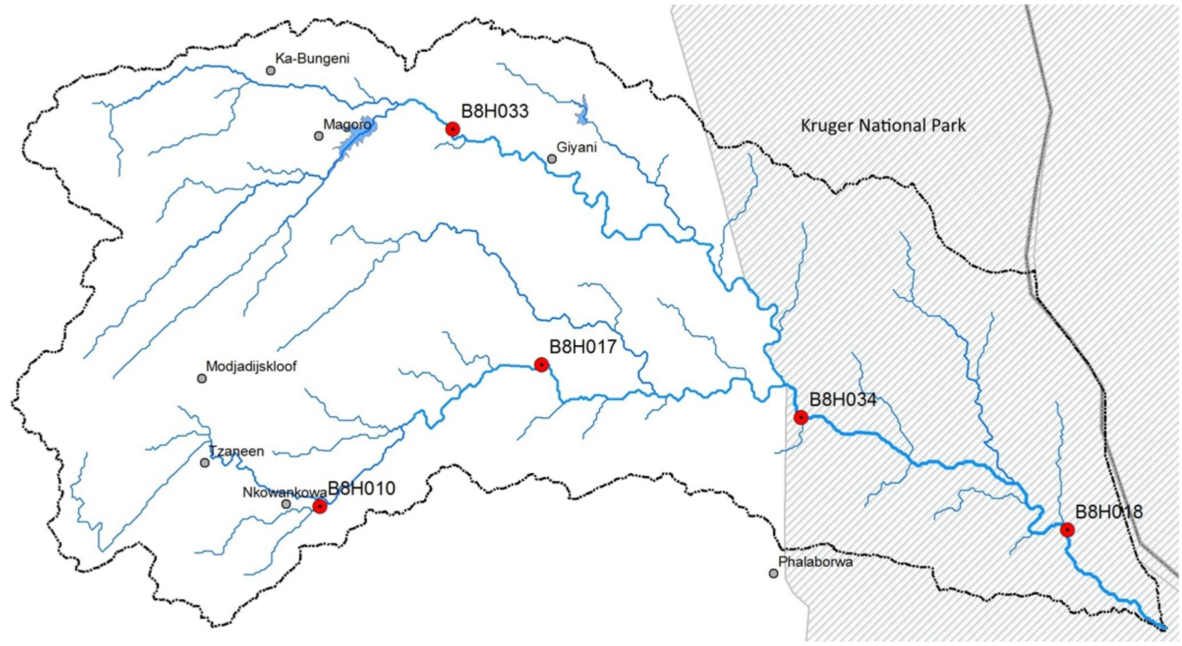
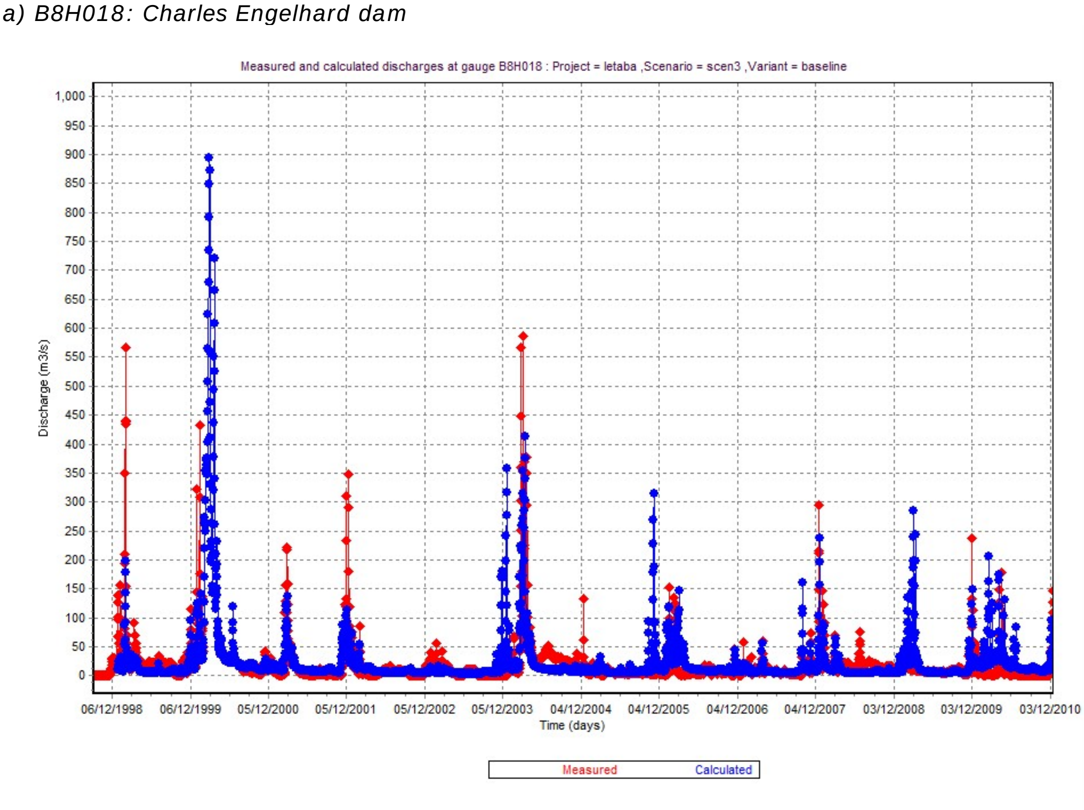


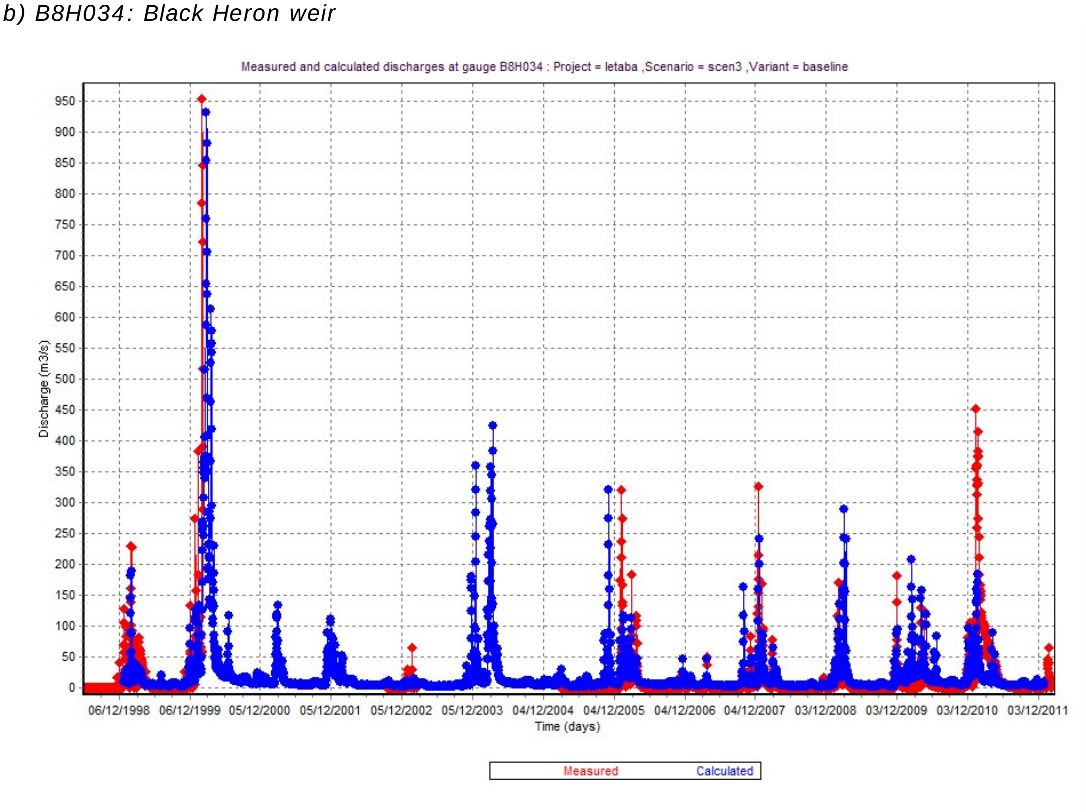
Figure 3.9 *Locations of the gauging stations used in the calibration phase.*

