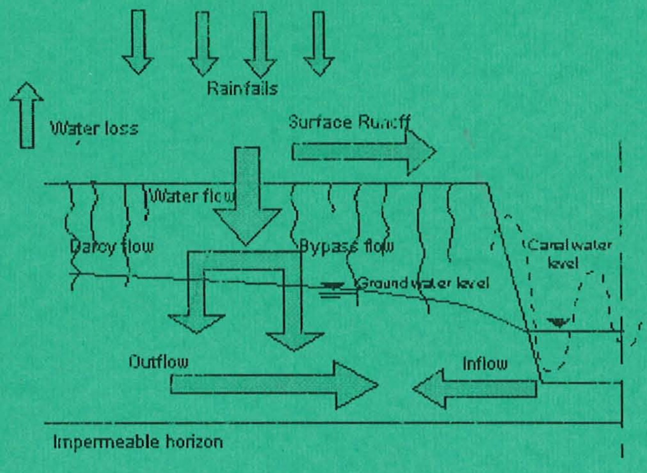
# Water Flow Paths During the Rainy Season in an Acid Sulphate Soil

## Field study in the Plain Reeds of the Mekong Delta, Vietnam

**Vo Khac Tri**

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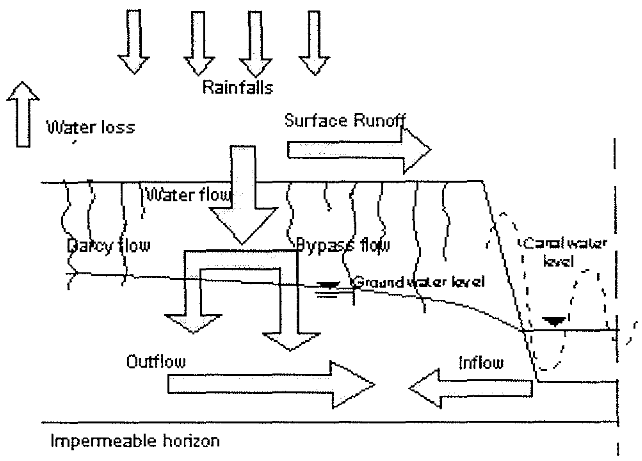


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# ABSTRACT

Management of acid sulphate soils is one of main problems in the search for sustainable development of the Mekong Delta. This study was carried out within the Management of Acid Sulfate Soil Project (MASSP) at Tan Thanh experimental farm situated in middle of the Plain of Reeds of the Mekong delta, Vietnam, from 1990 until now. The present study concentrated on water flow patterns through the soil profile especially in the rainy season, a time when the chemical and physical processes in acid sulphate soils are very important. With measurements in the field under the two controlling boundary conditions: local weather (upper boundary) and canal water levels (dynamic lower boundary), SOIL model was used as a tool to simulate soil water contents, matric potentials and the distribution of water flow in soils. The results showed an agreement between model simulations and measurements especially in ground water level and soil temperatures. However, simulation of the groundwater level became complicated since it was affected by the both high quantity of infiltration and the fluctuation of water flow from canals. The major part of the rain infiltrated and rarely formed soil surface runoff because of high storage capacity and high infiltration capacity. Partitioning between bypass flow and total water flow in the unsaturated part of the profile was estimated at about 50 %, 35 % and 20 % in 10, 20, 30 cm levels respectively. The water exchange between canal water and groundwater was established by the hydraulic gradient of flows (canal levels - ground levels). The ratios of inflow to outflow were about 4.5 from observed data and from simulated data. The reasonable value of the saturated hydraulic conductivity ($k_s$) used in the simulations was in the range of 1.4 - 1.8 cm $min^{-1}$ for distances to canals in the range of 1 to 5 m.

# 1 INTRODUCTION

## 1.1 Potentials and problems with acid sulfate soils

The area of acid sulphate soils (ASS) in the Mekong River Delta is in the range 1.6 - 1.8 million hectares. Development of this area during the last decade, much by trial and error, has contributed considerably to Vietnamese economic development. However, management of acid sulphate soils, especially for acid water drainage, is also one of main problems encountered in the search for reasonable strategies for sustainable development of this area. The reason is the high acidity, which during crucial periods causes serious problems for cultivation and the surrounding environment.

