Global sensitivity analysis of the Soil-Water-Atmosphere-Plant (Swap) model

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ABSTRACT

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To gain insight in the sensitivity of the results of the one-dimensional simulation model for transient unsaturated/saturamodel Swap to changes on some of its input parameters a sensitivity analysis was performed with this model. Generation of parameter values and the analysis were carried out with the statistical package Usage for different crop-soil combinations. The large influence of the bottom boundary condition is shown. The influence of input parameter strongly varies with the chosen crop/soil combination. It is recommended to perform a more extensive research on all input parameters.

Keywords: Swap, Usage, Sensitivity, Uncertainty, input parameters, output values.

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Preface

A long tradition of cooperation between the DLO-Winand Staring Centre (SC-DLO) and the Wageningen Agricultural University (WAU) resulted in operational versions of the numerical simulation model Swap (Soil-Water-Atmosphere-Plant). At present (January 1998) version 2.02 of the model is available for users inside and outside SC-DLO and WAU.

Currently the model is being applied in several projects at different scales. Especially at a regional scale a global insight into the sensitivity of model-results to changes in input-parameters is essential. To investigate this sensitivity the SwapSens project was started in October 1997. Joop Kroes (Project leader) and Jan Wesseling carried out the investigations. A steering group gave criticism and suggestions on the course of the project. This group consisted of:

- P.J.T. van Bakel (Staring Centre-DLO),
- P. Kabat (Staring Centre-DLO),
- P. Groenendijk (Staring Centre-DLO),
- M.J.W. Jansen (Centrum voor Biometrie Wageningen, part of Centrum voor Plantenveredelings- en Reproduktieonderzoek-DLO),
- J.C. van Dam (Wageningen Agricultural University, Department of Water Resources),
- K. Metselaar (private).

Summary

Swap (Soil-Water-Atmosphere-Plant) is a frequently used model for one-dimensional transient moisture flow in the saturated/unsaturated soil. This model is based upon the SWATRE-model, which has been used in numerous projects inside and outside the Netherlands. A sensitivity analysis of the output to the changes in input parameter values has never been performed. The goal of the analysis described in this report is to quantify the sensitivity of model results to changes in process-parameters. A sensitivity analysis is performed for a number of selected systems and corresponding input parameters. The analysis focussed on hydrological (output-) parameters that are important for regional applications.

The maximum number of input parameters to be analysed was limited by the required and the available CPU-time (24 hours) and the number of samples. Calculations were performed for a number of crop-soil combinations that occur most frequently in The Netherlands instead of considering crop and soil type as input parameters. This way we came to 3 crops and 3 soil types. However, some crop/soil combinations hardly occur in The Netherlands, and finally 6 combinations were analysed. Input parameters were selected from each of the following categories: soil physics, evapotranspiration, drainage and regional hydrology.

The analysis was performed with five different types of distributions: normal, log-normal, gamma, beta and uniform distributions.

The most important terms of the water balance and the groundwater level were selected as output variables. To obtain the sensitivity of the output of Swap to its input parameters, the Usage-package was applied. This is a Genstat-based procedure library developed for uncertainty and sensitivity analysis.

Results showed a large difference in CV (coefficient of variation) of the output variables between the 6 crop/soil combinations. A ranking of parameters by means of the top marginal variance is presented for each output variable, yielding the input variable that has most influence.

Results showed the crucial importance of the boundary conditions (both upper and lower). Large differences were found between different soil/crop combinations. The function describing the leaf area index strongly influenced soil and crop evaporation. Maximum (highest) values of groundwater levels are strongly related to given surface water levels. Minimum groundwater levels depend on a combination of LAI, soil physical parameters and surface water levels. Average groundwater levels are mainly determined by the level in the primary drainage system.

1 Introduction

1.1 Background

A long tradition of cooperation between the DLO-Winand Staring Centre (SC-DLO) and the Wageningen Agricultural University (WAU) resulted in operational versions of the numerical simulation model Swap (Soil-Water-Atmosphere-Plant). At present the model Swap (Van Dam et al., 1997) is available for common use.

Currently the model is being applied in several projects at different scales. Especially at a regional scale a global insight into the sensitivity of model-results to changes in input-parameters is essential. Choices have to be made regarding horizontal and vertical schematisation (spatial distribution and soil profile characterisation). For this purpose insight is required in the sensitivity[1] of Swap-output to the value of selected input parameters. This might answer questions related to the input variables, simplification of the model and assignment of research priorities.

1.2 Problem

The application domain of the model Swap is broad. Some of the various fields of research where the program is applied are:
- Ecology
- Desalinisation
- Design of drainage systems
- Irrigation scheduling
- Hydrological base for nutrient and pesticide transport
- Estimation of crop yield
- Analysis of surface water management

In all of these fields of research one or more of the following processes are dominant:
- Soil moisture flow (soil physical characteristics)
- Evaporation
- Crop growth
- Drainage
- Heat transport
- Solute transport

At this moment insufficient information is available about the sensitivity of model results to changes in parameters of each of the processes.

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1 The term sensitivity analysis is used for those studies which are primarily concerned with the question how the model reacts to variations on (very often) unknown values of model parameters; with a large range it becomes 'global' and with a small range it becomes 'local' sensitivity analysis. An uncertainty analysis focusses on the uncertainty or natural variability of model parameters and tries to determine how this uncertainty shows up in the model results (Janssen et al, 1992).

1.3 Goal

The goal of the analysis described in this report is to quantify the sensitivity of model results to changes in process-parameters. A sensitivity analysis is performed for a number of selected systems and corresponding input parameters. The analysis will focus on hydrological (output-)parameters that are important for regional applications.

1.4 This report

This report consists of eight chapters. Chapter 2 presents the applied crop, soil and meteorological data. The input parameters selected from the categories soil physics, evapotranspiration, drainage and regional hydrology are described in Chapter 3. Chapter 4 presents the five different types of statistical distributions applied in this research. The output variables to be analysed in order to see the effect of each parameter on model results are described in Chapter 5. The reader may find a short description of the Usage package and the applied calculation procedure in Chapter 6, followed by the results of the sensitivity analysis in Chapter 7. Chapter 8 is completely devoted to conclusions and recommendations. As we wanted to present some details about the procedure we followed and some more detailed results as well, 10 appendices were added.

2 Selection of simulated systems

2.1 General

Due to its global character this analysis was limited to the input parameters of the soil system only and we considered the other input-variables as fixed. The maximum number of input parameters to be analysed was limited by the required and available CPU-time and the number of samples. It was decided not to consider crop- and soil-type as an input parameter, but to perform calculations for a number of crop-soil combinations that occur most frequently in The Netherlands. Finally we investigated 15 parameters for each soil-crop-combination, except for the clay soil, for which 2 additional soil parameters were required.

2.2 Crops

Grassland, maize and potatoes were selected as crops to be simulated in the present study. The following arguments lead to this choice:

- Grassland is the most common crop in the Netherlands (about 40% of culture land is grassland) and has a full calendar year growth period.
- (Forage) Maize is the second crop in the Netherlands.
- Potatoes because it is an economically important crop.

Two options for crop growth are included in Swap: a detailed and a simple crop growth model (Van Dam et al., 1997). The simple crop model was applied during this study. During this study a limited number of parameters was investigated. Detailed sensitivity analyses of crop growth models have been performed elsewhere, e.g. by Lambert and Reicosky (1984), MacKerron and Waister (1985), Place and Brown (1987).

2.3 Soil types

Wösten et al (1988) applied a soil physical schematisation to the Dutch Soil Information System. This resulted in 21 different soil types, which were an important base for nutrient calculations (Kroes et al, 1990) in the framework of the Third Policy Analysis of The Netherlands and more recently (Boers et al, 1997) during the preparation of the Fourth Policy Analysis. From these 21 soil types the 3 most dominant peat, clay and sand soil types were selected:

- peat soil, 119000 ha (Wösten, 1988, soil type nr 5)
- sandy soil, 378 000 ha (Wösten, 1988, soil type nr 9)
- clay soil, 397 000 ha (Wösten, 1988, soil type nr 16)

Some characteristics of the selected soil types are given in Table 1.

Table 1 Three soil types with their most important characteristics (Wösten et al., 1988).

Soil type	Horizon (nr +code)	Depth (m-surf.)	Soil Unit	Phys. Dry bulk density ($kg\ m^{-3}$)	Org.Matter (mass %)	Lutum (% of min.parts)
Peat	1 Aanp	0.00–0.20	B02	890	10.0	4
	2 D1	0.20–0.50	O16	180	85.0	4
	3 D2	0.50–0.75	O16	160	85.0	4
	4 C11	0.75–1.00	O02	1700	0.5	3
	5 Gx	1.00–7.00	O02	1700	0.5	3
Sand	1 Ap	0.00-0.20	B02	1300	5.0	3
	2 B2	0.20-0.50	B02	1500	3.0	3
	3 B3	0.50-0.75	O02	1600	2.0	3
	4 C1g	0.75-1.00	O02	1600	0.5	3
	5 G1gx	1.00-7.00	O02	1600	0.5	3
Clay	1 A11	0.00-0.25	B10	1400	5.0	28
	2 C12	0.25-0.60	O10	1400	2.0	28
	3 C22g	0.60-1.00	O10	1400	1.0	20
	4 Cx	1.00-7.00	O10	1400	1.0	20

Within each soil type it was decided to analyse only those soil-crop combinations that occur frequently in The Netherlands. This resulted in the six cases that are presented in Table 2.

Table 2 The selected combination of crops and soils.

	Grass	Maize	Potatoes
Sand	-	+	+
Clay	+	-	+
Peat	+	-	+

2.4 Meteorology

At first we planned to select a set of separate years with different degrees of drought and apply the precipitation deficit or the year-number as a separate input parameter. This would imply simulations of one year only, which would result in losing the long-term effects. One possibility was to perform calculations with the meteorological data of these years in a number of arbitrary combinations. This would yield a series of years that contain the most extreme values and the average ones, but in a fully artificial combination. Therefore we choose to run Swap for 10 years only and selected the years 1981-1990, because these years were available from other studies. To give an impression of the years selected, a short analysis of the precipitation surplus of a number of years has been made. The meteorological data of the meteorological station of Wageningen was analysed for the years 1952-1995. For each year the potential evaporation was calculated with the equation of Makkink on a daily basis. The daily precipitation was known as well so the precipitation surplus can be calculated. Three different periods are considered:

January 1st – March 31st
April 1st – September 30th
January 1st – December 31st

The results of this calculation are presented in Table 3.

Table 3 The precipitation surplus (mm) during the years 1952-1995 for the meteorological station Wageningen for three different periods.

Year	January 1st – March 31st	April 1st – September 30th	January 1st – December 31st
1952	150	-113	252
1953	72	-61	49
1954	89	12	275
1955	81	-165	105
1956	112	11	254
1957	141	109	364
1958	168	6	327
1959	123	-359	-113
1960	94	-49	393
1961	148	15	430
1962	152	-54	277
1963	62	65	276
1964	46	-87	202
1965	137	227	655
1966	187	124	625
1967	102	-105	293
1968	100	121	355
1969	99	2	211
1970	185	-37	379
1971	93	-179	3
1972	52	-20	139
1973	79	-60	231
1974	103	1	459
1975	128	-184	55
1976	107	-323	-77
1977	158	-98	300
1978	124	-126	153
1979	171	-5	383
1980	150	-21	353
1981	*243*	*-47*	*518*
1982	*77*	*-220*	*88*
1983	*186*	*-10*	*367*
1984	*237*	*-9*	*409*
1985	*47*	*4*	*237*
1986	*144*	*-154*	*300*
1987	*102*	*131*	*423*
1988	*335*	*372*	*887*
1989	*190*	*297*	*661*
1990	*186*	*320*	*716*
1991	87	340	649
1992	148	446	918
1993	122	473	881
1994	220	514	1024
1995	316	373	798
Average	138	34	375

For all years the precipitation surplus during the three periods is calculated. The years we considered in this study are presented in italic.

To analyse the presence of dry and wet years, years were sorted from dry to wet. From this it was shown that the selected 10 years (1981-1990) included dry, average and wet years (Table 4).

Table 4. Distribution of selected years according to dryness.

Period		Dry		Average		Wet	
Number	Description	Year	% dry	Year	% dry	Year	% dry
1	Jan.-March	1985	5	1986	60	1988	100
2	April-Sept.	1982	7	1985	64	1990	87
3	Jan.-Dec.	1982	14	1983	57	1988	95

From Table 4 it can be seen that the first period includes a 5%, a 60% and a 100% dry year. Considering the second period (the growing season) the series includes 7%, 64% and 87% dry years. Considering the third period (the entire year) yielded a 14%, a 57% and a 95% dry year. This implies that the sensitivity analysis included average and extreme meteorological data.

3 Selection of input parameters

3.1 General

Input parameters were selected that are associated with a number of processes of the Swap-model: soil physics, evapotranspiration, drainage, regional hydrology.

3.2 Soil physics

The soil physical characteristics of each soil layer (see Table 1) are described with the Mualem-Van Genuchten parameters (see Van Dam et al., 1997). These parameters can be found for Dutch soils in the analysis of Wösten et al. (1994). From this reference the appropriate parameter values and their distributions were selected. Investigated input parameters are:
- The saturated moisture content (θ_{sat}) and saturated hydraulic conductivity (K_{sat}) of each soil layer.
- The ratio (C) between the parameters α_w and α_d is generated to take into account hysteresis, if any.

3.3 Evapotranspiration

As mentioned in the previous chapter, we used the simple crop model. The following crop parameters were investigated:
- The so-called crop factor f (Van Dam et al., 1997; Wesseling, 1997) will be treated as uncertain.
- Rooting depth was described by a simple curve. In this study the maximum rooting depth (RDTBY(2)) was varied, as well as the development stage (RDTBX(2)) at which the maximum rooting depth is reached. See Fig.1.