Figure 3.10 shows that in winter, during low flows, the measurements fit the data reasonably well. The figures also show that there are periods, particular during and after floods, that measurements were not available; this applies in particular for the gauge at Black heron weir.

a) B8H018: Charles Engelhard dam



b) B8H034: Black Heron weir



c) B8H010: Letsitele River at Mohlaba S Reserve 567

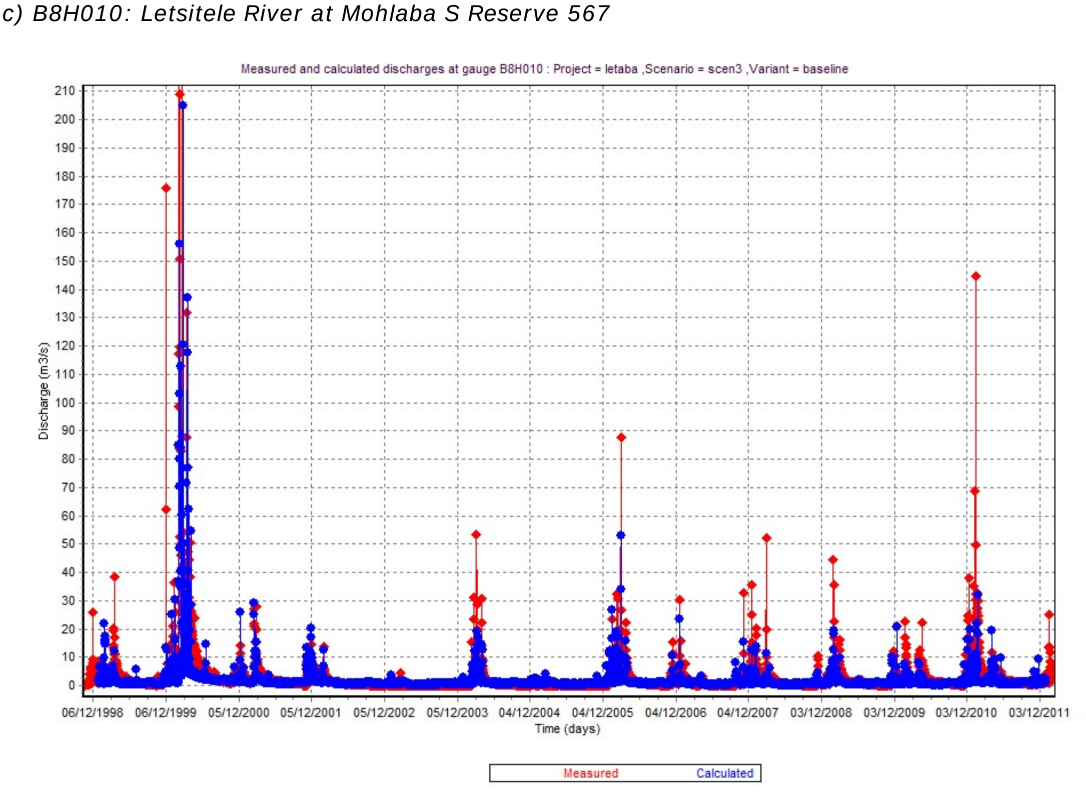


Figure 3.10 *Comparison of measured and calculated discharges for 3 gauges: a) Charles Engelhard Dam; b) Black Heron weir; c) Letsitele River at Mohlaba Reserve.*

For the presentation of the differences between measured and calculated discharge, the Nash-Sutcliffe modelling efficiency E has been used (Nash and Sutcliffe, 1970). Table 3.9 shows the current model efficiency for the five gauges, based on daily discharges or average monthly discharges. The efficiency

Figure shows how reliable the model simulates the real situation. The closer the model efficiency is to 1, the more accurate the model is. Values above 0.25 will be regarded for the conditions in the Letaba basin as accepTable in this study. An efficiency of lower than zero indicates that the average value of the measured time series would have been a better predictor than the simulations of the model (Krause et al., 2005). Using daily discharges, gauge B8H018 (Charles Engelhard dam) has a low modelling efficiency of 0.09. Gauge B8H034 and B8H010 show the best comparison of measured and calculated discharges. If we take the monthly average discharges and compare these, then the model efficiency becomes much higher (Table 3.9). Gauge B8H018 goes from 0.09 to 0.44 and B8H017 goes from 0.27 to 0.80). Since the comparison is on a daily basis, a high efficiency could not be expected. In most studies, the comparison is only done on a monthly basis, which will show a much higher efficiency as shown in Table 3.9.

Table 3.9

Nash-Sutcliffe model efficiencies for the 5 gauging stations used in the Letaba basin (for location of gauges see Figure 3.9)

Gauge number	Nash-Sutcliffe model efficiency	
	Daily discharges	Monthly average discharges
B8H018	0.09	0.44
B8H034	0.29	0.42
B8H033	0.04	0.05
B8H010	0.37	0.76
B8H017	0.27	0.80

Groundwater levels

From the Department of Water Affairs we received measured groundwater levels from 19 locations as shown in Figure 3.11. These measurements are available for the period 2005 to 2011.
The average difference between measured and calculated groundwater levels are given in Table 3.10. Calculated groundwater levels tend to be generally higher than measured levels. The differences range between -42 m and 54 m. It should be noted that model results are average groundwater levels for an area of a node (approx. 2.25 km^2) and measurements are for a point location with influences from its surroundings. The comparison of groundwater levels measured and calculated gives a very rough indication on how well the model predicts the reaction of groundwater levels in time.

Table 3.10 shows for some piezometers a large difference between measured and calculated which could be caused by local hydro-geological conditions, as well as nearby groundwater extractions. Therefore we also estimated the difference in fluctuation of measured and calculated groundwater levels. The RMSE of the difference in fluctuation between measured and calculated levels are also presented in Table 3.10. These values are for 7 piezometers more than 1.0 m and for the other 12, less than 1.0 m. This means that the seasonal or annual dynamics of the groundwater levels are more or less the same, and shows that interactions with other compartments in the model are sufficiently reliable. As an example in Fig. 3.12, the measured and calculated groundwater levels for piezometer H17-0861 are shown. The average difference of 3.58 m is small and the RMSE-fluctuation is with 4.62 m reasonable good.

Figure 3.11 *Locations of the 19 piezometers with measured groundwater levels (green dots).*

Table 3.10

Differences between measured and calculated groundwater levels (period 2005 – 2011).

Name	Average measured (m+MSL)	Average calc. (m+MSL)	Meas. – calc. (m)	RMSE of fluctuation (m)
B8Chavani	597.97	630.88	-32.91	0.56
B8Femane	538.39	551.60	-13.21	0.71
B8Haenertsburg	1385.00	1401.37	-16.37	1.44
B8Letsitele	499.64	514.04	-14.39	0.6
B8Lwamondokop	633.55	654.84	-21.29	1.69
B8Mamitwa	503.16	512.42	-9.26	0.99
B8Mbaula	346.58	348.82	-2.24	0.43
B8Middelletaba	514.55	543.10	-28.55	3.57
B8Mphagani	419.96	430.59	-10.63	0.76
B8Nghalalume	500.04	445.93	54.11	0.87
B8Nyagelani	357.92	385.40	-27.49	0.11
B8Sekgopo	840.17	874.60	-34.43	
B8Chavani	597.97	630.88	-32.91	0.56
B8Femane	538.39	551.60	-13.21	0.71
B8Haenertsburg	1385.00	1401.37	-16.37	1.44
B8Letsitele	499.64	514.04	-14.39	0.6
B8Lwamondokop	633.55	654.84	-21.29	1.69
B8Mamitwa	503.16	512.42	-9.26	0.99
B8Mbaula	346.58	348.82	-2.24	0.43