At the end of dry season when the groundwater level is lowered, cracks are created on the soil surface by high evaporation. Acid water from the deep soil layers is raised by capillary forces through the soil and precipitates acid salt on the soil surface (Sen, 1988). At this stage the rain season starts, with rainfalls of high intensity and frequency which dissolve salts precipitated on the soil surfaces and crack walls. Acid water movement is a source of pollution for both cultivated soils and fresh water resources in the canal network of neighbouring areas.

## 1.2 Hydrological background

Figure 1.1 is an overview of water flow patterns due to rainfall. When the first high rainfalls have moistened the soils and increased the groundwater level, then events of surface runoff may occur. If these early rainfalls continue with high intensity, they will induce water flow, which includes two flow patterns. Soil surface runoff will be formed when the intensity of rainfalls exceeds the saturated hydraulic conductivity or if the groundwater level is raised to the soil surface. The water inflow to soils will branch into two parts: matric flow occurs in soil micropores and bypass flow or 'short-circuiting' (Bouma and Dekker, 1978) which is the rapid downward flow in soil macropores which are formed by cracks and fissures when smaller pores are only partially filled with water. Bypass plays a significantly more important role in leaching aluminum from raised beds than runoff (Minh et al., 1996).

The matric water flow obeys Darcy's Law assuming a common water potential gradient as the governing force for the water flow in the entire pore system. Bypass flow in unsaturated soils will be zero if inflow is smaller than the rate of sorption by the soil aggregate. In saturated soils, where effective porosity is low, a rapid horizontal transfer of water to and from the canals is enabled because of the high saturated hydraulic conductivity. The water outflow/inflow between the soils and the canals is governed by the hydraulic gradient.

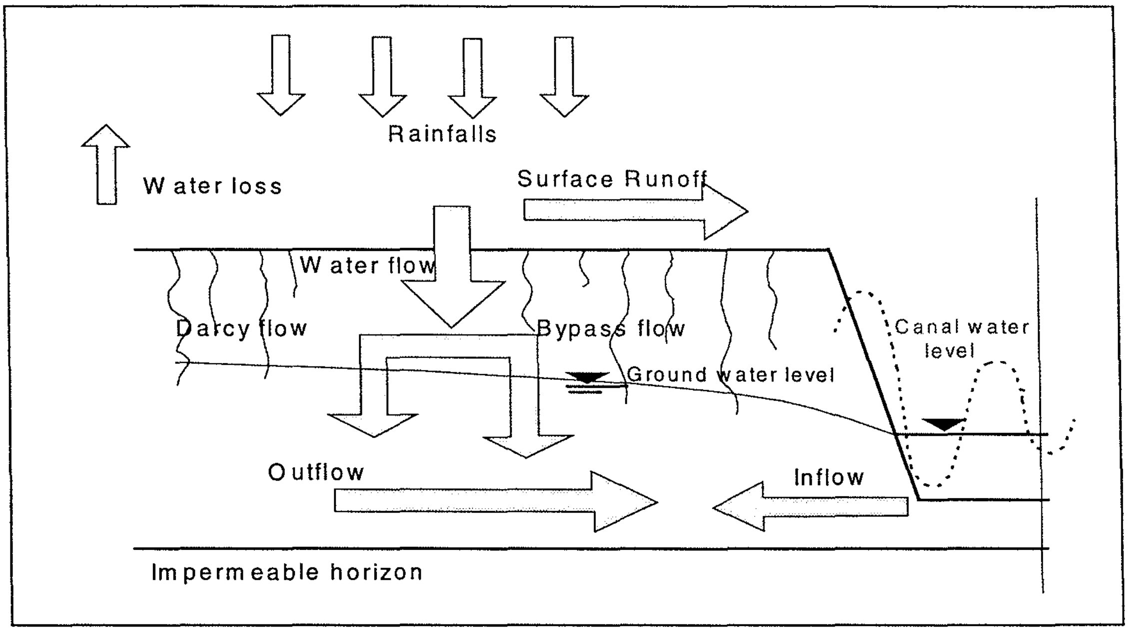



**Figure 1.1** The water flow pattern of the early rainfalls at the end of dry season.

### 1.3 Objectives

This study concentrated on quantification of the water flow patterns through the soil profile by measurement in the field under two controlling boundary conditions: local meteorology (upper boundary) and canal water levels (lower boundary). Specific aims were:

