WETSYS model: Improvements and global sensitivity analysis

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Internship report

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Introduction

1.1 Site description and the context of the internship

Today as mankind faces environmental problems of a diverse character and different ecosystems and their services degrade rapidly, wetland ecosystems do not make an exception. It was estimated in the Millennium Ecosystem Assessment that more than 50% of different kind of wetlands were eliminated during twentieth century in industrialized countries (Alder et al., 2005).The importance of these ecosystems arises from the numerous services they are able to provide for the human well-being. Among many others wetlands provide flood protection and flow regulation services, they supply water and food for people and animals and have religious and cultural values. The exploitation of the wetland services by humans to support their life can degrade their value for future generations (de Groot et al., 2006).

The study area of this research is Ga-Mampa wetland situated in South Africa in the province of Limpopo. The wetland lies in the valley of the same name, in the catchment of the Mohlapitsi River which is a contributor of the Olifants River downstream. The wetland, being approximately 120 ha, is surrounded by five villages with 394 households (2758 people) (Kotze, 2005; Adekola, 2007). As these communities are quite remote from the big cities, they greatly rely on the wetland (and other natural surrounding areas) to satisfy their basic need. Due to certain failures of irrigation schemes, local population uses the wetland to produce crops. More than 50% of the wetland were converted to agricultural land in the period from 1996 to 2004 and this trend continues (Sarron, 2005; Adekola, 2007). The remaining natural part of the wetland is used for animal grazing and plant collection.

An ecological assessment of the Ga-Mampa wetland health showed that some changes in wetland functioning are already occurring due to anthropogenic activities. Most of wetland processes and services are modified moderately while some are affected severely. If the activities in the wetland do not gain more sustainable character the ecosystem functioning will degrade significantly in the future affecting the soil quality and water supply (Kotze, 2005). This compromises the livelihoods of local communities and introduces some trade-offs between different services of the wetland. These trade-offs include a conflict between wetland crop production and hydrological regulation as well as crop production and other uses of the wetland (Morardet et al., 2009).

An attempt to establish a sustainable use of Ga-Mampa wetland is undertaken under the WETwin project, funded by the European Union under its 7th Framework Programme. This project focuses on the conservation of wetland ecosystems while taking into account the needs of communities that depend on them for their livelihoods. The project has several study sites in Europe, Africa and South America (Kis and D'Haeyer, 2009). To analyze the trade-offs of Ga-Mampa wetland the dynamic system model called WETSYS was developed. This model replicates interactions between socio-economical and ecological aspects present in Ga-Mampa wetland. The model is planned to be used as a decision support tool in the development of a management plan of the wetland. At the moment this model is in the state of development. It faces several challenges related to data availability, its further use in a scenario analysis and better understanding of its interactions. The aim of this internship study is to introduce new features and improvements in the model that will increase its accuracy and facilitates its use in scenario analysis. Moreover, as the model includes a lot of parameters and inputs of which the true values are uncertain, it is necessary to perform a sensitivity analysis in order to identify which parameters are the most important or not important at all for the model output.

1.2 WETSYS model

1.2.1 General description

WETSYS model is an integrated dynamic model of Ga-Mampa wetland. It links socio-economical and ecological aspects of the system. The model simulates the influence of alternative wetland strategies and external pressures on wetland functioning and community well-being (Morardet et al., 2009). It consists of six sectors. The first five are hydrology, crop production, community well-being, land use and natural resources. They are interactive and linked in such a way that one parameter calculated in one sector can be used for calculations in the other. The model runs at monthly time steps. The sixth sector is a time control sector. It controls annual and seasonal activity cycles.

Figure 0-1 shows the model outline and the interconnections between sectors. Hydrology influences the services that wetland can provide (crop production and natural resources collection) by the water supply. In turn these services together with some external factors (social transfer, paid jobs) have an impact on the community well-being. The use of wetland services by humans links back to the hydrological process through water use. There is also an interconnection between provision sectors (crop production and natural resources) via land use sector. This is done to account for the changes in wetland use. Thus, the increase in wetland area under crop cultivation causes natural wetland to decrease and vice versa. The decisions on wetland use are determined by the satisfaction in services provided by the wetland and land and water availability (well-being indicator).

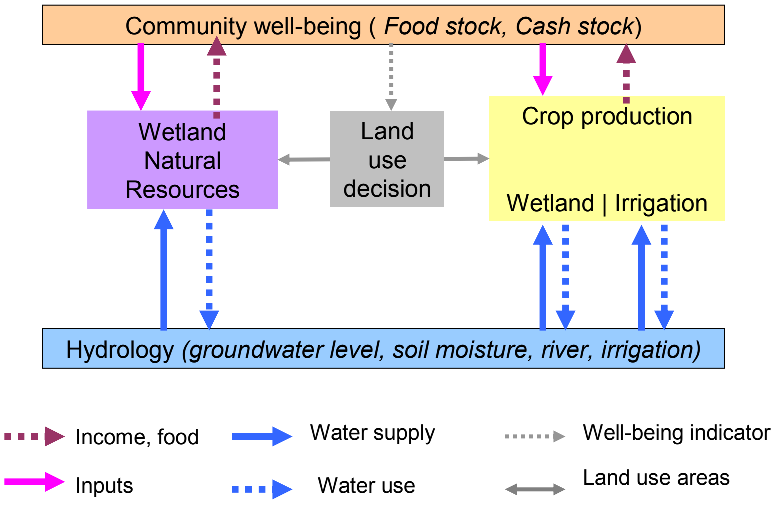


Figure 0-1: Outline of the WETSYS model (Morardet et al., 2009)

1.2.2 Model sectors

Hydrology sector. This sector simulates water dynamics in wetland and irrigation schemes. The dynamics is represented by four stocks (soil water content in the irrigation shceme, cultivated and natural wetland, and shallow aquifer. Water is stored in soil and the wetland shallow aquifer. There are three categories of soil: soil in natural and cultivated wetland and soil in irrigation scheme. Soil water content depends on different factors such as rainfall, capillarity rise, recharge to the groundwater, evapotranspiration of crops or natural vegetation and the presence of irrigation. The equation of soil water content hydrology sector has slight modifications depending on the type of area (natural wetland, cultivated wetland or irrigation scheme). For soil water content in cultivated wetland the equation is as follows:

$$MC_{t+1}^{w} = MC_{t}^{w} + P_{eff} + CR^{w} - ET_{a}^{w} - E_{bs}^{w} - R^{w},$$

where MC is water soil content, P_{eff} is efficient rainfall (it is defined here as rainfall minus runoff), CR is capillarity rise, ET_a is actual evapotranspiration of vegetation, E_{bs} is evapotranspiration from bare soil and R is recharge from root zone to ground water. W subscripts refer to wetland cultivated area. For natural areas the equation is the same, but due to vegetation cover throughout the year E_{bs} is left out. For water dynamics in the irrigation scheme an extra inflow is added, as diverted water from the river contributes to the soil moisture, besides, capillarity rise from the groundwater does not occur in the irrigated soil.

For water storage in the wetland and its aquifer, the water balance is formulated as follows:

$$S_{t+1}^{w} = S_{t}^{w} + R + GW_{i} - LF + IL - CR,$$

where S is a water storage in the wetland, R is recharge from the soil, GW_i is ground water inflow from surrounding catchments, LF is lateral flow or groundwater outflow from the wetland to the river, IL is losses from irrigation scheme and CR is capillarity rise (Morardet et al., 2009).

The main outputs of this sector are the ground water level and the river outflow. These are important indicators of the wetland health as wetland aquifer is a vital contributor to the wetland itself and Mohlapitsi River which in its turn contributes to the Olifant River during dry season (Adekola, 2007). Moreover, hydrology sector estimates actual evapotranspiration of natural wetland, cultivated wetland and irrigated area. The evapotranspiration of cultivated wetland and irrigated area is used further in crop production sector for yield estimation. With regard to the evapotranspiration of the wetland natural area, currently there is no connection between this parameter and biomass dynamics (natural resources sector).

Crop production sector. In Ga-Mampa valley agriculture occurs in the wetland and irrigation scheme. Therefore, this sector estimates crop production in the cultivated wetland and irrigated area. Irrigated area is assumed to be stable over time while the area of cultivated wetland varies from year to year as natural land is converted to cultivated land or cultivated land is abandoned. These land use changes are estimated in the land use sector.

At the start of the internship WETSYS model considered only maize production. It was assumed that the harvest occurs only once a year. To estimate the crop yields the model uses the following equation:

$$Y_a = Y_m \left[1 - k_y \times \left(1 - \frac{ET_a}{ET_m} \right) \right],$$

where Y_a is actual yield (ton/ha), Y_m is maximal yield (ton/ha), ET_a is actual evapotranspiration over the cropping season (mm), ET_m is maximal evapotranspiration over the cropping season (mm) and k_y is a crop yield response to water stress factor.

Maximal yield values (Y_m) are taken from household surveys. Maximal evapotranspiration (ET_m) is calculated from potential evapotranspiration (ETP) and actual evapotranspiration (ET_a) is estimated in hydrology sector. Value of k_y is derived from the literature.

Crop production sector estimates yields for both cultivated wetland and irrigated area using the same equation, but different values of Y_m. Total crop production is derived from yields and respective land area. The sector also considers crop input and output prices which are further used in community-well being sector.

Land use sector. The aim of this sector is to model the processes that determine the land use change. The model considers two types of land use in the wetland: cultivated wetland and natural wetland. The area of natural wetland is estimated as the difference between total wetland area (fixed at 120 ha) and cultivated wetland. The previous analyses showed, that conversion of natural land into cultivated occurs when food production in irrigated scheme is scarce. The number of new wetland farmers relates to the food security index (ratio between food consumptions and food needs, calculated in community well-being sector) and the number of wetland farmers.

$$New\_wetland\_farmers = a \times Wetland\_farm\_hhlds \times food\_\mathrm{sec}urity\_index$$

The equation was calibrated in accordance with observations and *a* is a proportional coefficient included for adjustment.

The land use sector considers the abandonment of cultivated area as well.

Natural resources sector. Natural vegetation harvest is an important source of income for the wetland communities. Therefore, any change in natural biomass leads to a change in the community well-being. The aim of this sector is to model the dynamics of wetland natural biomass. The change in natural biomass stock is estimated as a difference between biomass growth and biomass harvest:

$$X_{t+1} - X_t = rX_t(1 - \frac{X_t}{k_x}) - h_t,$$

where X_t is wetland biomass (ton/ha) at time t, r is intrinsic growth rate of biomass wetland stock, k_x is a carrying capacity of the wetland (ton/ha) and h_t is harvest of biomass (ton/ha). $1 - \frac{X_t}{k_x}$ is a density factor that allows to capture the growth rate change due to feedbacks from biomass stock or harvest. Biomass stock has negative feedback to the biomass growth rate. This means that when biomass increases the actual growth rate decreases. On the contrary, biomass harvest has a positive feedback on the growth rate, as the removal of biomass causes the growth rate to increase. At the current stage, there is no connection between natural resources sector and hydrology sector. This means, that the biomass growth rate is assumed to be independent from the soil water content or ground water level.

Harvest of natural biomass is estimated with the following equation:

$$h_t = \frac{H_t \times hph_t}{N_t},$$

where H_1 is the number of harvesters, hph_t is the harvest per head and N_t is a natural wetland area at time t. The number of harvesters changes every year as the biomass availability changes. If biomass available per head exceeds per head maximum harvest, the number of harvesters goes up. The rate of this increase is proportional to the relative difference between available biomass (per head) and the maximum harvest (per head). The sector also considers harvester drop out. Thus, when the actual harvest is close to maximum harvest then drop out occurs slowly, but when actual harvest is very small, the drop out rate is high.

Besides the change in biomass and its harvest, the sector estimates the income that community receives from harvested natural resources. This value is used to model cash stock dynamics in community well-being sector.

Community well-being sector. This sector assesses community well-being in terms of food and money sufficiency and natural wetland state. It considers population, food and cash dynamics.

Population dynamics determines the demand for wetland resources and, therefore, influences food and cash dynamics. Population growth occurs exponentially and depends on the natural population growth rate (considers birth and death) and emigration rate. It is assumed that immigration does not happen in the region. Natural population growth and emigration rates are set constant over the whole period of simulation considered in the model (1.7% per year and 1% per year respectively).

Cash stock dynamics is determined by cash inflow and cash outflow. Cash inflow includes social transfers from government, off-farm wages and income from natural resources. Cash outflow consists of food purchase and non-food expenditures (domestic expenditures and expenditures for crop inputs calculated in crop production sector). Community well-being sector assesses cash availability through income index, which is calculated from cash stock and population number. Income index is a relative difference between cash available per person and poverty line:

$$Income\_index = \frac{\frac{Cash\_stock}{Population\_number} - poverty\_line}{poverty\_line}$$

Poverty line is set at the amount of cash that is necessary to cover non-food expenditures of one person according to South African national statistics.

Food stock dynamics depends on the food inflow (food production and food purchase) and food outflow (food consumption). It assumed that maize (the only crop that the model considered at the start) is used only for consumption. If the cash stock is sufficient, the community can buy food from outside when the food stock is empty. The food security index is the ratio of food consumption over food needs. The model estimates this index once a year and uses it to make a decision to convert natural wetland into agricultural area (land use sector).

The sector assesses community well being with community well being index. This index takes into account food, money and natural wetland health. It is estimated as follows:

$$Community\_wellbeing = (w_1 \times food\_\mathrm{sec}urity\_index + w_2 \times income\_index + w_3 \times wetland\_index)$$

where w_1, w_2 and w_3 are weights that are attached to each of the components by local community.

The community well being index is the main output of the WETSYS model on the basis of which the scenarios are to be evaluated.

It is planned to use the model for simulation of different management options under global scenarios that consider climate and socio-economical trends. The management options include rehabilitation of irrigation scheme, introduction of crops that are more suitable for cultivation in the wetland, development of ecotourism (additional source of income for the community) and conservation of wetland.

For further development of the WETSYS model it is important to identify model parameters that bring the highest uncertainty to the model (sector output). This will help to improve the model robustness. Besides, the model needs some improvements in its accuracy and additional data for management option simulation.

2 Activities and results

2.1 Model correctness

Prior to making improvements that will increase accuracy and fitness of the model, its equations and their explanatory notes have been checked (Wabha and Lai, 2001). One of the aims of this check was to complement the documentation of model variables. STELLA platform has an option to create explanatory notes for equations and source of data. It is important that this documentation is complete as it makes communication between model creators easier. The other reason to perform this check is to locate the constants that are embedded in the equations. Constants in the equations would create difficulty when the model is applied to other similar systems or when future scenarios are to be tested. This means that each time the parameters of the model are to be changed, the equations have to be changed as well. Introducing constants as separate model elements makes it easier to perform simulations for future scenarios on the same system or other wetland ecosystems.

The check revealed some inconsistency of documentation and a lack of explanatory notes on data sources and equations. The documentation was corrected and added where necessary. Constants in the equations were detected as well. They were separated from the equations to form new variables. The variables that needed correction and the changes made to them are presented in ANNEX 1.

2.2 Contribution to the model documentation

Along with the activities that concern the model directly, a contribution has been made to its documentation. This documentation is intended for internal use. It includes a descriptive table of all model variables and a list of model versions. The descriptive table provides an easy way to get acquainted with the model and its interactions. The list of model versions is necessary to keep track of the changes that were applied to it (ANNEX 2). Maintaining model documentation in order enhances communication between modelers and ensures well-established monitoring of model improvements. Besides, a search for additional data series including price indices and social transfers was carried out.

2.3 Model calibration, validation and improvements

This section presents the results of calibration, validation and model improvements that were accomplished during the internship period. In 2.3.1 the initial analysis of hydrology sector dynamics of groundwater is performed. First, modeled groundwater dynamics are compared to the observation. Second, the failures of hydrology sector are identified. Third, in an attempt to identify the sources of these failures, the model sensitivity to the changes in dt intervals (the time step at which model software solves equations) was tested (2.3.1.2) and the analysis of each inflow and outflow contribution to the groundwater level is presented. Flow contribution analysis is followed by the test of different upper catchment contribution. And finally, modelled groundwater level and evapotranspiration from natural areas are compared to the observations.

In 2.3.2 improvements are implemented to the hydrology sector. The same tests and comparison with observations as in 2.3.1 are performed with modified model and the results are discussed. In 2.3.3 the output of crop production sector was validated against the observations. Improvements introduced to the crop production sector are described in 2.3.4.

2.3.1 Initial analysis of hydrological sector dynamics

2.3.1.1 Comparison with observation sector

As the observations for groundwater level were available only for the years 2005, 2006 and 2007, the model was run for only these years as well. In order to avoid the accumulative effect from the simulation of the previous years, the model was set in such a way that it starts simulations from October 2005. Therefore, some input and parameter values had to be changed to correspond with the year 2005 as the beginning of the simulation. Changes had been made as follows:

- Population

Initial value is 2519 for the year 1994. For the year 2005 it is set at 2720. At the end of 2006 the population number in the area was estimated at 2758 (Adekola, 2007). Knowing the assumed growth and emigration rates (1.7% and 1% respectively), it is possible to estimate the population number at the end of 2004. This estimation is used as an initial value of population number in the year 2005.

- Food stock

The initial value of food stock is estimated as a sum of crop production from irrigation scheme and cultivated wetland minus a part of the harvest that is consumed by population as the simulation starts at the mid point from last cropping season. Crop production is calculated as yields multiplied by the area (irrigation scheme or cultivated wetland). The part of the harvest that is consumed by the community is calculated as population number multiplied by the amount of food consumed by a household of 7 people in six months. To set the initial value of food stock at the level of 2005, it is necessary to change the yields, area irrigation scheme and cultivated wetland and population number to the level of 2005.

The yields from cultivated wetland and irrigation scheme are set at 3 and 1.39 T/ha respectively. These values are taken from the model run in the harvesting period previous to October 2005 for the full simulation period 1994-2007. The population number is set at 2720 (discussed above) and cultivated land area is set at 62 (see below).

- Cash stock

In the equation of the initial value of cash stock only population number is changing with years, other components are assumed to be constant over the simulation period. Therefore, only the population number was changed to the value of 2005.

- Wetland farming households

Initial value is 21, which is the number of wetland farmers in 1994. According to the survey of Adekola (2007) in 2006 there were 33 farmers that cultivated the wetland in the household sample. Two of the farmers started cultivating the wetland in 2006. The sample represents 1/3 of the total population of wetland farmers. It can be estimated, that in 2006 99 farmers were present in the wetland and 6 of them were new, which means that in 2005 93 farmers were present in the wetland. Therefore, the initial value of wetland farming households for simulations beginning in 2005 is set at 93.

- Wetland cultivated area

Initial value for the current simulation is set at 62 ha. It is estimated from the number of farmers in the wetland (93) and average wetland plot size.

- Harvesters

To calculate the initial value of the harvesters in 2005, only the population number had to be changed to the level of 2005.

-Initial groundwater level

The variation of the groundwater level within a month can be significant therefore it is difficult to determine the initial groundwater level for the model that uses time step of one month. Two simulations were performed using two initial values of groundwater level. This is done to show the influence of the different initial values on groundwater dynamics.

First, the initial value is changed to the observed value of 718.59; it corresponds to the measurements of T604 LB piezometer on the 5th of October 2006. This value is used because there are no measurements for the month of October in 2005. Second, the initial value of 718.69 is used.

- Upper catchment rainfall

This variable is a function of time. Data series for simulation are used from 1994 till 2007. The last 24 data points are taken in order to run the model only for the last two years (2005-2007).

- Rainfall valley

This variable is a function of time. Data series for simulation are used from 1994 till 2007. The last 24 data points are taken in order to run the model only for the last two years (2005-2007).

After the described changes in the model, it was run and the estimated groundwater level was compared to monthly mean measurements of three piezometers (T604 LB, T306RB, T403LB) each in different transactions within the wetland. These piezometers are situated in different locations and groundwater dynamics can differ due to this. The WETSYS model considers the wetland as homogeneous and therefore more then one piezometers were chosen for comparison. Moreover, unlike other piezometers in the wetland, T604 LB, T306RB, T403LB have continuous measurements for the considered period (Kogelbauer, 2010).

Figure 2-1 presents the results for comparison of measured and modeled groundwater level. It should be noted that measurements of groundwater level exist for the period of two years. This period is very small and therefore poses some limitations for model validation.

The comparison proved that delay exists in the modeled groundwater dynamics. The observed dynamics of groundwater level slightly differ depending on piezometers. During first year observed groundwater level peaks at the end of wet season (month 5 or 6, corresponding to February or March). During the second year, observations show that the peak happens in the middle of wet season for piezometers T306RB and T403LB (month 14 or 15, corresponding to November or December) and at the end of the wet season for piezometer T604LB (month 18, corresponding to March). Modeled groundwater level peaks in the middle of dry season (month 10 and 22, corresponding to July). Moreover, modeled groundwater dynamics has significantly smaller amplitude of change than observations.

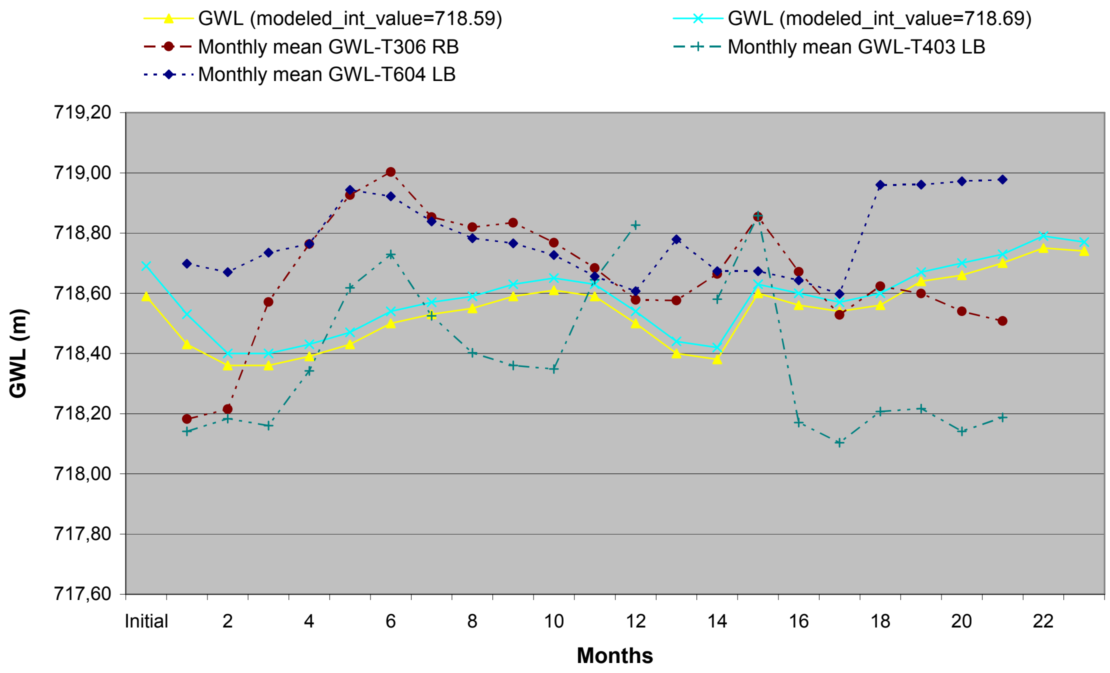


Figure 2-1 : Observed and modeled groundwater level (simulation from 2005 till 2007)
The version of model used for simulations: WETSYS_25052010_Run2005-2007 (refer to the ANNEX 2 for the description of the model version).

Identification of failures in hydrology sector

Several problems were identified in this sector. First, after the flood occurring in the year 2000 (around month 66) groundwater level does not go down staying always above the ground level (Figure 2-2), which is contrary to what Ga-Mampa people experienced in reality. Second, the comparison of modeled groundwater dynamics with observations showed that four month delay in groundwater dynamics exists in the model. Groundwater level peaks in the middle of dry season which seems not corresponding to the observations discussed above (Figure 2-1). On this graph it can be seen that groundwater level peaks correspond to 10, 22, 34 and 46 (July).

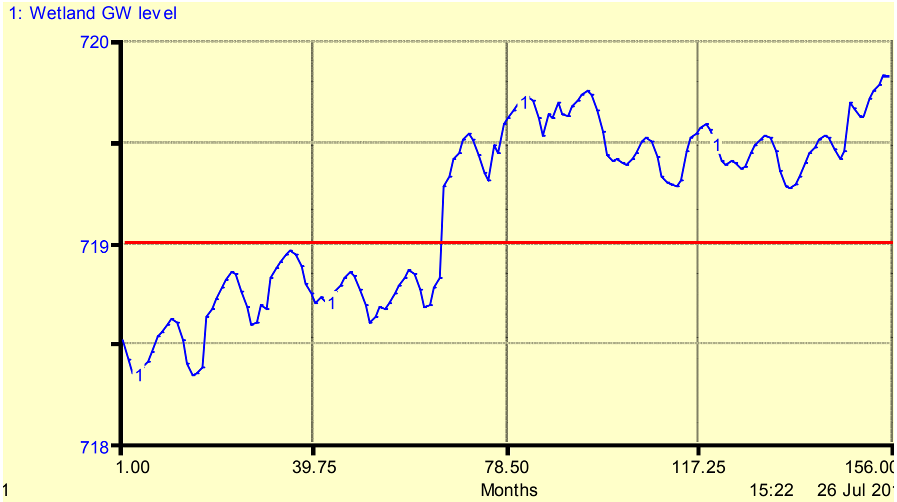


Figure 2-2 : Groundwater level dynamics through whole period of simulation (1994-2007)
The version of model used for simulations: WETSYS_28052010 (refer to the ANNEX 2 for the description of the model version).