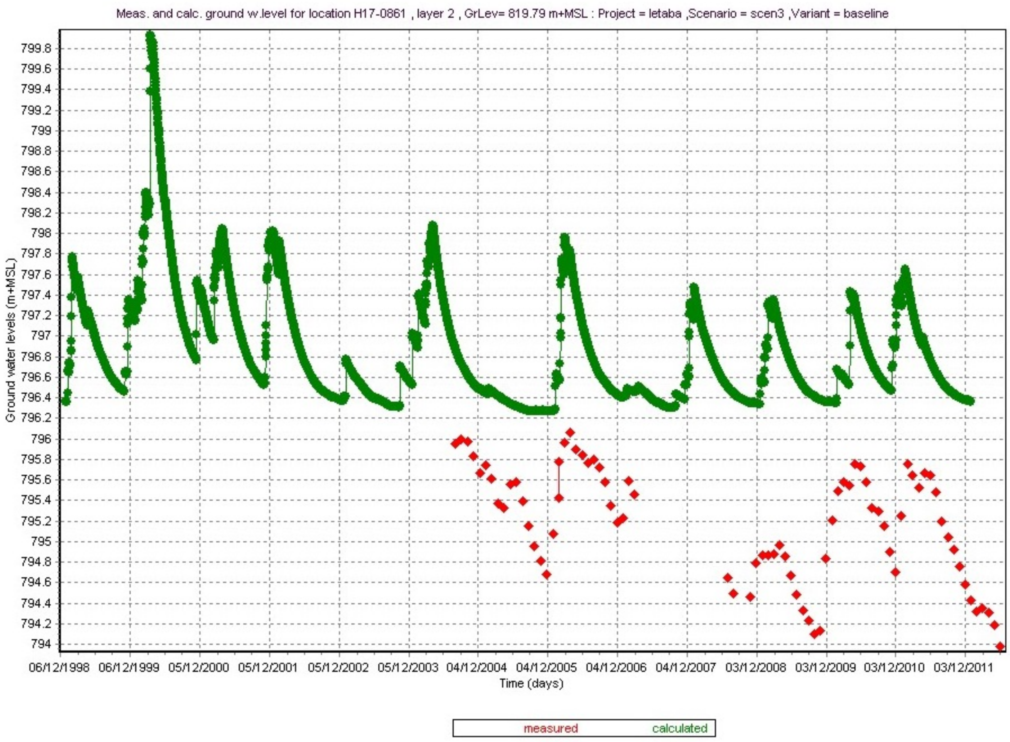


Figure 3.12 *Example of comparison between measured and calculated groundwater levels for piezometer H17-0861 (for location see Fig. 3.11).*

Conclusions on model performance

The complexity of the model and insufficient filed data does not allow for a full calibration in the scope of the current project. In this study, the model has been calibrated by varying and adapting some of the parameters that are least certain or improved data has been obtained, as the data on the transmissivity from Holland (2011) gave much better results. The storage capacity in the dams and especially the operation of the releases, are uncertain.
For the comparison of the discharges, the calculation extended over the period 1999-2011. The observed and simulated discharges were shown in Figure 3.10 for the 3 gauging stations. In addition, the Nash-Sutcliffe model efficiencies are given. The values range between 0.09 and 0.37 for comparing daily discharges, which are not high, but for a complex system this is reasonable. If we use average monthly discharges, the efficiency becomes for the 3 main gauges presented in Fig. 3.10 between 0.42 and 0.76, which seems to be an improvement, but off course is cosmetic.

The same applies to the groundwater levels presented in Table 3.10. Differences between measured and calculated are sometimes large, but the dynamics of measured and calculated compare reasonably well.

3.4 Groundwater sustainability indicator

To control the groundwater resource development and protection, it is important to have controlled aquifer exploitation and as little contamination as possible. Intensive abstraction from aquifers may affects springs, base-flow of streams, groundwater levels, and groundwater storage. Figure 3.6 showed the extractions from groundwater, which gives an indication on the amount of withdrawal.

Therefore, we give for the present situation a groundwater indicator based on total groundwater abstraction and groundwater recharge (Vrba & Lipponen, 2007). Both parameters are part of the SIMGRO model results. Thus, we estimate the groundwater indicator GW_{ind}, as:

GW_{ind} = (total gr. water abstraction / groundwater recharge)

The involved parameters are shown in Fig. 3.12. If the amount of groundwater abstraction reaches the amount of groundwater recharge (rainfall minus actual evapotranspiration) then over-exploitation could occur. Figure 3.13 shows the results of the equation. It shows for each cel in the model the value GSi. Isolated cells with a high value of Gi will get groundwater from neighboring cells. The values shown in Figure 3.13 ranges mainly from 0.4 to more than 1.0. In the western part of the basin, in the mountains with high rainfall, the indicator is low, but going eastwards to Giyani the values are much higher, showing that over-exploitation takes place.

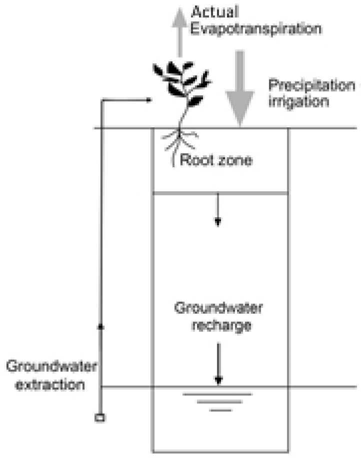


Figure 3.12 *Schematic schematization of the groundwater system showing the parameters to estimate the groundwater sustainability indicator.*

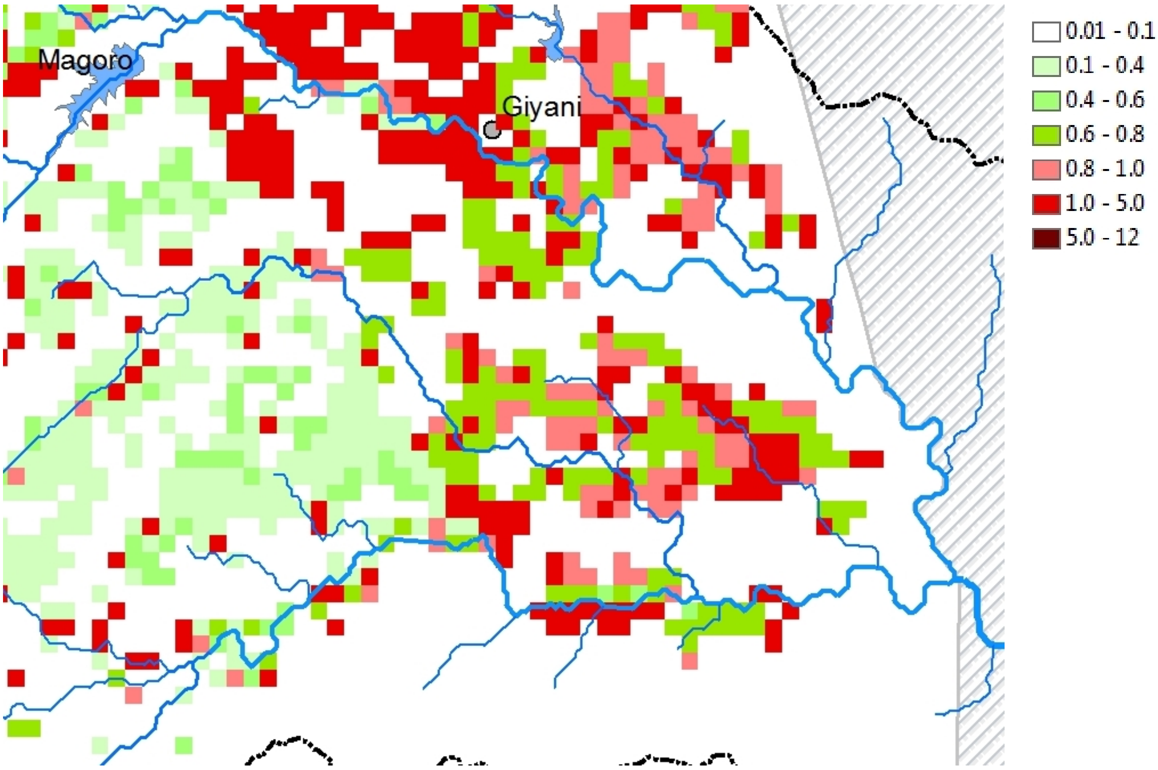


Figure 3.13 *Groundwater indicator GW_{ind} as the factor of groundwater abstraction divided by the groundwater recharge. Values close to unity and above show overexploitation (calculation period 1999-2011).*

4 Scenario analysis

4.1 Introduction

To assess the changes in the hydrological conditions in the Letaba basin, historical changes as scenarios have been defined as model experiments. The historical scenarios give an indication of the changes to be expected when changes in land use occur; the effect of increased crop production or differences in irrigation water are applied. These historical analyses are presented in Par. 4.2.