The leaf area index was varied to analyse a different distribution of covered and bare soil. Here a simple relationship was assumed as well. It was assumed that the leaf-area index varies with development-stage as a roof-shaped function (Fig. 2). The development-stage at which the maximum value of the leaf-area index is reached (GCTBX(2)) is varied, as well as the maximum value itself (GCTBY(2)). Finally the leaf-area index at maturity (GCTBY(3)) was varied. Because this value may not exceed the maximum value, a fraction f_{LAI} was introduced. This fraction (ranging from 0 to 1) is the ratio of the leaf-area index at maturity over the maximum leaf-area index. Now the leaf-area index at maturity is calculated by multiplying the maximum value (GCTBY(2)) with this fraction:

$$GCTBY(3) = f_{LAI} * GCTBY(2)$$

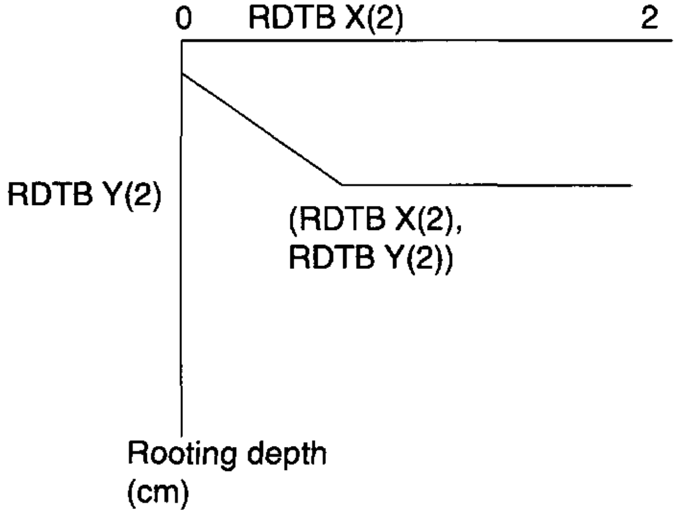

Fig. 1 The parameters of the rooting-depth function

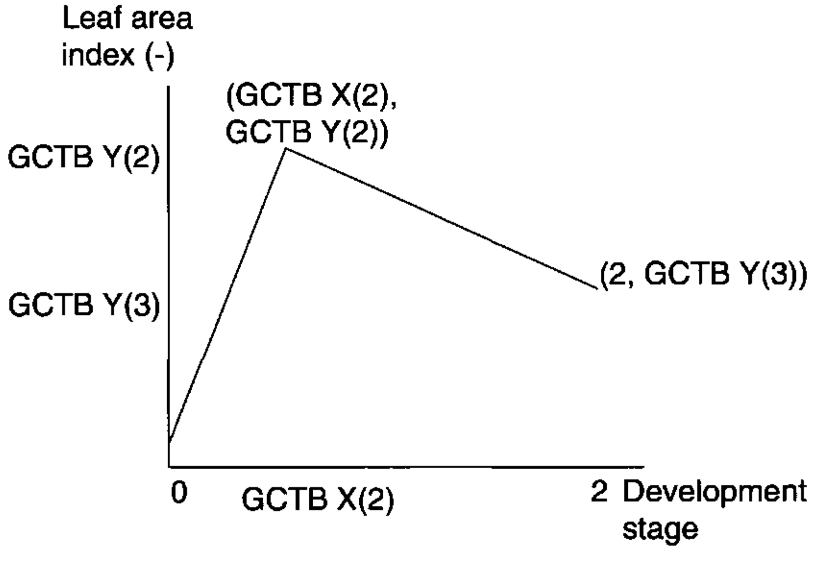

Fig. 2 The leaf area index as a function of the development stage

3.4 Drainage

The lateral boundary was considered to consist of 2 surface water systems. The influence of the drainage resistance of each system was analysed, as well as the water level in the drainage media. No infiltration of surface water into the soil profile was allowed.

3.5 Regional flow

The bottom boundary conditions at the bottom of the soil profile was considered to interact with a regional groundwater system. Originally we specified a flux (q_{bot}) as a function of time. After the first analyses we decided to fix these values (see par. 7.1).

4 Uncertainty of selected input parameters

4.1 Distribution types

In this study selections were made from 5 different distribution types, using the following criteria:

- given knowledge about minimum and maximum values of the boundaries of the distributions originating from expert-judgement;
- given knowledge about average and variance originating from other studies

A selection had to be made for each input parameter from the possible distribution types that are presented in Table 5.

Table 5 Possible distribution types with their boundaries

Distribution	Lower boundary	Upper boundary
Normal	$-\infty$	$+\infty$
Log-normal	Value	$+\infty$
Gamma	Value	$+\infty$
Beta	Value	Value
Uniform	Value	Value

A brief general explanation of these 5 distribution types is given hereafter. Examples for these distributions were generated with a sample size of 1000 values (Fig. 3).

One of the most frequently used distributions is the normal distribution (Fig. 3a). If the values should be positive, the lognormal distribution can be chosen (Fig. 3b). If the values are limited by a minimum and a maximum, the beta-distribution can be applied (Fig. 3c). A distribution that looks like the log-normal distribution is the gamma-distribution (Fig. 3d). Finally, the most simple distribution type is the uniform one (Fig. 3e). In this distribution each value between a minimum and a maximum has the same chance to be selected.

4.2 Distribution of input parameters

Considering the parameters discussed in the previous chapter and choosing between the distributions described above, we selected for each parameter a distribution type, its average, variance, minimum and maximum value. The different combinations are presented in Annex 1.

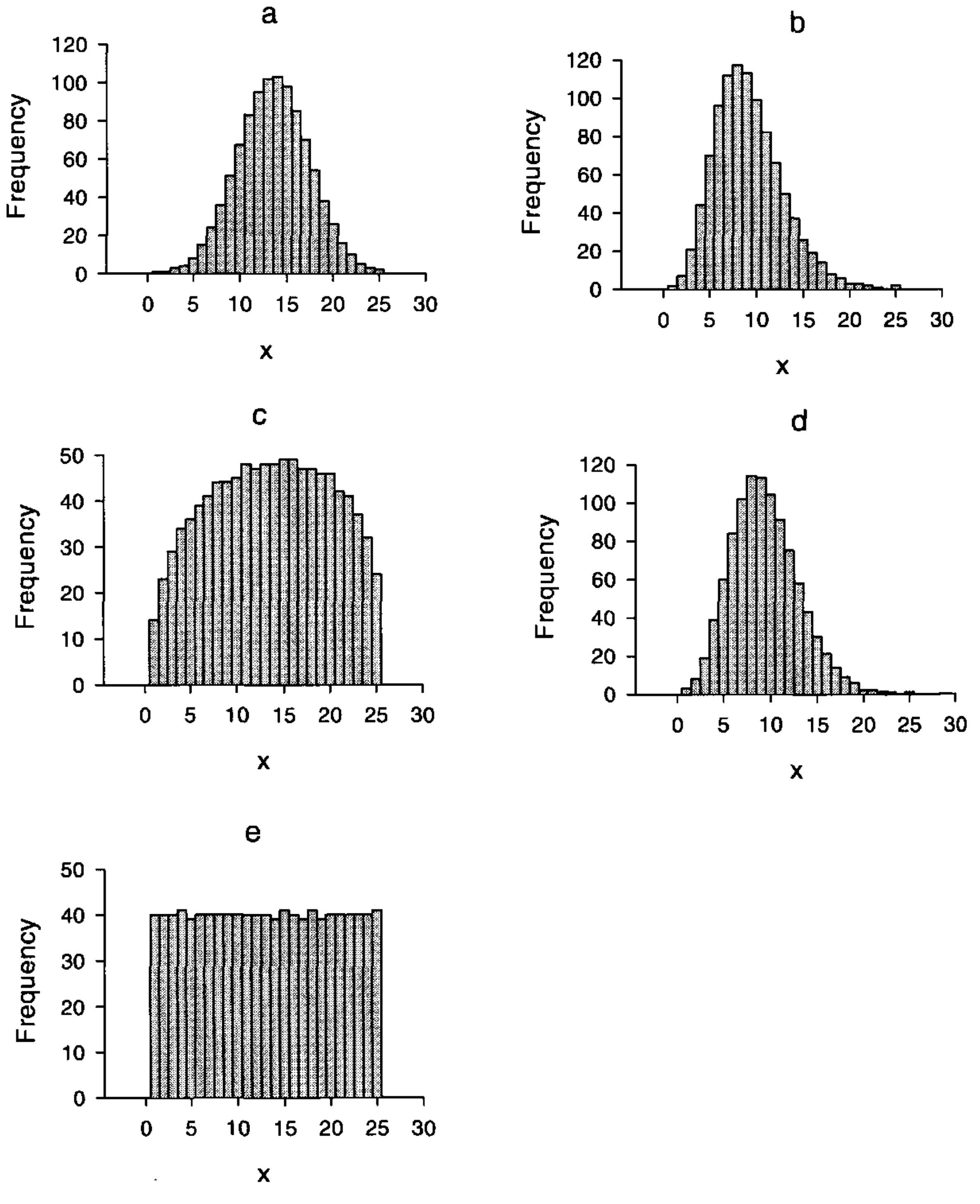

Fig. 3 Frequency distributions of different samples (size 1000) of distribution: a. normal; b. lognormal; c. beta ; d. gamma; e. uniform. In these figures x means the value generated by the number-generator

5 Selection of model output

In order to analyse the effect of each input parameter on the model results, a number of output-variables should be analysed. We selected the generally most important terms of the waterbalance and the groundwater level (Table 6).

Table 6 Description of the selected output variables.

Description	Symbol	Units
Cumulative actual crop evaporation (transpiration)	E_p	cm
Cumulative actual soil evaporation	E_s	cm
Cumulative drainage to 1st order system	Q_{d1}	cm
Cumulative drainage to 2nd order system	Q_{d2}	cm
Cumulative leaching across bottom boundary	Q_b	cm
Groundwater level	Gwl	cm

Cumulative values are yearly accumulated terms of the water balance and constitute no problem in the output analysis. The groundwater level had to be analysed in a different way. We choose a number of values to characterise the groundwater level:

- *Minimum value* (Gwl_{min})[2]
- *Average value* (Gwl_{ave})
- *Maximum value* (Gwl_{max})
- *GLG (long-term averaged lowest groundwater level)*
- *GHG (long-term averaged highest groundwater level)*
- Gt (Groundwater class)

The first 5 summary values (printed in italic) will be considered in the sensitivity analysis.

As an indicative value the CPU-time required for one simulation run of 10 years on the Quasar computer of the Staring Centre (Digital Alpha processor) was considered in the output as well.

[2] In the remainder of this report, these variables may be written in a slightly different way. Sometimes tables were copied into the document directly from outputfiles without converting the symbols. This means that variables like Gwl_{min}, GWL_{min}, GwlMin, GWLmin, and GWLMIN all mean the same: the minimum value of the groundwater level.

6 Methods and tools

6.1 General

In this Chapter the procedure will be described that we followed to obtain the results described in the next chapter. In the previous chapters we described the input parameters we investigated with their uncertainty and also mentioned the output parameters we wanted to analyse for their sensitivity for a change in the input parameters. We applied the package USAGE (Jansen and Withagen, 1997) which we shall briefly describe in paragraph 6.2. In the following paragraphs the entire procedure of parameter-generation, calculations and analysis will be described, together with the programs we created for it.

6.2 The Usage-package

USAGE contains (Genstat) procedures for sampling from continuous multivariate distributions of model input. Various procedures are available for the analysis of uncertainty or sensitivity. The distributions of the individual inputs are defined per input. Association between inputs is specified via rank correlation. Restricted random samples (latin hypercube samples or samples with forced correlations) can be generated for efficiency reasons. The USAGE procedures for the analysis of uncertainty or sensitivity focus upon the effect of individual inputs. Uncertainty and uncertainty contributions are expressed in terms of relative variances and variance components.

The model is conceived as follows. A one-dimensional model output y depends on a k-vector $\underline{x} = (x_1...x_k)$ of inputs:

$$y = f(\underline{x}) = f(x_1...x_k).$$

The function f is deterministic; f represents a single output. Different outputs are analysed separately. The input vector x may comprise initial values, parameters, exogenous variables etcetera. Input variability is represented by a multivariate probability distribution, D, of the vector $\underline{x} = (x_1...x_k)$:

$$\underline{x} = (x_1...x_k) \sim D.$$

where ~ means 'has probability distribution'. The resulting output variance, the total variance, is a measure of prediction variability. Uncertainty and sensitivity contributions are defined as the answers to questions of the type: *`How much would output variance decrease if specific information about the input would become available, in addition to the information contained in input distribution D ?'.*

The top-marginal variance of x_i is the *percentage of variance accounted for by x_i*, whereas the bottom-marginal variance of x_i is the *percentage of variance not* *accounted for without x_i*. The top-marginal variance is known in the statistical literature as the correlation ratio. In the standard calculations, the model output studied is approximated by a function of the form $f(x) \approx E_i\, s_i(x_i)$, where $s_i(x_i)$ denotes a smoothing spline in x_I and $\approx$ means 'is approximated by'. (Alternatively, a linear approximation may be chosen, but in general linear approximations perform worse than splines.) If the x-es interact strongly, the method approximation will be poor. The quality of the approximation is high when the percentage of variance accounted for is high. If that percentage is far below 100, alternative (more computer intensive) methods are to be used. Options for such analyses are sketched in the USAGE-manual.

6.3 The applied directory structure

At the start of the project we realised that a huge amount of data would be generated when performing the sensitivity analysis. We also realised that a tremendous number of runs with Swap should be performed. Therefore we had the following demands when setting up the structure of the directories for our calculations:
- USAGE should run with Genstat on one of the Alpha's.
- The Swap-calculations should be performed in SlowBatch on one of the Alpha-computers.
- New programs should be developed in Delphi-3 on PC.
- As little copying of data should be done as possible.
- All output should be available to the PC for wordprocessing.

For these reasons we created the directory structure discussed in Annex 2.

6.4 The calculation procedure

The calculation procedure consisted of the following steps:
1. Generate a set of input parameters with USAGE/GENSTAT
2. Convert the input parameters into Swap files
3. Run Swap for each input set
4. Select output to be considered in analysis
5. Prepare file for USAGE/GENSTAT
6. Apply regression and analyse output
7. Create tables of sensitivities and ranking

These steps will be discussed in this paragraph.

6.4.1 Generate a set of input parameters

To generate the required parameters, the program GenPars was written for each crop-soil combination. It is an (Alpha-) Genstat program that generates the parameter values, according to the Latin Hypercube Sampling method as included in USAGE. These parameter values were written to separate files (grouped by the type of process). A complete listing of the program GenPars applied for maize on sand is included as Annex 3. To ensure that there is no undesired correlation between the input parameters, the Iman-method was chosen with a correlation matrix which contains a diagonal with only 1's and all off-diagonal values 0. The number of parameter-vectors generated was 100.

The output of this program consists of three files: one with crop parameters, one with soil parameters and one with drainage parameters. Parts of these files are presented in Annex 4.

6.4.2 Convert the input parameters into Swap files

All of the parameter-sets have to be converted into input-files for the model Swap. For this reason the program CreateSwapInput has been written in Delphi-3. It reads the output-files of GenPars and creates the input-files for Swap with it. The program checks for the existence of the directories and if they do not exist, they will be created. This program also creates the command-files that run Swap and delete the input-files. These files are submitted by starting a single command-file.