2.3.1.2 Testing different dt intervals

In an attempt to eliminate the delayed groundwater dynamics, model response to different dt intervals was tested. Dt interval determines the interval of time between calculations of the model variables. WETSYS model has a time step of one month and dt interval equaling to one. It means that model solves its equations once in one month and it takes one dt interval (or one month) for any change in the model to occur. However, the changes in some processes may have to occur more often. And as calculations are performed once a month it does not allow for taking these changes into account. Therefore having large dt interval may cause an inaccurate behavior of the model dynamics (Breierova, 1998). Therefore, the model was run with different dt intervals (1, 1/2, 1/4, 1/8, 1/16 and 1/32).

Figure 2-3 presents the result of model runs with different dt intervals. The comparison of groundwater level dynamics showed that with a change of dt, no change occurs with regard to the groundwater level peaks. It peaks at months 10, 22, 34 and 46 (month of July) which are the middle of dry season. However, differences in the amplitude of ground water level can be observed when different dt's are applied. With smaller dt intervals the groundwater level decreases faster after the 2000 year flood. Dt intervals of 1/2 show rather strange behavior after considerable increase in the level of groundwater corresponding to the flood of the year 2000. With dt higher then 1/8, the results do not change to a large extent, therefore it can be seen as an optimal interval for calculations.

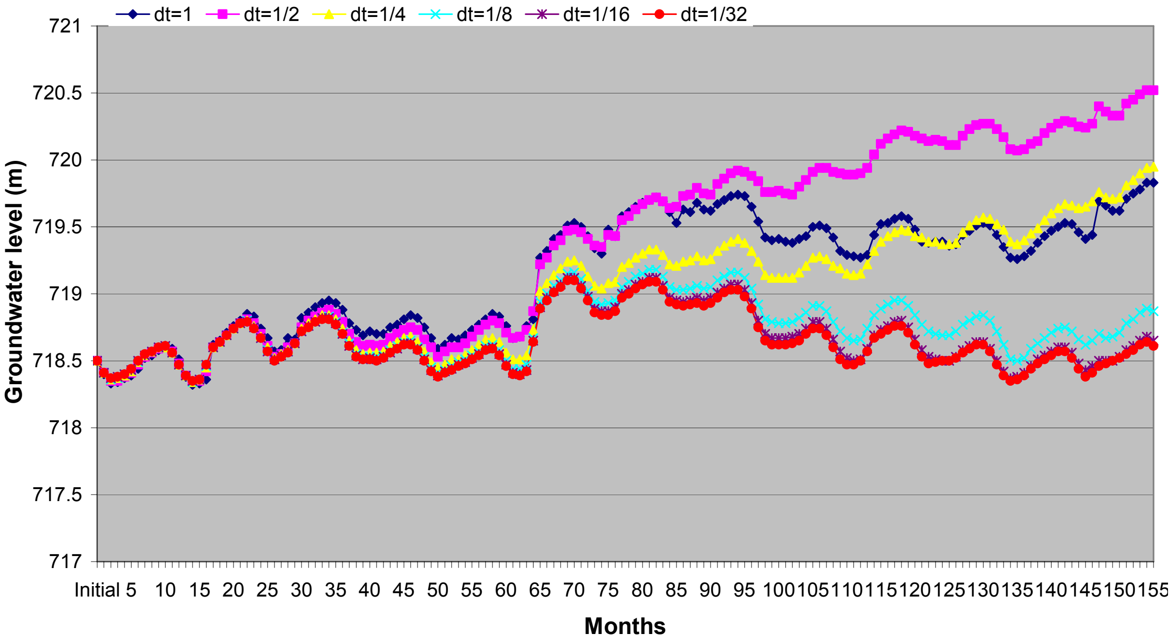


Figure 2-3 : Modeled groundwater level dynamics with different dt intervals
The version of model used for simulations: WETSYS_28052010 (refer to the ANNEX 2 for the description of the model version).

2.3.1.3 Flow contribution analysis

To identify the source of the delay in groundwater dynamics the analysis of each inflow and outflow contribution to the ground water level was performed. Groundwater in Ga-Mampa valley recharges from rainfall in the upper catchment, losses in the irrigation scheme and from soils (when water content exceeds field capacity) in irrigation scheme (irrigation percolation), natural and cultivated wetland. All these contributions to the inflow are embedded in the equation of groundwater recharge. To identify the contribution of each component, they were calculated separately for a period of 50 months. Outflow from groundwater consists of capillarity rise, groundwater seepage and artificial drainage. Groundwater artificial drainage was not included in the analysis, because its value equals to 0 for the chosen period of simulation (50 months). It represents evaporation losses from drains when groundwater level in wetland is higher than ground level (it is assumed that drains do not discharge into the river as most drainage canals do not reach the river) (Morardet et al., 2009). These outflows are calculated in the model separately therefore no additional calculations were performed to identify their contribution to the groundwater level changes.

Figure 2-4 presents the contribution of each inflow and outflow component to the change in groundwater level. The bars above the x axis represent the inflow contribution and the bars below it show outflow contribution. Among inflows the biggest contribution comes from the irrigation scheme losses and natural wetland recharge while the recharge of ground water from upper catchment rainfall is very limited. Among the outflows capillarity rise is very important while seepage is quite small. The contribution of outflow due to artificial drainage is not presented on the graph. In the equation of groundwater artificial drainage the conditions are set in such a way, that it remains zero unless the groundwater level rises above 719.5. During simulation period of 50 months groundwater level does not rise above this value, constantly keeping artificial drainage at zero. This condition is set with the assumption that drainage occurs only when the groundwater level is above the bottom of the drainage canals which depth is estimated at 50 cm. As the model uses ground level being 719 m, the threshold condition for artificial drainage should be set at 718.5 m.

This analysis revealed that groundwater dynamics is mostly driven by capillarity rise, recharge from natural wetland and losses from irrigation scheme. It also showed that groundwater seepage and rainfall have small contribution. This distribution of the importance between the flows may cause the delaying dynamics of groundwater and its inaccurate behavior after 2000 year flood. For example, there is only one outflow (capillarity rise) that is important while groundwater seepage and artificial drainage have very limited contribution to the outflow of groundwater. In order to identify if these contributions are reasonable for the flows more profound hydrological insights are necessary.

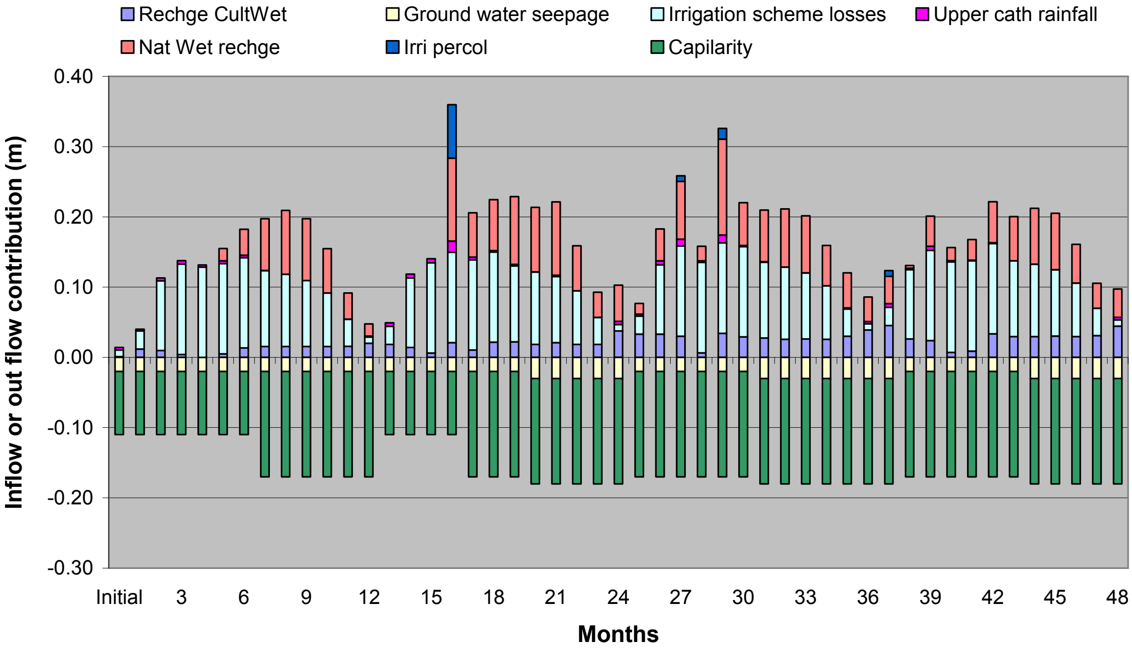


Figure 2-4 : Contribution of the flows to groundwater level dynamics for the simulation period of 50 months
The version of model used for simulations: WETSYS_28052010 (refer to the ANNEX 2 for the description of the model version).

2.3.1.4 Testing different percentages of upper catchment inflow

Following the results of the flow contribution analysis different percentages of upper catchment inflow and their influence on groundwater dynamics were tested. It is assumed in the model that 5 % of upper catchment rainfall recharges groundwater. This percentage is arbitrary. The test was performed with 10% and 20% of upper catchment rainfall contribution. The results of the model runs were compared to the observation (Figure 2-5).

Modeled groundwater dynamics appeared to be rather sensitive to the change in upper catchment rainfall contribution. Higher upper catchment inflow increases the recharge of groundwater and therefore its level increases as well. However, it has no influence on the groundwater seasonal peaks and the amplitude of variation. The gap between results for different percentages of recharge tends to increase over time.

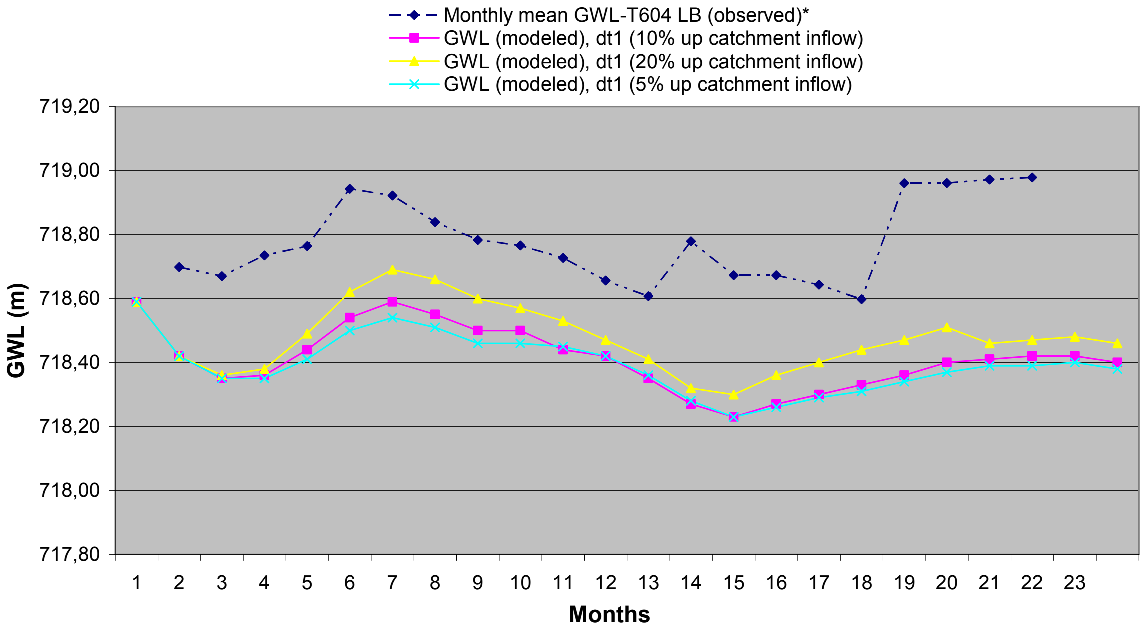


Figure 2-5 : Observed and modeled groundwater level with different % of inflow from upper catchment (simulation from 2005 till 2007)
The version of model used for simulations: WETSYS_28052010 (refer to the ANNEX 2 for the description of the model version).

2.3.1.5 Validation of evapotranspiration from natural areas (ETn)

Validation of the model simulations was also performed for actual evapotranspiration from natural areas. Evapotranspiration varies over the year depending on the season. Based on hydrological model ACRU, evapotranspiration from wetland natural vegetation in north-western Zambia fluctuating from 2.37 mm/day in winter (dry season) to 5.63 mm/day in summer (wet season) (von der Heyden and New, 2003). The estimates of actual evapotranspiration from the Nylsvlei floodplain, South Africa which is located close to the Ga-Mampa wetland (Table 2-1) (Kleynhans, 2005). Daily evapotranspiration from reed bed measured in Orkney (located in Free State province of South Africa, in the Vaal River catchment) varies from 1mm/day in June-July to 5-6 mm/day in January (Dye et al., 2008).

Table 2-1 : Estimates of evapotranspiration from the Nylsvlei floodplain

Month	Actual evapotranspiration (mm/day)
October	2.3
November	3
December	3.7
January	4.4
February	4.7
March	2.6
April	2.2
May	1.9
June	1.6
July	1.6
August	0.4
September	2.3

WETSYS model was run for a period of 50 months and the output for evapotranspiration from natural vegetation was compared to values stated in the literature.

Figure 2-6 presents the results of the comparison. The amplitude of seasonal variation of modeled evapotranspiration appears to be consistent with the estimates from the literature. During the first two years of the simulation the peaks of modeled ETn occur at the same time as estimates from the literature. After this period it shifts and modeled ETn peaks two months earlier remaining at the maximum for a period of three month. This can be attributed to the fact that evapotranspiration varies with meteorological conditions of the year and location.

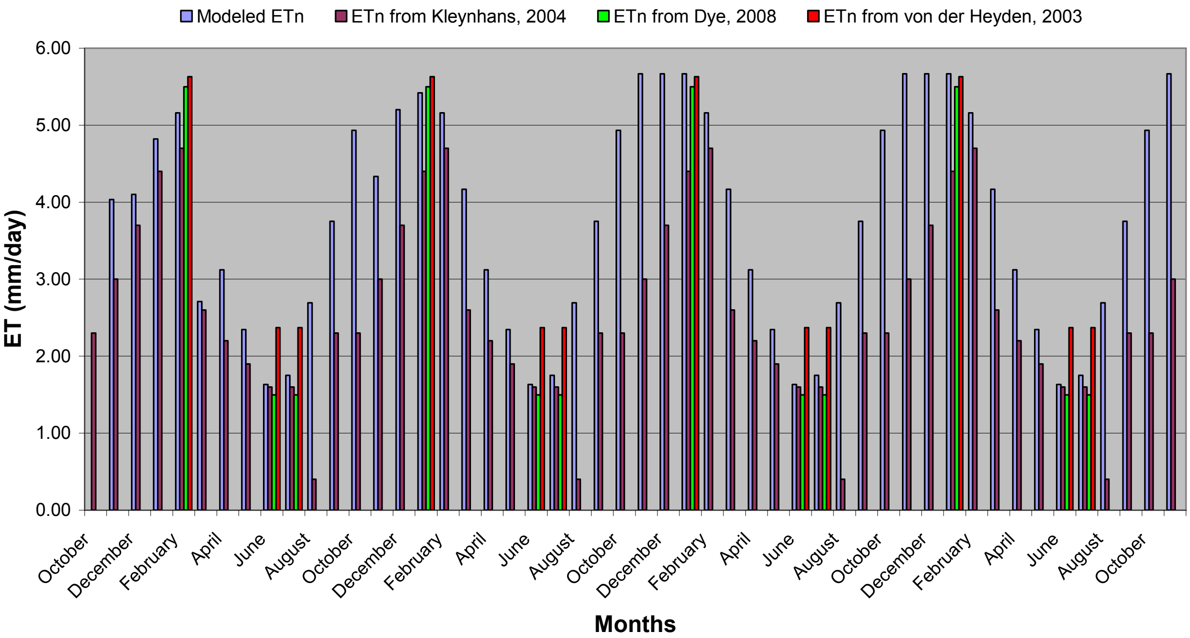


Figure 2-6 : Modeled and estimated evapotranspiration from wetland natural vegetation
The version of model used for simulations: WETSYS_28052010 (refer to the ANNEX 2 for the description of the model version).

2.3.2 Improvements in hydrology sector

In order to determine the reason for groundwater dynamics delay and reasonableness of flow contribution hydrological insights were necessary. The results of the performed analyses were discussed with a specialist from IWMI. Some improvements were introduced in the model on the basis of this discussion.

First of all, new data series for rainfall (upper catchment rainfall and rainfall in the valley) and potential evapotranspiration (ETP) were applied to the model. Rainfall data for the upper catchment and data for ETP were originally obtained from Department of Water Affairs and Forestry (DWAF) from rainfall station B7E006 and A-pan ETP station B7E006[1]. Rainfall data for valley was prepared by S. Morardet. The time series for Fertilis station (which is located in the valley) were available from South African Weather Services only for the period of 1972-1989. Therefore, a regression based on series of 1972-1989 was made from other station of South African Weather Services, Wolkberg, located in the upper catchment of the Mohlapitsi River and the equation was then used to estimate rainfall data series in the valley for the period 1994-2007. For the period of 2005-2007 values for Wolkberg are not available. For this period the values for Wolkberg station are estimated from B7E006 station values based on a regression performed for the period 1992-2005.

Second, changes to the equation of artificial drainage were made. In previous version the drainage (and evaporation from drains) occurred only when groundwater level was higher than ground level. In the new version this condition is changed so that the drainage occurs when groundwater level is above the bottom of the drains (drainage canal are estimated to be 50 centimetres deep).

---

[1] Data provided by S. Morardet

After the improvements were implemented different dt intervals were tested and the flow contribution analysis and model validation were performed again.

2.3.2.1.1 Testing different dt intervals with implemented improvements

Model with implemented changes was run with different dt intervals (1, 1/2, 1/4, 1/8, 1/16 and 1/32). Figure 2-7 shows the influence of different dt intervals on the groundwater dynamics. Unlike in old version of the model (before implemented changes) (Figure 2-3), the new model shows decrease in groundwater table after the flood of 2000 (month 66) for all dt intervals except 1/2. However, this decrease happens too slowly, especially for higher dt intervals. On Figure 2-8 the difference between old and new versions of the model can bee seen with regard to groundwater decrease after the flood in year 2000.

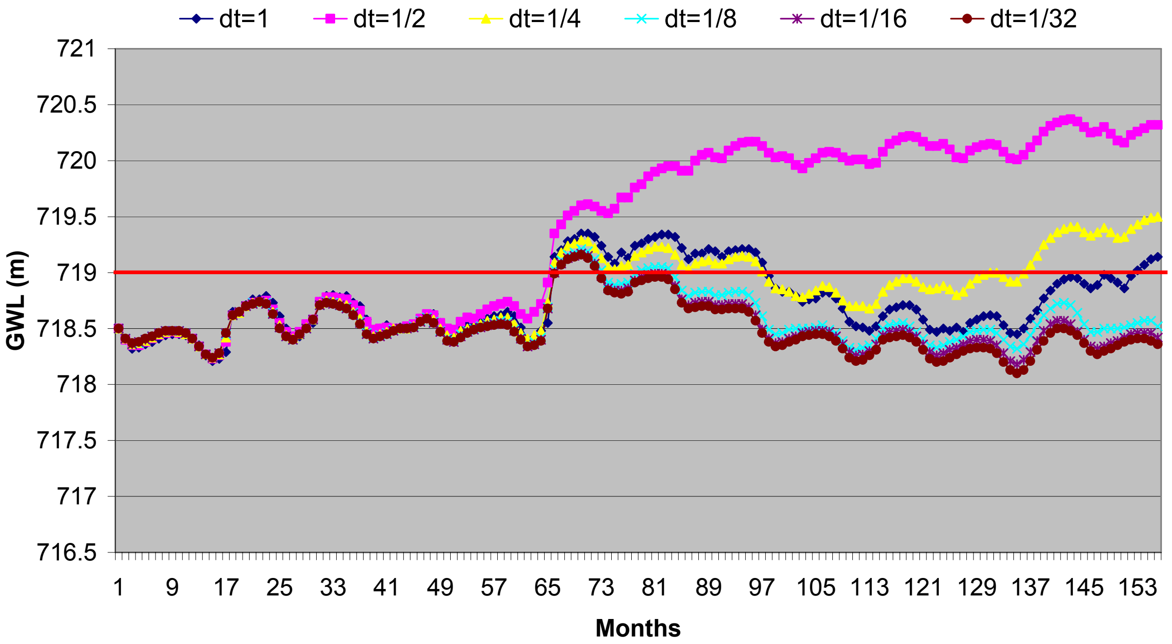


Figure 2-7 : Modeled ground water level dynamics with different dt intervals (after implementation of improvements to hydrology sector)
Red line indicates the ground level; the version of model used for simulations: WETSYS_21072010 (refer to the ANNEX 2 for the description of the model version).

The improvements of the hydrology sector had a positive influence on the delay of groundwater dynamics as well. Figure 2-8 shows that seasonal peaks shifted one month to the right after the improvements in the hydrology sector. However, this shift is not sufficient as the delay constituted four months before the changes.

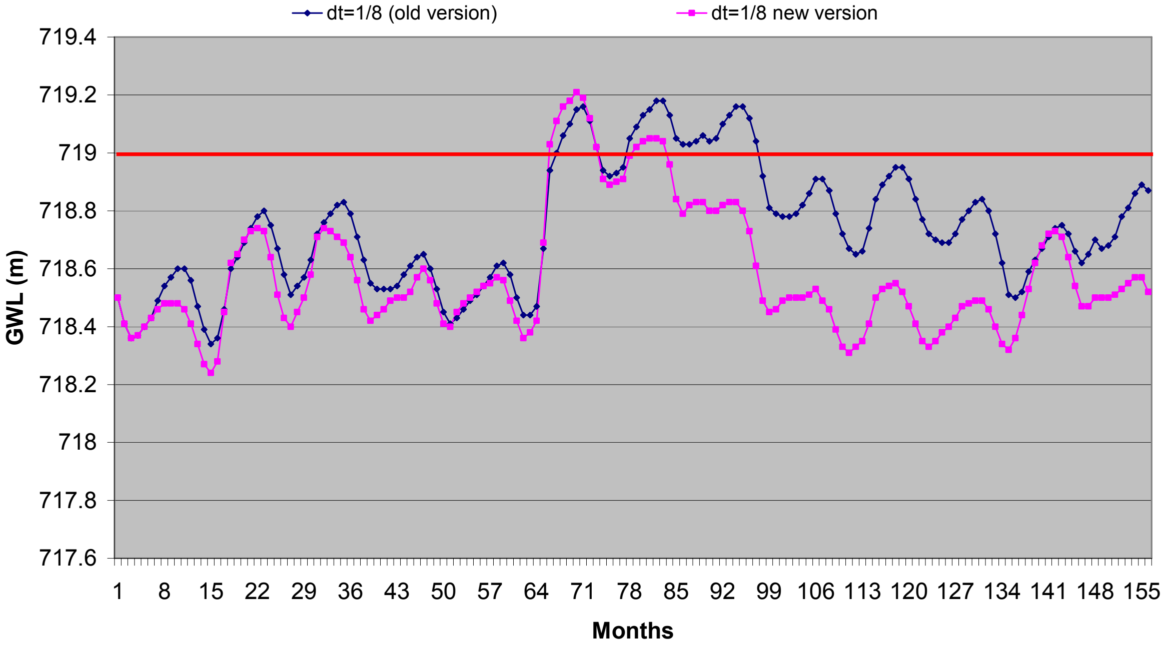


Figure 2-8 : Comparison of groundwater dynamics of the model before (old version) and after (new version) change sin hydrology sector
Red line indicates the ground level; the version of model used for simulations: WETSYS_21072010 (refer to the ANNEX 2 for the description of the model version).

2.3.2.1.2 Flow contribution analysis with implemented improvements

The procedure of performing the analysis is exactly the same as described above (see 2.3.1.3). Figure 2-9 presents the contribution of each flow to the groundwater dynamics after the improvements were implemented to the hydrology sector. Modifications implemented in hydrology sector slightly changed the results of the analysis. Recharge from natural wetland has an important contribution, but unlike in the old version of model (Figure 2-4) its contribution becomes important after one year of simulation. Rainfall contribution increased to some extent in comparison with the old version of the model. It is attributed to the new rainfall time series. Revision of artificial drainage equation made this flow component slightly more important compared to the previous version of the model. Contribution of other flows did not alter with improvements applied to the hydrology sector.