- To estimate partitioning of water pathways in the field.
- To quantify the surface run-off, by-pass flow, groundwater flow, and canal water flow as a part of the water balance.
- To evaluate the influence of high and frequent rainfalls on soils water during the transition from dry to wet soil conditions.

## 2 MATERIAL AND METHODS

### 2.1 Location of study area

The field site was located at Tan Thanh farm at 10°38'N and 106°2'E in Long An province in the Plain of Reeds of the Mekong Delta, Vietnam (Figure 2.1). The Tan Thanh experimental farm belongs to the Southern Institute of Water Resources Research (SIWRR). It has been set up under the financial support of SIDA (Sweden) through the Mekong River Commission Secretariat (MRC) within Management of Acid Sulfate Soil Project (MASS) from 1989 until now.

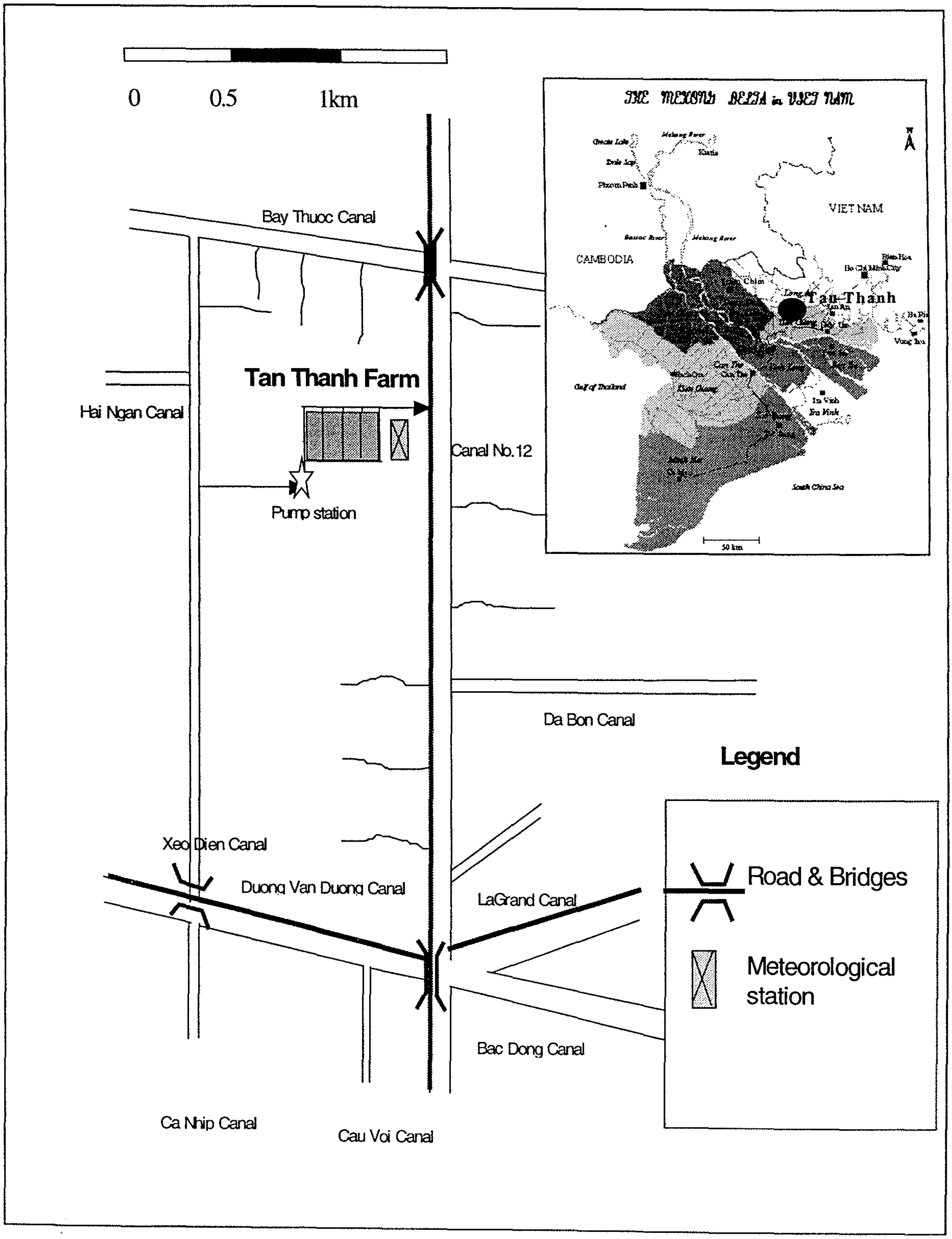



**Figure 2.1** The location of Tan Thanh experimental farm in The Mekong Delta of Vietnam.

## 2.2 Site characteristics and soil profile description

A preliminary investigation of soil profiles within the study area has been carried out within MASS project (Table 2.1).

**Table 2.1** A general introduction to Tan Thanh experimental farm

***Information on the site:***

| | |
|---|---|
| Classification | Typic Sulfaquept |
| Location | Tan Thanh farm, Long An, 4 km South West of Tan Thanh district, beside road No.49 |
| Elevation | AMSL (above mean sea level) 1.0 m |
| Water regime | Characterized by highly contrasting flood and dry seasons<br>Flood period: from Sept. to Dec.<br>Dry period: from Jan. to May<br>Inundation level: 0.6 - 1.0 m |
| Meteorology | Mean rainfall: 1,400 - 1,500 mm/year<br>Mean temperature: 26 – 27 °C<br>Sunshine hour: 6.5 - 9.5 hours/day<br>Evaporation: 1,600 mm/year |