6.4.3 Run Swap for each input set

The calculations were planned to be made with Version 2.02 (released november 1997) of the program Swap (Van Dam et al., 1997). This version had a few minor improvements compared to Version 2.01, and the input was completely performed by the TTUTIL-library. The required CPU-time of the model varied strongly, depending on the chosen combination of input parameters. Because we did not want one run to delay the entire job, we created a separate job for each run. We set the maximum CPU-time the program was allowed to use to 1 hour. If a job required more CPU-time, it was aborted.

6.4.4 Select output to be considered in analysis

To obtain the data required for the sensitivity analysis, the program PickData has been written in Delphi-3. It reads the output file of Swap with water-balance data from the appropriate directories and the corresponding log-file. The output that was discussed before (Chapter 5) is selected from all files. Then the groundwater levels are processed as described in Chapter 5. A summary of outputfiles is presented in Table 7. See Annex 5 for an example of these files.

6.4.5 Analyse the output and the sensitivity of the output to the input parameters.

The output files of the Swap-runs that are created by PickData and the input parameters generated by GenPars are read for analysis by the Genstat program AnalPars (Annex 6). This program first checks the correlation between the generated input parameters.

Table 7 The files created by the program PickData

Filename	Description
Epa.sim	Actual plant evaporation (cm)
Epp.sim	Potential plant evaporation (cm)
Esa.sim	Actual soil evaporation (cm)
Esp.sim	Potential soil evaporation (cm)
Gwl.sim	Groundwater levels (cm b.g.s. for each day)
Qb.sim	Amount of water through the bottom of the profile (cm)
Qd.sim	Amount of water to the drainage system (cm)
Qd1.sim	Amount of water to the first level of drainage system (cm)
Qd2.sim	Amount of water to the second level of drainage system (cm)
Times.sim	CPU-time and elapsed time for job (s)

In the next step the output of Swap will be analysed. Values for different variances are calculated. Results from AnalPars are read by the Delphi-3 program CreateTables which produces two output files: params.out and tmvs.out. These files contain the tables presented in Chapter 7 and Annex 10.

7 Results of sensitivity analysis

7.1 General

In this chapter the results of the analyses described in the previous chapters will be discussed. Before getting to the results, a number of remarks should be made:

- As mentioned before, we planned to investigate the sensitivity of the output parameters to the bottom boundary condition. When simulations were carried out with a generated flux density across the lower boundary, it appeared that about 80 – 95% of the variance in all output could be explained by the variation of the bottom flux. Simulations with this lower boundary condition diminished all other variances, which could not be interpreted. To overcome this, we fixed the value for the lower boundary to zero (no seepage/percolation).
- In reality, grass has a constant soil-cover of 1. This means that during this study the value of GCTBX(2) should have remained constant for grass. In our study we varied this value. This means that the results for 'grass' should be interpreted as the results for 'a shallow rooting crop with a growing season of 1 year'.
- In the planning of the project we assumed to run Swap 2.02. During the course of this study, Swap 2.03 was released. As some bugs were removed from this version, we choose to use it. Originally the hysteresis factors were planned to vary. However, in Swap version 2.03 hysteresis and scaling could not be combined with mobile/immobile flow. As we expected the model to be most sensitive to the mobile/immobile flow, this option was chosen.
- J.H.M. Wösten (personal communication, 1997) supplied the distribution (average and standard deviation) of the values of the saturated hydraulic conductivity and the saturated moisture content for each unit in the Staring-series. These values are presented in Annex 8. However, when we tried to generate parameter sets with Usage, error messages were obtained and we did not have time to analyse this thoroughly. It seemed to us that the variation was too high for Usage to generate the distributions we demanded.

7.2 Uncertainty of input

As said before, we generated 100 sets of input parameters with the selected distribution, mean and variance. The generated input parameters and their minimum, mean and maximum values for each soil-crop combination are presented in Annex 8.

7.3 Sensitivity of output

In this section the obtained output will be analysed statistically. The complete results are presented in Annex 9 and will be discussed briefly here using mainly the coefficient of variation because it gives an impression of the dynamics of the system.
A summary of all CV's is given in Table 8. The high CV-values of the actual soil evaporation (EsaTot) for grassland are caused by the year-round soil cover. The

opposite is true for the CV of the plant evaporation (EpaTot). The drainage-flux has the same CV for all cases. The minimum groundwater level has a CV of 7% for the sand profile, 20% for the clay-profile and 14% for the peat profile. The groundwater in clay profile reacts much faster to a change in storage than the sand profile. The CPU-time has a large CV, resulting from the fact that at least one simulation that did not finish within the specified time limit of 1 hour.

Table 8 The Coefficients of Variation (CV) (%) for the output of the simulations

	Sand		Clay		Peat	
	Maize	Potatoes	Grass	Potatoes	Grass	Potatoes
EsaTot	5	4	13	4	14	5
EpaTot	10	10	7	10	7	11
QdTot	30	30	30	30	30	29
GwlMin	7	7	20	20	14	13
GwlAve	12	12	13	14	12	12
GwlMax	58	45	140	79	133	96
GLG	7	8	17	17	13	11
GHG	47	45	39	41	37	41
CPUTime	4	6	246	244	250	233

The output for each crop-soil combination will be discussed briefly in this section.

Maize on sand

The largest coefficient of variation occurred for the highest groundwater levels. However, this is relative, as there is only a very small variation in GHG (between 0 and 1 cm). This is caused by the selected bottom boundary condition (0 cm/day). It causes rather high groundwater levels during winter for this soil profile in combination with the generated drainage situation. The actual soil evaporation has the smallest CV, i.e. 4.5%. It ranges from 1794 to 2242 mm for the entire simulation period of 10 years.

Potatoes on sand

Comparing table A9.2 with A9.1 (maize on sand) shows only minor differences between them.

Grass on clay

The coefficient of variation for soil evaporation is larger than the one for plant evaporation. This is contrary to the values in the previous tables. It was caused by the fact that grass covers the soil for the entire year, while in the other cases the soil is fully covered during the growing season only. Looking at the number of observations, it can be seen that 6 runs out of 100 did not yield an output set. In 2 of these cases the saturated conductivity of the subsoil was below 0.01 cm d^{-1}. In these cases Swap produced a range-check error. Inspecting the data generated for the other runs, it was seen that in all these cases the saturated conductivity was below 0.06 cm d^{-1}.

Potatoes on clay

The highest CV was found for the GwlMax. Once more this was caused by almost no variation in values of maximum groundwater level. For this crop-soil combination 8 runs did not yield an output set. Two of them had a generated value of saturated conductivity that was below the lower limit set in Swap, the other four did not have sufficient CPU-time. Checking the input file showed that these cases all had a conductivity for the lower layer of less than 0.04 cm d^{-1}.

Grass on peat
The number of observations is now 96 instead of 100, so there have been four combinations of parameters that caused problems. Checking the input files shows that the generated saturated conductivity of the second soil layer is less than 0.057 cm d^{-1} in all these cases. All problems were CPU-limits. For this crop/soil combination the smallest coefficient of variation is for the plant evaporation: 7.6%.

Potatoes on peat
In this case 95 out of 100 runs reached the end. The five runs that did not finish had a problem with the CPU-time. Here the same limit can be seen as in the previous case: 0.057 cm d^{-1}.

7.4 Sensitivity contribution of parameters

In this section of the report the results of the sensitivity analysis will be discussed as a function of the input parameter.

7.4.1 General

Usage presents the so-called 'variation accounted for'. This is an indicator of the variation of output parameters that can be explained by the variation of input parameters. The percentages obtained in this study are summarised in Table 9. The percentage of variation that is accounted for is rather high for the most important output parameters. It becomes clear there are two aspects that are not accounted for by this method of analysis: the maximum groundwater level and the used CPU-time. The first variable does not change enough to give a fair estimation of changes. In the system we considered the highest groundwater levels always remain at the surface. In case of the CPU-time other interactions do play a role.

Table 9 The accounted percentages for each output variable.

	E_s	E_p	Q_d	GWL_{min}	GWL_{avc}	GWL_{max}	GLG	GHG	CPUtime
Maize /sand	98.8	98.5	98.4	96.1	98.1	21.9	97.2	91.1	40.8
Potatoes/sand	98.3	97.7	98.2	94.3	97.0	33.6	96.4	86.8	39.3
Grass/ clay	97.9	93.4	94.6	74.6	71.8	33.3	73.8	74.2	8.0
Potatoes/clay	99.0	96.0	96.3	74.1	78.7	26.7	74.2	80.7	4.5
Grass/ peat	97.8	90.1	98.4	74.2	84.2	54.6	73.7	88.7	10.6
Potatoes/peat	97.7	97.6	97.8	77.2	93.7	26.2	78.9	85.7	28.6

7.4.2 Ranking of parameters by means of top marginal variances

From the tables presented in Annex 10 the ranking of parameters can be obtained for each combination of land use and soil type. This ranking will be presented in this section for five output parameters with a sufficient high percentage accounted for: E_s, E_p, Q_d, GWL_{min}, GWL_{ave}.

The input parameters can be combined into three groups:
- Crop parameters: CFET, GCTBX2, GCTBY2, GCTBY3, RDTBX, RDTBY
- Drainage parameters: Level1, Resist1, Level2, Resist2
- Soil physical parameters: ThetaS1, Ksat1, ThetaS2, Ksat2, ThetaS3, Ksat3, FM1

The top marginal variances of the input parameters for the five output parameters will be discussed in this section.

Table 10 Top marginal variances for EsaTot

		Sand		Clay		Peat	
		Maize	Potatoes	Grass	Potatoes	Grass	Potatoes
Crop	CFET	-	-	-	-	-	1.1
	GCTBX2	2.0	4.8	3.6	6.9	3.2	3.3
	GCTBY2	60.3	55.3	70.7	58.9	73.1	54.4
	GCTBY3	66.1	64.0	43.4	64.6	43.4	55.5
	RDTBX	-	-	-	-	-	-
	RDTBY	1.4	-	-	-	-	-
Drainage	Level1	5.2	-	-	-	-	-
	Resist1	-	-	-	-	-	-
	Level2	-	-	-	-	-	0.5
	Resist2	-	-	-	-	3.7	0.1
Soil physics	ThetaS1	3.2	3.1	1.7	3.1	-	-
	Ksat1	0.1	0.7	-	-	-	-
	ThetaS2	-	-	-	-	-	0.6
	Ksat2	-	-	0.2	-	-	2.2
	ThetaS3	-	-	-	-	-	1.1
	Ksat3	-	-	-	-	2.6	2.5
	FM1	-	-	-	-	-	1.2

Table 10 presents the top marginal variances for the total soil evaporation. From this table it can be seen that in all considered cases the value was influenced mainly by crop parameters. The development-stage where maximum leaf-area-index is reached has only minor influence. The two y-values of the CGTB-line have most influence. In the cases where grass is the crop, the GCTBY2-value is the most important. In all other cases the GCTBY3-value is dominant. The soil physical parameters have only minor influence in the considered cases and considered years. The mobile-immobile fraction only plays a role in the case with potatoes on peat.

Similar results are obtained for EpaTot. These are presented in Table 11. Once again the importance of the CGTB-values is shown here. They are dominant in all cases. In case of sand the other parameters show such a low TMV they are not shown anymore. In case of peat this is different: almost every parameter plays a role.

From these two tables it can be seen that the crop parameters, and specially the leaf-area index, have a large influence on both soil evaporation and plant evaporation.

Table 11 Top marginal variances for EpaTot

		Sand		Clay		Peat	
		Maize	Potatoes	Grass	Potatoes	Grass	Potatoes
Crop	CFET	0.9	-	-	-	-	0.1
	GCTBX2	1.7	4.3	2.1	5.3	2.5	-
	GCTBY2	55.4	49.7	56.8	47.0	66.9	65.8
	GCTBY3	63.9	62.6	15.7	57.0	17.8	56.2
	RDTBX	-	-	3.1	0.4	-	-
	RDTBY	-	-	0.5	1.2	0.2	-
Drainage	Level1	5.4	-	-	-	-	-
	Resist1	-	-	-	-	-	-
	Level2	-	-	-	0.5	1.1	-
	Resist2	-	-	2.5	0.3	5.2	-
Soil physics	ThetaS1	1.6	1.7	0.5	1.8	0.8	-
	Ksat1	0.3	-	14.1	3.1	-	-
	ThetaS2	-	-	-	-	0.3	1.6
	Ksat2	-	-	10.0	1.2	15.1	6.9
	ThetaS3	-	-	-	-	0.1	4.0
	Ksat3	-	-	-	-	1.9	3.8
	FM1	-	-	-	-	-	-

Table 12 Top marginal variances for QdTot

		Sand		Clay		Peat	
		Maize	Potatoes	Grass	Potatoes	Grass	Potatoes
Crop	CFET	-	-	-	-	-	-
	GCTBX2	-	-	1.2	1.1	0.1	-
	GCTBY2	3.0	0.3	3.1	0.8	21.2	6.9
	GCTBY3	3.3	4.0	0.9	2.7	4.6	3.5
	RDTBX	-	-	-	-	3.5	-
	RDTBY	-	-	-	-	-	-
Drainage	Level1	58.0	57.9	54.9	51.7	55.5	61.3
	Resist1	36.4	32.9	28.8	34.5	24.0	36.6
	Level2	-	-	-	-	-	-
	Resist2	-	-	-	-	-	1.6
Soil physics	ThetaS1	0.8	-	-	-	3.6	0.1
	Ksat1		7.8	4.8	7.0	-	-
	ThetaS2	-	-	-	-	-	-
	Ksat2	-	0.1	0.7	-	-	-
	ThetaS3	-	-	-	-	4.6	2.4
	Ksat3	-	-	-	-	-	-
	FM1	-	-	-	-	-	-

A completely different table is Table 12 for the volume of water flown to the channels (QdTot). Here it becomes clear that the properties of the primary system are the most influential ones for the cases under consideration. Specially the water levels have quite some influence (as could be expected). A bit surprising is the very low influence of the secondary system. In the selected cases it has hardly any influence. The influence of the soil is mainly limited to the saturated conductivity of the top layer. In general we can say that the most critical factor for the drainage flux is the water level in the primary systems. Of course the CGTB-values do have an influence as well, as they control the evaporation from soil and plant, which in turn influences the drainage flux. These parameters do play a role in the case of grass.