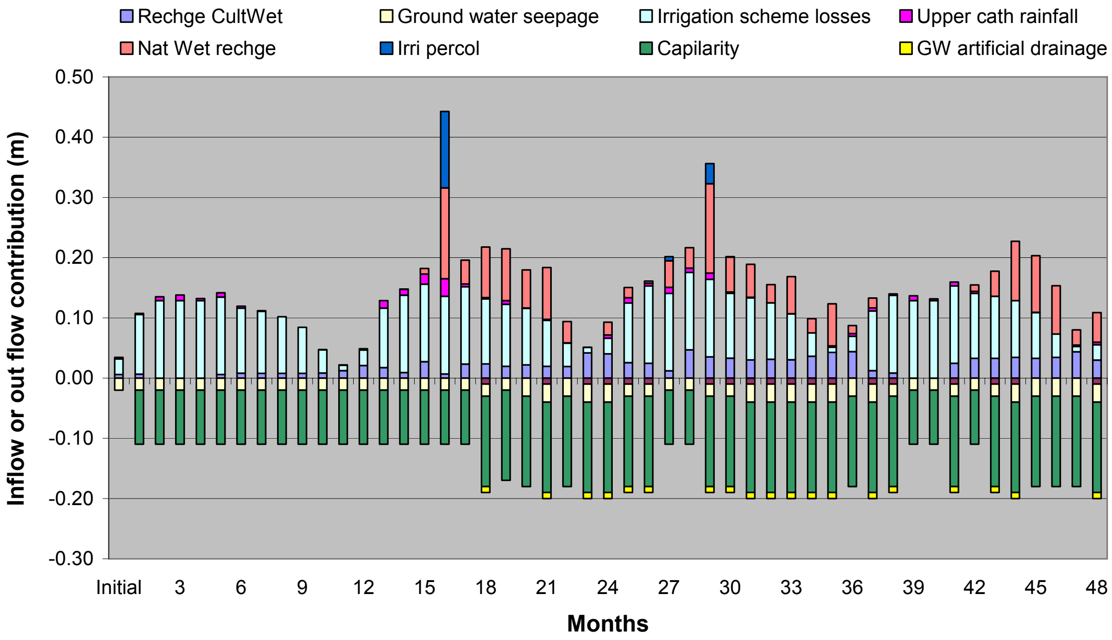


Figure 2-9 : Contribution of the flows to the groundwater level dynamics (after implementation of improvements to hydrology sector) for the simulation period of 50 months
The version of model used for simulations: WETSYS_21072010 (refer to the ANNEX 2 for the description of the model version).

2.3.2.1.3 Validation of modeled groundwater dynamics with implemented improvements

As implemented improvements had an influence on groundwater dynamics the validation of modeled groundwater level was performed again. The improved model was run for the period of 2005-2007. All the necessary changes for the 2005-2007 runs were applied to the improved model as described in 2.3.1.1. The results of the simulations were compared to the observations. Model results have better fit with observations after the improvement of hydrology sector (Figure 2-10). It should be noted that the period of measurements is of a short duration. This hinders a sound validation of the model results. For the first year of simulation the seasonal peaks of modeled groundwater level occur at the same time as the peaks of observed dynamics. However, in the second year the modeled dynamics differ from the measurements. The amplitude of modeled groundwater seasonal variation is still less important than for observed data. Different dt intervals and different initial values of groundwater level have little influence on the model results.

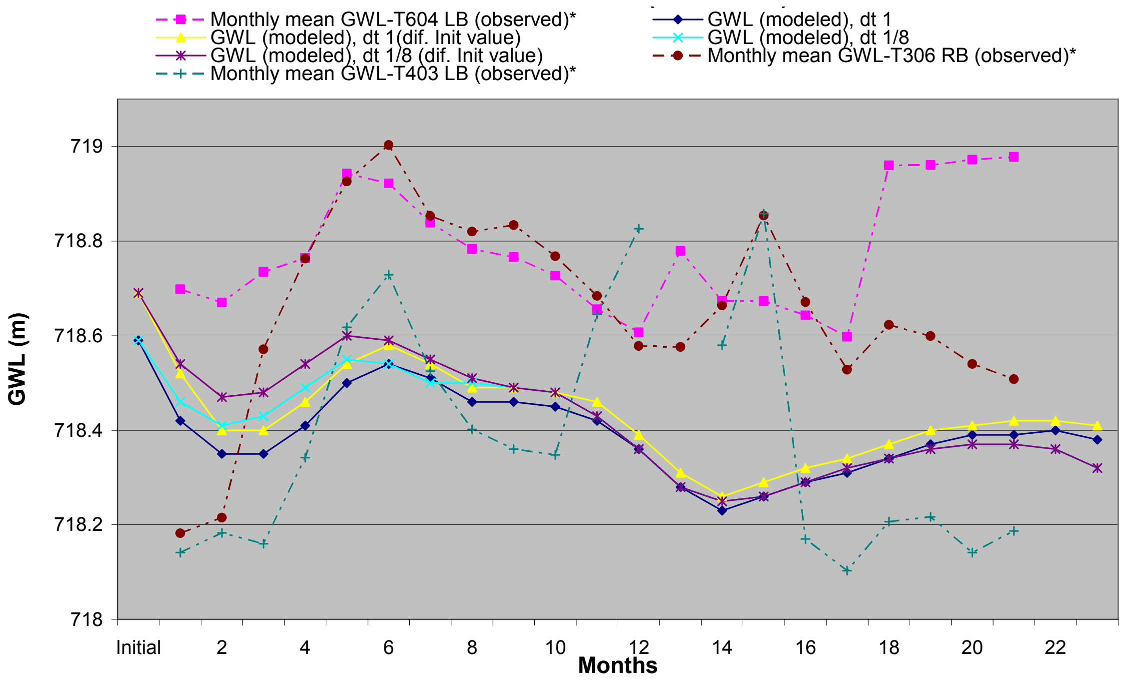


Figure 2-10 : Observed and modeled groundwater level after implemented improvements (simulation from 2005 till 2007)
The version of model used for simulations: WETSYS_21072010_Run2005-2007 (refer to the ANNEX 2 for the description of the model version).

To have more insights in the origin of seasonal groundwater level peaks, the dynamics of rainfall and groundwater (modeled and observed) were analysed for the period of 2005-2007. The data series of the rainfall (in the upper catchment and valley) that are applied to the improved model were used for this analysis. Observed dynamics show strong dependency on the rainfall. But due to different locations of the piezometers this dependency is stronger for T-306RB than for T-403LB and T-604 LB. This means that in the locations of piezometers T-403LB and T-604 LB other important sources of groundwater recharge than just the rainfall exist. In the first year of the period the seasonal peaks of both modeled and observed groundwater levels show clear dependency on the rainfall (Figure 2-11). The peaks occur one or two month after the rainfall peaks. In the second year few months delay in the modeled groundwater dynamics takes place. Therefore, these peaks cannot be directly attributed to the dynamics of rainfall in the model.

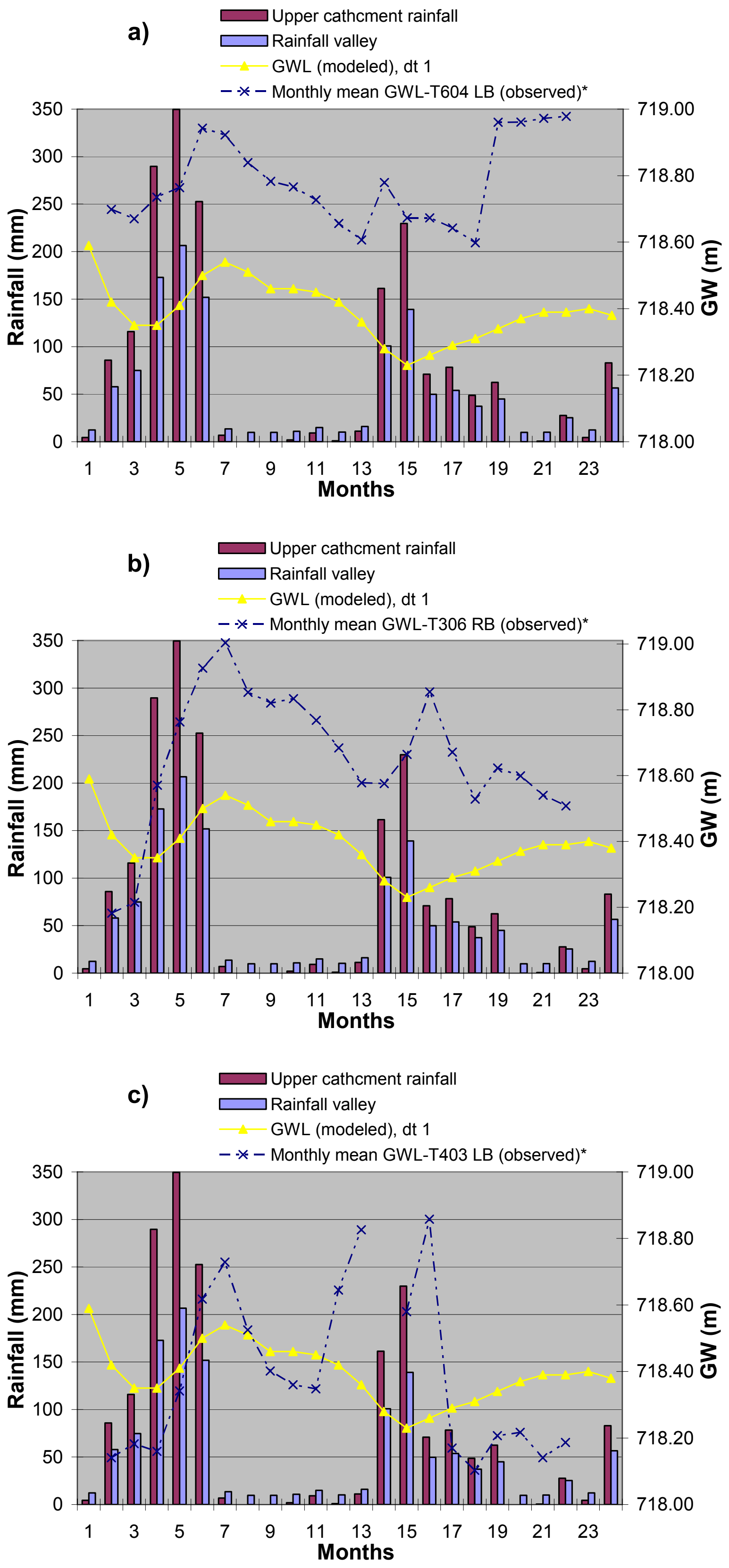


Figure 2-11 : Rainfall and observed groundwater dynamics (2005-2007)
a) Observed groundwater level for piezometer T604 LB, b) observed groundwater level for piezometer T306 RB, c) observed groundwater level for piezometer T403 LB.
Initial value of modeled groundwater level = 718.59; the version of model used for simulations: WETSYS_21072010_Run2005-2007 (refer to the ANNEX 2 for the description of the model version).

2.3.2.1.4 Validation of modeled evapotranspiration from natural areas (ETn) with implemented improvements

Modeled evapotranspiration from natural areas was validated against estimates stated in the literature after hydrology sector was subjected to the mentioned modifications. The procedure of the validation is described in 2.3.1.5. Although the results of the improved model slightly differ from the results produced before, modeled ETn still peaks earlier than estimated ETn (Figure 2-6 and Figure 2-12). The modeled amplitude of ETn seasonal variation is in line with estimates as well.

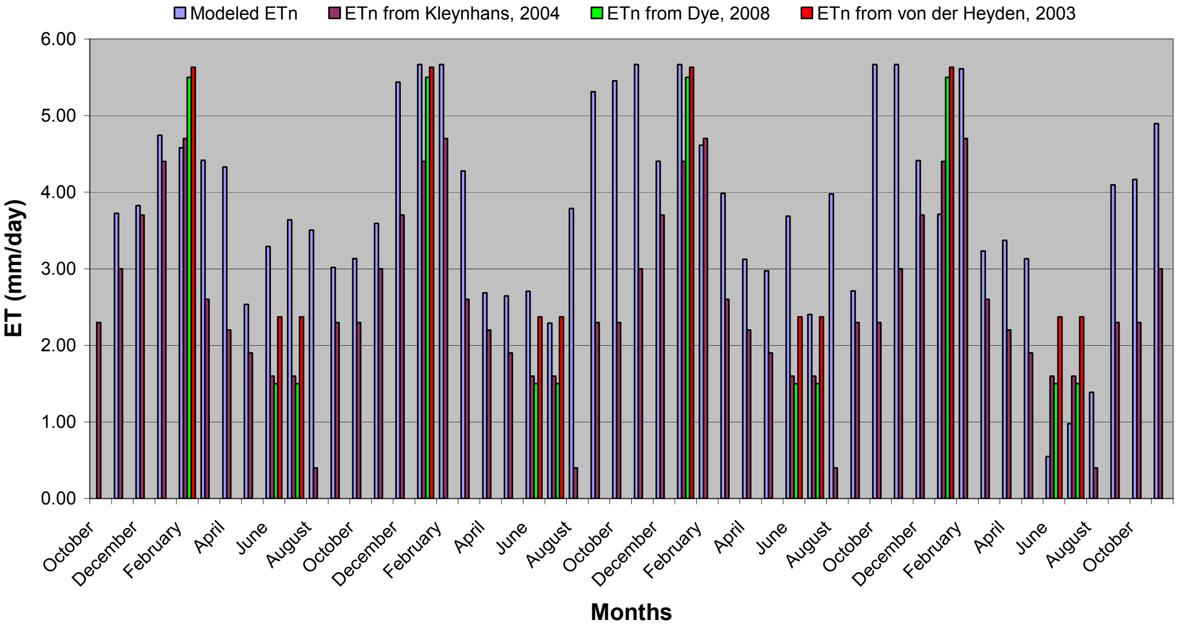


Figure 2-12 : Modeled and estimated evapotranspiration from wetland natural vegetation after implemented improvements
The version of model used for simulations: WETSYS_21072010 (refer to the ANNEX 2 for the description of the model version).

2.3.3 Validation of crop production sector

2.3.3.1 Validation of modeled yields

The output of the crop production sector was compared with observed maize yields. The validation was carried out after the improvements in the hydrology sector were implemented. The observed ranges of yields were obtained from the study of Chiron (2005). It should be noted that these data are very limited. Chiron (2005) reports the ranges for maize yields being 1.25-2.5 tons/ha in the irrigated scheme and 2.2 and 3.8 tons/ha in the cultivated wetland. These ranges are given only for one year as they account for the difference in yields between the farmers. In the study of Adekola (2007) the average yields of maize were estimated for three growing seasons, but they are available only for cultivated wetland. These yields are somewhat smaller than in the study of Chiron (2005).

Figure 2-13 presents the results of the sector validation. Modeled yields in the irrigation scheme lie outside the range for the years 1995, 1998, 2003-2005 and 2007. It can be attributed to the limited rainfall during these years. Moreover, the observed data limitation makes validation of crop production sector difficult. Modeled yields in cultivated wetland stay within the range of observations during the whole period of simulation.

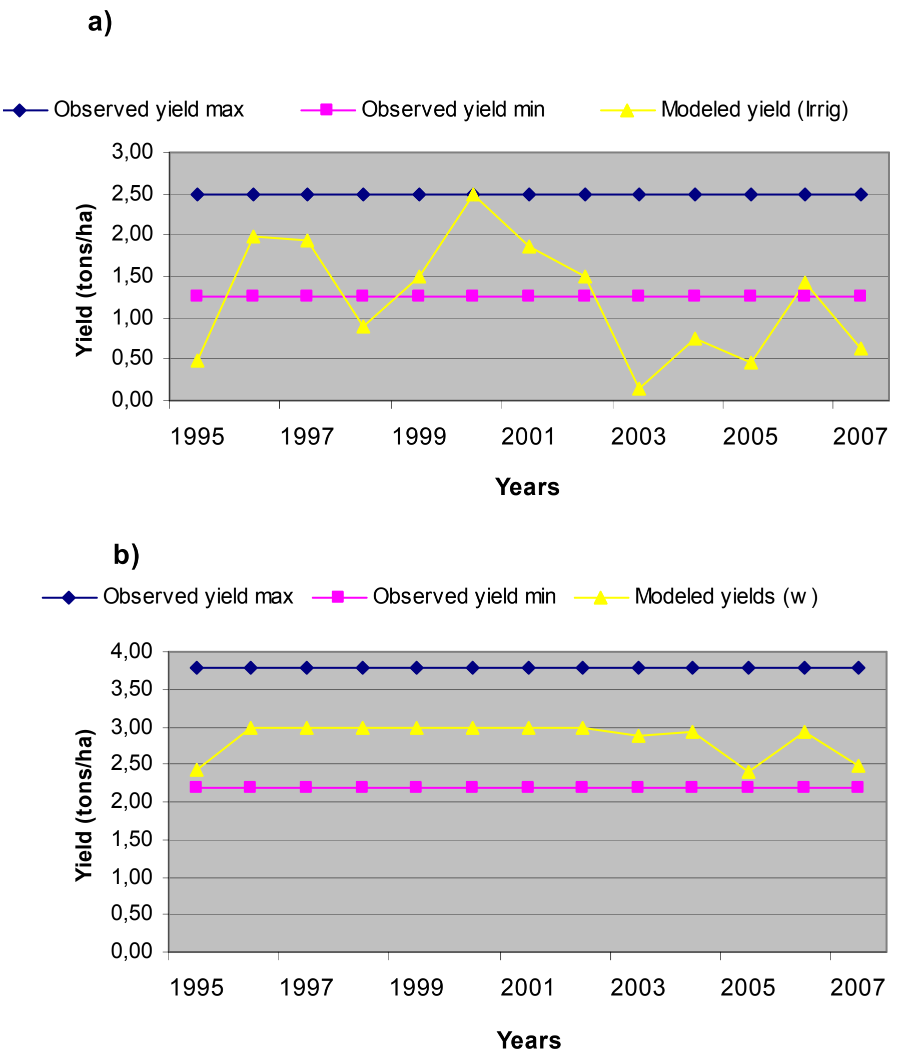


Figure 2-13 : Modeled and observed yields
a) Irrigation scheme; b) Cultivated wetland; the version of model used for simulations: WETSYS_21072010 (refer to the ANNEX 2 for the description of the model version).

2.3.3.2 Testing different values of maximum yields

The modeled maize yields are calculated from maximum possible yields (see equation in section 1.2.2). The value of maximum yield will influence the actual modeled yield. To determine this influence the model was run with different values of maximum yields for irrigation scheme and cultivated wetland. The model uses 2.5 and 3 ton/ha as maximum yields in irrigation scheme and cultivated wetland, respectively. The simulations were carried out with original values and the values that are 50% more and less.

The model appeared to be rather sensitive to the reduction and increase in maximum yields (Figure 2-14). In the irrigation scheme, actual modeled yields increase or decrease proportionally to the increase or decrease of maximum yield values (Figure 2-14a). All three curves have the same behavior. For cultivated wetland even though the behavior of the curves is not exactly the same the general behavior is unchanged (Figure 2-14b). Actual yields increase when higher maximum yields are applied and decrease when maximum yield is reduced.

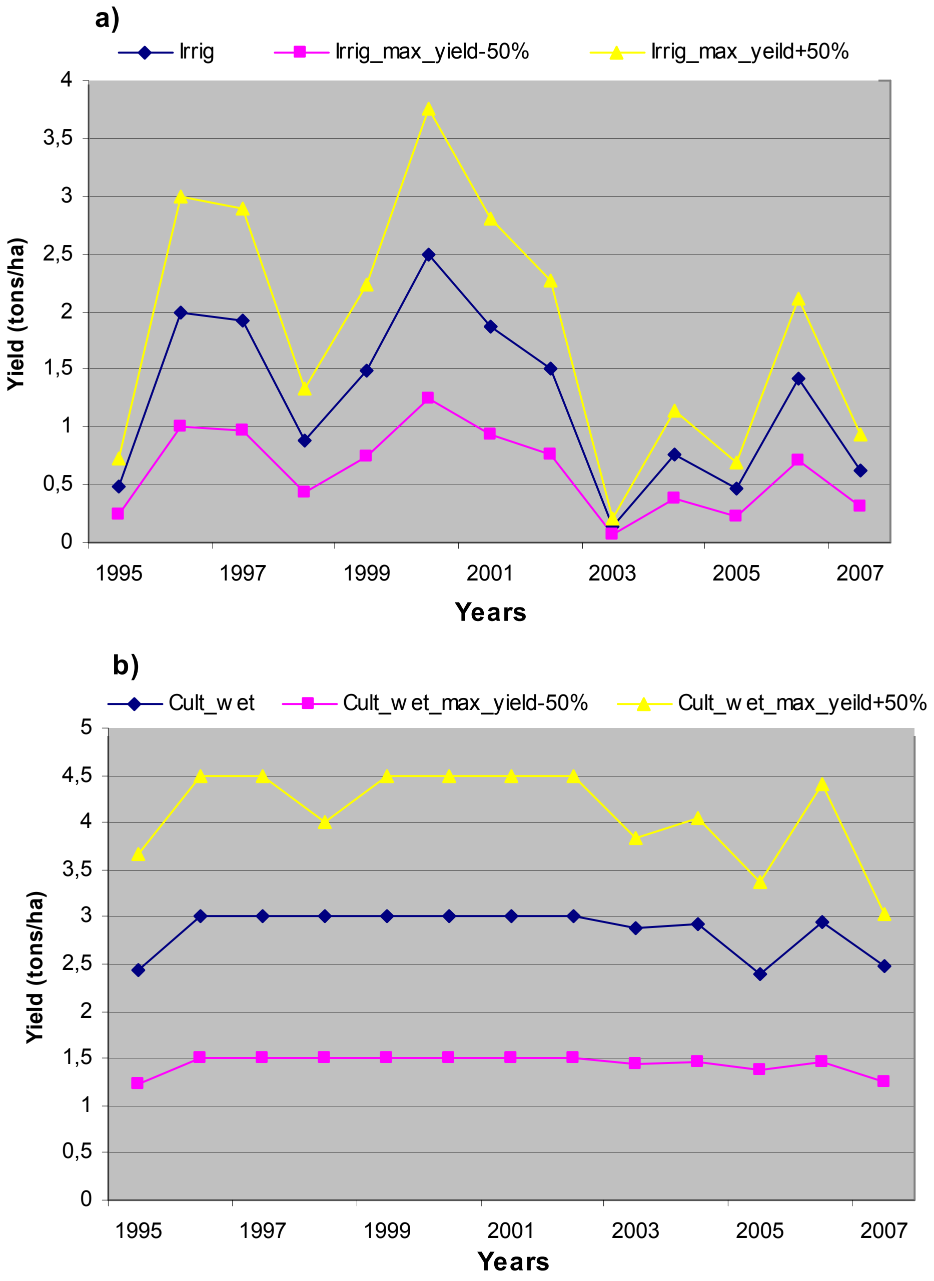


Figure 2-14 : Modeled maize yields with different maximum yield values
a) Maize yields in the irrigation scheme; b) maize yields in the cultivated wetland; the version of model used for simulations: WETSYS_21072010 (refer to the ANNEX 2 for the description of the model version).

2.3.4 Improvements of crop production sector

As it is planed to consider different scenarios in the model it is necessary to introduce certain changes. One of the scenarios focuses on agriculture and crops grown in the wetland. Several types of crops should be taken into account in this scenario (the model considers only maize so far) during rainy season as well as during dry season. Section 2.3.4.1 describes the changes applied to the model in order to introduce new crops.

Another improvement of the crop production sector concerns yield dependency on the depth of groundwater table. In the initial model this dependency was not taken into account. This means that when groundwater level is too high the yields in the cultivated wetland do not decrease. The issue is discussed in 2.3.4.2.

2.3.4.1 Introduction of new crops

Introduction of new crops in the model resulted in some necessary changes in the crop production sector as well as in other sectors. This resulted in a more complex model diagram. Due to this certain parts of the crop production sector were moved out and new sectors were created. ANNEX 3 presents model diagram before and after introduction of new crops. The most important changes in crop production and other sectors are discussed below.

Agricultural activities in Ga-Mampa valley mostly take place during summer, from November till March. However, some farmers cultivate in winter, from April till September (Chiron, 2005). Along with maize, which is the main crop grown in the area, farmers cultivate crops like groundnut, tomato, onion, sweet potato and coriander (Chiron, 2005; Adekola, 2007).

It was decided to include groundnut, tomato and onion into the WETSYS model. If needed and if necessary data are available other crops could be introduced as well. Maize and groundnut are grown during summer (wet) season and tomato and onion during winter (dry) season (Chiron, 2005). It was assumed that wet season crops are followed by dry season crops on the same plot. Thus, six different crop successions (plots) are considered. Table 2-2 presents the scheme of plots for the news crops introduced in the model. For modeling crop production for new crops the same structure as for maize production was used. STELLA software provides useful tool to present these parallel structures. Instead of having several diagrams with similar structure, array function incorporates them into one diagram with parallel layers. For the particular case of modeling crop successions it is necessary to use two-dimensional arrays. Table 2-3 presents an overview of the crop succession matrix.