Participatory modelling is the process of incorporating stakeholders and decision-makers (COP/LPA staff), into the modelling process. A hydrological model can then be used in a policy process to benefit from both hydrological knowledge and the perspectives and local knowledge of stakeholders. In Par. 4.3 the participatory modelling is discussed and a scenario analysis is presented. In Par. 4.4 the effect of climate change in the near future is discussed and consequences for river discharges and groundwater levels are presented.

4.2 Historical scenario analysis

As a first example of the model use, two scenarios were defined and evaluated by the SIMGRO model. A change of irrigation was considered only for the land-use no. 8 and 11 (cultivated and irrigated: commercial and smallholders). These land-uses were shown in Fig. 3.5 and the area was presented in Table 3.3.

The two model runs are:

- Run 1 (blue line Fig. 4.1) — No irrigation at all for agriculture
- Run 2 (red line Fig. 4.1) — Baseline, irrigation mainly from surface water (commercial farms) or groundwater (smallholders)

We assumed an irrigation gift depending on the land use type (Table 3.8). Irrigation is applied once a week on a rotational basis, when moisture conditions are low, thus irrigation is skipped when a rainfall event took place. In such a model run, quite a drastic change for all farms in irrigation strategy was considered. The effect of this change in surface water and groundwater use on river flows is shown in Figure 4.1.

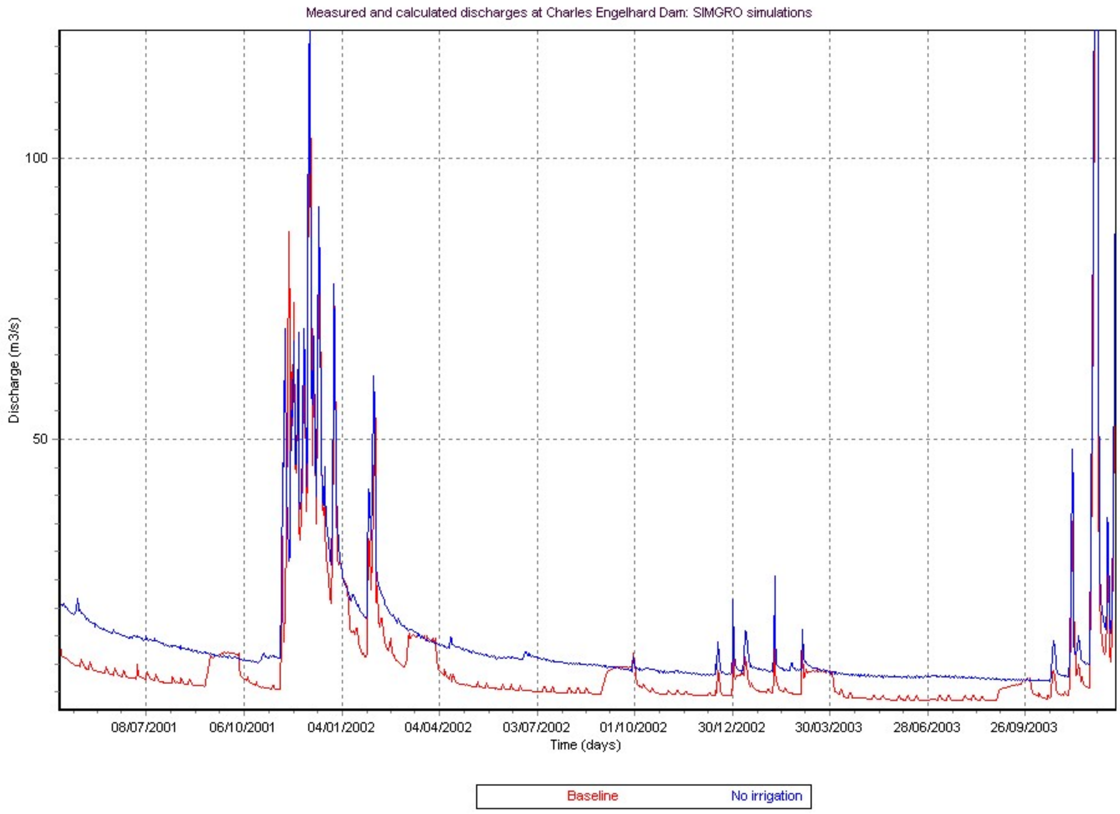


Figure 4.1 *River flows at the Charles Engelhard dam for the present situation (run 2) and when there is no irrigation from groundwater applied (run 1).*

4.3 Participatory modelling

When hydrological models are used in support of water management decisions, stakeholders often disagree with the results obtained using these models because they perceive certain aspects to be inadequately addressed (Bots et al., 2011). A good communication between modellers and stakeholders is needed about what the model should preferably be able to do, from the stakeholders perspectives, and what it actually can do, from the modellers perspectives. Participatory modelling is a concept that can contribute to increased cooperation between various stakeholder groups and experts in the development of feasible measures to increase food production. Using modelling results as a platform for dialogues, it can assist in new strategies. By involving authorities, experts and stakeholders in all steps of the process, suggested actions are formulated based on scientific foundations, as well as on recognitions of views from the farming community, which increases the possibility that the action plans will be implemented locally. Different stakeholders do often have different experiences and perceptions with regard to the nature of a problem, including its causes, impacts, links to other issues, as well as way to solve it. Consequently, it is a challenge to agree on a common strategy or action plan.

The scenarios presented in Par. 4.2 shows already on how the Letaba basin reacts on changes in the hydrological system and could form the bases of model use in the participatory process.

4.3.1 Scenarios analysis

The selected steps in the scenario analysis were based on the work presented in the Midterm progress report of 2014. The suggested scenarios envisaged are listed in Table 4.1. The aim in the scenario analysis is to increase crop production, using more effectively water and nutrient resources. Higher crop production means more water use, which was given as an increase of the crop factors (Table 3.7), to simulate the higher evapotranspiration of the crops. The irrigation gift as given in

Table 4.1 is the standard application depth from Table 3.8 (land use no. 11 for semi commercial farming), which is used in the scenario analysis. For more production, the irrigation gift in the scenarios increases. The model experiments will give an indication of the increase in water use and the influence on downstream water flows in the river and thus water availability for other users.

Scenario 1 in Table 4.1 is the present situation (baseline). In that scenario the area of smallholder agricultural farmers is 7500 ha as described in Par. 3.2.5. It is 4.1% of the area classified as semi-commercial in Table 3.3. In Par. 3.2.5, the crop water use was described.
In scenario 2, different irrigation strategies are considered and higher crop yields. Changes of yields in relation to crop water use is shown in Table 3.7 and the change in irrigation gift is given in Table 4.1.
In scenario 3, an increase in agricultural area with smallholder farms is envisaged. The 50% increase means for the Letaba basin the area of 7500 ha increases to 11 250 ha. In Par. 4.3.2 the results of the scenario analysis is presented.

Table 4.1
List of scenarios related to the smallholder farming

Scenario-	Description	Details on assumptions in the scenario	Irrigation gift (mm)
1	Baseline (present situation)	4.1% agric, remaining for livestock and bush land	15
2.1	Water crop yield	Maximum water applied	22
2.2	Environmental crop yield	Increase in pot. evapotr.	30
2.3	Maximum crop yield	Max water and nutrients applied	30
3	Increase the agric. area by 50%	Area agric. of smallholders 6.15% (11 250 ha)	15

4.3.2 Results of the scenarios

The scenarios listed in Table 4.1 were run by the SIMGRO model. The calculation period was taken from the year 1999–2011. In Annex 1 the annual precipitation is shown, ranging from as low as 132 mm to 850 mm (station B8E008 near Giyani in Fig. 4.2). The area of smallholder farms in the Letaba basin were estimated in the order of 7500 ha and cover about 0.5% of the total basin area.