Table 13 Top marginal variances for GwlMin

		Sand		Clay		Peat	
		Maize	Potatoes	Grass	Potatoes	Grass	Potatoes
Crop	CFET	1.9	-	-	-	-	-
	GCTBX2	-	1.0	-	-	-	1.2
	GCTBY2	23.0	20.5	-	-	1.3	8.2
	GCTBY3	21.9	16.3	-	1.5	-	3.8
	RDTBX	-	-	-	-	-	-
	RDTBY	1.7	-	-	-	7.2	-
Drainage	Level1	12.7	3.9	-	-	0.9	-
	Resist1	1.9	1.1	6.1	6.3	-	4.4
	Level2	0.5	0.1	-	-	1.8	-
	Resist2	-	-	0.2	1.0	4.1	1.0
Soil physics	ThetaS1	6.7	3.9	1.8	3.9	1.1	-
	Ksat1	19.2	27.9	2.7	2.3	-	-
	ThetaS2	5.3	4.6	2.6	1.5	3.3	2.6
	Ksat2	1.9	-	73.8	71.6	72.4	65.8
	ThetaS3	-	-	-	-	0.6	5.9
	Ksat3	-	-	-	-	-	0.1
	FM1	12.4	12.5	1.0	0.5	-	5.2

In case of the minimum groundwater level (Table 13), there is a large difference between the sand-profile and the clay/peat profiles. In the first profile the leaf area-index function plays an important role again, together with the saturated hydraulic conductivity of the top layer. In the other cases the hydraulic conductivity of the second layer has the largest TMV-value. Note that the values of the growing curve play a role on the sand profile only. The differences mentioned here may be related to the low value of the percentage accounted for in these cases (see Table 9). Note that the TMV for the mobile/immobile fraction has a value here.

Table 14 Top marginal variances for GwlAve

		Sand		Clay		Peat	
		Maize	Potatoes	Grass	Potatoes	Grass	Potatoes
Crop	CFET	1.0	0.3	-	-	-	-
	GCTBX2	2.8	2.0	-	-	1.4	1.4
	GCTBY2	24.6	22.9	8.2	13.1	9.4	18.0
	GCTBY3	19.9	16.2	3.3	16.2	3.1	14.4
	RDTBX	-	-	0.9	-	-	-
	RDTBY	-	-	-	-	2.1	1.0
Hydrology	Level1	43.6	41.4	11.3	17.5	40.3	41.7
	Resist1	11.9	9.1	5.0	3.7	3.6	12.8
	Level2	0.6	0.4	-	1.2	-	-
	Resist2	-	-	-	0.2	2.3	-
Soil	ThetaS1	3.8	1.7	3.3	5.9	-	-
	Ksat1	-	7.3	2.4	2.1	-	-
	ThetaS2	0.8	-	2.4	0.4	4.5	0.4
	Ksat2	-	-	42.4	31.3	20.1	9.3
	ThetaS3	-	-	-	-	-	8.5
	Ksat3	-	-	-	-	0.5	-
	FM1	-	1.0	1.5	0.6	-	-

The top marginal values for the average groundwater level are presented in Table 14. Once more the difference between the sand profile and the other two profile can be noticed. On the sand profile the values of the growing curve have a large influence, together with the drainage characteristics. In case of the other two profiles the drainage characteristics do have the largest influence. In general the water level in the primary drainage system is the most important factor here.

7.4.3 Graphical results

To show the results of the simulations, two graphs are presented here showing one output variable versus one input variable. These graphs are meant as an illustration only. Two cases will be presented.

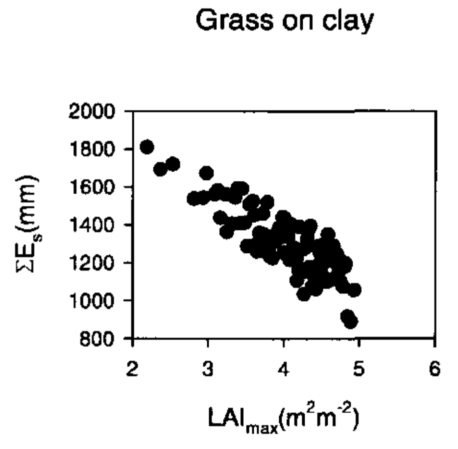

Fig. 4 Total soil evaporation versus maximum Leaf Area Index (GCTBY2)

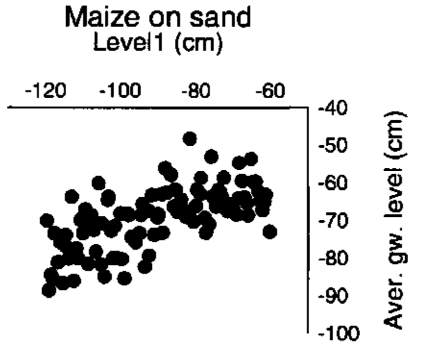

Fig. 5 Average groundwater level versus the water level in the primary system (Level1).

8 Conclusions and recommendations

8.1 Conclusions

From the analysis described in this report some general conclusions and some conclusions for the different processes can be drawn. Even though this was a general analysis, one should keep in mind that these conclusions are based on a limited number of crop/soil combinations only.

8.2 General

- The influence of the crop factor on the considered cases is surprisingly low;
- Boundary conditions (both upper and lower) are of crucial importance when applying the model Swap;
- The effect of preferential flow on the water balance is very small.

8.3 Soil moisture flow

- There is a large difference between the parameter influence for the sand profile and the clay/peat profile in case of the average groundwater level. This is mainly caused by the different hydraulic characteristics of each profile.
- At low values for the saturated hydraulic conductivity the model Swap did not succeed in finishing the simulations; this occurred for peat at values below 0.1 cm d^{-1}. and for clay at values below 0.06 cm d^{-1}
- Maximum (highest) values of groundwater levels are strongly related to given surface water levels
- Low groundwater levels depend on a combination of LAI, soil physical parameters and surface water levels;
- The average groundwater level is mainly determined by the level in the primary drainage system.

8.4 Evaporation

- For all soil-crop combinations the soil and crop evaporation were strongly determined by the function describing the Leaf Area Index (LAI).

8.5 Drainage

- Drainage, simulated as lateral discharge, is very sensitive to the given surface water levels;

- In the considered cases the influence of the secondary channels is neglectable considered with the influence of the primary channels.

8.6 Recommendations

- The procedure developed during this study yields the results we expected from it: a ranking of sensitivities of output parameters for a number of input parameters. Up to now we considered a limited number of input and output values, but it may be worthwhile to perform this study for a larger range of parameters.
- Truncated lognormal distributions for the saturated moisture content (2_{sat}) is statistically not satisfactory. Possible alternative is the beta-distribution.
- To analyse the influence of the sample size, future simulations should be made with either a different seed for the random generator or a larger sample size.
- The characterisation of time series like groundwater level data requires additional research.
- It would be worthwhile to investigate the influence of only 1 parameter at a time, just to see its direct influence (fixing the other parameters)
- The variation of the values of soil physical parameters of the Staring Series requires further analysis
- To analyse groundwater levels as a time-series or apply a Fourier-analysis would be the most sophisticated way, but that would require additional software to be developed. This analysis should be performed in a future study.
- To quantify the effect of preferential flow on solute leaching, the balance of a solute should be included in the study additional to the water balance.
- In this study the effects on actual soil and crop evaporation were considered. It is recommended to investigate the effect on transpiration reduction due to wet or dry conditions as well.
- A more extensive literature research on the sensitivity of model parameters may help in reducing the required amount of parameters to investigate.

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Annex 1 The applied distribution for each input parameter.

Table A1.1 Maize on sand

Process	Input-parameter				Distribution	Mean	CV or s.d.	Min.	Max
	Symbol	Description	Code-name	Unit			(%) or -		
Soil physics	θ_{sat1}	Sat.Moist.1	COFGEN(2)	$m^3.m^{-3}$	Uniform			0.39	0.47
	K_{sat1}	Sat.Hyd.Cond.1	COFGEN(3)	$cm.d^{-1}$	Lognormal	9.441	6.157		
	θ_{sat2}	Sat. Moist. 2		$m^3.m^{-3}$	Uniform			0.33	0.42
	K_{sat2}	Sat. Hyd. Cond. 2		$cm.d^{-1}$	Lognormal	16.482	3.475		
Transpi-ration		CropFactor	CFET		Beta	1.0	15	0.8	1.2
		Dvs max Drz	RDTB X(2)	-	Beta	1.0	15	0.5	1.5
		Max Drz	RDTB Y(2)		Beta	0.6	15	0.2	1.0
		GrowthCurve	GCTB X(2)		Beta	1.0	15	0.5	1.5
			GCTB Y(2)		Beta	4	15	0.3	8
			C = Y(3)/Y(2)	-	Uniform			0	1
Drainage	Y1	Resistance1	DRARES1	d	Lognormal	1000	25		
		WaterLevel1	OWLTAB1		Uniform	-		60	120
	Y2	Resistance2	DRARES2	d	Lognormal	300	25		
		WaterLevel2	OWLTAB2		Uniform			60	100
Soil hetero-geneity	F	Mobile fraction	FM1,FM2	-	Uniform			0.6	1.0

Table A1.2 Potatoes on sand

Process	Input-parameter				Distribution	Mean	CV or s.d.	Min.	Max
	Symbol	Description	Code-name	Unit			(%) or -		
Soil physics	θ_{sat1}	Sat.Moist.1	COFGEN(2)	$m^3.m^{-3}$	Uniform			0.39	0.47
	K_{sat1}	Sat.Hyd.Cond.1.	COFGEN(3)	$cm.d^{-1}$	Lognormal	9.441	6.157		
	θ_{sat2}	Sat. Moist. 2		$m^3.m^{-3}$	Uniform			0.33	0.42
	K_{sat2}	Sat. Hyd. Cond. 2.		$cm.d^{-1}$	Lognormal	16.482	3.475		
Transpi-ration		CropFactor	CFET		Beta	1.0	15	0.8	1.2
		Dvs max Drz	RDTB X(2)	-	Beta	1.0	15	0.5	1.5
		Max Drz	RDTB Y(2)		Beta	0.5	15	0.2	0.8
		GrowthCurve	GCTB X(2)		Beta	1.0	15	0.5	1.5
			GCTB Y(2)		Beta	4	15	0.3	6
			C = Y(3)/Y(2)	-	Uniform			0	1
Drainage	Y1	Resistance1	DRARES1	d	Lognormal	1000	25		
		WaterLevel1	OWLTAB1		Uniform	-		60	120
	Y2	Resistance2	DRARES2	d	Lognormal	300	25		
		WaterLevel2	OWLTAB2		Uniforom			60	100
Soil hetero-geneity	F	Mobile fraction	FM1,FM2	-	Uniform			0.6	1.0

Table A1.3 Potatoes on clay.

Process	Input-parameter				Distribution	Mean	CV or s.d.	Min.	Max
	Symbol	Description	Code-name	Unit			(%) or -		
Soil physics	θ_{sat1}	Sat.Moist.1	COFGEN(2)	$m^3.m^{-3}$	Uniform			0.40	0.47
	K_{sat1}	Sat.Hyd.Cond.1.	COFGEN(3)	$cm.d^{-1}$	Lognormal	4.266	3.2278		
	θ_{sat2}	Sat. Moist. 2		$m^3.m^{-3}$	Uniform			0.42	0.56
	K_{sat2}	Sat. Hyd. Cond. 2		$cm.d^{-1}$	Lognormal	4.467	30.9		
Transpi-ration		CropFactor	CFET		Beta	1.0	15	0.8	1.2
		Dvs max Drz	RDTB X(2)	-	Beta	1.0	15	0.5	1.5
		Max Drz	RDTB Y(2)		Beta	0.5	15	0.2	0.8
		GrowthCurve	GCTB X(2)		Beta	1.0	15	0.5	1.5
			GCTB Y(2)		Beta	4	15	0.3	6
			C = Y(3)/Y(2)	-	Uniform			0	1
Drainage	Y1	Resistance1	DRARES1	d	Lognormal	1000	25		
		WaterLevel1	OWLTAB1		Uniform	-		60	120
	Y2	Resistance2	DRARES2	d	Lognormal	300	25		
		WaterLevel2	OWLTAB2		Uniform			60	100
Soil hetero-geneity	F	Mobile fraction	FM1,FM2	-	Uniform			0.6	1.0

Table A1.4 Grass on clay

Proces	Input-parameter				Distribution	Mean	CV or s.d.	Min.	Max
	Symbol	Description	Code-name	Unit			(%) or -		
Soil physics	θ_{sat1}	Sat.Moist.1	COFGEN(2)	$m^3.m^{-3}$	Uniform			0.40	0.47
	K_{sat1}	Sat.Hyd.Cond.1	COFGEN(3)	$cm.d^{-1}$	Lognormal	4.266	3.2278		
	θ_{sat2}	Sat. Moist. 2		$m^3.m^{-3}$	Uniform			0.42	0.56
	K_{sat2}	Sat. Hyd. Cond. 2		$cm.d^{-1}$	Lognormal	4.467	30.9		
Transpi-ration		CropFactor	CFET		Beta	1.0	15	0.8	1.2
		Dvs max Drz	RDTB X(2)	-	Beta	1.0	15	0.5	1.5
		Max Drz	RDTB Y(2)		Beta	0.3	15	0.15	0.5
		GrowthCurve	GCTB X(2)		Beta	1.0	15	0.5	1.5
			GCTB Y(2)		Beta	4	15	0.3	5
			C = Y(3)/Y(2)	-	Uniform			0	1
Drainage	Y1	Resistance1	DRARES1	d	Lognormal	1000	25		
		WaterLevel1	OWLTAB1		Uniform	-		60	120
	Y2	Resistance2	DRARES2	d	Lognormal	300	25		
		WaterLevel2	OWLTAB2		Uniform			60	100
Soil hetero-geneity	F	Mobile fraction	FM1,FM2	-	Beta			0.6	1.0