| Land use | Almost abandoned with natural vegetation in this area such as *Malaleuca lecadendron (L.), Ischamum Indicum, Eleocharis Dulcis, Xyris Indica, Cyperus sp, Eucalyptus sp,...* some areas were cultivated with rice, sugarcane,... |

***Description of soil profile:***

| | |
|---|---|
| Ap1: 0 - 6 cm | clay, very dark brown (10YR 2/2), small fine granular blocky, slightly sticky, plastic, ripe, gradual boundary. |
| A2 : 6 - 15 cm | clay, black (10YR 2/1), small fine granular blocky, plastic, slightly sticky, ripe, clear boundary. |
| Bg1: 15 - 23 cm | clay, pink gray (7.5YR 7/2), little organic matter, non structure, plastic, slightly sticky, ripe, few yellow mottles (10YR 7/8) at 15 %, diffuse boundary. |
| Bg2: 23 - 48 cm | clay, pink white (7.5YR 8/2), small strong brown mottles (7.5YR 5/6) at 25 %, non structure, ripe, slightly sticky, very little organic matter, clear boundary. |
| Bg3: 48 - 72 cm | clay, pale brown (10YR 6/3), small yellowish brown mottles (10YR 5/6) at 30 %, jarosite mottles (5Y 8/6) at 7%, jarosite mottles are covered by small yellowish brown mottles, non structure, plastic, slightly sticky, half ripe, abrupt boundary. |
| C1 : 72 - 100cm | clay, brown (7.5YR 5/2), non structure, sticky, very few organic matter, common yellowish brown mottles (10YR 5/6) and jarosite mottles (5Y 8/6), unripe. |

## 2.3 Experimental setup

The measurements were mainly carried out on plot 4 (uncultivated, natural vegetation) on Tan Thanh experimental farm with an area about 0.6 ha (100 x 60 m). Adjacent canals (Fig. 2.2) surround the plot. Variation in these canal water levels in the study area was caused by the semi-diurnal tide regime from the East Sea.