The calculated annual flow at the Charles Engelhard dam varies yearly between 292 and 2691 mln m^3. The year 2000 was extremely wet with a large flood taken place. Also in 2004 the annual flow was quite above the average (1003 mln m^3). The flow over the calculation period, but excluding 2000 and 2004, gives an average flow of 459 mln m^3/a.

Model result as the change in river flow, at the Charles Engelhard dam, are presented in Table 4.2. For the present situation about 34 mln m^3/a of water is used, both from groundwater and surface water. This is slightly less than the 38 mln m^3/a estimated in par 3.2.5, based on expert judgement. The majority of the irrigation water comes from groundwater, since a few smallholders are located next to a stream and are able to pump the water out of a river. When more water is applied representing more crop yield the water use increases by 7 mln/a. For environmental crop yield, which uses more water and more nutrients, shows an increase of 11 mln, as compared to the present situation. Using the maximum amount of nutrients giving the maximum yield, uses 19 mln m^3/a more water.
If the area of smallholders is increased by 50% this requires in total 51 mln or an increase of 17 mln m^3/a (Table 4.2).

Because the area of smallholder farms in the basin is only 0.5% of the basin area, this means as well that changes in crops or changes in varieties with a larger evapotranspiration has a very small influence on downstream river flows.

Table 4.2

Model results for five scenarios considering more water, more fertilisers and an increase in agricultural land with of smallholder farms.

Description of scenario		Irrigation	Model results, flow at Engelhard dam			
			Total		Change from scen 1	
		(mm/a*)	(mln m^3/a)	(m^3/s)	(mln m^3/a)	(m^3/s)
1	Present situation	450	34	1.08	-	-
2.1	Max. water for crop yield	550	41	1.30	7	0.22
2.2	Environmental crop yield	600	45	1.43	11	0.35
2.3	Maximum crop yield	700	53	1.68	19	0.60
3	Increase agric. area by 50%	450	51	1.62	17	0.54

* Irrigation water extracted from either groundwater or surface water.

Conclusions on the scenario analysis

The irrigation water used by the smallholders is around 34 mln m^3/a. When they want to increase the production the water consumption for irrigation can increase in the order of 60%. The change in river flows between the different scenarios are relatively small. Enlarging the irrigated area by 50% has a pronounced effect. Changes between crops and thus a different water use has a small effect on river flows, since the smallholder area at present is only 0.5% of the basin area. The ecological reserve for the Kruger National Park is recommended to be 12% of the total river flow (Aurecon, 2010). Other resources report 8 mln m^3/a should be reserved (DWAF, 2006).

4.4 Climate change

Currently, 98% of South Africa's surface water yield has been allocated to use (Davis, 2010). As a consequence water resources will be directly impacted by climate change and threatening the future water availability. Therefore, the agricultural sector is likely to feel the direct and indirect impacts of projected climatic changes in a number of ways (Davis, 2010). Crop productivity may decrease although a small increase in temperature is expected and thus a higher evaporation is likely to increase irrigation demands. In the Letaba basin the existing water supply and water quality is already under stress by the high demand of water in the irrigated agriculture and domestic sector and thus climate change will increase the water competition.

The expected climate change was considered in this study of the Letaba basin. At meetings of the EAU4FOOD project (see www.eau4food.info) this issue was raised and it was requested to be examined. Climate change was incorporated into the modelling scenarios by using data provided by the Council for Scientific and Industrial Research (CSIR) for the study of Van Breda (2014). The forecasted climate data was available on a 50 km^2 grid scale and includes values for precipitation, temperature, solar radiation, relative humidity and wind speed for the period 2010 to 2050. Figure 4.2 shows the 7 grids (centroids) of the climate data used in the analysis for the Letaba basin. The climate data has been based on average annually temperature increase of about 0.04 °C and changes in rainfall patterns over the long term.

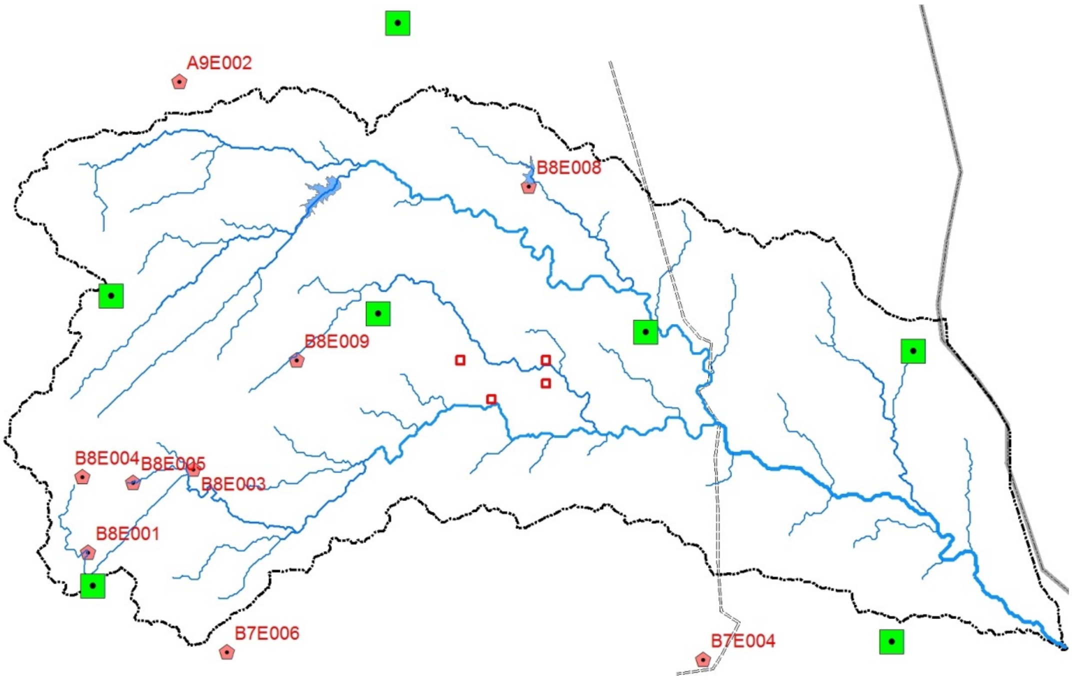


Figure 4.2 *Grid cells from the CSIR climate models and the local precipitations stations.*

The simulated weather data of the CSIR was compared with observed weather data from the region. The observed precipitation as presented in Table 3.5 showed clearly that rainfall is much higher in the western part of the catchment. The CSIR climate data shows a similar annual pattern, however the variation of precipitation over the basin is much smaller, and the western part of the basin does not have a significantly higher rainfall (Table 4.3). Variation of the CSIR climate data over the Letaba basin is only 35-45 mm, but measured rainfall vary even more than 900 mm as presented in Table 3.5. Therefore, in our study we considered only the changes in average seasonal data from the climate models on precipitation, temperature and evapotranspiration. We used the delta change approach: the climate model gives per season, winter and summer, a change in precipitation, a change in temperature and a change in potential evapotranspiration (Supit et al., 2012). The seasonal changes were used to convert the daily meteorological data for the period 2001-2010, to the 2050s (Table 4.4). This approach assumes that temporal and spatial rainfall distribution for the 10 years remain unchanged. It appears that precipitation until 2050 reduces slightly: on average, the precipitation intensity decreases by 9% in both summer and winter. The temperature is on average 0.04 °C higher and the reference evaporation increases by 9% in summer and in winter. These changes were imposed on the measured meteorological data from 2000 onwards to derive at the climate data for the 2050s. The SIMGRO model was run using that data as input.

Table 4.3
Variation in rainfall from the 7 grids cells with climate data for the period 2000-2010 and 2040-2050.