Table A1.5 Potatoes on peat

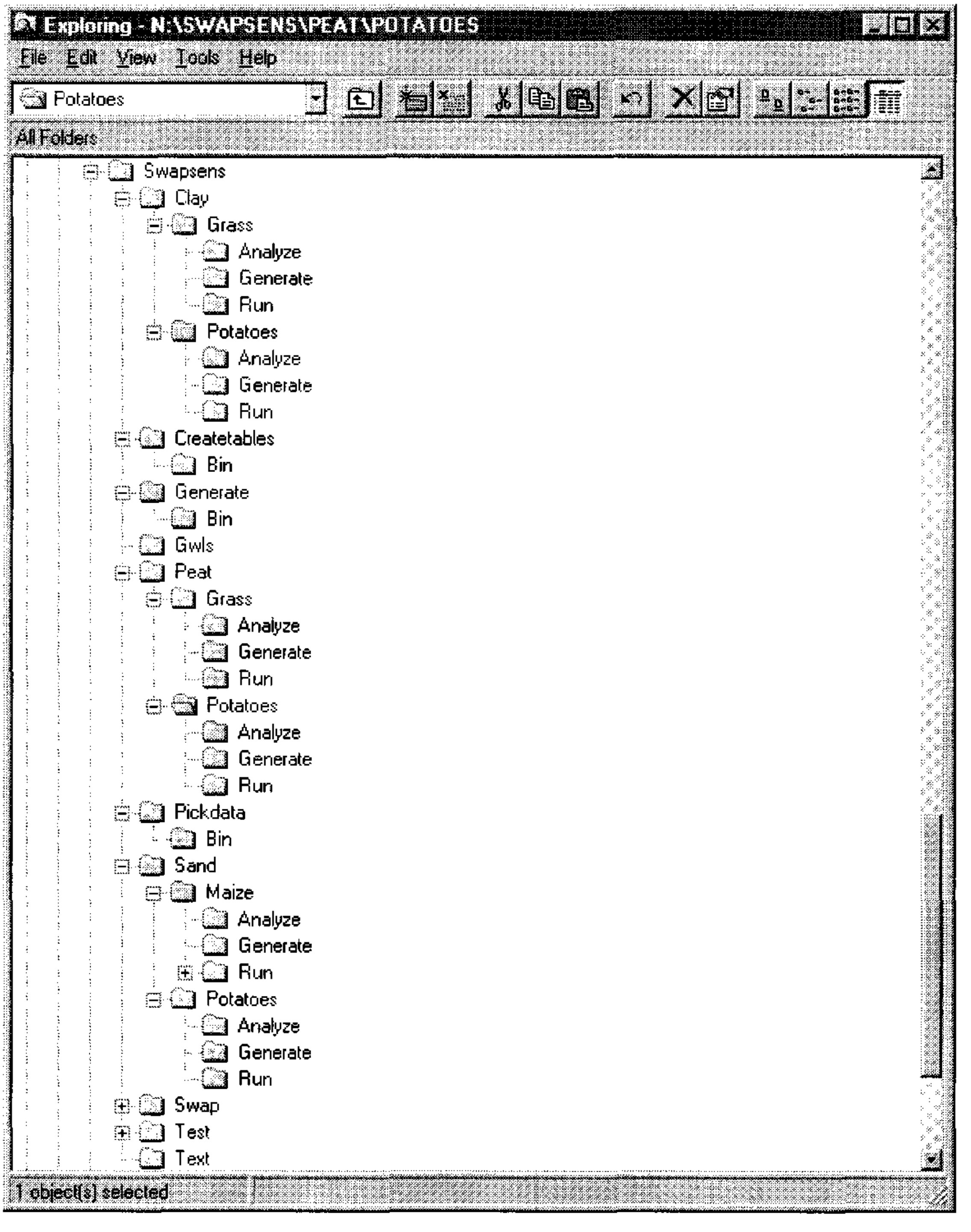
Proces	Input-parameter				Distribution	Mean	CV or s.d.	Min.	Max
	Symbol	Description	Code-name	Unit			(%) or -		
Soil physics	θ_{sat1}	Sat.Moist.1	COFGEN(2)	$m^3.m^{-3}$	Uniform			0.39	0.47
	K_{sat1}	Sat.Hyd.Cond.1	COFGEN(3)	$cm.d^{-1}$	Lognormal	9.441	6.157		
	θ_{sat2}	Sat. Moist. 2		$m^3.m^{-3}$	Uniform			0.85	0.95
	K_{sat2}	Sat. Hyd. Cond. 2		$cm.d^{-1}$	Lognormal	2.084	5.573		
	θ_{sat3}	Sat. Moist. 3		$m^3.m^{-3}$	Uniform			0.33	0.42
	K_{sat3}	Sat. Hyd. Cond. 3		$cm.d^{-1}$	Lognormal	16.482	3.475		
Transpi-ration		CropFactor	CFET		Beta	1.0	15	0.8	1.2
		Dvs max Drz	RDTB X(2)	-	Beta	1.0	15	0.5	1.5
		Max Drz	RDTB Y(2)		Beta	0.5	15	0.2	0.8
		GrowthCurve	GCTB X(2)		Beta	1.0	15	0.5	1.5
			GCTB Y(2)		Beta	4	15	0.3	6
			C = Y(3)/Y(2)	-	Uniform			0	1
Drainage	Y1	Resistance1	DRARES1	d	Lognormal	1000	25		
		WaterLevel1	OWLTAB1		Uniform	-		60	120
	Y2	Resistance2	DRARES2	d	Lognormal	300	25		
		WaterLevel2	OWLTAB2		Uniform			60	100
Soil hetero-geneity	F	Mobile fraction	FM1,FM2	-	Uniform			0.6	1.0

Table A1.6 Grass on peat

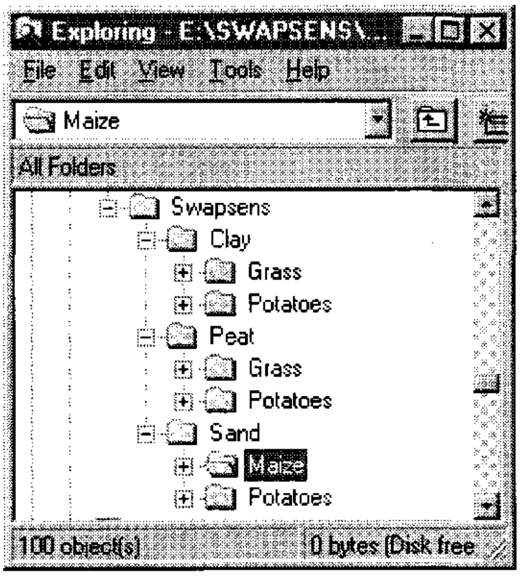
Proces	Input-parameter				Distribution	Mean	CV or s.d.	Min.	Max
	Symbol	Description	Code-name	Unit			(%) or -		
Soil physics	θ_{sat1}	Sat.Moist.1	COFGEN(2)	$m^3.m^{-3}$	Uniform			0.39	0.47
	K_{sat1}	Sat.Hyd.Cond.1	COFGEN(3)	$cm.d^{-1}$	Lognormal	9.441	6.157		
	θ_{sat2}	Sat. Moist. 2		$m^3.m^{-3}$	Uniform			0.85	0.95
	K_{sat2}	Sat. Hyd. Cond. 2		$cm.d^{-1}$	Lognormal	2.084	5.573		
	θ_{sat3}	Sat. Moist. 3		$m^3.m^{-3}$	Uniform			0.33	0.42
	K_{sat3}	Sat. Hyd. Cond. 3		$cm.d^{-1}$	Lognormal	16.482	3.475		
Transpi-ration		CropFactor	CFET		Beta	1.0	15	0.8	1.2
		Dvs max Drz	RDTB X(2)	-	Beta	1.0	15	0.5	1.5
		Max Drz	RDTB Y(2)		Beta	0.3	15	0.15	0.5
		GrowthCurve	GCTB X(2)		Beta	1.0	15	0.5	1.5
			GCTB Y(2)		Beta	4	15	0.3	6
			C = Y(3)/Y(2)	-	Uniform			0	1
Drainage	Y1	Resistance1	DRARES1	d	Lognormal	1000	25		
		WaterLevel1	OWLTAB1		Uniform	-		60	120
	Y2	Resistance2	DRARES2	d	Lognormal	300	25		
		WaterLevel2	OWLTAB2		Uniform			60	100
Soil hetero-geneity	F	Mobile fraction	FM1,FM2	-	Uniform			0.6	1.0

Annex 2 The directory structure applied in this study

The directory structure at the N-disk looks as follows:



All processed output will be stored here as well. The disk quota of this disk was insufficient to store all input for and output from Swap. So this should be stored on one of the scratch-disks. There a SwapSens directory was created that looks as follows:



At the lowest level each directory is divided into a number of subdirectories again with the names run001 to run100.

Annex 3 The program Genpars.gen

```
job  'genpars'
\ generate the parameters for the input of Swap (sensitivity project)
\ Maize on Sand
\ Version 22-Jan-1998

scalar cv; 25
scalar cvbeta; 15
scalar NValues; 100
scalar NVars ; 18
scalar seed; 421234
Symmetric [NVars] rc;
variate [NValues] uni[1...NVars], Ksat1, ThetaS1, CAlpha1, Ksat2, ThetaS2, \
                  CAlpha2, fm1, fm2, CFET, GCTBX2, GCTBY2, GCTBY3, \
                   RDTBX, RDTBY, Level1, Resist1, Level2, Resist2

for i=1...NVars
  for j=1...i
    if j .ne. i
      calc rc$[i;j]=0
    else
     calc rc$[i;j]=1
    endif
  endfor
endfor

\ first generate the uniform part
unitcube [nvar=NVars; nval=NValues; method=iman; rcor=rc; strat=latin; \
  seed=seed] variates=uni

\ Now generate the Swap-values
\ the theta-s values for the top layer (B2)
calc mu = 0.4246
edcontinuous [dist=uniform; lower=0.39; upper=0.47]  \
     ThetaS1; uni[1]

\ the Ksat-values for the top layer (B2)
calc mu = 9.441
calc deviat = 6.157
calc sigma2 = deviat * deviat
print mu, sigma2
edcontinuous [dist=lognormal; mean=mu; variance=sigma2] Ksat1; uni[2]

\ The alfa-conversion for the upper layer
calc mu = 2
calc deviat = cvbeta * mu / 100.0
calc sigma2 = deviat * deviat
print mu, sigma2
edcontinuous [dist=beta; mean=mu; var=sigma2; lower=1; upper=10] \
  CAlpha1; uni[3]

\ the theta-s values for the lower layer (O2)
calc mu = 0.378
edcontinuous [dist=uniform; lower=0.33; upper=0.42]\
    ThetaS2; uni[4]

\ the Ksat-values for the lower layer (O2)
calc mu = 16.482
calc deviat = 3.475
calc sigma2 = deviat * deviat
print mu, sigma2
edcontinuous [dist=lognormal; mean=mu; variance=sigma2] Ksat2; uni[5]

\ The alfa-conversion for the lower layer
calc mu = 2
calc deviat = cvbeta * mu / 100.0
calc sigma2 = deviat * deviat
print mu, sigma2
```

```
edcontinuous [dist=beta; mean=mu; var=sigma2; lower=1; upper=10] CAlpha2; uni[6]

\ immobile fms
edcontinuous [dist=uniform; lower=0.6; upper=1] fm1; uni[7]
edcontinuous [dist=uniform; lower=0.6; upper=1] fm2; uni[8]

\ The CGTB-values
calc mu = 1
calc deviat = cvbeta * mu / 100.0
calc sigma2 = deviat * deviat
print mu, sigma2
edcontinuous [dist=beta; mean=mu; var=sigma2; lower=0.5; upper=1.5] \
  GCTBX2; uni[9]
calc mu = 4
calc deviat = cvbeta * mu / 100.0
calc sigma2 = deviat * deviat
print mu, sigma2
edcontinuous [dist=beta; mean=mu; var=sigma2; lower=0.3; upper=8] \
  GCTBY2; uni[10]
Calculate GCTBY3 = GCTBY2 * uni[11];

\ the rooting depth
calc mu = 1
calc deviat = cvbeta * mu / 100.0
calc sigma2 = deviat * deviat
print mu, sigma2
edcontinuous [dist=beta; mean=mu; var=sigma2; lower=0.5; upper=1.5] \
  RDTBX; uni[12]
calc mu = 60
calc deviat = cvbeta * mu / 100.0
calc sigma2 = deviat * deviat
print mu, sigma2
edcontinuous [dist=beta; mean=mu; var=sigma2; lower=20; upper=100] \
  RDTBY; uni[13]

\ crop factor
calc mu = 1
calc deviat = cvbeta * mu / 100.0
calc sigma2 = deviat * deviat
print mu, sigma2
edcontinuous [dist=beta; mean=mu; var=sigma2; lower=0.8; upper=1.2] \
  CFET; uni[14]

\ the waterlevels for the primary drainage system
edcontinuous [dist=uni; lower=60; upper=120] Level1; uni[15]

\ the resistances for the primary system
calc mu = 1000.0
calc deviat = cv * mu / 100.0
calc sigma2 = deviat * deviat
print mu, sigma2
edcontinuous [dist=lognormal; mean=mu; variance=sigma2] Resist1; uni[16]

\ the waterlevels for the secondary drainage system
edcontinuous [dist=uni; lower=60; upper=100] Level2; uni[17]

\ the resistances for the secondary system
calc mu = 300
calc deviat = cv * mu / 100.0
calc sigma2 = deviat * deviat
print mu, sigma2
edcontinuous [dist=gamma; mean=mu; variance=sigma2] Resist2; uni[18]

open    name='Soil.var'; channel=2; filetype=output
print   [channel=2] ThetaS1, Ksat1, CAlpha1, ThetaS2, Ksat2, CAlpha2,\
         fm1, fm2; fieldwidth=8(10); decimals=8(3);
close    Channel=2; Filetype=output

open    name='Crop.var'; channel=2; filetype=output
print   [channel=2] GCTBX2, GCTBY2, GCTBY3, RDTBX, RDTBY, CFET; \
```

```
        fieldwidth=6(10); decimals=6(3);
close   Channel=2; Filetype=output

open    name='Drain.var'; channel=2; filetype=output
print   [channel=2] Level1, Resist1, Level2, Resist2; \
          fieldwidth=4(15); decimals=4(3);
close   Channel=2; Filetype=output

stop
```

Annex 4 The output files of GenPars.gen

The file soil.var:

ThetaS1	Ksat1	CAlpha1	ThetaS2	Ksat2	CAlpha2	fm1	fm2
0.462	14.422	2.755	0.414	13.327	2.107	0.655	0.945
0.398	13.443	2.029	0.389	12.716	2.049	0.889	0.620
0.453	5.198	1.545	0.350	16.186	2.002	0.657	0.707
0.463	4.530	1.749	0.412	15.479	1.530	0.831	0.665
0.446	20.062	2.325	0.365	13.864	1.963	0.874	0.640
0.417	9.247	1.756	0.351	16.603	2.121	0.921	0.767
	.						
	.						
	.						
0.455	3.404	1.843	0.407	16.268	1.380	0.882	0.738
0.428	14.137	2.139	0.393	13.438	2.291	0.726	0.709
0.420	9.904	1.903	0.354	12.759	2.449	0.941	0.825
0.411	5.144	2.233	0.374	16.648	1.994	0.939	0.987
0.418	12.761	1.827	0.332	12.604	1.972	0.966	0.890
0.409	15.562	2.522	0.352	11.978	2.080	0.690	0.896

The file crop.var:

GCTBX2	GCTBY2	GCTBY3	RDTBX	RDTBY	CFET
1.124	3.928	3.341	1.284	59.766	0.869
0.970	3.805	2.097	1.008	64.481	1.194
1.134	4.543	1.174	1.243	45.558	1.123
1.094	2.910	2.113	1.039	46.925	1.178
1.150	4.033	2.662	1.159	50.985	0.989
	.				
	.				
	.				
1.052	4.610	2.327	1.086	62.200	1.198
1.157	4.074	2.095	0.960	57.752	1.155
0.799	4.101	1.713	1.321	40.513	1.165
0.977	4.417	3.596	0.980	36.995	1.127
1.375	3.713	0.746	1.148	79.491	1.019

The file drain.var:

Level1	Resist1	Level2	Resist2
66.173	733.949	70.537	283.556
80.658	772.544	81.204	316.507
68.681	797.190	78.327	253.731
68.212	902.039	91.227	325.515
111.755	928.227	80.549	195.997
114.601	897.652	93.757	372.511
	.		
	.		
	.		
88.031	1284.785	93.044	186.612
71.436	1166.833	72.983	230.066
61.175	853.136	74.230	395.004
115.980	1037.085	72.622	199.952
102.321	1538.209	71.447	355.484
92.639	820.735	94.844	294.176

Annex 5 The output files of PickData

As all files look the same (except the groundwater level file), here only the file with actual plant evaporation data will be presented.