Table 2-2 : Scheme of crop plots as assumed in the model

Plots	Wet season crops	Dry season crops
1	Maize	Onion
2	Maize	Tomato
3	Maize	No crop
4	Groundnut	Onion
5	Groundnut	Tomato
6	Groundnut	No crop

Table 2-3 : Crop succession matrix

Dimensions	**Dimension 1: wet season crop**		
Dimension 2: dry season crop	**Crops**	**Maize**	**Groundnut**
	Onion	Maize-onion succession	Groundnut-onion succession
	Tomato	Maize-tomato succession	Groundnut-tomato succession
	No crop	Maize-no crop succession	Groundnut-no crop succession

When the model variables associated with the crop production are arrayed according to this matrix, it means that the values of these variables are calculated per crop succession. While this is desirable for calculation of some variables, it is not desirable for the calculation of crop yields and crop production. Production has to be calculated by crop as well as yields, but yields of the same crop can differ depending on the succession. Thus, the yields of tomato coming after maize can be different from the yields of tomato coming after groundnut if the evapotranspirations of maize and groundnut are different. For this reason and because summer and winter crops do not occur at the same time the distinction between summer crop season and winter crop season is made.

The duration of growing seasons varies with crops. Table 2-4 presents the duration of the growing period for the crops grown in the summer and winter seasons.

Table 2-4 : The duration of growing periods for different crops as applied to the WETSYS model

Growing periods (in the model)												
Annual cycle												
Wet season	1	2	3	4	5	6	7	8	9	10	11	12
Maize			🟧	🟧	🟧	🟧						
Groundnut		🟧	🟧	🟧	🟧	🟧						
Dry season												
Onion								🟧	🟧	🟧	🟧	🟧
Tomato								🟧	🟧	🟧	🟧	🟧
No crop	🟧						🟧	🟧	🟧	🟧	🟧	🟧

The model computes crop yields as a function of evapotranspiration. This function involves different parameters that are crop specific (Morardet et al., 2009). Therefore, introducing new crops in the model implies introduction of new crop parameters (Kc and Ky). Kc is a crop evapotranspiration coefficient and Ky is yield response to water stress. Kc takes different values depending on the growing period. As the model uses the time step of one month the durations of crop growing phases stated in the literature were simplified. Table 2-5 presents the values of the crop parameters and an overview of applied simplification.

Table 2-5 : Parameters values for crop production sector for a) groundnut; b) tomato and c) onion

a) Planting date (as assumed in the model): 01/11

Parameter values for the crop production sector (groundnut)				
Growing stages	**duration (days)** (1)	**duration (days) (simplified for the model)**	**Kc**	**Ky** (3)
Initial stage	30	30	0.4 (2)	
Crop development	50	60	0.775	
Mid-season	40	30	1.15 (1)	
Late season	25	30	0.60 (2)	
Total growing period	145	150		0.7

b) Planting date (as assumed in the model): 01/05

Parameter values for the crop production sector (tomato)				
Growing stages	**duration (days)** (2)	**duration (days) (simplified for the model)**	**Kc**	**Ky** (3)
Initial stage	30	30	0.6	
Crop development	40	30	0.85	
Mid-season	40	60	1.10 (1)	
Late season	25	30	0.80 (4)	
Total growing period	135	150*		1.05

c) Planting date (as assumed in the model): 01/05

Parameter values for the crop production sector (onion)				
Growing stages	**duration (days)** (1)	**duration (days) (simplified for the model)**	**Kc**	**Ky** (3)
Initial stage	45	30	0.7 (2)	
Crop development	45	30	0.8	
Mid-season	45	60	0.9 (1)	
Late season	20	30	0.75 (2)	
Total growing period	155	150		1.1

* The total growing period for tomato is 5 months according to Chiron (2005);
Sources: (1) (van Heerden and Crosby, 2002)
(2) (Allen et al., 1998)
(3) (FAO, 2006)

To calculate the production of each crop the area this crop occupies has to be defined. As the total area for crop production is known, only the proportion of the land under certain crop has to be calculated. It is assumed that in one succession summer crop occupies the same area as winter crop, it is followed by. Each succession and thus each crop in the succession (as they do not exist simultaneously) occupies a proportion of the total area available for cultivation. It is possible to exclude the crop succession from simulation by simply assigning a null value to the corresponding proportion. This option creates an opportunity for scenario analysis.

The changes in the crop production sector to incorporate several crops triggered changes in other sectors of the model. The sectors involved in this are hydrology and community-wellbeing.

Hydrology sector. Crop production influences soil water content dynamics through crop evapotranspiration. Soil water content is different for each succession, and therefore the changes were made in such a way (with use of array function) that it is calculated per succession. Soils under different successions contribute to the dynamics of groundwater with their moisture (through capillarity rise and recharge). As groundwater level is supposed to be homogeneous in the whole wetland, and thus has only one value, the contribution of each plot under the various crops successions is calculated with the use of the proportion of area under each succession.

Community well-being sector. Changes in community well-being sector involved some modifications of food and cash dynamics. The model assumes that maize is the only crop used for self consumption and therefore only maize production is considered in food dynamics. Other crops are assumed to be sold on the market and therefore new type of income (income from crop sales) was introduced. This new income is adding up to the cash inflow. The calculation of non food expenditures is adjusted as well, since new crops introduce new input costs. The crop input expenditures and crop income are calculated as the sum of costs for all successions.

Besides the changes attributed to the new crops incorporated in the model, a new parameter, a priority coefficient for non food expenditures was introduced in community well-being sector. The coefficient can take values from 0 to 1 and allows assigning preference to either basic non food expenditures (when 1) or food expenditures (when 0) in the use of cash stock. This gives a possibility to test different decision rules with regard to the prioritizing of community expenditures.

2.3.4.2 Introduction of yield dependency on the depth of groundwater table

Cultivation in the wetlands is hindered by increasing groundwater table (Kang et al., 2001; van der Molen et al., 2007). While WETSYS model takes into account the decrease of yields due to water stress with K_y coefficient, it does not consider yield dependency on the depth of groundwater table. Two approaches to model this dependency were addressed.

First approach is based on introducing a flood tolerance coefficient to correct the yields in cultivated wetland when groundwater is too high. The assumption was made that shallow groundwater table affects only maize yields as the root depth for maize is greater than for other crops considered in the model and maize is known to be sensitive to soil saturation. Moreover, no studies that describe the relationship of groundwater table and other crops considered here were found.

Molen et al. (2007) provides the relationship between the average depth of groundwater table (Z) and relative maize yields (Y) (Figure 2-16). Figure 2-16 shows the way this relationship was applied to the model. Relative yield correspond to the flood tolerance coefficient. Figure 2-15 presents model diagram for computation of mean groundwater table depth. Mean groundwater table depth is calculated as the seasonal average difference between ground level and groundwater level. The depth of groundwater table (add GWL depth) is calculated each month during summer crop season (maize is grown during summer season) and stored over the season in the stock of sum GWL depth. The stock empties at the end of each summer crop season and then divided by the duration of the season (4 months).

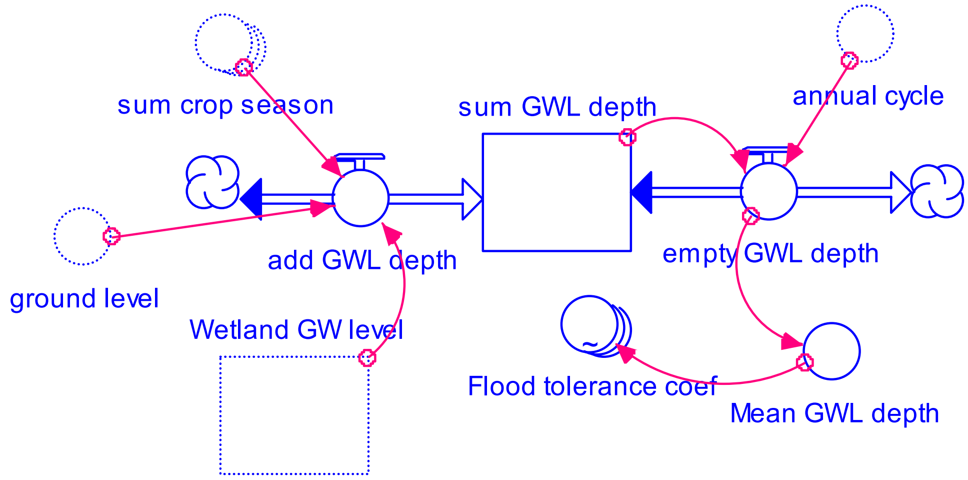


Figure 2-15 : Model diagram for computation of mean groundwater table depth
The model version used: WETSYS_17062010_flood tolerance (refer to the ANNEX 2 for the description of the version).

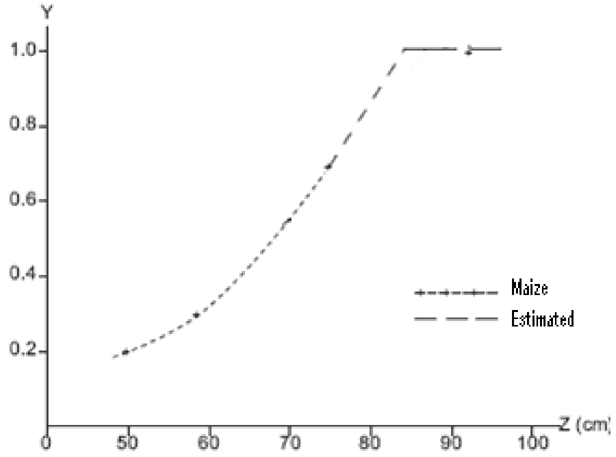
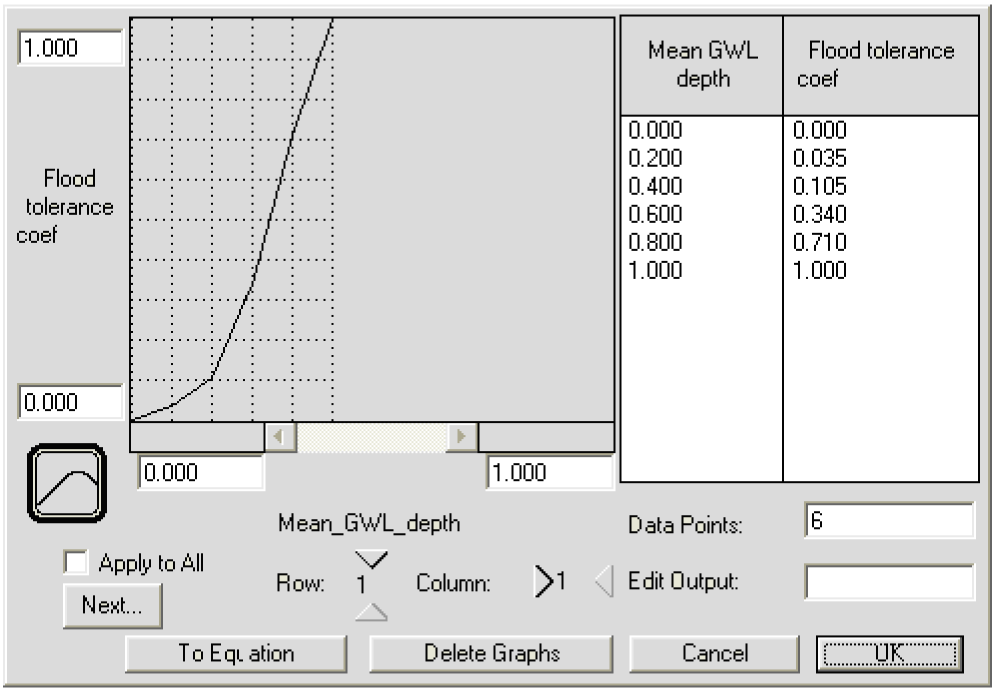


Figure 2-16 : Relationship between the average depth of the water table and maize yields
Source: Adapted from Molen et al. (2007).



Mean GWL depth	Flood tolerance coef
0.000	0.000
0.200	0.035
0.400	0.105
0.600	0.340
0.800	0.710
1.000	1.000

Flood tolerance coef: 1.000 / 0.000

Mean_GWL_depth: 0.000 / 1.000

Data Points: 6

Row: 1 Column: 1

Figure 2-17 : Relationship between the average depth of the water and maize yields as applied to the WETSYS model
The model version used: WETSYS_17062010_flood tolerance (refer to the ANNEX 2 for the description of the version).

Introduction of the flood tolerance coefficient had a significant effect on the maize yields in cultivated wetland, decreasing them down to 0 after the year 2000 (Figure 2-18).The considerable drop in yields is associated with 2000 year flood and inaccuracy of modeled groundwater dynamics after this flood. Therefore, it is important to resolve the failures in hydrology sector prior to establishing the relationship between yields and water table depth.

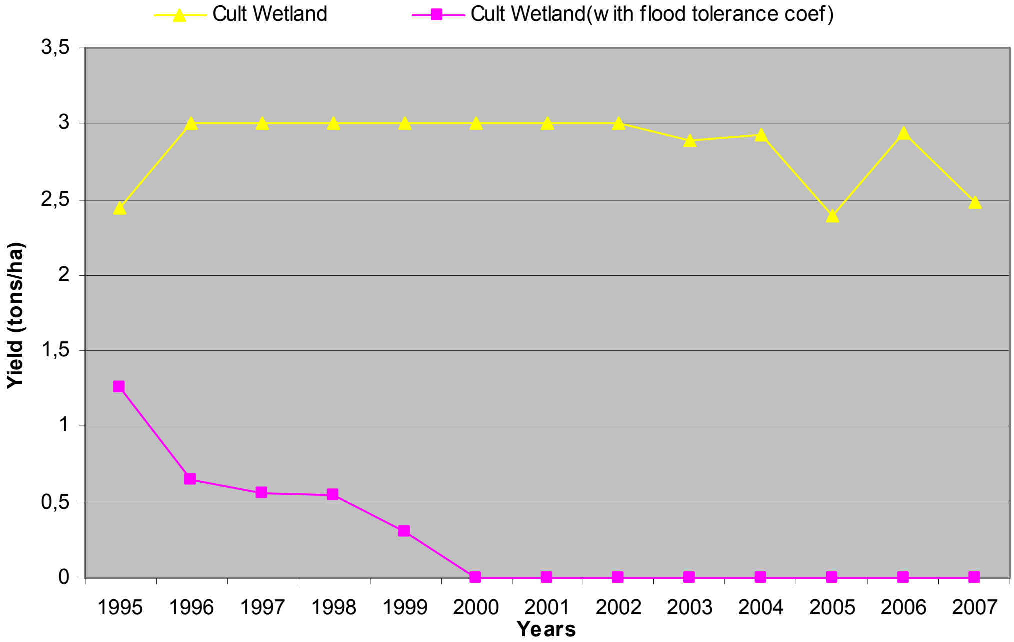


Figure 2-18 : Modeled yields of maize in cultivated wetland with without flood tolerance coefficient
The model version used: WETSYS_17062010_flood tolerance (refer to the ANNEX 2 for the description of the version).

The second approach to introduce yield dependency on the groundwater level concerns crop evapotranspiration coefficient (K_c). This coefficient depends not only on the crop and its growing stage, but also on a groundwater table (if it is present) and its depth (Allen et al., 1998; Kang et al., 2001). While K_c values applied in the model consider the former, they do not take into account the latter. Kang et al, 2001 developed a simplified relationship between K_c coefficient and groundwater table depth applying linear, polynomial and exponential models for the cases of winter wheat and maize. The results of this study showed that a linear model can be used to estimate the relationship between water table depth and K_c coefficients for maize during sowing and emerging periods. To estimate this relationship in latter periods polynomial model can be used. Although this approach is rather feasible for implementation in the model, due to time constraints it was not tested.

2.4 Sensitivity analysis (SA)

Models being just a simplified reflection of the reality always involve uncertainties in their results. These uncertainties can be attributed to the model inputs and parameters, to equations, that describe its behavior and stochasticity (Cariboni et al., 2007). Sensitivity analysis provides a way to investigate the uncertainty brought in by model inputs and parameters. Different methods can be used to perform a sensitivity analysis of a model. The choice of the method depends on the aim of the analysis itself, on the model properties and a number of uncertain factors (Campolongo et al., 2007). The aim and methodology of SA performed on WETSYS model followed by the discussion of the results are presented further.

2.4.1 Aim of SA

The aim of the SA of WETSYS model is to determine its input factors that are most responsible for the variance of the output and the ones that are neither influential themselves nor their interactions with other factors and therefore can be fixed at any value within their range. This will simplify further research by concentrating its focus on determination of the true value of the influential input factors while leaving out the least important ones.

2.4.2 Methodology and experiment design

Global approach was chosen for sensitivity analysis of WETSYS model. This approach allows estimating the influence of the input factor on the output taking into account variation of the other factors considered in the analysis. Within this approach variance-based methods are said to be the best practice as they are model independent and provide the most accurate sensitivity measures (Campolongo et al., 2007). However, the drawback of these methods is computational costs that increase considerably when the number of input factors exceeds 20 (Cariboni et al., 2007). Despite this drawback, variance-based methods with factor prioritization and factor fixing settings were chosen for sensitivity analysis of WETSYS model. The settings are defined by the aim of the SA experiment. Factor prioritization setting involves the calculation of the first-order (or main effect) sensitivity index of each input factor considered. The index describes the main contribution of the input factor (without considering the interactions this factor is involved in) to the output variance (Cariboni et al., 2007; Saltelli and Ratto, 2008). The setting allows for identification of the factors which if once fixed will reduce the variance of the output to the greatest extent. Under factor fixing setting total effect index is computed. It gives information on the contribution of the input factor to the output variance considering all its interactions with other factors (Cariboni et al., 2007; Saltelli and Ratto, 2008; Saltelli et al., 2010). The first-order effect is computed as:

$$S_i = \frac{V(E(Y|Xi))}{V(Y)},$$

where $V(E(Y|Xi))$ measures the resulting variance of Y (model output) when input factor X_i is fixed and V(Y) is the total variance of model output when all factors are varying. $V(E(Y|Xi))$ is always lower or equal to V(Y). If the value of the former is close to the value of the latter it means that the total variance of the output does not change significantly when factor X_i is fixed and therefore this factor has a small influence on the output variance.

The total effect is calculated as:

$$S_{Ti} = \frac{V(Y) - V(E(Y|X \sim i))}{V(Y)} = 1 - \frac{V(E(Y|X \sim i))}{V(Y)},$$

where $V(Y) - V(E(Y|X \sim i))$ is a measure for the remaining variance of the model output Y when all the factors except factor X_i are fixed. When this remaining variance is divided by the V(Y) the total effect index for X_i can be obtained.

Sensitivity indices can vary from 0 to 1. The sum of first-order sensitivity indices always equals to 1 while the sum of total order indices can take values higher then 1 as it accounts for the interactions the input factors are involved in. High value of first-order index signal important variable and the other way around. However, when the first-order effect of a given factor is not significant and its total effect index is rather high, this means that this factor is involved into important interactions that influence the output variance. The difference between first-order and total order effect give the information about the magnitude of the factor interaction contribution to the variance of the model output. If S_T of the input factor is close or equal to 0, this factor is considered as non influential and can be fixed at any value within its range (Saltelli and Ratto, 2008)

Different schemes to calculate sensitivity indices are available. Here, Monte-Carlo based scheme was applied with computational costs of C=N(2k+2) (Saltelli, 2002).C is the number of runs that is necessary to perform the analysis, N is the sample size used for the Monte-Carlo estimates and k is a number of input factors used in sensitivity analysis. In order to use this scheme, two independent matrixes of random numbers (Monte Carlo points) have to be generated using values from the ranges of input parameters. They are presented on the Figure 2-19 as A and B. Each matrix has a number of rows being equal to N. Then two other matrixes are defined (D_i and C_i) as proposed by Saltelli (2002). Matrix D_i is formed by all columns of A except column i which is taken from B and matrix C_i is formed by all columns from B except column i which is taken from A.

The procedure of calculation of sensitivity indices is the best available today and therefore it was chosen for SA in this study.

$$A = \begin{matrix} X_1^{(1)} & X_2^{(1)} & X_i^{(1)} & X_k^{(1)} \\ X_1^{(2)} & X_2^{(2)} & X_i^{(2)} & X_k^{(2)} \\ \dots & \dots & \dots & \dots \\ X_1^{(N)} & X_2^{(N)} & X_i^{(N)} & X_k^{(N)} \end{matrix} \qquad B = \begin{matrix} X_1^{(1+N)} & X_2^{(1+N)} & X_i^{(1+N)} & X_k^{(1+N)} \\ X_1^{(2+N)} & X_2^{(2+N)} & X_i^{(2+N)} & X_k^{(2+N)} \\ \dots & \dots & \dots & \dots \\ X_1^{(2N)} & X_2^{(2N)} & X_i^{(2N)} & X_k^{(2N)} \end{matrix}$$

$$D_i = \begin{matrix} X_1^{(1)} & X_2^{(1)} & X_i^{(1+N)} & X_k^{(1)} \\ X_1^{(2)} & X_2^{(2)} & X_i^{(2+N)} & X_k^{(2)} \\ \dots & \dots & \dots & \dots \\ X_1^{(N)} & X_2^{(N)} & X_i^{(2N)} & X_k^{(N)} \end{matrix} \qquad C_i = \begin{matrix} X_1^{(1+N)} & X_2^{(1+N)} & X_i^{(1)} & X_k^{(1+N)} \\ X_1^{(2+N)} & X_2^{(2+N)} & X_i^{(2)} & X_k^{(2+N)} \\ \dots & \dots & \dots & \dots \\ X_1^{(2N)} & X_2^{(2N)} & X_i^{(N)} & X_k^{(2N)} \end{matrix}$$

Figure 2-19 : Matrixes for sampling of the input factors
x_1, x_i and x_k are input factors for SA and each column for these factors presents N number of values randomly picked from the ranges of their variation.

Since the computational costs increase significantly with increasing number of input factors, SA of WETSYS model was limited to the hydrology sector as it is the most complex sector and is at the core of the system functioning. For this reason it was separated from the other sectors and only one crop scenario (maize) was considered (version WESYS_21072010a_hydrology sector; refer to the ANNEX 2). Model estimation of hydrology dynamics depends on calculations within other sectors like land use and crop production. These interactions were taking into account and certain modifications of hydrology sector were performed. Thus, the percentage of natural area calculated in land use sector and used in modeling groundwater dynamics was moved to hydrology sector and treated as a parameter for SA. Crop production interacts with hydrology sector through the calculation of ET_m (maximum crop evapotranspiration). Therefore, the calculation of ET_m was moved from crop production to the hydrology sector. Moreover, the calculation of yearly actual crop evapotranspiration was moved to hydrology sector as well since it was chosen as one of the model outputs for SA.

Another simplification of SA that was imposed by computational costs concerns the choice of input factors. Hydrology sector includes input factors of two types: parameters and inputs. Parameters are factors related to the modeled system (e.g. soil characteristics) while inputs are factors that change with scenarios (climatic data series or irrigation scheme efficiency). Due to time constraints and rather high computational costs, the SA was performed only for parameters as they appeared to be more uncertain for the modelers than inputs.

The parameters considered in SA and the ranges of their variation are presented in Table 2-6. Capillarity 1, 2 and 3 is a capillarity rise for groundwater table depth smaller than 0.5 m, between 0.5 and 1m and greater than 1 m, respectively. The ranges of capillarity rise for different soil depths are derived from UPFLOW model that assesses water movements from shallow aquifers (Raes and Deproost, 2003). Irrigation contribution coefficient determines the recharge of groundwater level from irrigation scheme. This recharge can be very important for groundwater dynamics or have no influence at all depending on the location of irrigation scheme with regards to the wetland. Therefore, irrigation contribution coefficient can vary from 0 (no contribution at all) to 1 (contribution is very important for the recharge of groundwater level). Percentage of natural wetland area was moved to hydrology sector as explained above. It can range from 0 if the entire natural wetland is converted into cultivated area to 1 when no conversion takes place. Runoff coefficient quantifies the proportion of rainfall that does not contribute to soil moisture content due to surface runoff. The range of this coefficient was identified based on expert opinion. Wilting point and field capacity of the soils depends on the soil texture and can be calculated with Soil Water Characteristics Calculator included in SPAW model (Saxton and Rawls, 2006). Different soil textures are present in the wetland and irrigation scheme (Nell and Dreyer, 2005). These textures were used to obtain the range for wilting point and field capacity. The range of the initial value for groundwater level was set as a range of daily measurements of groundwater level for piezometer T-604 LB in October 2006. The data was obtained from personal communication with S. Morardet (July, 2010). Soil water content can vary from wilting point to field capacity. Therefore, the range for initial water content of different soils (in irrigation scheme, cultivated wetland and natural wetland) is derived from the ranges of wilting point and field capacity. Minimum value in the range of soil water content corresponds to the minimum value of the wilting point range; maximum value corresponds to the maximum value of the field capacity range. Transmissivity range was obtained based on expert opinion.