	Variation of rainfall data over the 7 selected grids		
		min (mm)	max (mm)
2000-2010	Summer	573	610
	Winter	120	150
	Total per year	693	760
2040-2050	Summer	526	569
	Winter	121	153
	Total per year	647	722

Table 4.4

The change in precipitation, temperature and potential evapotranspiration over the period 2001-2050.

	Precipitation	Temperature		Potential evapo-transpiration
		Summer	Winter	
2001-2010	100%	100%	100%	100%
2041-2050	91%	107%	90%	109%
	less rain	warmer	colder	more water needed

For the climate change scenario, only the meteorological data were changed. Simulations were performed for 10 years, so that the results show the hydrological situations for the present situation (2001 – 2010) and for the 2050s, being the period 2041-2050. In the climate scenario, no changes in land use and irrigation intensity were considered. In Table 4.5 the change in discharge per season is presented. The changes are given for the gauge at Engelhard Dam and situated in the Kruger National Park. From the present situation the river flows, period 2040 – 2050, are much lower, around 70%. Such a reduction is quite large, since the water resources in the basin are limited. In wintertime, a period with hardly any rain the reduction in river flow is much smaller, which shows that the drainage from groundwater storage is more dominant.

Table 4.5

Changes in discharge at Engelhard dam for the period 2041 – 2050, as compared to the period 2001 – 2010.

Jan - Mar	Apr - Jun	Jul - Sep	Oct - Dec	All year
68%	73%	80%	70%	69%

Because of the climate change and resulting smaller precipitation, the groundwater levels are also lowered. Figure 4.3 shows the groundwater levels at Mzilele farm for the period 2001-2010 and projected levels for the period 2041-2050. The changes are in the order of 0.4 – 0.8 m.

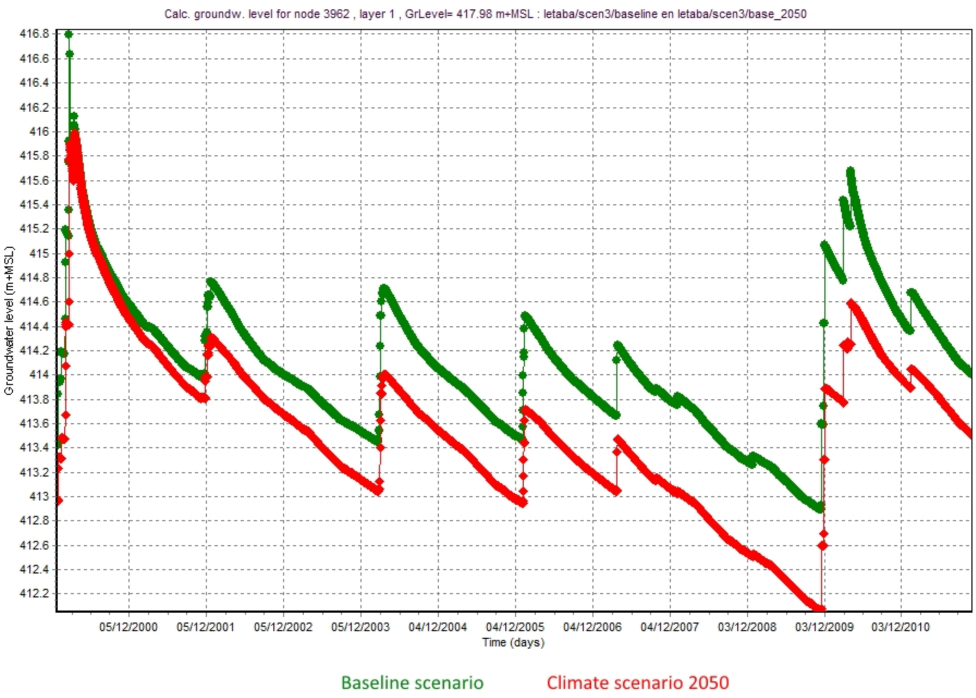


Figure 4.3 *Change in groundwater levels at Mzilele farm because of climate change (for location of farm see Fig. 2.4).*

Conclusions on climate change analysis

The Letaba basin consists of mountains in the western part and elevations of more than 2000 m+MSL, but in the eastern part of the basin, it is as low as about 300 m+MSL. Measured rainfall varies from approx. 1400 mm in the western part to 300 mm in the eastern part. The climate models were not able to predict these drastic changes in precipitation as presented in Table 4.3. Therefore, for model predictions the climate data is not sufficient. We used the predicted changes of the climate data between 2000 and 2050 and superimposed that on the measured precipitation and evapotranspiration data to derive at values for 2050. Using these values in the SIMGRO model resulted in much lower discharges for 2050: on average to 69% of the river flows at present. Less rainfall and a higher evapotranspiration mainly cause the changes in river flows. Consequently, groundwater levels will also be lower. Thus, climate change has an enormous effect on the water resources of the Letaba basin.

5 Conclusions

The application of the SIMGRO model for the Letaba basin has been achieved and scenario analysis were carried out. Due to the lack of sufficient input data, together with the size of the model and the large number of parameters, the model could not be fully calibrated. Particular for the input data such as the hydrogeology, crop water use, rooting depth, the availability of input data was limited. This lack of data makes it hard to fully assess the reliability of the model. However, an attempt has been made to find the best possible fit of calculated discharges and groundwater levels against the available measurements.

Groundwater systems, like the Letaba basin, are highly complex and there are many faults present. This may lead to large variations of groundwater levels over short distances. To make the model more reliable would mean that more details are required in the model, thus more field data to be collected. Important is to make a model that is used for practical situation, and that has been achieved for the Letaba basin.

The major conclusions are described in the sections below.

Model performance
For the comparison of the discharges, the calculation extended over the period 1999-2011. The observed and simulated discharges were shown in Figure 3.10 for three gauging stations. In addition, the Nash-Sutcliffe model efficiencies were calculated, these range between 0.09 and 0.37 when comparing daily discharges, which is not high, but for a complex system this is reasonable. If we use average monthly discharges, the efficiency becomes for the three main gauges between 0.42 and 0.76, which seems to be an improvement, but off course, it is cosmetic.

The same applies to the groundwater levels presented in Table 3.10. Differences between measured and calculated are sometimes large, but the dynamics of measured and calculated compare reasonably well. Large differences between measured and calculated levels could be caused by local hydro-geological conditions or as well by nearby groundwater extractions. The RMSE of the difference in fluctuation between measured and calculated levels are for 7 piezometers more than 1.0 m and for the other 12, less than 1.0 m. This means that the seasonal or annual dynamics of the groundwater levels are more or less the same, and shows that interactions with other compartments (unsaturated zone and surface water) in the model are sufficiently reliable.

Groundwater sustainability indicator
To control the groundwater resource development and protection, it is important to have controlled aquifer exploitation and as little contamination as possible. Intensive abstraction from aquifers may affects springs, base-flow of streams, groundwater levels, and groundwater storage.

Therefore, we give estimated for the present situation a groundwater indicator based on total groundwater abstraction and groundwater recharge (Vrba & Lipponen, 2007). Both parameters are part of the SIMGRO model results. If the amount of groundwater abstraction reaches the amount of groundwater recharge (rainfall minus actual evapotranspiration) then over-exploitation could occur. In the western part of the basin, in the mountains with high rainfall, the indicator is low, but going eastwards to Giyani the values are much higher, showing that over-exploitation takes place.

Scenario analysis
Model result as the change in river flow, at the Charles Engelhard dam, were analyzed. For the present situation about 34 mln m^3/a of water is used, both from groundwater and surface water. The majority of the water comes from groundwater, since a few smallholders are located next to a stream to pump water from a river. When more water is applied representing more crop yield the water use increases by 7 mln/a. For environmental crop yield, which uses more water and nutrients, shows an increase of

11 mln, as compared to the present situation. Using the maximum amount of nutrients and thus the maximum yield is obtained, uses 19 mln m^3/a more water. Thus when the smallholders want to increase the production the water consumption for irrigation can increase in the order of 60%. If the area of agriculture of smallholders is increased by 50% this requires in total 51 mln or an increase of 17 mln m^3/a.