1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	
198	241	204	178	149	217	162	178	249	224	2000
138	168	148	121	105	151	109	119	174	154	1387
176	213	184	150	129	189	121	151	219	197	1729
	.									
	.									
	.									
176	214	194	159	133	192	140	151	219	198	1776
170	210	173	127	124	181	112	145	217	190	1649
171	209	180	128	112	173	104	139	214	190	1620
196	238	216	179	175	215	166	184	245	222	2036

The file with groundwater data looks like follows:

Minimum	Average	Maximum	GLG	GHG	Gt
-127	-48.851	1	-95.9	-7.3	3a
-130	-44.423	1	-93.7	-3.3	3a
-121	-35.955	1	-80.4	-0.7	2*
-110	-32.141	1	-72.8	-0.6	2*
-122	-34.256	1	-78.3	-1.2	2*
-122	-36.018	1	-82.7	-1.5	3a
.					
.					
.					
-129	-44.715	1	-93.8	-3.2	3a
-140	-45.988	1	-96.4	-4.3	3a
-126	-36.169	1	-86.5	-0.5	3a
-135	-35.447	1	-85.3	-0.6	3a
-154	-62.702	1	-118.2	-9.6	3a

Annex 6 The program AnalPa rs.Gen

```
job  'analpars'
\ analyze the output of Swap (sensitivity project)
\ maize on sand
\ version 26-jan-1998

Text Gt
scalar Aantal; 100
scalar seed; 314509
scalar mv; value=*
pointer SoilVars; !p( ThetaS1, Ksat1, CAlpha1, \
                      ThetaS2, Ksat2, CAlpha2, fm1, fm2)
pointer CropVars; !p( GCTBX2, GCTBY2, GCTBY3, Rdtbx, Rdtby, Cfet)
pointer DraiVars; !p( Level1, Resist1, Level2, Resist2)
pointer AllVars; !p( ThetaS1, Ksat1, \
                 ThetaS2, Ksat2, fm1, GCTBX2, GCTBY2, \
                 GCTBY3, Rdtbx, Rdtby, Cfet, Level1, Resist1,\
                     Level2, Resist2)
pointer ALLVARS; !p( THETAS1, KSAT1,  \
                 THETAS2, KSAT2, FM1, GCTBX2, GCTBY2, \
                 GCTBY3, RDTBX, RDTBY, CFET, LEVEL1, RESIST1, \
                     LEVEL2, RESIST2)
variate  [Aantal} SoilVars[], CropVars[], DraiVars[], AllVars[], \
              Epa[1981...1990], EpaTot, \
              Esa[1981...1990], EsaTot, \
              Qd[1981...1990], QdTot, \
              Qd1[1981...1990], Qd1Tot,\
              Qd2[1981...1990], Qd2Tot,\
              GwlMin, GwlAve, GwlMax, GLG, GHG, \
              CPUTime, ElapTime
variate ALLVARS[]

Device  6

\ read the soil physical parameters
open    name='[wesseling.SwapSens.Sand.Maize.Generate]Soil.var'; \
      channel=2; filetype=input
Skip    [channel=2] 2
read    [channel=2] SoilVars[]
close   Channel=2; Filetype=input

\ read the crop parameters
open    name='[wesseling.SwapSens.Sand.Maize.Generate]Crop.var'; \
      channel=2; filetype=input
Skip    [channel=2] 2
read    [channel=2] CropVars[]
close   Channel=2; Filetype=input

\ read the drainage parameters
open    name='[wesseling.SwapSens.Sand.Maize.Generate]Drain.var';
\
      channel=2; filetype=input
Skip    [channel=2] 2
read    [channel=2] DraiVars[]
```

```
close   Channel=2; Filetype=input


\ check for a correlation between the parameters
correlate [cor=C; prin=*] AllVars[]
Calc    C = 100 * C
print   C; deci=0; field=4

\ investigate the actual soil evaporation
open    Name='Esa.sim'; Channel=2; Filetype=input
Skip    [channel=2] 1
read    [channel=2] Esa[1981...1990], EsaTot
close   Channel=2; Filetype=input

describe [selection=nval,nobs,min,max,mean,sd,%cv] EsaTot

subset [cond=(EsaTot .NE. mv)] new=ESATOT, ALLVARS[];
old=EsaTot,AllVars[]
suna    [method=spline; EDF=3] y=ESATOT; x=ALLVARS

\ investigate the actual plant evaporation
open    Name='Epa.sim'; Channel=2; Filetype=input
Skip    [channel=2] 1
read    [channel=2] Epa[1981...1990], EpaTot
close   Channel=2; Filetype=input

describe [selection=nval,nobs,min,max,mean,sd,%cv] EpaTot

subset [cond=(EpaTot .NE. mv)] new=EPATOT, ALLVARS[];
old=EpaTot,AllVars[]
suna    [method=spline; EDF=3] y=EPATOT; x=ALLVARS

\ investigate the drainage flux
open    Name='Qd.sim'; Channel=2; Filetype=input
Skip    [channel=2] 1
read    [channel=2] Qd[1981...1990], QdTot
close   Channel=2; Filetype=input

describe [selection=nval,nobs,min,max,mean,sd,%cv] QdTot

subset [cond=(QdTot .NE. mv)] new=QDTOT, ALLVARS[];
old=QdTot,AllVars[]
suna    [method=spline; EDF=3] y=QDTOT; x=ALLVARS

\ investigate the groundwater changes
open    Name='gwl.sim'; Channel=2; Filetype=input
Skip    [channel=2] 1
read    [channel=2] GwlMin, GwlAve, GwlMax, GLG, GHG, Gt
close   Channel=2; Filetype=input

describe [selection=nval,nobs,min,max,mean,sd,%cv] GwlMin

describe [selection=nval,nobs,min,max,mean,sd,%cv] GwlAve

describe [selection=nval,nobs,min,max,mean,sd,%cv] GwlMax
```

```
describe [selection=nval,nobs,min,max,mean,sd,%cv] GLG

describe [selection=nval,nobs,min,max,mean,sd,%cv] GHG


subset [cond=(GwlMin .NE. mv)] new=GWLMIN, ALLVARS[];
old=GwlMin,AllVars[]
suna    [method=spline; EDF=3] y=GWLMIN; x=ALLVARS

subset [cond=(GwlAve .NE. mv)] new=GWLAVE, ALLVARS[];
old=GwlAve,AllVars[]
suna    [method=spline; EDF=3] y=GWLAVE; x=ALLVARS

subset [cond=(GwlMax .NE. mv)] new=GWLMAX, ALLVARS[];
old=GwlMax,AllVars[]
suna    [method=spline; EDF=3] y=GWLMAX; x=ALLVARS

subset [cond=(GLG .NE. mv)] new=GLGx, ALLVARS[]; old=GLG,AllVars[]
suna    [method=spline; EDF=3] y=GLGx; x=ALLVARS

subset [cond=(GHG .NE. mv)] new=GHGx, ALLVARS[]; old=GHG,AllVars[]
suna    [method=spline; EDF=3] y=GHGx; x=ALLVARS

\ analyze the CPU-times
open    name='[wesseling.SwapSens.Sand.Maize.Analyze]Times.sim'; \
      channel=2; filetype=input
read    [channel=2] CPUTime, ElapTime
close   Channel=2; Filetype=input

describe [selection=nval,nobs,min,max,mean,sd,%cv] CPUTime

subset [cond=(QdTot .NE. mv)] new=CPUTIME, ALLVARS[];
old=CPUTime,AllVars[]
suna    [method=spline; EDF=3] y=CPUTIME; x=ALLVARS

\ write
open  Name='GWLS.DAT'; Channel=2; FileType=output
print [Channel=2] Level1, GwlAve
Close Channel=2; filetype=output

\ make some graphs
open    NAME='GwlAve.hpg'; Channel=6; Filetype=graphics
Axes    WINDOW=1; YTITLE='GwlAve (cm)'; XTITLE='Level1 (cm)'
dgraph  [Window=1; title=''] GwlAve; Level1
Close   Channel=6; Filetype=graphics


Stop
```

Annex 7 Statistical distribution of soil physical parameters for the different soil horizons (J.H.M. Wösten, 1997, personal communication)

The values of θ_{sat} and K_{sat} are distributed lognormal. The average μ and the standard deviation s.d. are presented in the following table of the ^{10}log-transformed values.

Table 7.1 The average and standard deviation of the transformed values of the saturated moisture content and the saturated hydraulic conductivity of the units of the Staring series.

	θ_{sat}			K_{sat}		
Unit	μ	s.d.	average	μ	s.d.	average
B1	-0.3807	0.0815	0.4162	1.3170	0.4688	20.7491
B2	-0.3720	0.0322	0.4246	0.9750	0.7900	9.4406
B3	-0.3471	0.0520	0.4497	1.2510	0.4959	17.8238
B4	-0.3790	0.0359	0.4178	1.7390	0.3280	54.8277
B7	-0.3845	0.0806	0.4126	1.1210	0.8912	13.2130
B8	-0.3607	0.0420	0.4358	0.7430	0.8204	5.5335
B9	-0.3630	0.0315	0.4335	0.9220	0.5743	8.3560
B10	-0.3660	0.0250	0.4305	0.6300	0.5089	4.2658
B11	-0.2146	0.0501	0.6101	0.6210	0.8586	4.1783
B12	-0.2581	0.0480	0.5520	0.9910	0.3469	9.7949
B14	-0.3752	0.0226	0.4215	0.1150	0.8356	1.3032
B16	-0.1349	0.0594	0.7330	1.1280	0.9889	13.4276
B17	-0.1393	0.0432	0.7256	0.6210	0.5839	4.1783
B18	-0.1150	0.0379	0.7674	0.8830	0.6251	7.6384
O1	-0.4410	0.0440	0.3622	1.5290	0.6620	33.8065
O2	-0.4220	0.0511	0.3784	1.2170	0.5410	16.4816
O3	-0.4600	0.0516	0.3467	1.5270	0.4360	33.6512
O4	-0.4451	0.0272	0.3588	1.7250	1.1629	53.0884
O5	-0.5000	0.0638	0.3162	1.6190	0.6270	41.5911
O6	-0.3842	0.1360	0.4129	0.7390	1.5157	5.4828
O8	-0.3353	0.0465	0.4621	1.3690	0.9986	23.3884
O9	-0.3294	0.0540	0.4684	1.0390	0.8104	10.9396
O10	-0.3098	0.0592	0.4900	0.6500	1.4900	4.4668
O11	-0.3707	0.0460	0.4259	1.6670	0.4558	46.4515
O12	-0.2503	0.0857	0.5620	0.7410	0.8876	5.5081
O13	-0.2424	0.0454	0.5723	1.3170	0.8647	20.7491
O14	-0.4227	0.0155	0.3778	-0.3460	0.2920	0.4508
O15	-0.3846	0.0185	0.4125	0.6180	0.8252	4.1495
O16	-0.0478	0.2116	0.8958	0.3190	0.7461	2.0845
O17	-0.0613	0.0274	0.8684	0.9130	0.6323	8.1846

Annex 8 The generated input parameters

Table A8.1. Generated input parameters for maize on sand

Name	Minimum	Mean	Maximum
ThetaS1	0.390	0.430	0.47
Ksat1	1.423	9.424	36.06
ThetaS2	0.331	0.375	0.42
Ksat2	9.250	16.470	28.07
Fm1	0.602	0.800	1.00
GCTBX2	0.671	1.001	1.38
GCTBY2	2.504	3.998	5.53
GCTBY3	0.009	2.000	4.99
Rdtbx	0.602	0.999	1.33
Rdtby	36.990	60.010	85.19
Cfet	0.800	1.000	1.20
Level1	60.030	89.990	119.67
Resist1	533.000	1001.000	1963.00
Level2	60.210	79.990	99.90
Resist2	146.900	300.700	559.30

Table A8.2. Generated input parameters for potatoes on sand

Name	Minimum	Mean	Maximum
ThetaS1	0.391	0.430	0.47
Ksat1	1.647	9.455	38.93
ThetaS2	0.331	0.375	0.42
Ksat2	8.970	16.490	29.47
fm1	0.602	0.800	1.00
GCTBX2	0.606	1.000	1.38
GCTBY2	2.433	4.000	5.32
GCTBY3	0.043	2.002	4.89
Rdtbx	0.629	1.000	1.33
Rdtby	31.920	49.980	68.11
Cfet	0.800	1.000	1.20
Level1	60.010	90.030	119.89
Resist1	513.200	998.900	1731.10
Level2	60.060	80.010	99.93
Resist2	152.100	300.000	509.70

Table A8.3. Generated input parameters for grass on clay

Name	Minimum	Mean	Maximum
ThetaS1	0.401	0.435	0.47
Ksat1	0.578	4.273	20.61
Calpha1	1.365	2.004	3.40
ThetaS2	0.421	0.490	0.56
Ksat2	0.002	4.661	190.86
Calpha2	1.386	2.000	2.92
fm1	0.602	0.800	1.00
fm2	0.603	0.800	1.00
GCTBX2	0.606	1.000	1.38
GCTBY2	2.190	4.001	4.94
GCTBY3	0.042	2.001	4.62
Rdtbx	0.629	1.000	1.33
Rdtby	19.830	29.990	41.44
Cfet	0.800	1.000	1.20
Level1	60.010	90.030	119.89
Resist1	513.200	998.900	1731.10
Level2	60.060	80.010	99.93
Resist2	152.100	300.000	509.70

Table A8.4. Generated input parameters for potatoes on clay

Name	Minimum	Mean	Maximum
ThetaS1	0.401	0.435	0.47
Ksat1	0.578	4.273	20.61
Calpha1	1.365	2.004	3.40
ThetaS2	0.421	0.490	0.56
Ksat2	0.002	4.661	190.86
Calpha2	1.386	2.000	2.92
fm1	0.602	0.800	1.00
fm2	0.603	0.800	1.00
GCTBX2	0.606	1.000	1.38
GCTBY2	2.433	4.000	5.32
GCTBY3	0.043	2.002	4.89
Rdtbx	0.629	1.000	1.33
Rdtby	31.920	49.980	68.11
Cfet	0.800	1.000	1.20
Level1	60.010	90.030	119.89
Resist1	513.200	998.900	1731.10
Level2	60.060	80.010	99.93
Resist2	152.100	300.000	509.70

Table A8.5 Generated input parameters for grass on peat.