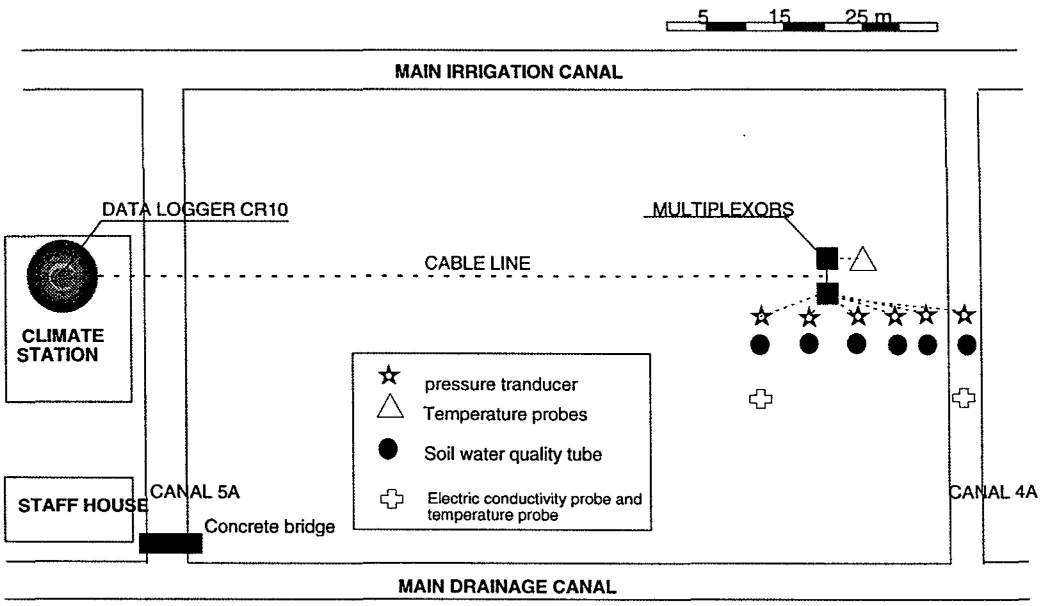



**Figure 2.2** Experimental set-up at Tan Thanh farm.

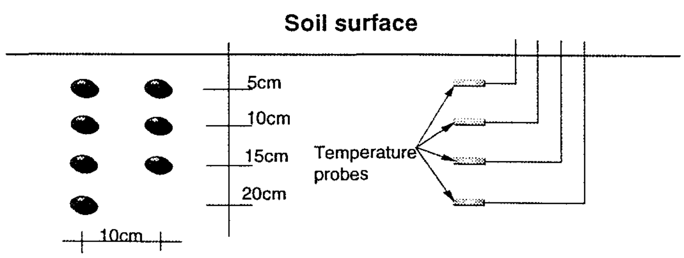



**Figure 2.3** Positions of temperature probes in soil profile.

The data logger Campbell CR10 with solar cells was installed at Tan Thanh farm next to the measuring plot to collect data on climate and water levels (Table 2.2). The monitoring system consists of a meteorological station and a set of sensors for soil and water (Fig. 2.2).

The latter include:

* Thermocouples to measure temperature in the soil profile and temperature in ground water and surface water.
* Pressure transducers to measure the ground water level at 2, 5, 8, 13 and 18 m distances from canal and the water level in canal.
* EC probes to measure electrical conductivity in the ground water and the canal water.

Thermocouples were installed in one soils profile at 5, 10, 15 and 20cm depths (Fig. 2.3)

Monitoring was carried out from 30 May to 10 Sept.1996. The output interval period was set at 30 min for sampling as arithmetic mean values from measurements every 30 seconds were used to produce mean values as shown in Table 2.2.