Because the area of smallholder farms in the basin is only 0.5% of the basin area, this means as well that changes in crops or changes in varieties with a larger evapotranspiration has a very small influence on downstream river flows.

The change in river flows between the different scenarios are relatively small. Enlarging the irrigated area by 50% has a pronounced effect. Changes between crops and thus a different water use has a small effect on river flows, since the smallholder area at present is only 0.5% of the basin area.

The ecological reserve for the Kruger National Park is recommended to be 12% of the total river flow (Aurecon, 2010). Other resources report that 8 mln m^3/a should be reserved (DWAF, 2006).

Climate change

The Letaba basin consists of mountains in the western part and elevations more than 2000m+MSL, but in the eastern side of the basin, it is as low as about 300m+MSL. Measured rainfall varies from approx. 1400 mm in the western part to 300 mm in the eastern part. The climate models were not able to predict these drastic changes in precipitation. We used the predicted changes of the climate data between 2000 and 2050 and superimposed that on the measured precipitation and evapotranspiration data to derive at values for 2050. Using these values in the model resulted in much lower discharges for 2050: on average about 69% of river flows at present. Less rainfall and a higher evapotranspiration mainly cause the changes in river flows. Consequently, groundwater levels will also be lower. Thus, climate change has an enormous effect on the water resources of the Letaba basin.

The main conclusions of this study can be summarized as follows:

- Water resources in the Letaba basin are limited;
- Increased production by smallholders farmers has some effect on the river flows downstream, because the area of smallholder farm is only 0.5% of the basin;
- Climate change (2050) will result in river flow of about 70% of the present flows, thus climate change has an enormous effect on the water resources.

References

Allen, R.G., L.S. Pereira, D. Raes & M. Smith, 1998. Crop evapotranspiration. Guidelines for computing crop water requirements. FAO Irrigation Drainage Paper no. 56, FAO, Rome, Italy, 300 pp.

Annandale, J.G., N. Benade, N.Z. Jovanovic, J.M. Steyn & N. du Sautoy, 1999. Facilitating irrigation scheduling by means of the soil water balance model. Report to the Water Research Commission. WRC Report No: 753/1/99. ISBN No: 1 86845 559 9.

Aurecon, 2010. Groot Letaba River Water Development Project (GLeWaP). Technical report P WMA 02/B810/00/0608, Cape Town.

Boesten, J.J.T.I. & L. Stroosnijder, 1986. Simple model for daily evaporation from fallow tilled soil under spring conditions in a temperate climate. Neth. J. Agric. Sci., 34, 75-90.

Bots, P. W. G., R. Bijlsma, Y. Von Korff, N. Van der Fluit & H. Wolters. 2011. Supporting the constructive use of existing hydrological models in participatory settings: a set of “rules of the game.” Ecology and Society 16(2): 16 (http://www.ecologyandsociety.org/vol16/iss2/art16/)

Conijn, J.G., E. Querner, Marie-Luise Rau, H. Hengsdijk, Tom Kuhlman, G. Meijerink & B. Rutgers, 2011. Agricultural resource scarcity and distribution; A case study of crop production in Africa. Plant Research International, Feb. 2011, Report 380.

CSIR, 2012. Benchmark Report on Agricultural, Environmental, Socio-economic and Institutional Conditions - Case Study in South Africa. Deliverable 2.4 of the EAU4Food project. South Africa: CSIR Natural Resources and the Environment.

Dallas, H. & J. Fowler, 2000. Delineation of river types for rivers of Mpumalanga, South Africa: establishing a spatial framework for selection of reference sites. Southern Waters Ecological Research and Consulting. February 2000.

Davis, C., 2010. A climate change handbook for North-Eastern South Africa. Climate Change Research Group, Council for Scientific and Industrial Research.

De Bruin, H.A.R., 1987. From Penman to Makkink. Comm. Hydrol. Research TNO, The Hague. Proc. and Inf. 39: 5-31.

DWAF, 2003. Luvuvhu and Letaba Water Management Area - Overview of Water Resources Availability and Utilisation. Report No. P WMA 02/000/00/0203. Pretoria, South Africa: Department of Water Affairs and Forestry.

DWAF, 2004. Internal Strategic Perspective: Luvuvhu/ Letaba Water Management Area. Report No. PWMA 02/000/00/0304. Pretoria, South Africa: Department of Water Affairs and Forestry.

DWAF, 2006. Letaba catchment Reserve Determination Study. February 2006. Pretoria, South Africa: Department of Water Affairs and Forestry.

DWAF, 2010a. Groot Letaba River Water Development Project - Technical Study Module: Groundwater Vol. 3. Report No. P WMA 02/B810/00/0608/3. Pretoria, South Africa: Department of Water Affairs and Forestry.

DWAF, 2010b. Groot Letaba River Water Development Project (GLeWaP) - Technical Study Module: Hydrology Vol. 4. Report No. P WMA 02/B810/00/0608/4. Pretoria, South Africa: Department of Water Affairs and Forestry.

DWAF, 2012. Development of a Reconciliation Strategy for the Luvuvhu and Letaba Water Supply System: Inception Report. Report No. P WMA 02/P810/00/1412/1. Pretoria, South Africa: Department of Water Affairs and Forestry.

DWAF, 2013. Hydrological Services - Surface Water (Data, Dams, Floods and Flows). http://www.dwaf.gov.za/Hydrology (accessed 22-11-2014).

Dye, P. & Versfeld, D., 2007. Managing the hydrological impacts of South African plantation forests: An overview, Forest Ecology and Management, Volume 251, Issues 1–2, pp. 121-128.

FAO, 1986. Irrigation Water Management: Irrigation water needs by C. Brouwer and H. Heibloem. Training manual no. 3.

Farr, T. G., et al., 2007. The Shuttle Radar Topography Mission, Rev. Geophys., 45, RG2004, doi:10.1029/2005RG000183.

Feddes, R.A., 1987. Crop factors in relation to • Makkink • reference crop evapotranspiration. Comm, Hydrol. Res. TNO, The Hague. Proc. and Inf. 39: 33-44.