Name	Minimum	Mean	Maximum
ThetaS1	0.391	0.430	0.47
Ksat1	1.647	9.455	38.93
ThetaS2	0.851	0.900	0.95
Ksat2	0.012	2.142	48.01
fm1	0.331	0.375	0.42
GCTBX2	0.629	1.000	1.33
GCTBY2	2.122	3.999	4.94
GCTBY3	0.006	1.992	4.54
Rdtbx	0.577	1.000	1.38
Rdtby	19.760	29.990	40.61
Cfet	0.800	1.000	1.20
Level1	60.560	90.000	119.51
Resist1	529.000	999.500	1805.20
Level2	60.090	79.980	99.68
Resist2	145.200	299.600	507.20

Table A8.6 Generated input parameters for potatoes on peat.

Name	Minimum	Mean	Maximum
ThetaS1	0.390	0.430	0.47
Ksat1	1.096	9.398	38.45
Calpha1	1.407	1.999	2.82
ThetaS2	0.851	0.900	0.95
Ksat2	0.024	2.049	34.52
Calpha2	1.407	1.999	2.83
fm1	0.331	0.375	0.42
fm2	8.210	16.520	32.22
GCTBX2	0.666	1.000	1.34
GCTBY2	1.610	3.992	5.33
GCTBY3	0.016	1.997	4.70
Rdtbx	0.644	1.000	1.33
Rdtby	33.240	50.020	68.51
Cfet	0.800	1.000	1.20
Level1	60.060	90.000	119.80
Resist1	518.000	999.900	1849.50
Level2	60.010	80.010	100.00
Resist2	136.400	299.600	504.50

Annex 9 Statistics of generated output parameters

Table A9.1. Output parameters for maize on sand

Variable	Number of values	Number of observations	Minimum	Mean	Maximum	s.d.	CV
EsaTot	100	100	1794.000	2043.330	2242.000	92.098	4.507
EpaTot	100	100	1861.000	2638.110	3242.000	267.077	10.124
QdTot	100	100	549.000	1276.500	2434.000	380.038	29.772
GwlMin	100	100	-197.000	-168.370	-136.000	11.377	-6.757
GwlAve	100	100	-88.794	-69.547	-48.445	8.220	-11.819
GwlMax	100	100	0.000	0.750	1.000	0.435	58.026
GLG	100	100	-154.600	-131.224	-100.200	9.814	-7.479
GHG	100	100	-28.800	-11.286	-3.000	5.332	-47.246
CPUTime	100	100	106.000	115.600	132.000	4.697	4.063

Table A9.2. Output parameters for potatoes on sand

Variable	Number of values	Number of observations	Minimum	Mean	Maximum	s.d.	CV
EsaTot	100	100	1781.000	2042.560	2236.000	90.764	4.444
EpaTot	100	100	1894.000	2593.691	3244.000	264.312	10.191
QdTot	100	100	451.000	1278.060	2273.000	377.216	29.515
GwlMin	100	100	-198.000	-166.730	-140.000	11.772	-7.061
GwlAve	100	100	-88.362	-68.864	-47.685	8.078	-11.731
GwlMax	100	100	0.000	0.830	1.000	0.378	45.485
GLG	100	100	-154.900	-129.975	-102.500	9.954	-7.659
GHG	100	100	-25.100	-10.146	-3.600	4.593	-45.266
CPUTime	100	100	106.000	117.870	142.000	6.986	5.927

Table A9.3 Output parameters for grass on clay

Variable	Number of values	Number of observations	Minimum	Mean	Maximum	s.d.	CV
EsaTot	100	94	888.000	1302.638	1807.000	172.921	13.275
EpaTot	100	94	2628.000	3396.405	3987.000	245.074	7.216
QdTot	100	94	254.000	730.479	1315.000	219.891	30.102
GwlMin	100	94	-345.000	-220.702	-140.000	45.705	-20.709
GwlAve	100	94	-148.781	-109.700	-85.374	14.230	-12.972
GwlMax	100	94	0.000	0.340	1.000	0.476	139.940
GLG	100	94	-248.600	-173.318	-121.400	29.133	-16.809
GHG	100	94	-59.300	-18.519	-9.600	7.182	-38.782
CPUTime	100	100	5.000	278.410	3600.000	684.946	246.021

Table A9.4 Output parameters for potatoes on clay

Variable	Number of values	Number of observations	Minimum	Mean	Maximum	s.d.	CV
EsaTot	100	92	1787.000	2056.684	2236.000	84.957	4.131
EpaTot	100	92	1910.000	2536.837	3199.000	250.014	9.855
QdTot	100	92	350.000	965.294	1809.000	281.324	29.144
GwlMin	100	92	-340.000	-224.500	-134.000	45.494	-20.265
GwlAve	100	92	-133.522	-100.072	-62.484	14.033	-14.023
GwlMax	100	92	0.000	0.620	1.000	0.488	78.790
GLG	100	92	-249.000	-177.097	-113.900	30.750	-17.363
GHG	100	92	-36.300	-11.254	-4.900	4.583	-40.720
CPUTime	100	100	5.000	341.440	3600.000	830.697	243.292

Table A9.5. Output parameters for grass on peat

Variable	Number of values	Number of observations	Minimum	Mean	Maximum	s.d.	CV
EsaTot	100	96	886.000	1295.427	1779.000	177.585	13.709
EpaTot	100	96	2702.000	3568.510	4054.000	270.486	7.580
QdTot	100	96	344.000	925.677	1905.000	278.039	30.036
GwlMin	100	96	-198.000	-155.094	-107.000	22.071	-14.231
GwlAve	100	96	-98.312	-78.943	-56.984	9.305	-11.787
GwlMax	100	96	0.000	0.365	1.000	0.484	132.710
GLG	100	96	-150.800	-121.464	-84.100	15.353	-12.640
GHG	100	96	-36.600	-18.907	-8.700	6.999	-37.017
CPUTime	100	100	110.000	273.050	3600.000	683.904	250.468

Table A9.6 Output parameters for potatoes on peat

Variable	Number of values	Number of observations	Minimum	Mean	Maximum	s.d.	CV
EsaTot	100	95	1849.000	2033.905	2324.000	91.945	4.521
EpaTot	100	95	1354.000	2550.537	3088.000	280.109	10.982
QdTot	100	95	531.000	1223.747	1972.000	355.043	29.013
GwlMin	100	95	-193.000	-151.095	-94.000	19.523	-12.921
GwlAve	100	95	-85.320	-68.818	-47.719	8.446	-12.273
GwlMax	100	95	0.000	0.526	1.000	0.502	95.372
GLG	100	95	-153.300	-122.203	-79.500	13.881	-11.359
GHG	100	95	-21.400	-8.753	-3.300	3.572	-40.807
CPUTime	100	99	53.000	258.323	3600.000	602.136	233.094

Annex 10 The Top marginal variances and ranking

Table A10.1. Top marginal variance and ranking for maize on sand.

	ESATOT		EPATOT		QDTOT		GWLMIN		GWLAVE		GWLMAX		GLGx		GHGx		CPUTIME	
Accounted		98.8		98.5		98.4		96.1		98.1		21.9		97.2		91.1		40.8
1	CGTBY3	66.1	CGTBY3	63.9	LEVEL1	58.0	CGTBY2	23.0	LEVEL1	43.6	KSAT1	18.0	CGTBY2	31.6	LEVEL1	49.5	KSAT1	32.4
2	CGTBY2	60.3	CGTBY2	55.4	RESIST1	36.4	CGTBY3	21.9	CGTBY2	24.6	GTBX2	5.5	CGTBY3	27.9	RESIST1	29.4	LEVEL1	10.3
3	LEVEL1	5.2	LEVEL1	5.4	CGTBY3	3.3	KSAT1	19.2	CGTBY3	19.9	RESIST1	5.1	LEVEL1	24.7	CGTBY2	9.2	CGTBY2	3.7
4	THETAS1	3.2	CGTBX2	1.7	CGTBY2	3.0	LEVEL1	12.7	RESIST1	11.9	RDTBY	2.5	THETAS1	8.7	CGTBY3	4.8	FM1	2.6
5	CGTBX2	2.0	THETAS1	1.6	THETAS1	0.8	FM1	12.4	THETAS1	3.8	CFET	1.9	KSAT1	6.8	THETAS1	2.8	LEVEL2	2.3
6	RDTBY	1.4	CFET	0.9	KSAT1	-	THETAS1	6.7	CGTBX2	2.8	CGTBY2	1.8	FM1	3.7	KSAT1	-	RESIST2	1.7
7	KSAT1	0.1	KSAT1	0.3	THETAS2	-	THETAS2	5.3	CFET	1.0	LEVEL1	1.0	THETAS2	2.9	THETAS2	-	RESIST1	1.5
8	THETAS2	-	THETAS2	-	KSAT2	-	KSAT2	1.9	THETAS2	0.8	CGTBY3	0.8	RESIST1	2.4	KSAT2	-	CGTBX2	0.7
9	KSAT2	-	KSAT2	-	FM1	-	CFET	1.9	LEVEL2	0.6	RDTBX	0.4	CFET	1.4	FM1	-	CGTBY3	0.4
10	FM1	-	FM1	-	CGTBX2	-	RESIST1	1.9	KSAT1	-	THETAS1	-	LEVEL2	0.8	CGTBX2	-	THETAS1	-
11	RDTBX	-	RDTBX	-	RDTBX	-	RDTBY	1.7	KSAT2	-	THETAS2	-	CGTBX2	0.2	RDTBX	-	THETAS2	-
12	CFET	-	RDTBY	-	RDTBY	-	LEVEL2	0.5	FM1	-	KSAT2	-	RDTBX	-	RDTBY	-	KSAT2	-
13	RESIST1	-	RESIST1	-	CFET	-	CGTBX2	-	RDTBX	-	FM1	-	RDTBX	-	CFET	-	RDTBX	-
14	LEVEL2	-	LEVEL2	-	LEVEL2	-	RDTBX	-	RDTBY	-	LEVEL2	-	RDTBY	-	LEVEL2	-	RDTBY	-
15	RESIST2	-	RESIST2	-	RESIST2	-	RESIST2	-	RESIST2	-	RESIST2	-	RESIST2	-	RESIST2	-	CFET	-

Table A10.2 Top marginal variance and ranking for potatoes on sand

	ESATOT		EPATOT		QDTOT		GWLMIN		GWLAVE		GWLMAX		GLGx		GHGx		CPUTIME	
Accounted		98.3		97.7		98.2		94.3		97.0		33.6		96.4		86.8		39.3
1	CGTBY3	64.0	CGTBY3	62.6	LEVEL1	57.9	KSAT1	27.9	LEVEL1	41.4	KSAT1	24.0	CGTBY2	29.2	LEVEL1	50.4	KSAT1	17.2
2	CGTBY2	55.3	CGTBY2	49.7	RESIST1	32.9	CGTBY2	20.5	CGTBY2	22.9	LEVEL1	6.5	CGTBY3	24.0	RESIST1	27.3	RESIST1	9.0
3	CGTBX2	4.8	CGTBX2	4.3	KSAT1	7.8	CGTBY3	16.3	CGTBY3	16.2	CGTBY2	6.1	LEVEL1	18.3	KSAT1	9.4	LEVEL1	3.9
4	THETAS1	3.1	THETAS1	1.7	CGTBY3	4.0	FM1	12.5	RESIST1	9.1	RESIST1	5.0	KSAT1	12.1	CGTBY2	1.7	THETAS1	3.4
5	KSAT1	0.7	KSAT1	-	CGTBY2	0.3	THETAS2	4.6	KSAT1	7.3	THETAS2	4.2	FM1	5.5	LEVEL2	0.9	CGTBY3	2.6
6	THETAS2	-	THETAS2	-	KSAT2	0.1	THETAS1	3.9	CGTBX2	2.0	KSAT2	3.4	THETAS1	5.4	FM1	0.4	RESIST2	1.8
7	KSAT2	-	KSAT2	-	THETAS1	-	LEVEL1	3.9	THETAS1	1.7	RDTBX	0.8	RESIST1	1.5	THETAS1	-	CGTBX2	1.7
8	FM1	-	FM1	-	THETAS2	-	RESIST1	1.1	FM1	1.0	CGTBY3	0.3	CGTBX2	1.0	THETAS2	-	CGTBY2	0.6
9	RDTBX	-	RDTBX	-	FM1	-	CGTBX2	1.0	LEVEL2	0.4	THETAS1	-	THETAS2	0.6	KSAT2	-	RDTBY	0.4
10	RDTBY	-	RDTBY	-	CGTBX2	-	LEVEL2	0.1	CFET	0.3	FM1	-	KSAT2	-	CGTBX2	-	THETAS2	-
11	CFET	-	CFET	-	RDTBX	-	KSAT2	-	THETAS2	-	CGTBX2	-	RDTBX	-	CGTBY3	-	KSAT2	-
12	LEVEL1	-	LEVEL1	-	RDTBY	-	RDTBX	-	KSAT2	-	RDTBY	-	RDTBY	-	RDTBX	-	FM1	-
13	RESIST1	-	RESIST1	-	CFET	-	RDTBY	-	RDTBX	-	CFET	-	CFET	-	RDTBY	-	RDTBX	-
14	LEVEL2	-	LEVEL2	-	LEVEL2	-	CFET	-	RDTBY	-	LEVEL2	-	LEVEL2	-	CFET	-	CFET	-
15	RESIST2	-	RESIST2	-	RESIST2	-	RESIST2	-	RESIST2	-	RESIST2	-	RESIST2	-	RESIST2	-	LEVEL2	-