Table 2-6 : Input parameters included in SA of WETSYS model

Parameter	Abbreviation	Minimum	Maximum	Reference
Capillarity 1	C1	0	0,165	Raes and Deproost, 2003
Capillarity 2	C2	0,087	0,165	Raes and Deproost, 2003
Capillarity 3	C3	0,0051	0,111	Raes and Deproost, 2003
Irrigation contribution coefficient	IC	0	1	Assumed range
Percentage of natural wetland area	pctN	0	1	Assumed range
Runoff coefficient	RC	0,05	0,3	Based on expert opinion (Matthew McCarteney from IWMI*)
Wilting point of soil in wetland	WWP	90	170	Nell and Dreyer, 2005; Saxton and Rawls 2006
Field capacity of wetland soil	WFC	230	320	Nell and Dreyer, 2005; Saxton and Rawls 2006
Wilting point of soil in irrigation scheme	IWP	90	170	Nell and Dreyer, 2005; Saxton and Rawls 2006
Field capacity of soil in irrigation scheme	IFC	220	320	Nell and Dreyer, 2005; Saxton and Rawls, 2006
Initial value of groundwater level	GWL	718,102	718,666	Piezometer T-604 LB
Initial value of soil water content in natural wetland	SWCN	90	320	Nell and Dreyer, 2005; Saxton and Rawls 2006
Initial value of soil water content in cultivated wetland	SWCCt	90	320	Nell and Dreyer, 2005; Saxton and Rawls 2006
Initial value of soil water content in irrigation scheme	SWCI	90	320	Nell and Dreyer, 2005; Saxton and Rawls 2006
Transmissivity	T	50	250	Based on expert opinion (Matthew McCarteney from IWMI*)

*IWMI stands for International water management institute.

Random sampling was applied to these parameters with a sample size N=1000 as described previously. Sampling and estimation of sensitivity indices was performed in a statistical software R using a scheme provided by Saltelli (2002). Thus, the computation costs of SA (C) are 32000 model runs, given that the number of parameters is 15. Sensitivity indices were computed with regard to the six important model outputs (Table 2-7). The level of groundwater is a key output as it assumed to represent the health of the wetland system in the model. The water content of different soils is essential for the hydrological dynamics of the whole system. The output of crop evapotranspiration is an important output because it is used for computation of crop yields. As WETSYS is a dynamic model that runs for 156 months and gives output at a month step it was necessary to decide on the time step at which the outputs are considered for computation of indices. Two time steps were selected: outputs for months 79 (5 years and 7 months) and 151 (12 years and 7 months). First of all, these months approximately correspond to the middle and end point of the model simulation. Second, annual crop evapotranspiration for maize is reported only once in 12 months, at the end of the cropping season (month 7, month 19 and etc, including months 79 and 151.). This justified the choice of the time steps for SA.

Table 2-7 : Model output considered in SA

Output Name	Description
Wetland_GW_level	Groundwater level in wetland aquifer
SWC_Nat_Wet	Soil water content in natural wetland
SWC_Cult_Wet[Maize,No_crop]	Soil water content in cultivated wetland assuming that only maize is cultivated
SWC_Irrig[Maize,No_crop]	Soil water content in irrigation scheme assuming that only maize is cultivated
Empty_sum_ETa_Irrig[Maize]	Annual total maize evapotranspiration in irrigation scheme
Empty_sum_ETa_W[Maize]	Annual total maize evapotranspiration in cultivated wetland

2.4.3 Results of SA

The results of the SA performed for WETSYS model are presented by the model output. First-order and total sensitivity indices were estimated based on C=32000 model runs at time t=79 and t=151. For some input parameters the accuracy of estimation is weak due to small sample size. Due to the inaccuracy in estimation some values of indices have negative values. However, it was not feasible to increase the sample size due to time constraints. This issue is discussed below.

2.4.3.1 Results for maize evapotranspiration in irrigation scheme

The analysis showed that the input parameters such as IC and IFC are the most influential for maize evapotranspiration in irrigation scheme. At t=79 first-order sensitivity indices of IC and IFC explain 58 and 39% of the output variance, respectively (Figure 2-20). Other input parameters are non influential for the considered output. Total order sensitivity index of parameter IC explains 62% of the output variance while total index of IFC is responsible for 42% (Figure 2-21). Other parameters and all their interactions are not influential as their total order indices equal to 0. The sum of total sensitivity indices can be higher then 100% as factor interactions are taken into account with each S_T. The values of first-order and total order sensitivity indices differ only slightly for all input parameters. This implies the absence of any interactions involving these parameters that can significantly influence the model output.

The results estimated at the time step 151 are rather similar to the results at time step 79. IC and IFC input parameters are again the most important factors (Figure 2-22 and Figure 2-23). However the estimates for first order sensitivity indices are less accurate and no ranking of IC and IFC can be made. The confidence interval of IC index is too large going beyond the graph limits and overlapping with interval of IC index. The results for total order effect are rather precise. And as at time step 79, parameters IC and IFC together with their interactions are the most influential input factors accounting for 60% and 37% of model output variance, respectively. Other factors have very limited or no importance for the considered output. This can be explained by the structure of the model. Irrigation water losses influence the groundwater level and groundwater dynamics has no feedback onto soil water dynamics in irrigation scheme.

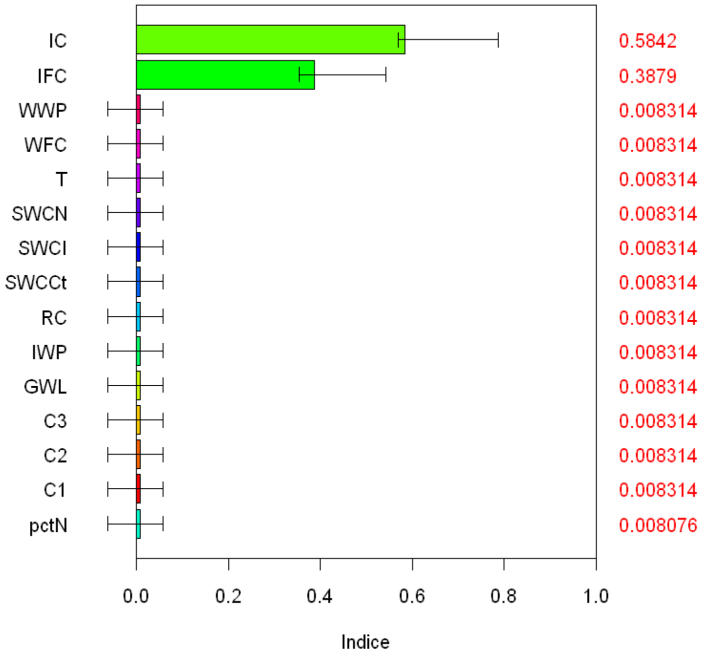


Figure 2-20 : Mean values of first-order sensitivity indices with 0.05 and 0.95 empirical percentiles over 100 replicas (90% confidence interval) for maize evapotranspiration in irrigation scheme at time step 79

IC=Irrigation contribution coefficient, IFC= Field capacity of soil in irrigation scheme, WWP= Wilting point of soil in wetland, WFC= Field capacity of soil in wetland; T=Transmissivity; SWCN= Initial value of soil water content in natural wetland, SWCI= Initial value of soil water content in irrigation scheme, SWCCt= Initial value of soil water content in cultivated wetland, RC= Runoff coefficient, IWP= Wilting point of soil in irrigation scheme, GWL= Initial value of groundwater level, C1=Capillarity 1,C2=Capillarity 2, C3=Capillarity 3, pctN= Percentage of natural wetland area.

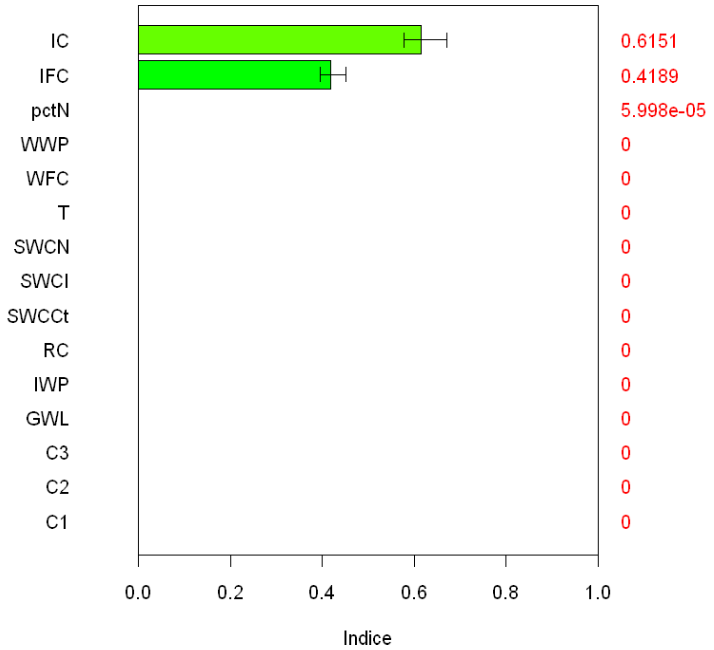


Figure 2-21 : Mean values of total-order sensitivity indices with 0.05 and 0.95 empirical percentiles over 100 replicas (90% confidence interval) for maize evapotranspiration in irrigation scheme at time step 79 See Figure 2-20 for abbreviations.

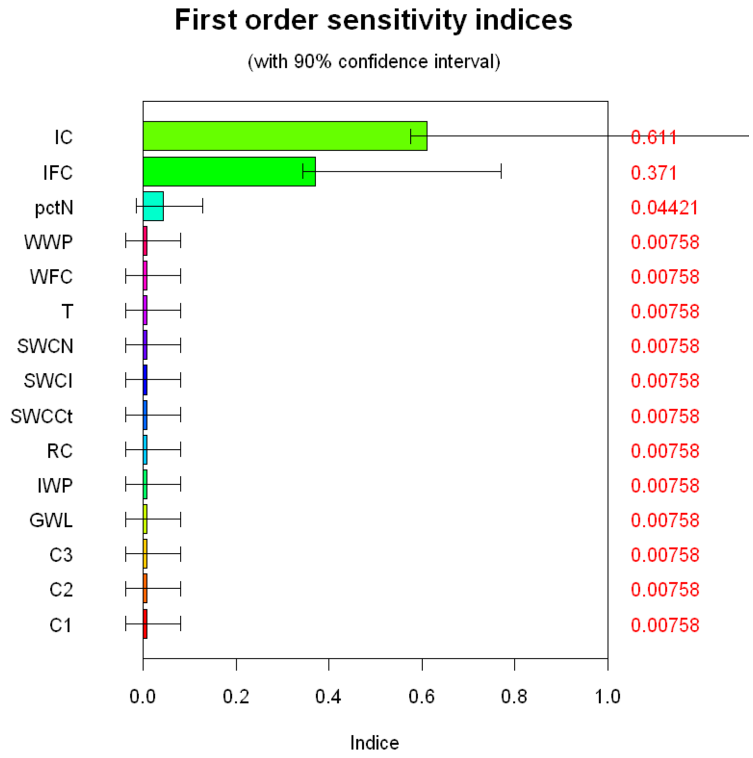


Figure 2-22 : Mean values of first-order sensitivity indices with 0.05 and 0.95 empirical percentiles over 100 replicas (90% confidence interval) for maize evapotranspiration in irrigation scheme at time step 151 See Figure 2-20 for abbreviations.

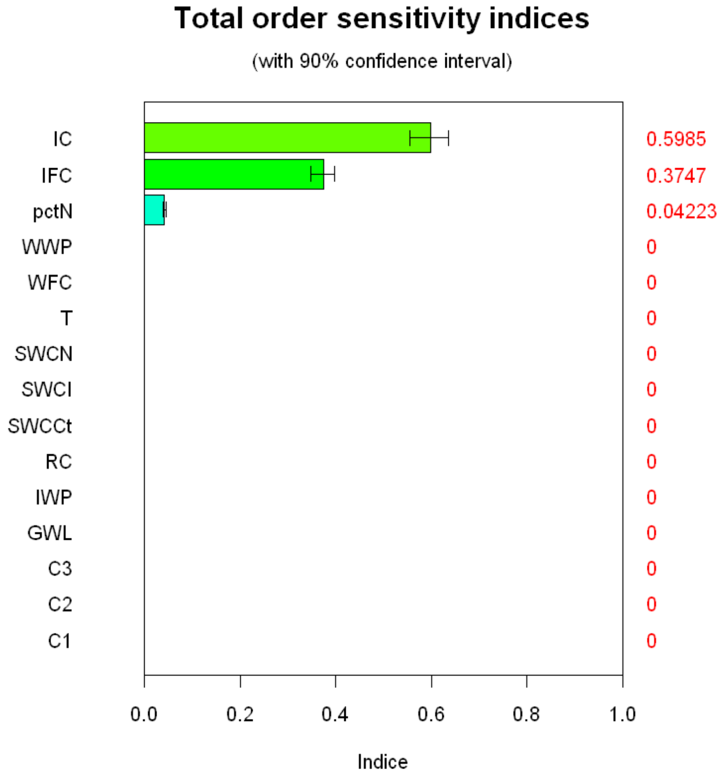


Figure 2-23 : Mean values of total-order sensitivity indices with 0.05 and 0.95 empirical percentiles over 100 replicas (90% confidence interval) for maize evapotranspiration in irrigation scheme at time step 151 See Figure 2-20 for abbreviations.

2.4.3.2 Results for maize evapotranspiration in cultivated wetland

The results for first-order sensitivity indices at time step 79 lack precision. The confidence intervals are too large and overlap each other. Therefore it is not possible to make any conclusion based on the estimates of first-order sensitivity indices. The results for these indices are presented in Table 2-8. However, the estimates of total order effects at time step 79 are more accurate. Total indices of T and WFC account for approximately 47 and 45% of the model output variance, respectively (Figure 2-24). Due to their overlapping confidence intervals, it is not possible to rank their importance. Input parameter C1 (together with interactions) is less influential than T and WFC, accounting for 32% of the output variance. Other parameters have very limited or no total order effect. Their total sensitivity indices are close to 0.

At time step 151 the estimation of both first-order and total sensitivity indices have higher precision than at time step 71 (Figure 2-25 and Figure 2-26). C1 is the most influential parameter. Its first-order sensitivity index accounts for 48% of the output variation. T and WFC are rather important as well. About 20 and 17 % of the output variation is attributed to first-order sensitivity indices of these parameters. However it is impossible to rank T and WFC according to their importance as their confidence intervals overlap. Total sensitivity indices of C1, T and WFC account for 53, 31 and 25% of the output variation, respectively. Insignificant difference between first-order and total sensitivity indices of C1, T and WFC indicates the absence of important interactions involving these input factors. It should be noted that C1 gains more importance than T and WFC at the time step 151. Furthermore, some input parameters like GWL, IWP, C3 and pctN and all their interactions being non-influential at time step 79, gain more importance at the end of the simulation (t=151). Although they still have rather small influence on the output, their total indices increase considerably at time step 151.

Table 2-8 : Mean values of first-order sensitivity indices with 0.05 and 0.95 empirical percentiles over 100 replicas (90% confidence interval) for maize evapotranspiration in cultivated wetland at time step 79 See Figure 2-20 for abbreviations.

Input parameter	First-order s.i.	min. c.i.	max. c.i.
C1	0,474941116	-1,1148	1,257951
C2	-0,013653302	-0,1168	0,062483
C3	-0,014298112	-0,12164	0,064568
GWL	-0,015318515	-0,12869	0,049482
IC	-0,014739454	-0,10278	0,049235
IFC	-0,014614289	-0,11805	0,049826
IWP	-0,014845106	-0,11084	0,052228
pctN	-0,014473103	-0,10082	0,060009
RC	-0,014220318	-0,12089	0,062642
SWCCt	-0,013899395	-0,11521	0,062333
SWCI	-0,013831847	-0,11521	0,062549
SWCN	-0,014535773	-0,12096	0,062016
T	0,317667415	0,244806	0,729036
WFC	0,318639428	-0,31922	0,739337
WWP	-0,0146735	-0,12126	0,062313

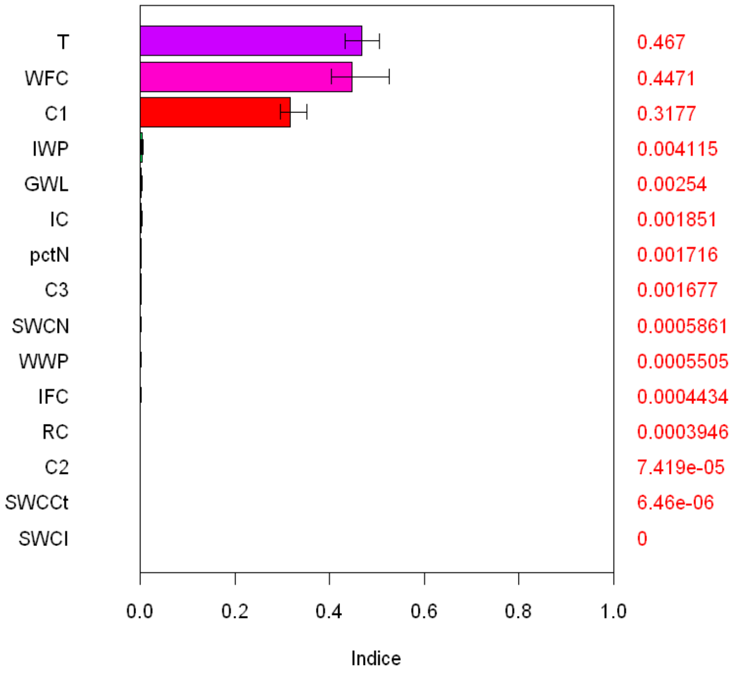


Figure 2-24 : Mean values of total-order sensitivity indices with 0.05 and 0.95 empirical percentiles over 100 replicas (90% confidence interval) for maize evapotranspiration in cultivated wetland at time step 79 See Figure 2-20 for abbreviations.

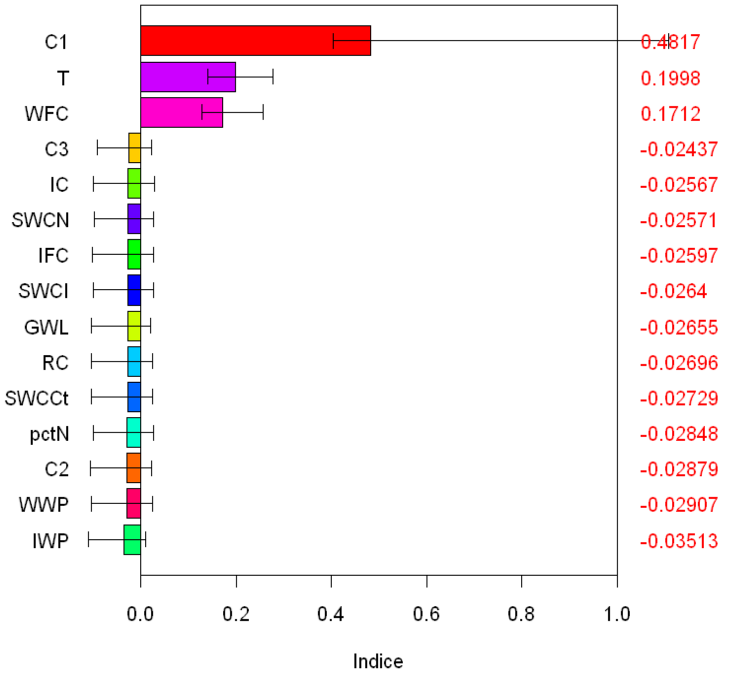


Figure 2-25 : Mean values of first-order sensitivity indices with 0.05 and 0.95 empirical percentiles over 100 replicas (90% confidence interval) for maize evapotranspiration in cultivated wetland at time step 151

See Figure 2-20 for abbreviations.

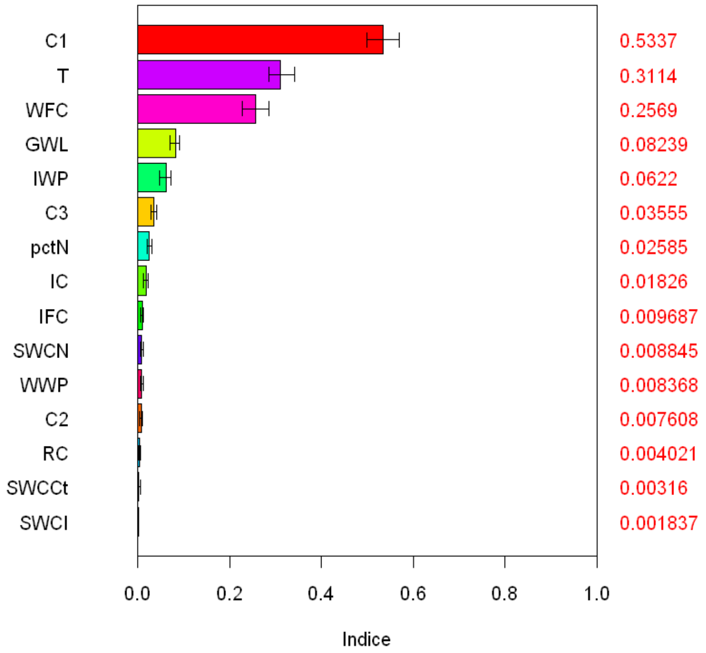


Figure 2-26 : Mean values of total-order sensitivity indices with 0.05 and 0.95 empirical percentiles over 100 replicas (90% confidence interval) for maize evapotranspiration in cultivated wetland at time step 151
See Figure 2-20 for abbreviations.

2.4.3.3 Results for soil water content in cultivated wetland

The estimates of the first-order sensitivity indices for soil water content in cultivated wetland at time step 79 are inaccurate. No conclusion about input factor importance at this time step can be made based on the first-order effect estimates (Table 2-9). Figure 2-27 presents the estimates for the total effect. According to these estimates input factor T and its interactions account for the largest part of the output variance. Factor C1 and its interactions are less important and account for approximately 25% of the output variance. Total effect of other input factors is negligible.

Figure 2-28 presents the estimates of the first-order effect at time step 151. Although these estimates have rather large confidence intervals it can be concluded that C1 and T are the most influential parameters among all the input factors. According to the estimates of the total order effect factor C1 and its interactions contribute the largest part (58%) to the output variance (Figure 2-29). Total effect of factor T accounts for 41% of the variance. The results for total order at time step 151 slightly differ from the results at time step 79. Factor T is the most influential in the middle of the simulations (t=79) while factor C1 gains more importance than factor T at the end of the simulation (t=151). Moreover, other input factors considerably increase their total order effect at t=151. Thus, the total effect of the input factors like GWL, WFC, IWP and C3 being negligible at t=79, become rather important at t=151. Each of these factors and their interactions account for 20-10% of the model output variance at t=151.

Table 2-9 : Mean values of first-order sensitivity indices with 0.05 and 0.95 empirical percentiles over 100 replicas (90% confidence interval) for soil water content in cultivated wetland at time step 79
See Figure 2-20 for abbreviations.

Input parameter	First-order s.i.	min. c.i.	max. c.i.
C1	0,171126536	0,034675	0,441272
C2	-0,014137137	-0,10057	0,051363
C3	-0,018622496	-0,10636	0,04535
GWL	-0,015081925	-0,09433	0,049004
IC	-0,016559715	-0,11296	0,047604
IFC	-0,015257615	-0,09935	0,051363
IWP	-0,017053189	-0,09527	0,054982
pctN	-0,008409959	-0,08621	0,059014
RC	-0,014100488	-0,09935	0,051363
SWCCt	-0,015257615	-0,09935	0,051363
SWCI	-0,014100488	-0,09935	0,051363
SWCN	-0,015297096	-0,10057	0,051363
T	0,77038241	-0,49569	1,805385
WFC	-0,020770776	-0,10447	0,049493
WWP	-0,014100488	-0,09935	0,051363

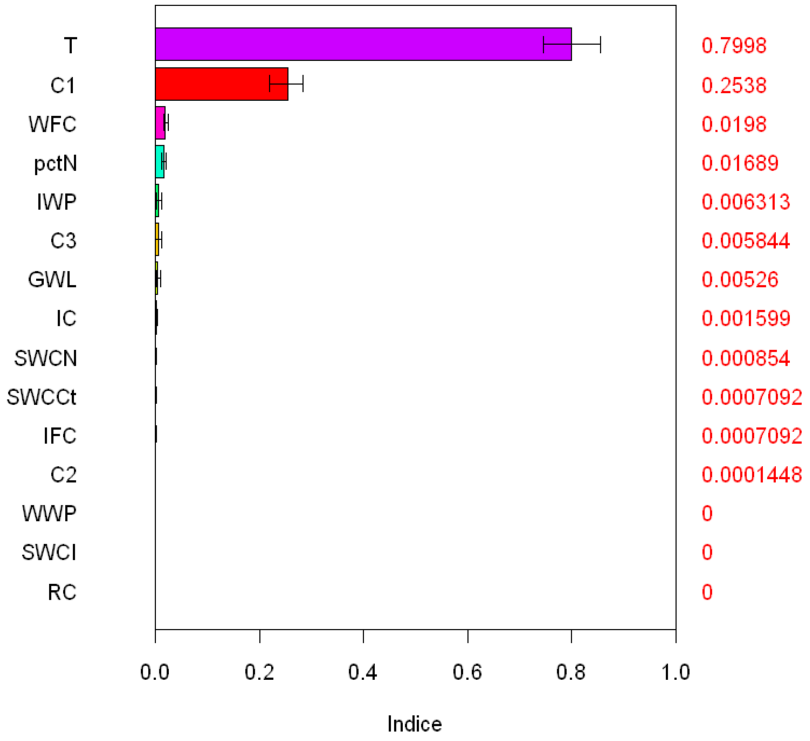


Figure 2-27 : Mean values of total-order sensitivity indices with 0.05 and 0.95 empirical percentiles over 100 replicas (90% confidence interval) for soil water content in cultivated wetland at time step 79
See Figure 2-20 for abbreviations.