Froebrich, J. et al., 2013. European Union and African Union cooperative research to increase Food production in irrigated farming systems in Africa. http://cordis.europa.eu/projects/rcn/99532_en.html (accessed 18-11-2014).
GLCN-LCTC (2000). South Africa Land Cover Legend - LCCS Translation. South Africa: GLCN-LCTC
GRIP-Limpopo, 2013. GRIP data base contains borehole point data for the Limpopo province. Website: http://griplimpopo.co.za (accessed 18-11-2014).
Holland, M, 2011. Hydrological characterization of crystalline basement aquifers within the Limpopo Province, South Africa. PhD thesis, University of Pretoria, South Africa.
ISRIC, 2013. (SOTER data base for Southern Africa at a scale of 1.2 million. Website: http://www.isric.org/projects/soter-southern-africa-sotersaf (accessed 12-01-2015).
Krause P., D. P. Boyle & F. Base, 2005. Comparison of different efficiency criteria for hydrological model assessment. Advances in Geosciences, 5: 89–97.
LDA, 2014. Personal communication on unregistered boreholes. Limpopo Provincial Department of Agriculture, Giyani Municipality Offices.
Limpopo Basin Permanent Technical Committee (LBPTC), 2010. Joint Limpopo River Basin Study Scoping Phase. Final Report. BIGCON Consortium.
Limpoporak, 2012. Website http://www.limpoporak.com/en/default.aspx (accessed 16-11-2014).
Meijer, E.C., Querner, E.P. & Boesveld, H., 2013. Impact of farm dams on river flows in the Limpopo River basin, Southern Africa. Wageningen, Alterra report 2394.
NDW, 1989. Review of the water resources of Maputo Province. National Directorate of Water, People's Republic of Mozambique. Mission report by Euroconsult, Arnhem.
Pienaar, C.J., 2014. Increased Water Productivity in irrigated Tomato production in the smallholder farming community of Giyani. MSc thesis for Faculty of Soil Science, University of Stellenbosch. 157 pp.
Povilaitis, A. & E.P. Querner, 2006. Analysis of water management measures in the Dovine River Basin, Lithuania Possibilities to restore a natural water regime. Wageningen, Alterra, Alterra-report 1370. 67 pp
Querner, E.P., 1993. Aquatic weed control within an integrated water management framework. Doctoral thesis, Agric. University Wageningen. Also published as Report 67, DLO Winand Staring Centre (SC-DLO). 204 pp.
Querner, E.P., 1997: Description and application of the combined surface and groundwater model MOGROW. Journal of Hydrology 192: 158-188.
Querner, E.P., J.A. Morábito & D. Tozzi, 2008. SIMGRO, a GIS-Supported Regional Hydrological Model in irrigated Areas: Case Study in Mendoza, Argentina. J. of Irrigation and Drainage Engineering. Vol. 134, No. 1 Jan/Feb. 2008: pp. 43-48.
Querner, E.P. & Povilaitis, A., 2009. Hydrological effects of water management measures in the Dovine River Basin, Lithuania. *Hydrol. Sci. J.*, 54(2), 363-374.
Querner, E.P. & M. van Zanen, 2013. Modelling water quantity and quality using SWAT; A case study in the Limpopo River basin, South Africa. Wageningen, Alterra, Alterra Report 2405. 60 pp.
Rogers, K.H. & Bestbier, R., 1997. Development of a Protocol for the Definition of the Desired State of Riverine Systems in South Africa. Department of Environmental Affairs and Tourism, Pretoria.
SADC, 2010. Explanatory Brochure for the Southern African Development Community: Hydrogeological Map & Atlas. SADC Hydrogeological Mapping Project, 31 March 2010, pp. 66.
SRTM, 2013. Website: http://www2.jpl.nasa.gov/srtm (accessed 04-11-2014).
Supit, I., C.A. van Diepen, A.J.W. de Wit, J. Wolf, P. Kabat, B. Baruth, and F. Ludwig, 2012. Assessing climate change effects on European crop yields using the Crop Growth Monitoring System and a weather generator. Agricultural and Forest Meteorology, Vol. 164, 96–111. http://dx.doi.org/10.1016/j.agrformet.2012.05.005
UNEP, 1992. World Atlas of Desertification, London: Edward Arnold, a Division of Hodder and Stoughton.
USGS, 2013. Website: http://hydrosheds.cr.usgs.gov (accessed 19-11-2014).
Van Breda, P. 2014. A methodology to evaluate the contribution of small-scale farms to the vision of regulating authorities. MSc thesis for Dep. of Industrial Engineering, University of Stellenbosch. 139 pp.
Vrba, J. & A. Lipponen, 2007. Groundwater Resources Sustainability Indicators. UNESCO, IHP/2007/GW-14.

Wichern, 2013. Water consumption of irrigating smallholders on catchment level; a case study from the Letaba catchment, South Africa. Draft Alterra Report. pp 72.

Wikipadia, 2013a. List of dams and reservoirs in South Africa. Website: www.en.wikipedia.org/wiki/List_of_dams_and_reservoirs_in_South_Africa (accessed 19-11-2014).

Wikipedia, 2013b. Pan evaporation. Website: www.en.wikipedia.org/wiki/Pan_evaporation (accessed 09-10-2014).

Wösten, J.H.M., S.J.E. Verzandvoort, J.G.B. Leenaars, T. Hoogland & J.G. Wesseling. 2012. Soil hydraulic information for river basin studies in semi-arid regions. Geoderma 195–196 (2013) 79–86. (http://dx.doi.org/10.1016/j.geoderma.2012.11.021)

Annex 1 Water requirements for irrigation

For a quick analysis of potential evapotranspiration and water requirements for irrigation we used data from the meteorological station B8E008 situated at the Nsama dam (Fig. 3.7) for the period 1997-2011. The evaporation available was measured using a class C pan type. The reference evaporations is assumed as a factor 0.8 times the values derived from the class C pan. As land use crop maize is considered with 2 times a 5 month growing period per year. Irrigation requirements were estimated based on the FAO guidelines (FAO, 1986) and analysis reported by Meijer *et al.* (2013).

For the period 1997-2011 the average annual precipitation was 323 mm, the average reference evapotranspiration was 1227 mm. The average net irrigation requirements is 1078 mm/year. Table A1 gives an overview of the annual values. Since rainfall events are intense and of short duration, the efficiency of the rainfall for use by the crops is rather low. In Figure A1 the monthly rainfall and irrigation needs are shown. The monthly net irrigation requirements are in the order of 50 to 200 mm. In most month the water need is about 100 mm, with some extreme situations of more than 150 mm. If 150 mm needs to be applied in one month, this would implicate say 4 to 5 gifts per month (or 30-38 mm per gift).

For conveyance and field losses it's been assumed that 10% more water is needed than the net irrigation requirements. On the other hand the irrigation requirement is now based on the difference between the potential crop water need and the effective precipitation. If we assume that 90% of the crop water requirements are supplied by precipitation and irrigation, it means that the net water requirements as listed in Table A1 or shown in Fig. A1 can be considered as the irrigation requirements.

Table A1
Annual and average precipitation, reference evapotranspiration and net irrigation requirements for maize, based on 2 crops per year (meteorological data from station B8E008 at the Nsama dam).

Year	Precipitation (mm)	ETref (mm)	Net irrigation req. (mm)
1997	132	1217	1250
1998	294	1321	1128
1999	225	1159	1044
2000	850	1059	796
2001	411	1128	909
2002	135	1294	1170
2003	142	1337	1273
2004	373	1308	1208
2005	133	1290	1176
2006	222	1005	872
2007	356	1358	1250
2008	188	1297	1230
2009	528	1208	869
2010	441	1178	992
2011	412	1241	998
Average	323	1227	1078

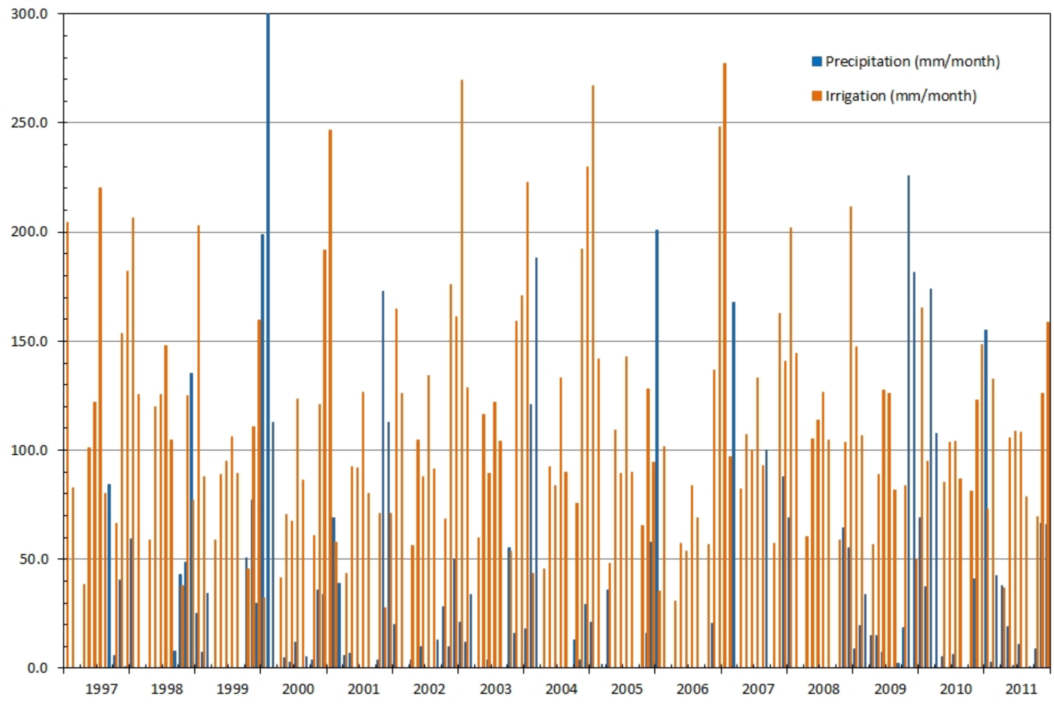


Figure A1 *Monthly net required irrigation for the period 1997-2011.*

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