Table A10.3 Top marginal variance and ranking for grass on clay

	ESATOT		EPATOT		QDTOT		GWLMIN		GWLAVE		GWLMAX		GLGx		GHGx		CPUTIME	
Accounted		97.9		93.4		94.6		74.6		71.8		33.3		73.8		74.2		8.9
1	CGTBY2	70.7	CGTBY2	56.8	LEVEL1	54.9	KSAT2	73.8	KSAT2	42.4	KSAT1	11.5	KSAT2	70.2	LEVEL1	40.2	RDTBY	6.4
2	CGTBY3	43.4	CGTBY3	15.7	RESIST1	28.8	RESIST1	6.1	LEVEL1	11.3	LEVEL1	11.5	RESIST1	6.2	RESIST1	12.9	RESIST2	6.2
3	CGTBX2	3.6	KSAT1	14.1	KSAT1	4.8	KSAT1	2.7	CGTBY2	8.2	RESIST1	9.0	THETAS2	3.4	KSAT1	10.5	KSAT2	4.2
4	THETAS1	1.7	KSAT2	10.0	CGTBY2	3.1	THETAS2	2.6	RESIST1	5.0	RDTBY	5.1	THETAS1	2.2	CGTBY3	8.4	THETAS2	3.7
5	KSAT2	0.2	RDTBX	3.1	CGTBX2	1.2	THETAS1	1.8	THETAS1	3.3	CGTBY3	4.2	KSAT1	1.9	KSAT2	4.5	LEVEL2	3.5
6	KSAT1	-	RESIST2	2.5	CGTBY3	0.9	FM1	1.0	CGTBY3	3.3	KSAT2	3.2	FM1	1.3	RESIST2	4.5	RESIST1	2.9
7	THETAS2	-	CGTBX2	2.1	KSAT2	0.7	RESIST2	0.2	KSAT1	2.4	CGTBX2	2.0	RESIST2	0.1	CGTBY2	3.9	CGTBY2	0.1
8	FM1	-	THETAS1	0.5	THETAS1	-	CGTBX2	-	THETAS2	2.4	THETAS1	1.1	CGTBX2	-	RDTBX	1.3	THETAS1	-
9	RDTBX	-	RDTBY	0.5	THETAS2	-	CGTBY2	-	FM1	1.5	THETAS2	-	CGTBY2	-	CFET	1.0	KSAT1	-
10	RDTBY	-	THETAS2	-	FM1	-	CGTBY3	-	RDTBX	0.9	FM1	-	CGTBY3	-	THETAS1	0.6	FM1	-
11	CFET	-	FM1	-	RDTBX	-	RDTBX	-	CGTBX2	-	CGTBY2	-	RDTBX	-	FM1	0.4	CGTBX2	-
12	LEVEL1	-	CFET	-	RDTBY	-	RDTBY	-	RDTBY	-	RDTBX	-	RDTBY	-	LEVEL2	0.4	CGTBY3	-
13	RESIST1	-	LEVEL1	-	CFET	-	CFET	-	CFET	-	CFET	-	CFET	-	THETAS2	-	RDTBX	-
14	LEVEL2	-	RESIST1	-	LEVEL2	-	LEVEL1	-	LEVEL2	-	LEVEL2	-	LEVEL1	-	CGTBX2	-	CFET	-
15	RESIST2	-	LEVEL2	-	RESIST2	-	LEVEL2	-	RESIST2	-	RESIST2	-	LEVEL2	-	RDTBY	-	LEVEL1	-

Table A10.4 Top marginal variance and ranking for potatoes on clay

	ESATOT		EPATOT		QDTOT		GWLMIN		GWLAVE		GWLMAX		GLGx		GHGx		CPUTIME	
Accounted		99.0		96.0		96.3		74.1		78.7		26.7		74.2		80.7		4.5
1	CGTBY3	64.6	CGTBY3	57.0	LEVEL1	51.7	KSAT2	71.6	KSAT2	31.3	LEVEL1	13.3	KSAT2	67.7	LEVEL1	45.6	RDTBY	5.1
2	CGTBY2	58.9	CGTBY2	47.0	RESIST1	34.5	RESIST1	6.3	LEVEL1	17.5	KSAT1	8.4	RESIST1	6.2	RESIST1	19.8	LEVEL1	4.7
3	CGTBX2	6.9	CGTBX2	5.3	KSAT1	7.0	THETAS1	3.9	CGTBY3	16.2	CGTBY3	5.9	THETAS1	4.3	KSAT1	12.3	RESIST2	3.8
4	THETAS1	3.1	KSAT1	3.1	CGTBY3	2.7	KSAT1	2.3	CGTBY2	13.1	RESIST1	5.8	CGTBY3	2.4	CGTBY3	8.7	RESIST1	2.6
5	KSAT1	-	THETAS1	1.8	CGTBX2	1.1	THETAS2	1.5	THETAS1	5.9	CGTBY2	5.2	THETAS2	1.7	RESIST2	6.1	KSAT2	1.7
6	THETAS2	-	KSAT2	1.2	CGTBY2	0.8	CGTBY3	1.5	RESIST1	3.7	KSAT2	4.9	KSAT1	1.4	CGTBY2	2.5	THETAS2	1.4
7	KSAT2	-	RDTBY	1.2	THETAS1	-	RESIST2	1.0	KSAT1	2.1	RDTBY	3.3	RESIST2	1.2	CFET	1.0	CGTBX2	0.2
8	FM1	-	LEVEL2	0.5	THETAS2	-	FM1	0.5	LEVEL2	1.2	CFET	1.3	FM1	0.3	THETAS1	0.8	RDTBX	0.1
9	RDTBX	-	RDTBX	0.4	KSAT2	-	CGTBX2	-	FM1	0.6	THETAS1	-	CGTBY2	0.3	LEVEL2	0.8	THETAS1	-
10	RDTBY	-	RESIST2	0.3	FM1	-	CGTBY2	-	THETAS2	0.4	THETAS2	-	CGTBX2	-	FM1	0.4	KSAT1	-
11	CFET	-	THETAS2	-	RDTBX	-	RDTBX	-	RESIST2	0.2	FM1	-	RDTBX	-	THETAS2	-	FM1	-
12	LEVEL1	-	FM1	-	RDTBY	-	RDTBY	-	CGTBX2	-	CGTBX2	-	RDTBY	-	KSAT2	-	CGTBY2	-
13	RESIST1	-	CFET	-	CFET	-	CFET	-	RDTBX	-	RDTBX	-	CFET	-	CGTBX2	-	CGTBY3	-
14	LEVEL2	-	LEVEL1	-	LEVEL2	-	LEVEL1	-	RDTBY	-	LEVEL2	-	LEVEL1	-	RDTBX	-	CFET	-
15	RESIST2	-	RESIST1	-	RESIST2	-	LEVEL2	-	CFET	-	RESIST2	-	LEVEL2	-	RDTBY	-	LEVEL2	-

Table A10.5 Top marginal variance and ranking for grass on peat

	ESATOT		EPATOT		QDTOT		GWLMIN		GWLAVE		GWLMAX		GLGx		GHGx		CPUTIME	
Accounted		97.8		90.1		98.4		74.2		84.2		54.6		73.7		88.7		10.6
1	CGTBY2	73.1	CGTBY2	66.9	LEVEL1	55.5	KSAT2	72.4	LEVEL1	40.3	KSAT2	12.5	KSAT2	63.3	LEVEL1	47.7	KSAT2	14.3
2	CGTBY3	43.4	CGTBY3	17.8	RESIST1	24.0	RDTBY	7.2	KSAT2	20.1	LEVEL2	8.6	LEVEL1	7.8	RESIST1	16.0	RDTBY	5.5
3	RESIST2	3.7	KSAT2	15.1	CGTBY2	21.2	RESIST2	4.1	CGTBY2	9.4	THETAS3	5.5	RDTBY	6.6	KSAT2	7.8	THETAS2	5.3
4	CGTBX2	3.2	RESIST2	5.2	THETAS3	4.6	THETAS2	3.3	THETAS2	4.5	RDTBX	3.4	THETAS2	4.8	CGTBY2	5.8	CGTBY2	2.3
5	KSAT3	2.6	CGTBX2	2.5	CGTBY3	4.6	LEVEL2	1.8	RESIST1	3.6	THETAS1	3.3	RESIST2	3.2	CGTBY3	4.4	LEVEL1	1.3
6	FM1	0.1	KSAT3	1.9	THETAS1	3.6	CGTBY2	1.3	CGTBY3	3.1	KSAT3	2.4	CGTBY2	2.5	RESIST2	2.5	LEVEL2	0.9
7	THETAS1	-	LEVEL2	1.1	RDTBX	3.5	THETAS1	1.1	RESIST2	2.3	CGTBX2	2.4	LEVEL2	0.9	RDTBX	2.4	RDTBX	0.6
8	KSAT1	-	THETAS1	0.8	CGTBX2	0.1	LEVEL1	0.9	RDTBY	2.1	RESIST1	2.4	THETAS1	0.5	CGTBX2	1.4	THETAS1	-
9	THETAS2	-	THETAS2	0.3	KSAT1	-	THETAS3	0.6	CGTBX2	1.4	LEVEL1	2.1	KSAT1	-	THETAS2	0.7	KSAT1	-
10	KSAT2	-	RDTBY	0.2	THETAS2	-	KSAT1	-	KSAT3	0.5	RESIST2	2.0	THETAS3	-	KSAT3	0.6	THETAS3	-
11	THETAS3	-	THETAS3	0.1	KSAT2	-	KSAT3	-	THETAS1	-	CFET	1.9	KSAT3	-	THETAS1	-	KSAT3	-
12	RDTBX	-	KSAT1	-	KSAT3	-	FM1	-	KSAT1	-	CGTBY2	0.9	FM1	-	KSAT1	-	FM1	-
13	RDTBY	-	FM1	-	FM1	-	CGTBX2	-	THETAS3	-	KSAT1	0.8	CGTBX2	-	THETAS3	-	CGTBX2	-
14	CFET	-	RDTBX	-	RDTBY	-	CGTBY3	-	FM1	-	CGTBY3	0.8	CGTBY3	-	FM1	-	CGTBY3	-
15	LEVEL1	-	CFET	-	CFET	-	RDTBX	-	RDTBX	-	FM1	0.6	RDTBX	-	RDTBY	-	CFET	-
16	RESIST1	-	LEVEL1	-	LEVEL2	-	CFET	-	CFET	-	THETAS2	-	CFET	-	CFET	-	RESIST1	-
17	LEVEL2	-	RESIST1	-	RESIST2	-	RESIST1	-	LEVEL2	-	RDTBY	-	RESIST1	-	LEVEL2	-	RESIST2	-

Table A10.6 Top marginal variance and ranking for potatoes on peat

	ESATOT		EPATOT		QDTOT		GWLMIN		GWLAVE		GWLMAX		GLGx		GHGx		CPUTIME	
Accounted		97.7		97.6		97.8		77.2		93.7		26.2		78.9		85.7		28.6
1	CGTBY3	55.5	CGTBY2	56.8	LEVEL1	61.3	KSAT2	65.8	LEVEL1	41.7	LEVEL1	10.9	KSAT2	56.1	LEVEL1	46.6	RESIST1	14.1
2	CGTBY2	54.4	CGTBY3	56.2	RESIST1	36.6	CGTBY2	8.2	CGTBY2	18.0	RESIST1	10.3	CGTBY2	12.3	RESIST1	28.6	KSAT2	6.1
3	CGTBX2	3.3	KSAT2	6.9	CGTBY2	6.9	THETAS3	5.9	CGTBY3	14.4	KSAT2	5.8	THETAS3	8.0	THETAS3	7.1	LEVEL1	6.0
4	KSAT3	2.5	THETAS3	4.0	CGTBY3	3.5	FM1	5.2	RESIST1	12.8	THETAS3	4.7	CGTBY3	6.1	KSAT2	4.7	THETAS3	5.2
5	KSAT2	2.2	KSAT3	3.8	KSAT3	2.4	RESIST1	4.4	KSAT2	9.3	RDTBX	3.1	RESIST1	5.0	CGTBY2	3.6	THETAS2	4.6
6	THETAS3	1.2	THETAS2	1.6	RESIST2	1.6	CGTBY3	3.8	THETAS3	8.5	RDTBY	3.0	THETAS2	3.7	CGTBY3	3.0	RDTBX	3.7
7	CFET	1.1	CGTBX2	1.6	THETAS1	0.1	THETAS2	2.6	CGTBX2	1.4	LEVEL2	1.4	LEVEL1	3.7	RESIST2	1.2	FM1	2.5
8	THETAS2	0.6	CFET	0.1	KSAT1	-	RDTBX	1.2	RDTBY	1.0	CGTBY3	1.2	FM1	2.8	RDTBY	1.1	LEVEL2	1.5
9	LEVEL2	0.5	THETAS1	-	THETAS2	-	RESIST2	1.0	THETAS2	0.4	CGTBY2	0.9	RESIST2	0.4	THETAS1	-	CGTBY2	0.5
10	RESIST2	0.1	KSAT1	-	KSAT2	-	KSAT3	0.1	THETAS1	-	RESIST2	0.8	KSAT3	0.1	KSAT1	-	RDTBY	0.3
11	THETAS1	-	FM1	-	THETAS3	-	THETAS1	-	KSAT1	-	THETAS2	0.5	RDTBX	0.1	THETAS2	-	THETAS1	0.2
12	KSAT1	-	RDTBX	-	FM1	-	KSAT1	-	KSAT3	-	THETAS1	-	THETAS1	-	KSAT3	-	CGTBX2	0.1
13	FM1	-	RDTBY	-	CGTBX2	-	CGTBX2	-	FM1	-	KSAT1	-	KSAT1	-	FM1	-	KSAT1	-
14	RDTBX	-	LEVEL1	-	RDTBX	-	RDTBY	-	RDTBX	-	KSAT3	-	CGTBX2	-	CGTBX2	-	KSAT3	-
15	RDTBY	-	RESIST1	-	RDTBY	-	CFET	-	CFET	-	FM1	-	RDTBY	-	RDTBX	-	CGTBY3	-
16	LEVEL1	-	LEVEL2	-	CFET	-	LEVEL1	-	LEVEL2	-	CGTBX2	-	CFET	-	CFET	-	CFET	-
17	RESIST1	-	RESIST2	-	LEVEL2	-	LEVEL2	-	RESIST2	-	CFET	-	LEVEL2	-	LEVEL2	-	RESIST2	-