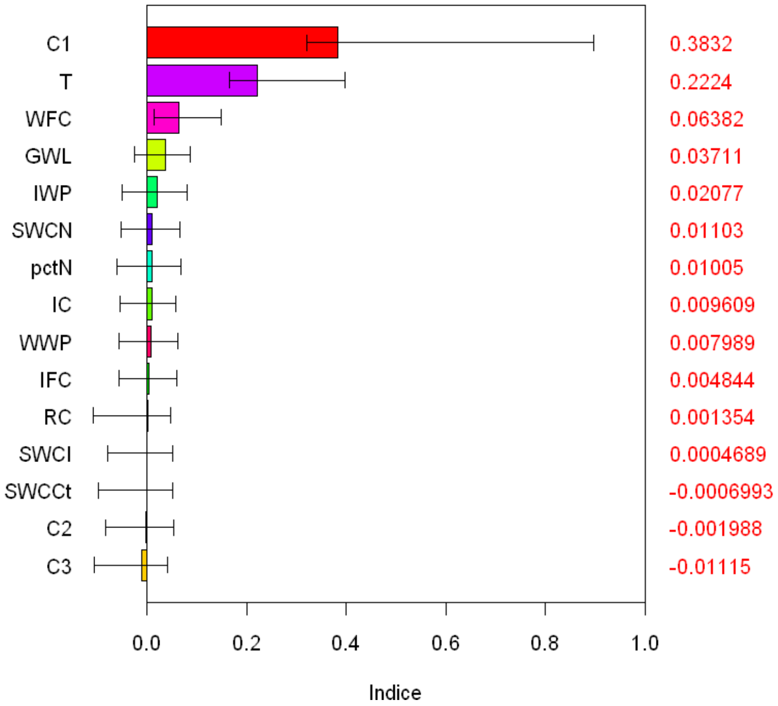


Figure 2-28 : Mean values of first-order sensitivity indices with 0.05 and 0.95 empirical percentiles over 100 replicas (90% confidence interval) for soil water content in cultivated wetland at time step 151 See Figure 2-20 for abbreviations.

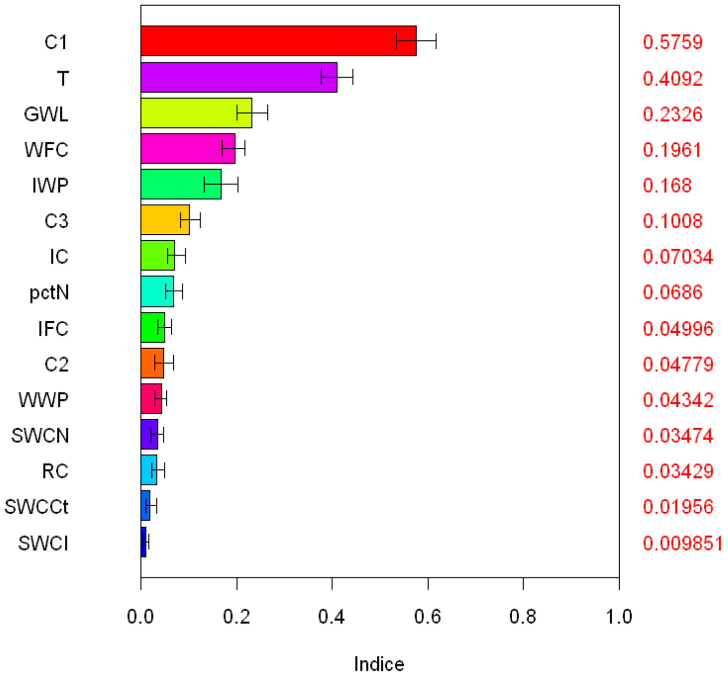


Figure 2-29 : Mean values of total-order sensitivity indices with 0.05 and 0.95 empirical percentiles over 100 replicas (90% confidence interval) for soil water content in cultivated wetland at time step 151 See Figure 2-20 for abbreviations.

2.4.3.4 Results for soil water content in irrigation scheme

The estimates for the first-order sensitivity indices and their confidence intervals at time step 79 are presented in Table 2-10. The high inaccuracy in the results caused by chosen sample size does not allow for any conclusions concerning these indices. The results for total effect are more accurate. According to these results three most important input factors can be determined (Figure 2-30). At time step 79 parameters IC, IFC and pctN together with all their interactions are responsible for 63, 36 and 17% of the variance of soil water content in irrigation scheme, respectively. With regard to the model it unexpected that pctN has an influence on the output for soil water content in irrigation scheme. Other input parameters are absolutely non-influential with regard to their total effect on the output.

At time step 151 the estimates of first-order effect have rather wide confidence intervals, especially for the input parameter IFC (Figure 2-31). Nevertheless, these results make it possible to qualitatively classify parameter IFC as the most influential one. Total order effect of IFC at time step 151 accounts for approximately 98% of the output variance. Due to high inaccuracy of the estimates for IFC first-order effect, it is impossible to quantify the contribution of the interactions involving this parameter. As opposed to the total order effect estimates at time step 79, parameters IC and pctN have very limited influence on the output variance at time step 151.

Table 2-10 : Mean values of first-order sensitivity indices with 0.05 and 0.95 empirical percentiles over 100 replicas (90% confidence interval) for soil water content in irrigation scheme at time step 79
See Figure 2-20 for abbreviations.

Input parameter	First-order s.i.	min. c.i.	max. c.i.
C1	-0,03632843	-0,25551	0,010444
C2	-0,03632843	-0,25551	0,010444
C3	-0,03632843	-0,25551	0,010444
GWL	-0,03632843	-0,25551	0,010444
IC	0,48211144	-0,42621	2,31384
IFC	0,227090788	-0,109	1,129686
IWP	-0,03632843	-0,25551	0,010444
pctN	0,101945557	0,039951	0,416698
RC	-0,03632843	-0,25551	0,010444
SWCCt	-0,03632843	-0,25551	0,010444
SWCI	-0,03632843	-0,25551	0,010444
SWCN	-0,03632843	-0,25551	0,010444
T	-0,03632843	-0,25551	0,010444
WFC	-0,03632843	-0,25551	0,010444
WWP	-0,03632843	-0,25551	0,010444

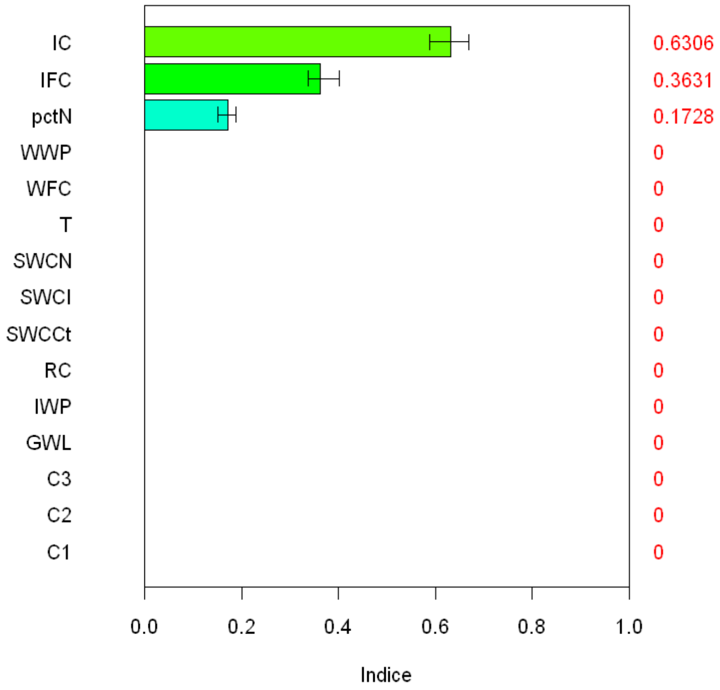


Figure 2-30 : Mean values of total-order sensitivity indices with 0.05 and 0.95 empirical percentiles over 100 replicas (90% confidence interval) for soil water content in irrigation scheme at time step 79
See Figure 2-20 for abbreviations.

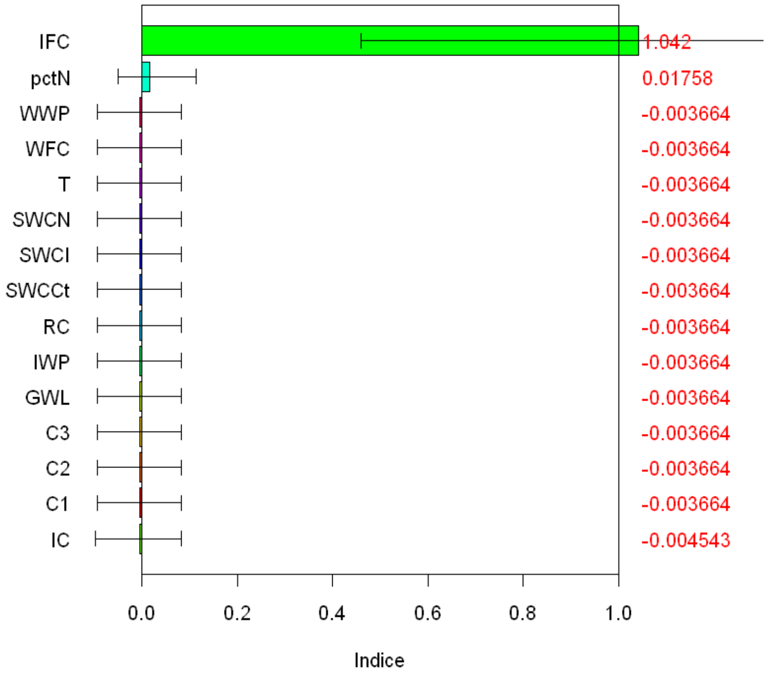


Figure 2-31 : Mean values of first-order sensitivity indices with 0.05 and 0.95 empirical percentiles over 100 replicas (90% confidence interval) for soil water content in irrigation scheme at time step 151
See Figure 2-20 for abbreviations.

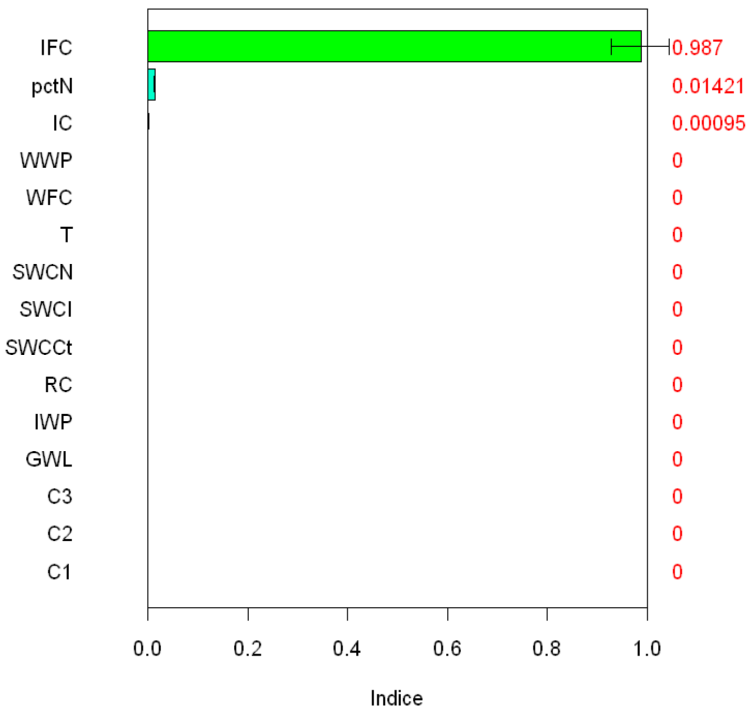


Figure 2-32 : Mean values of total-order sensitivity indices with 0.05 and 0.95 empirical percentiles over 100 replicas (90% confidence interval) for soil water content in irrigation scheme at time step 151
See Figure 2-20 for abbreviations.

2.4.3.5 Results for soil water content in natural wetland

The results for the first-order indices estimated at time step 79 with regard to soil water content in natural wetland are presented in Figure 2-33. The main effect contribution of the parameter C1 is estimated to be the highest among all input parameters. The first effect of T is rather important for the output as well. Other parameters contribute significantly less to the variance of the output. The results for the estimates of total-order effect at time step 79 are similar to those of first-order effect (Figure 2-34). Thus, total effect of parameter C1 accounts for about 74% of the output variance, while the total effect of parameter T – for 30%. Other parameters have none or very limited total effect contribution to the output variance.

At time step 151 parameter C1 remains the most influential parameter according to its main and total effect (Figure 2-35 and Figure 2-36). With regard to the other parameters main effect, it is difficult to draw a conclusion since the estimates have overlapping confidence intervals. In general, the total effect of the input parameters that are non-influential at time step 79, gain more importance at time step 151 (Figure 2-36). GWL and WFC together with their interactions account each for about 27% of the output variance at time step 151, while parameter T ceases to be as important as at time step 79.

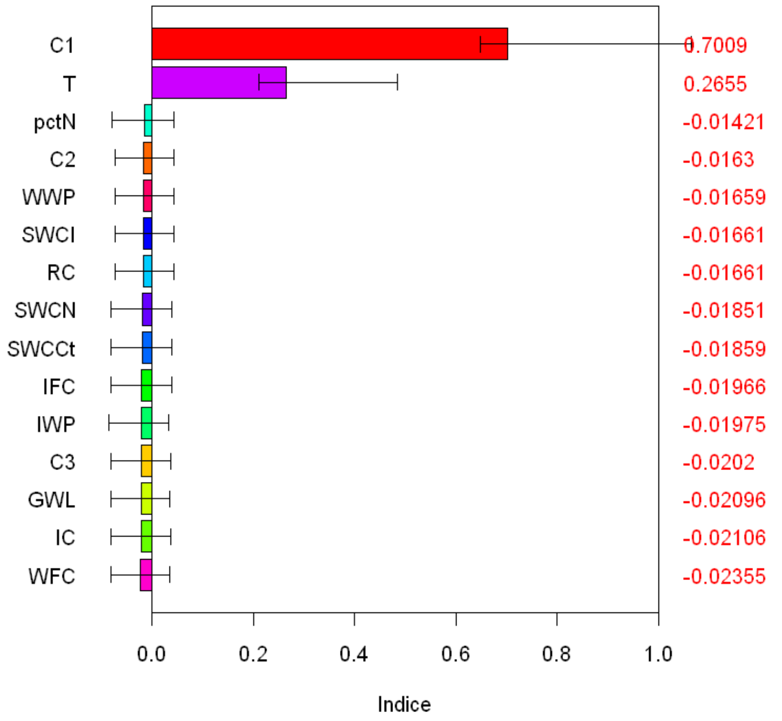


Figure 2-33 : Mean values of first-order sensitivity indices with 0.05 and 0.95 empirical percentiles over 100 replicas (90% confidence interval) for soil water content in natural wetland at time step 79 See Figure 2-20 for abbreviations.

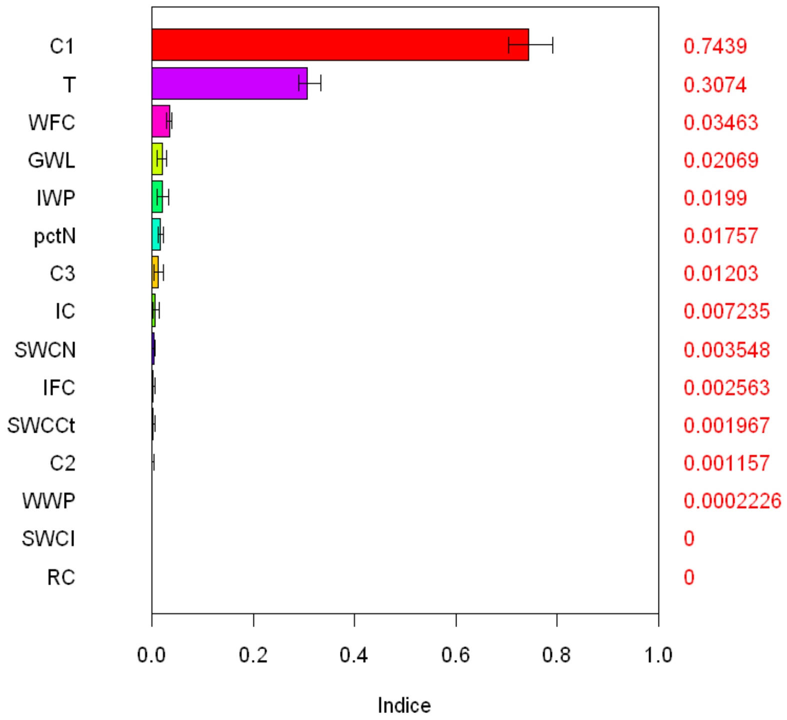


Figure 2-34 : Mean values of total-order sensitivity indices with 0.05 and 0.95 empirical percentiles over 100 replicas (90% confidence interval) for soil water content in natural wetland at time step 79 See Figure 2-20 for abbreviations.

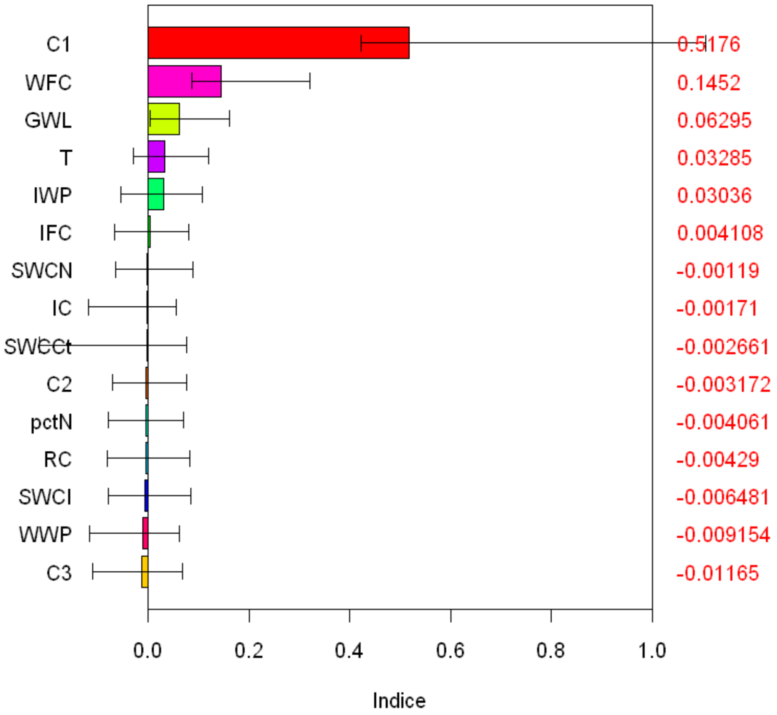


Figure 2-35 : Mean values of first-order sensitivity indices with 0.05 and 0.95 empirical percentiles over 100 replicas (90% confidence interval) for soil water content in natural wetland at time step 151
See Figure 2-20 for abbreviations.

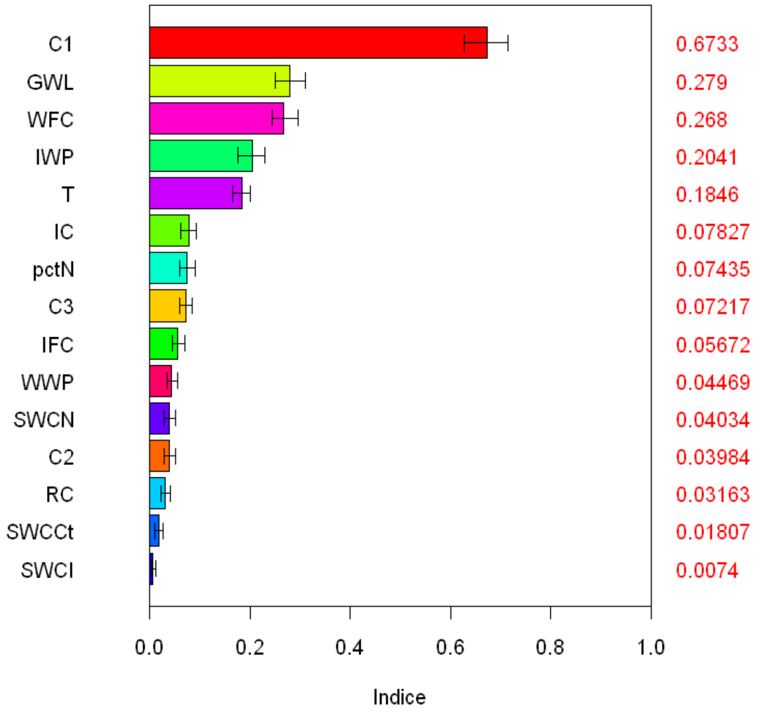


Figure 2-36 : Mean values of total-order sensitivity indices with 0.05 and 0.95 empirical percentiles over 100 replicas (90% confidence interval) for soil water content in natural wetland at time step 151
See Figure 2-20 for abbreviations.

2.4.3.6 Results for groundwater level

The results for groundwater level are the most affected with inaccuracy due to the sample size. No information based on these results can be obtained for the first-order effect of the input factors both at time step 79 and 151 (Table 2-11, Table 2-12). According to the results of the total-order results estimates only non-influential factors can be identified (Figure 2-37 Figure 2-38). These are pctN, IC, IFC, C2, C3, WWP, SWCI, SWCN, SWCCt and RC at both time steps.

Table 2-11 : Mean values of first-order sensitivity indices with 0.05 and 0.95 empirical percentiles over 100 replicas (90% confidence interval) for groundwater level at time step 79
See Figure 2-20 for abbreviations.

Input parameter	First-order s.i.	min. c.i.	max. c.i.
C1	1,35320949	-0,64799	0,86013
C2	-0,092932559	-0,01466	0,026698
C3	-0,749770351	-0,56126	0,025695
GWL	-0,802314953	-0,80231	0,054524
IC	0,234151661	-0,05533	0,270694
IFC	-0,641356056	-0,40092	0,004214
IWP	0,532167134	-0,40142	0,879601
pctN	0,377594525	-0,64676	0,48785
RC	0,098039555	-0,07136	0,137891
SWCCt	-0,532525051	-0,09325	0,022972
SWCI	-0,03791882	-0,02707	0,010641
SWCN	-0,046685273	-0,07344	0,083405
T	0,172098144	-0,53805	0,896541
WFC	-1,159568389	-1,3367	0,347973
WWP	0,349408515	-0,17604	0,379775

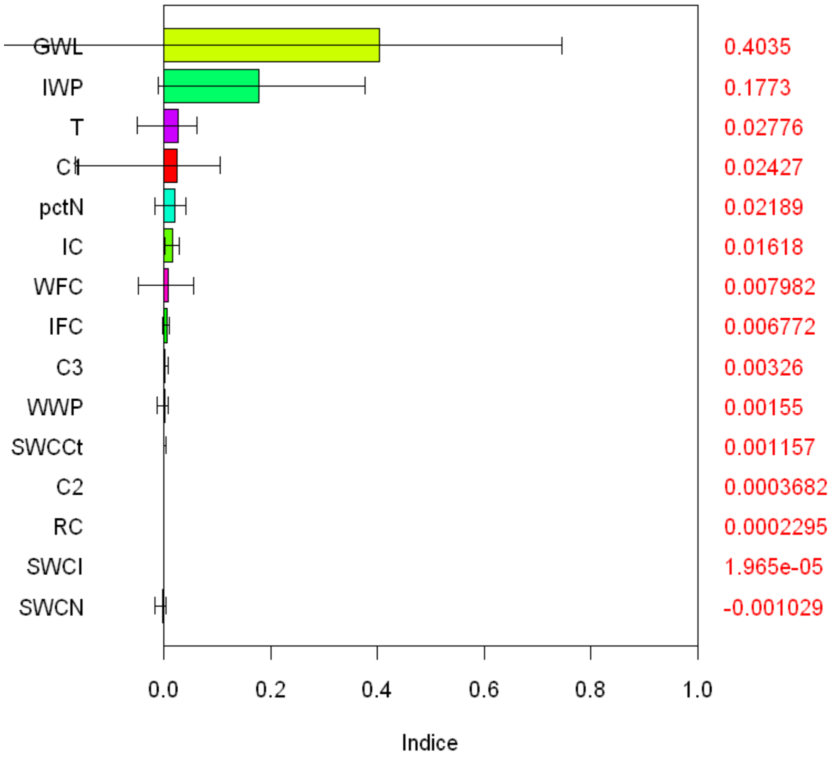


Figure 2-37 : Mean values of total-order sensitivity indices with 0.05 and 0.95 empirical percentiles over 100 replicas (90% confidence interval) for groundwater level at time step 79
See Figure 2-20 for abbreviations.

Table 2-12 : Mean values of first-order sensitivity indices with 0.05 and 0.95 empirical percentiles over 100 replicas (90% confidence interval) for groundwater level at time step 151
See Figure 2-20 for abbreviations.

Input parameter	First-order s.i.	min. c.i.	max. c.i.
C1	-1,781902507	-0,7324	0,881438
C2	0,110371191	-0,06874	0,081232
C3	-0,237046368	-0,51823	0,03827
GWL	0,608572854	-0,78656	0,596787
IC	-1,305745848	-0,71755	0,546731
IFC	-2,918168816	-0,47484	0,102261
IWP	-0,468135142	-0,81153	0,496628
pctN	-0,015282525	-0,20748	0,090092
RC	-0,056399861	-0,0564	0,031572
SWCCt	-0,515446053	-0,12289	0,040767
SWCI	0,094558421	-0,06906	0,034326
SWCN	0,121686947	-0,23416	0,316516
T	-0,593825525	-0,59383	0,733877
WFC	0,75523211	-0,67086	0,632663
WWP	-0,02405064	-0,17422	0,348385

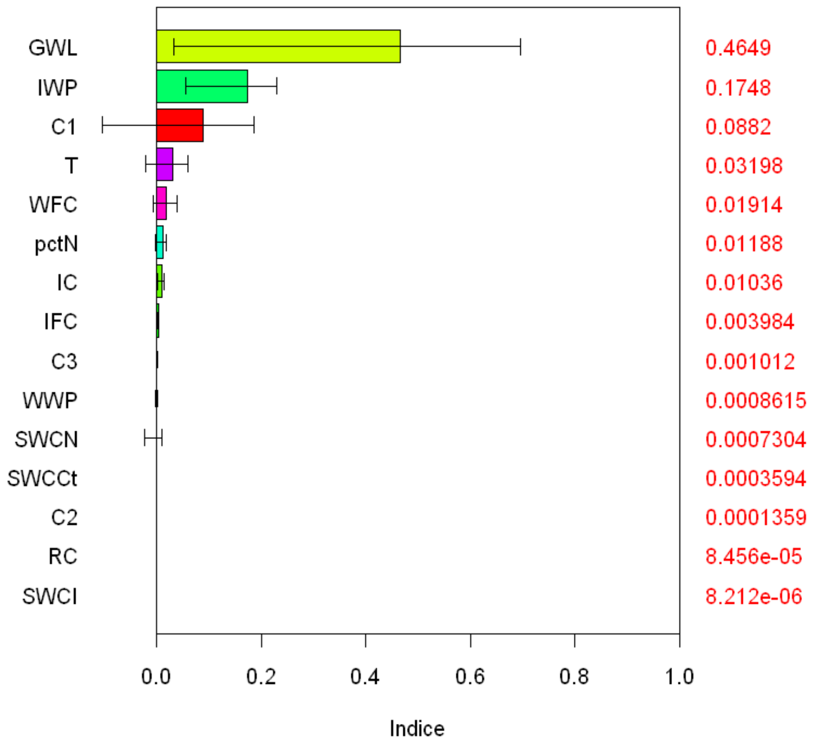


Figure 2-38 : Mean values of total-order sensitivity indices with 0.05 and 0.95 empirical percentiles over 100 replicas (90% confidence interval) for groundwater level at time step 151
See Figure 2-20 for abbreviations.

The results of the analysis revealed that different parameters are influential for different model outputs. For the outputs related to the irrigation scheme the input parameters IFC (field capacity of the soil in the irrigation scheme) and IC (coefficient that determines the irrigation scheme contribution to the recharge of groundwater level) play the most important role. This is an expected result that can be seen from the model structure. For the outputs related to the wetland (natural as well as cultivated) C1 (capillarity rise for groundwater depth smaller than 0.5) and T (transmissivity) are among the most influential parameters, with only slight variations depending on the time step at which the output is considered. This means that further research should focus on finding true values of these factors. For the output concerning groundwater level the estimates are heavily affected by inaccuracy and therefore, information was obtained only on non-influential parameters. One of these parameters is percentage of wetland natural area. As it was assumed that conversion of natural wetland into cultivated area can disrupt its hydrological processes, it an interesting finding from a management point of view that pctN has no impact on groundwater level.

The analysis also showed that some of the parameters were non influential for all the outputs at both time steps. These are SWCCt (initial value of soil water content in cultivated wetland), SWCI (initial value of soil water content in irrigation scheme), SWCN (initial value of soil water content in natural wetland), C2 (capillarity rise for soil depth between 0.5 and 1m), C3 (capillarity rise for soil depth greater than 1 m), WWP (wilting point of wetland soil), RC (runoff coefficient) and pctN (percentage of natural wetland). Non influence of C2 and C3 can be explained by the fact that GWL stays to close to the ground level making the depth to the water table less then 0.5 m. The total effect of these factors is close or equal to zero for all outputs in consideration.

Due to the high inaccuracy in the results in most cases it was not possible to compare first-order indices with total order indices and therefore no information can be obtained on the contribution of the factor interactions. However, where it was possible to compare the two indices for influential no significant difference was detected. This means that for the input factors where comparison was possible no interactions that can alter their contribution to the model output variance were found.

The difference in the results for time step 79 and 151 can be explained by the altered model behavior after 2000 year flood. At the time step 79 the model gives output before the flood while at time step 151 it occurs after the flood. As these two time steps are corresponding to the beginning of the dry season, it can be recommended for further improvements of the SA to use the time steps corresponding to the rainy season as well. Moreover, to increase the accuracy of the results larger sample size should be used.

3 Conclusion

Different activities, aimed at improving and exploring the behavior of the WETSYS model were performed during the internship period.

First, the model was checked against the presence of the constants in the equations and consistency of the explanatory notes. All inconsistencies were corrected and constants were reintroduced as variables. These changes helped to facilitate further use of the model.

Second, several tests were carried out with hydrology sector of the model in order to identify the origin of the groundwater dynamics delay. The results of these tests were discussed with hydrologist and necessary changes were introduced into the sector. The output of the model for groundwater level was validated before and after these changes. The results showed that the fit of the model improved after the changes as the delay of the groundwater dynamics reduced. However, it was not possible to eliminate this delay completely and therefore further investigation of this issue is necessary.

Third, the model output for crop yields and evapotranspiration from natural areas was compared to the observations. The results of the validation tests showed that the model performance with regard to these outputs is consistent with reality. However, it should be noted that a lack of data necessary for the comparison hindered the validation to some extent.

Forth, improvements to the crop production sector were made. WETSYS model considered only one crop, maize, as it is the main crop grown in Ga-Mampa valley. The possibility of having different crops (tomato, onion and groundnut) was introduced. However, it should be noted that more precise information on their cultivation area is necessary. It was assumed that newly introduced crops are sold on the market and therefore, the possibility of selling these crops was introduced. This had an impact on community well-being sector as it is a new source of income. The improvements associated with new crops are important for further use of the model in scenario analysis.

Furthermore, contribution to the model documentation was made. This documentation is intended for internal use in order to keep track of all changes incorporated into the model. This will also be useful if the model is being adapted to other case studies. The documentation included a descriptive table of all model variables and a list of model versions. Apart from the work with documentation, search for additional data and time series was performed.

Finally, global sensitivity analysis was performed on WETSYS model. Due to time constraints it involved only hydrology sector of the model and was focusing on the parameters leaving out the inputs. This analysis aimed at identifying factors that are most influential for the model output and thus deserve better attention when their value is set up. The analysis was also focused on determining unimportant factors that together with their interactions have no influence on the output variance and therefore can be left out from further research. The sensitivity analysis considered 15 input parameters and six outputs. First-order and total-order indices were estimated based on C=32000 model runs at time t=79 and t=151. The results of the analysis showed that more appropriate sample size has to be chosen to provide better estimates for sensitivity indices. Due to inadequate sample size some limitations in the results of SA were present. In general, the estimates for first-order indices are less accurate than for the total-order effect. This is a standard condition that is attributed to the estimation procedure of the indices. Therefore, in most cases it was not possible to estimate the contribution of different interactions that the input parameters are involved in. For the outputs related to the irrigation scheme the input parameters IFC (field capacity of the soil in the irrigation scheme) and IC (coefficient that determines the irrigation scheme contribution to the recharge of groundwater level) play the most important role. For the outputs related to the wetland (natural as well as cultivated) C1 (capillarity rise for soil depth smaller than 0.5) and T (transmissivity) are among the most influential parameters, with only slight variations depending on the time step at which the output is considered. For the output concerning groundwater level the estimates are heavily polluted with inaccuracy and therefore, information was obtained only on non-influential parameters. Estimating sensitivity indices at different time steps provided knowledge on importance of the parameters at different stages of the model simulation. Thus, some input parameters, being non influential in the middle of the simulation, gain more importance at the end of the simulation. The analysis also revealed that total effect (together with all the interactions) of SWCCt (initial value of soil water content in cultivated wetland), SWCI (initial value of soil water content in irrigation scheme), SWCN (initial value of soil water content in natural wetland), C2 (capillarity rise for soil depth between 0.5 and 1m), C3 (capillarity rise for soil depth greater than 1 m), WWP (wilting point of wetland soil), RC (runoff coefficient) and pctN (percentage of natural wetland) is very limited for all outputs and time steps considered.

In order to get more accurate results sensitivity analysis should be performed with increased sample size. This was not possible to accomplish during internship period due to time constraints. Sensitivity analysis performed here should be viewed as the first attempt to understand the origin of uncertainties and complicated relationships present in WETSYS model.

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ANNEX 1: Check of the model against the constants in the equations and parameter documentation.

Hydrology sector

Parameter/variable	Constant in the equation	Documentation	Changes made
1. Upper catchment rainfall	Exogenous variable	No source of data	Time series are revised Source of data is added: DWAF rainfall station B7E006.*
2. Pall canal efficiency	Exogenous variable	No source of data	Source of data added: Chiron, 2005.
3. Irrig percolation	No constant	No documentation	Explanation added: water content over field capacity drains to the shallow groundwater.
4. Wet groundwater rechge	Constants in the equation (inflow from the upper catchment: 5% and the area of irrigation: 88 ha)	OK	Fertilis area (88ha) variable is linked to recharge. Inflow from upper catchment is left as constant.
5. Open water drain evaporation	Exogenous variable	No documentation	Explanation added: open water evaporation equals to ETP.
6. Capillarity	Three constants in the equation: capillarity can take 3 different values depending on the GW table depth.	OK	The variable is decomposed: Capillarity1, Capillarity 2 and Capillarity 3.*
7. GW artificial drainage	Constants in the equation (open water evaporation: 0.6 and open drain area is used: 5%)	The documentation is not consistent (ground water level>718.5 in the documentation and ground water level>719.5 in the equation)	New variable is introduced: drain density (0.05). Equation is revised: 0.6 (open water evaporation is suppressed and new condition is applied (the drainage occurs when GW > then the bottom of the drains). Documentation is corrected accordingly.*
8. River outflow	Constants in the equation (Wetland area: 120 and River area: 4000*4)	OK	Wetland area was linked to River outflow. River area is left as constant.
9. River stage	Constants in the equation (values of coefficient of the estimated equation)	Documentation is not complete	No changes made.**

10. Groundwater seepage	Constants in the equation (River length: 5000m, Total wetland area: 120m and width of wetland: 400m, Transmissivity: 50 m2/day)	OK	New variables are introduced: Transmissivity*, River length, Wetland width. Total wetland area is linked to Groundwater seepage.
11. Inc SWC nat wet	Constant in the equation (Rainfall coefficient: 0.6)	OK	New variable is created (eff rainfall coef).
12. Dec SWC nat wet	No constant	No documentation	Documentation is copied from Dec SWC irrig.
13. Kc Nat wet	No constant	No source of data	No changes made.**
14. Ks Nat wet	Constant in the equation (fraction of the soil water content which is easily accessible by the plant is presented: 0,5)	No documentation	Documentation is copied from K_s irrig. Fraction of the soil water content comes from (Doorenbos and Kassam, 1986).
15. ETP	Exogenous variable	No source of data	Time series are revised Source of data is added: DWAF B7E006 station A-pan ETP.*
16. Fertilis area	Exogenous variable	No source of data	Source is added: Kotze 2005.
17. Inc SWC Irrig	Constant in the equation (Rainfall coefficient: 0.6)	OK	See 11.
18. Ks irrig	Exogenous variable	The documentation is not consistent (e.g. Irrig FC is 100 in this documentation, but the Irrig FC is set at 260) –	Documentation is changed to match value in the equation.
19. Irrig WP	Exogenous variable	No source of data	Source is added: (Nell and Dreyer, 2005), SPAW model ((Saxton and Rawls, 2006)).
20. E bare soil IS	Constant in the equation (TEW(total evaporable water): 20mm, (soil depth from which the evaporation takes place: 10 cm)	No source of data	New variables are introduced: TEWi. Soil depth is left as constant. Source is added: Allen et al. 1998.

21. Rainfall valley	Exogenous variable	No source of data	Time series are revised Source of data is added: values regressed from Wolkberg station (regression based on series 1972-1989) for the period 2005-2009 values for Wolkberg are regressed on B7E006 station).*
22. Inc SWC Cult	Constant in the equation (Rainfall coefficient: 0.6)	OK	See 11 and 17.
23. Dec SWC Cult Wet	Constant in the equation (WP: 140)	OK	WP is linked to Dec SWC Cult Wet.
24. SWC Cult Wet	No constant	Documentation is inconsistent (the value=WP (140) in documentation, but in the equation=200	Documentation is changed to match value in the equation.
25. E bare soil (Cult wet)	Constant in the equation (TEW(total evaporable water): 20mm, (soil depth from which the evaporation takes place: 10 cm)	No source of data	New variables are introduced: TEW_w. Soil depth is left as constant. Source is added: Allen et al. 1998.

Crop production sector

Parameter	Constant in the equation	Documentation	Changes made
1. Store ET_a irrigated	No constant	No documentation	Explanation is added: it stores ETa over the cropping season (when dry season = 0) for computation of yield.
2. ETm maize	No constant	No source of data	Source of data added: Dorenboos and Kassam 1986.
3. Max irrig yield	Exogenous variable	No source of data	Source is added: Chiron 2005.
4. Max cult yield	Exogenous variable	No source of data	Source is added: Chiron 2005.
5. Irrigation crop yields	Constant in the equation: 0.2 (condition for yield not to be negative, this condition is crop specific)	OK	New variable is introduced to account for the condition: a (0.2).*
6. Wetland crop yields	See 5	See 5	See 5.
7. Store ETa wet cult	No constant	No documentation	Explanation is added: it stores Eta over the cropping season (when dry season = 0) for computation of yield.
8. Eta season	No constant	No documentation	Explanation is added: this stock stores Eta over the cropping season (during 4 months starting in December).
9. Irrig. Crop yield	Constant in the equation (crop yield coefficient for maize:1.25)	No source of data	New variable is introduced: K_y maize. Source for K_y is added.
10. Wetland Crop Yield	Constant in the equation (crop yield coefficient for maize:1.25)	No source of data	See 9.
11. Irrig crop costs per ha	Three constants in the equation: cost for land preparation, costs for seeds and transport costs	OK	The variable is decomposed: Land costs, Seed costs and Transport costs.*
12. Wet crop costs per ha	See 11	See 11	See 11..

Natural resource sector

Parameter	Constant in the equation	Documentation	Changes made
1. Biomass growth rate	No constant	No source of data	Source id added: Woodwell, 1998 and Hellden, 2008.
2. Harvest per ha	No constant	No documetation	Explanation is added: July=10 in annual cycle
3. Biomass available per head	Constants in the equation: 0.2 (proportion of reeds in wetland); 0.025 (proportion of sedges); 0.15 (proportion of biomass suitable for crafting and roofing)	OK	New variables are introduced: Prop Reeds, Prop Sedges and PropUsableBiom.*
4. Nat resource icome	Constants in equation: 0,1 and 0,9 (proportion of reeds and sedges in biomass harvest); 0.19 and 0.8	No documentation	New variables are introduced: PropReedsSold and PropSedgesSold. Prop Reeds, Prop Sedges are connected to Nat res income. Explanation of the equation is added.*
5. Nat resource value	Constants in equation: 0,1 and 0,9 (proportion of reeds and sedges in biomass harvest)	No documentation	Prop Reeds, Prop Sedges are connected to Nat res value. Explanation of the equation is added.*
6. Harvest per head	Exogenous variable	No documentation	Explanation is added: harvest occurring in July, month 10, the value of max.
7. Drop out rate	No constant	No documentation	Explanation drop out equation is added.
8. New harvesters rate	Constant in the equation: 0.2 (proportional coefficient, set arbitrary)	No documentation	New variable is introduced: delta (0.2). Explanation drop out equation is added.*

Land use sector

Parameter	Constant in the equation	Documentation	Changes made
1. Wetland nat area	No constant	No source of data	Source is added: satellite images in 1996 (from Sarron 2005)
2. Wetland abandonment	Constant in the equation: 0.05 (ad hoc coefficient to calibrate in observed natural wetland)	No documentation	New variable is introduced: alpha (0.05).* Explanation of constant is added
3. New wetland farmers	Constant in the equation: 1.2 (ad hoc coefficient to calibrate on observed natural wetland)	No documentation	New variable is introduced: beta (1.2).* Explanation of constant is added.

Well being sector

Parameter	Constant in the equation	Documentation	Changes made
1. Max food purchase	Constant in the equation: 1.15 (maize market prices are 15% higher than output prices of community farmers)	No documentation	New variable is introduced: price coef (1.15).* Explanation of constant is added.
2. Cash inflow	Constants in the equation: 0.06 (proportion of pensioners in the population); 0.28 (proportion of children in the population); proportion of household with off farm income.	OK	New variables are introduced: prop children, prop pensioners, prop offfarm jobs.*
3. Community well being	The equation is not consistent with the model paper	Documentation is not consistent with model paper	Variables are introduced: w1 – weight for food satisfaction; w2 – weight for income index; 1-(w1+w2) – weight for wetland health. Explanation of the weights is added.

**The changes were applied to later versions of model*

*** The changes were not implemented due to unavailability of hydrologist who was involved in creating hydrology sector.*

ANNEX 2: List of the models

1. **WETSYS_16022010.STM** – the version of the model before Olga's arrival
2. **WETSYS_25052010_Run2005-2007.STM** – the version of model as the previous one but for the runs in the period 2005-2007.
3. **WETSYS_28052010.STM** – the version of the model after the check against the constants in the equations and parameter documentation.
4. **WETSYS_17062010.STM (**aka WETSYS_28052010.STM_all crops_past evolution**)** – the version of the model with new crops (array function, past evolution)
5. **WETSYS_17062010_baseline.STM –** the version of the model with new crops (array function) for the future evolution (2006-2016) for the base line scenario.

Changes made in the stock initial values for the baseline scenario:

The simulation starts in the year 2006 and ends in 2016.

Necessary changes: 1) Population = 2758 (the value of 2006)
2) Area of natural wetland = 171-66 ha
3) Area of cultivated wetland = 66 ha
4) Ground water level =718.64 (Average of measurements of Piezometer T604 LB)

5) Cash stock and Food stock – change according to population
6) ETP, Rainfall valley and Upper catchment rainfall – the time series are taken from randomly picked past years (1995-1999 and 2001-2007).
7) Wetland farming households = 99 in 2006 (survey)
8) Harvesters (in natural wetland) = 24% hh from the whole population (0.24*2758/7)

6. **WETSYS_17062010_rehab_irrg.STM -** the version of the model with new crops (array function) for the future evolution (2006-2016) for the scenario where rehabilitation of irrigation scheme is considered.

Changes in parameters: Irrigation scheme is rehabilitated therefore Irrigation distribution efficiency is changed from 0.2 to 0.4 and principal canal efficiency from 0.42 to 0.6.

7. **WETSYS_17062010_cashcrop.STM -** the version of the model with new crops (array function) for the future evolution (2006-2016) for the scenario where cash crop (onion) is introduced. There are two crop successions: maize followed by onion (takes 10% of area) and maize followed by no crop (80% of the area).
8. **WETSYS_17062010_nat_conserv.STM -** the version of the model with new crops (array function) for the future evolution (2006-2016) for the scenario where

conservation of wetland natural area takes place. Wetland natural area cannot be smaller then 30 ha.

9. **WETSYS_17062010_flood tolerance.STM –** the version of the model the version of the model with new crops (array function) as WETSYS_17062010.STM**,** but with flood tolerance coefficient.
10. **WETSYS_27062010.STM** – the version of the model where changes made by Silvie to **WETSYS_17062010.STM** (aka WETSYS_28052010.STM_all crops_past evolution). The changes: ETm dynamics moved to crop production sector, new sectors (Crop economics and Economic valuation) are added.
11. **WETSYS_04072010.STM** – the version of the model the same as WETSYS_17062010.STM, but with change from three weight (community well-being sector) to two weights. w_1 – weight for income index, w_2 – weight for food security index, 1-(w_1+ w_2)– weight for natural wetland percentage which is calculated form the first two. The names pct_children, pct_pensioners and pct_offfarm_jobs are changes to prop_children, prop_pensioners and prop_offfarm_jobs. New variable $a=k_y-1/k_y$ is added and a priority is given to the food purchase.

12. **WETSYS_13072010.STM** – the version of the model the same as WETSYS_04072010.STM but with new parameters (prior_coeff and Basic_exp) in community well-being sector. The prior_coeff gives priority to food purchase when 0 and to basic expenditures when 1. Basic_exp is total non food expenditures excluding crop input costs.

13. **WETSYS_14072010.STM** – the version of the model the same as WETSYS_13072010.STM, but with decomposed variables for sensitivity analysis (capillarity and crop costs per ha) and the initial value of SWC_Cult_Wet changed from 200 to 140 (which is a WP).

14. **WETSYS_21072010.STM** – the version of the model the same as WETSYS_14072010.STM, but with new data series for ETP, upper catchment and valley rainfall. The equation for artificial drainage is modified as well from IF(Wetland_GW_level>719.5) THEN(0.05*0.6*Open_water_drain_evaporation/1000) ELSE(0) to IF Wetland_GW_level>ground_level-0.5 THEN drain_density*ETP/1000 ELSE 0.

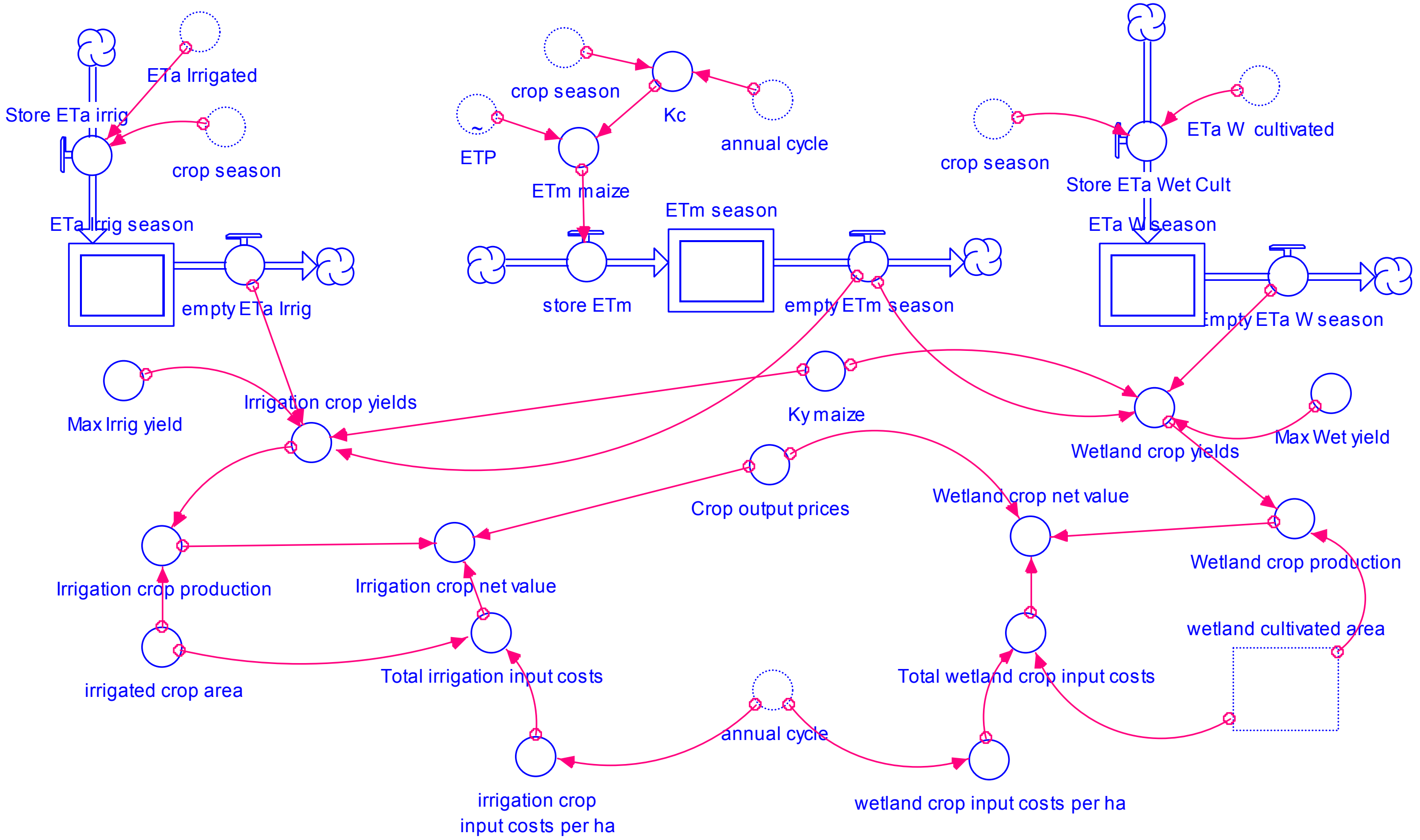
15. **WETSYS_21072010_Run2005-2007.STM -** – the version of the model the same as WETSYS_21072010.STM, but with changes for 2005-2007 runs.

16. **WETSYS_21072010a.STM** – the version of the model the same as WETSYS_21072010.STM but with small changes in documentation of the following variables: capillarity rise, river inflow and a_win/a_sum), priority coefficient set at 1; new price coefficient is introduced (maize prices on the market are 15 % higher, in the equation of max food purchase coefficient 1.15 is set as constant, the constant was deleted and new variable introduced); Wet_crop_proportion is connected to Global GW recharge (the connection of Irri_crop_proportion with Global GW recharge is suppressed); new variable Irrig contribution coefficient is added; new variable Runoff_coef and Runoff are added (variable Eff_rainfall is suppressed), a part of the equation of soil content increase is changed from Eff_Rainfall*Rainfall to Rainfall-Runoff.
17. **WETSYS_21072010a_hydrology sector** – the version of model with hydrology sector separately (on the basis of WETSYS_21072010a.STM). This version of the model was used for sensitivity analysis.

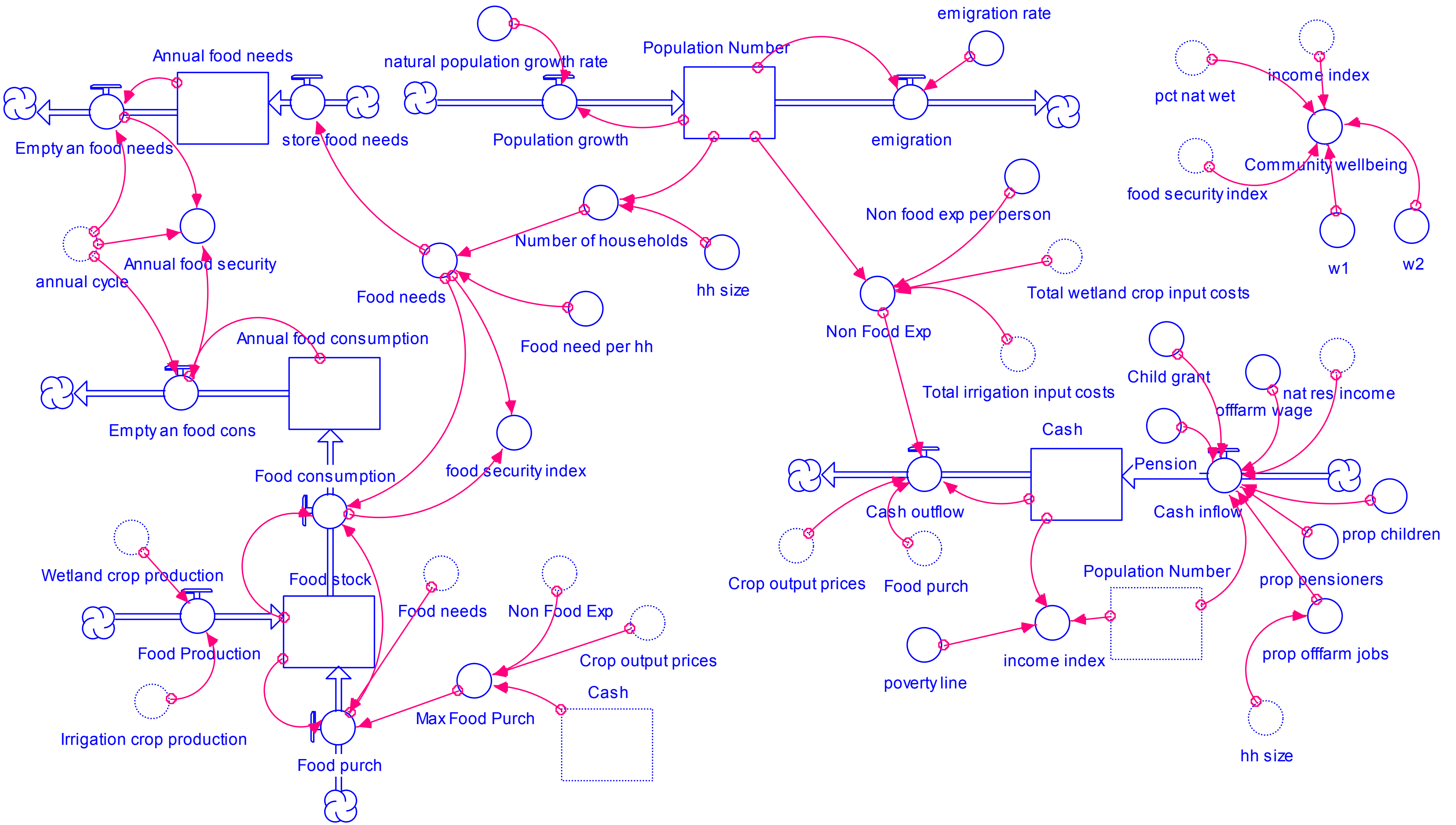
ANNEX 3: Model diagram

1. Model diagram: one crop (only includes sector subjected to changes)

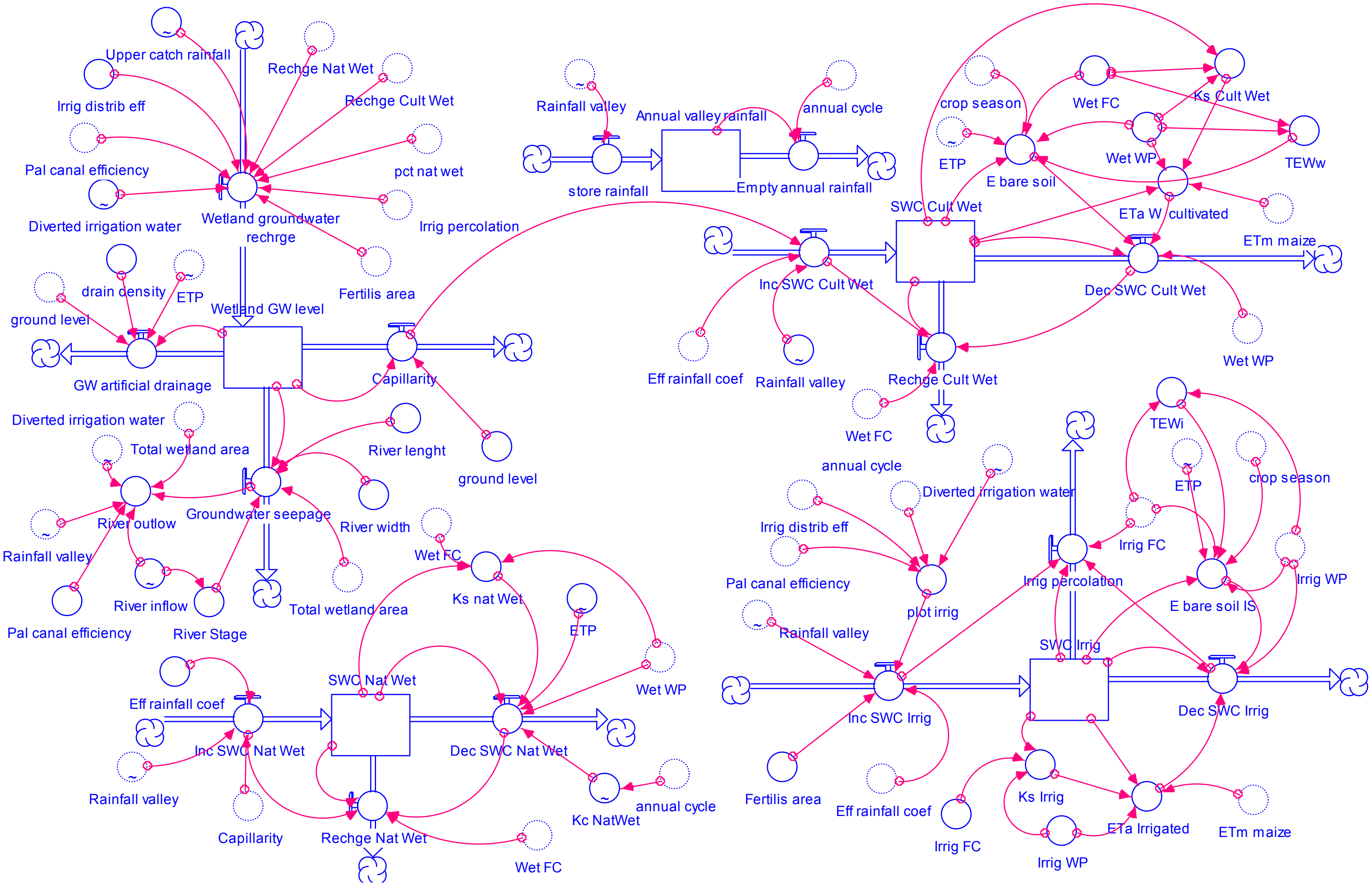
Crop production sector



Community well-being sector

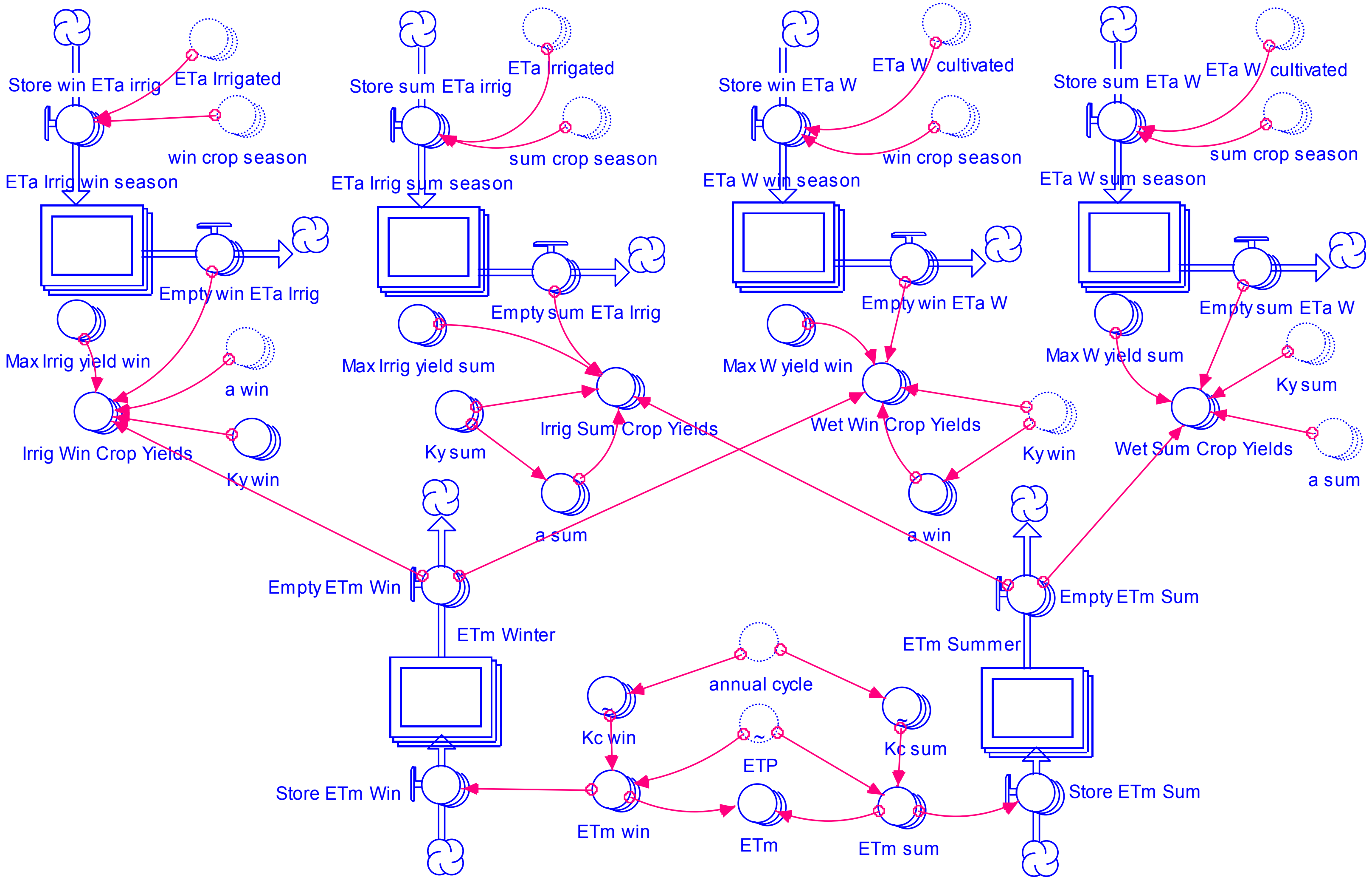


Hydrology sector

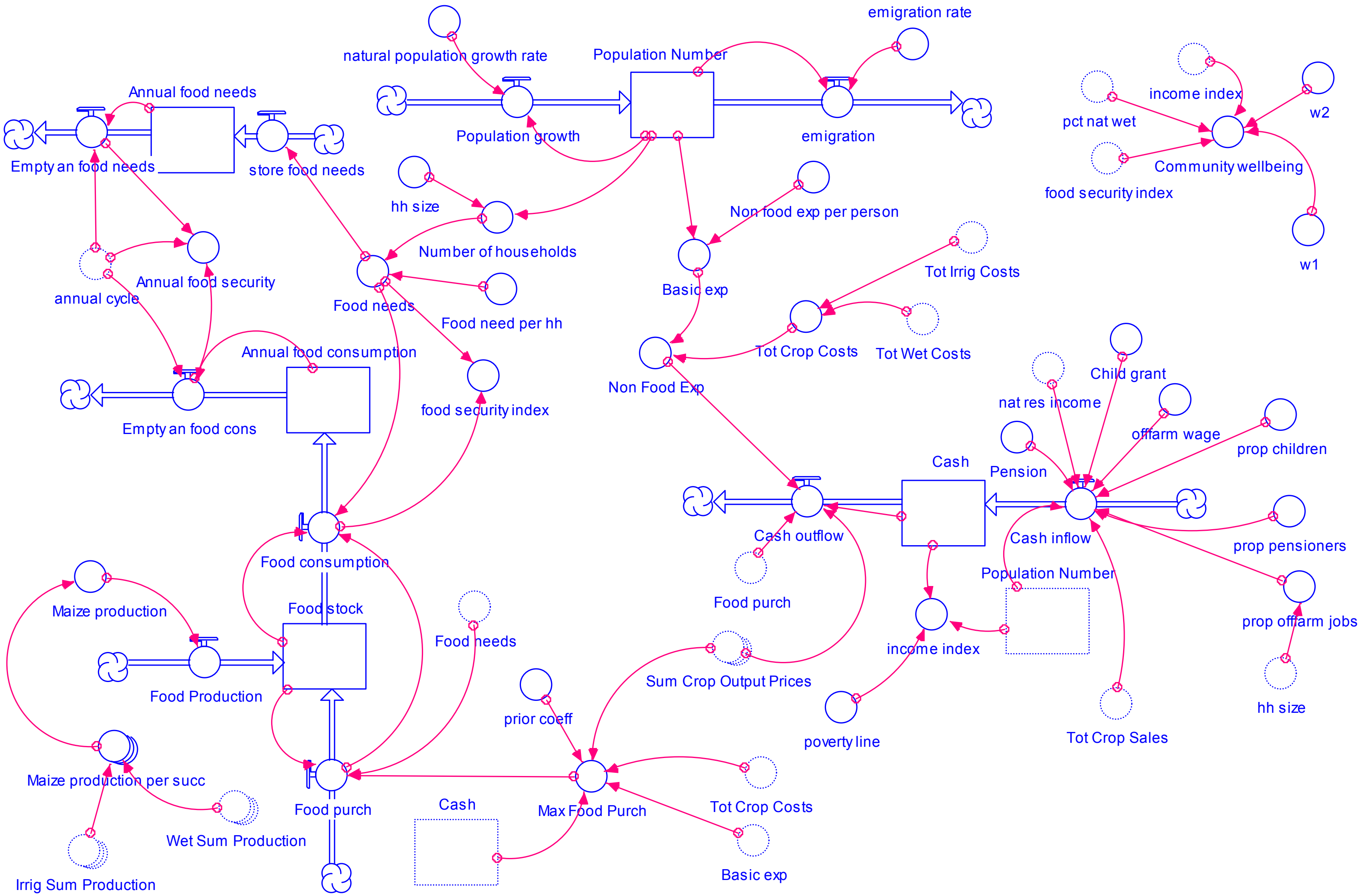


2. Model diagram: new crops (only includes sector subjected to changes)

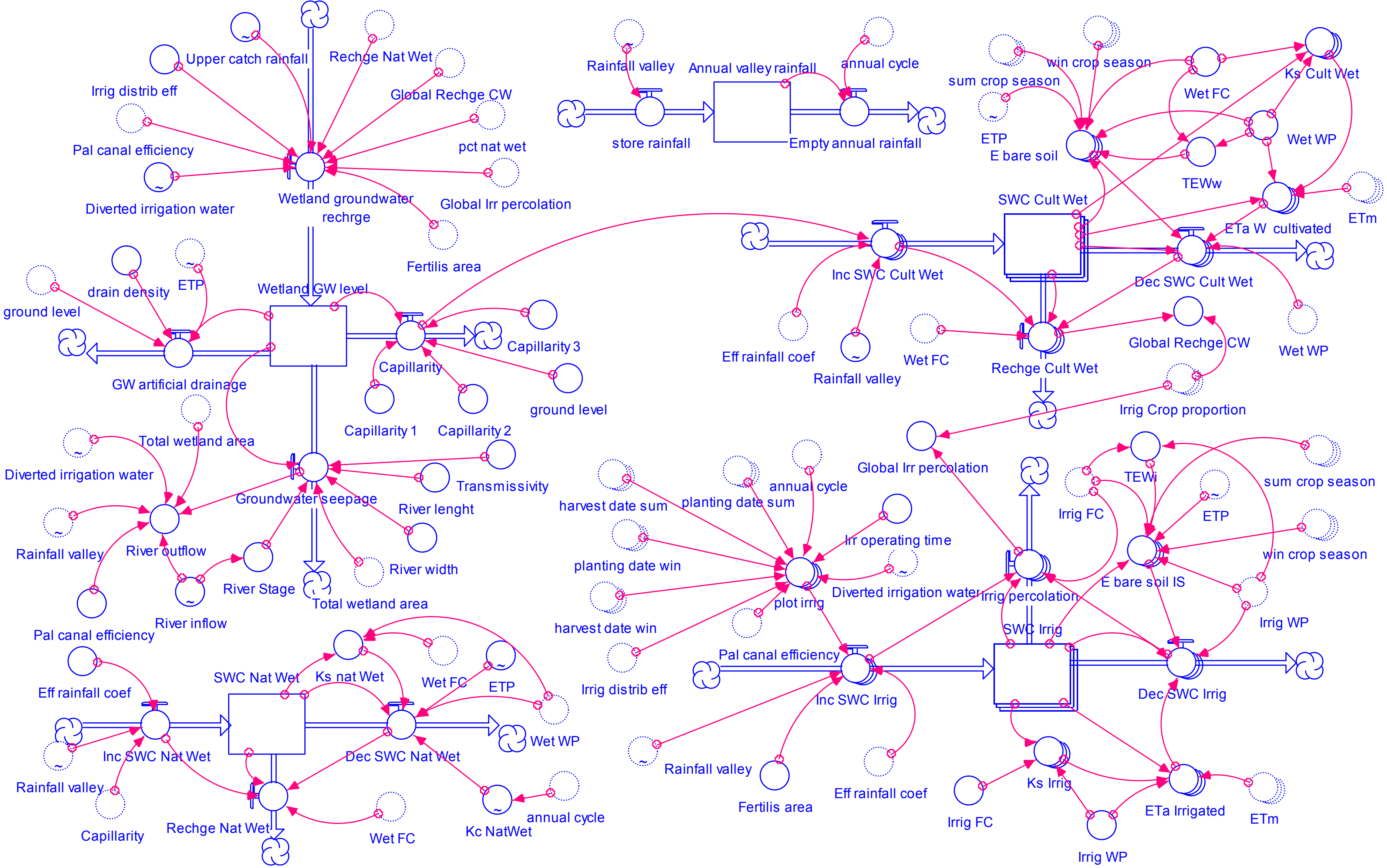
Crop production sector



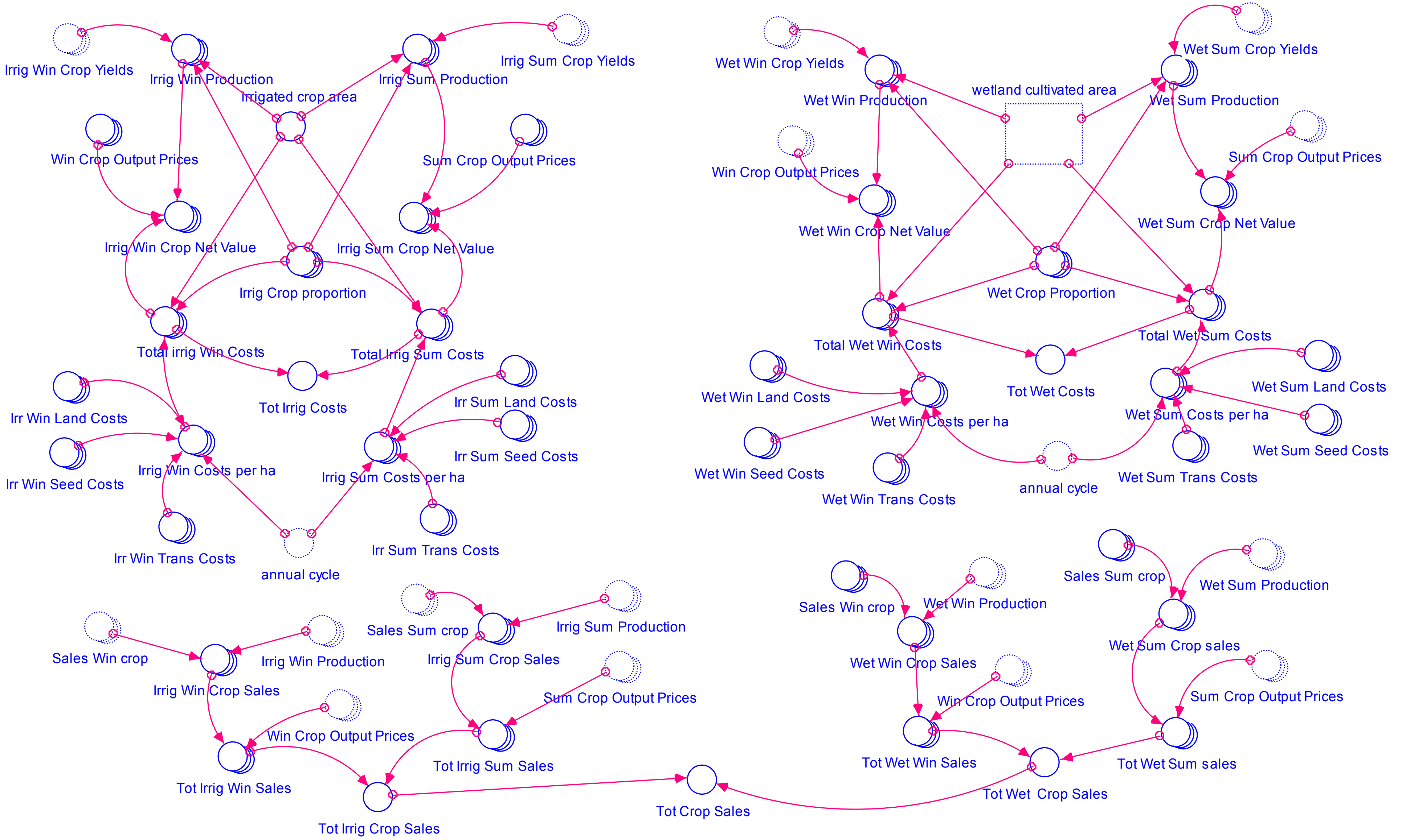
Community well-being sector



Hydrology sector



Crop economics (formerly included in crop production sector)



Abstract

The aim of this study is to introduce improvements and perform global sensitivity analysis of WETSYS model. This system dynamics model simulates environmental and socio-economical dynamics of a small South African wetland, Ga-Mampa. This study focuses on the improvements of hydrological and other processes simulated by the model. Several problems related to the hydrological sector of the model were identified. Different tests and analyses are carried out in order to eliminate these problems. New features such as possibility of having different crops and relationship between groundwater level and crop yields are introduced. Moreover, global sensitivity of hydrology sector is performed. Although the results of the analysis were negatively affected by rather small sample size, it was possible to obtain information on the magnitude of the input factors contribution to the model output variance.

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