**Table 2.2** Logger measurement at Tan Thanh farm

| No | Measured variables | Output intervals | Notes |
|---|---|---|---|
| 1 | Precipitation, relative humidity, wind speed, air temperature, global radiation | Every 30 min. | Data logger Campbell CR10 |
| 2 | Canal water level, Ground water level, soils and water temperature, electric conductivity in ground and canal water. | Every 30 min. | Data logger Campbell CR10 |

## 2.4 Description of simulation model

In this study the SOIL model (Jansson, 1998) was used as a main tool to estimate the partitioning of water flow patterns during the transition period using experimental data (including climate and soils properties) obtained from Tan Thanh farm.

### 2.4.1 Soil water flow

The Darcy's equation for one-dimensional unsaturated flow is given by as:

$$q_w = -k_w\left(\frac{\partial\psi}{\partial z} - 1\right) \tag{1}$$

Where $q_w$ is the flow rate, $\psi$ is the water potential, and z is the vertical distance from the soils surface.

Combination of equation (1) and the law of mass conservation results in the general equation, which is an extension of Richard equation for unsaturated water flow:

$$\frac{\partial\theta}{\partial t} = -\frac{\partial q_w}{\partial z} + S_w \tag{2}$$

where $S_w$ is net water source/sink flow in soils, and $\theta$ is the volumetric water content.

In addition to the Darcy water flow as given by equation (1) a bypass water flow may be calculated. The infiltration flow rate at the soils surface or vertical flow at any depth in the soils profile, $q_{in}$, includes the ordinary Darcy flow, $q_{mat}$, and bypass flow, $q_{bypass}$ as shown in Fig 2.4.

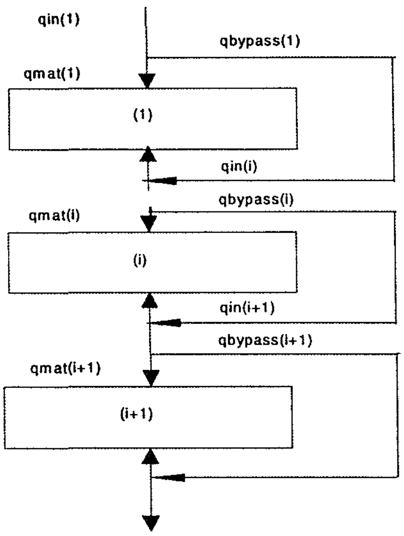



**Figure 2.4** Water flow path when bypass flow was considered.

$$q_{mat} = \max\left(k_w(\theta)\left(\frac{\partial\psi}{\partial z}+1\right), q_{in}\right) \qquad 0 < q_{in} < S_{mat} \qquad (3)$$

$$q_{bypass} = 0 \qquad 0 < q_{in} < S_{mat} \qquad (4)$$

$$q_{mat} = S_{mat} \qquad q_{in} \geq S_{mat} \qquad (5)$$

$$q_{bypass} = q_{in} - q_{mat} \qquad q_{in} \geq S_{mat} \qquad (6)$$

where $k(\theta)$ is the unsaturated conductivity at a given water content, $\Psi$ is the water potential and z is the depth co-ordinate. At all depths in the soil $q_{in}$ is the vertical flow rate in the macropores ($q_{bypass}$) from the layer immediately above. $S_{mat}$ (sorptivity capacity of aggregates) is defined as:

$$S_{mat} = a_{scale} . a_r . k_{mat} . pF \qquad (7)$$

where $k_{mat}$ is the maximum conductivity of smaller pores (i.e. matric pores), $a_r$ is the ratio between compartment thickness and the unit horizontal area represented by the model, pF is $^{10}\log$ of $\psi$ and $a_{scale}$ is an empirical scaling coefficient accounting for geometry of aggregates.

The calculated water flow in the matric pores ($q_{mat}$) is used to update the water contents and the water tensions in the numerical solution, whereas $q_{bypass}$ is directed without delay to the next soils compartment. However, $q_{bypass}$ can never reach layers below the ground table depth, which is the lower boundary condition for the use of Richard's equation.

### 2.4.2 Soil hydraulic properties

Two important functions of soils hydraulic properties are the water retention curve $\psi(\theta)$ and the unsaturated conductivity function $k_w(\theta)$ determined by experimental data on each soils type.

The function by Brooks & Corey (1964) is given by:

$$S_e = \left(\frac{\psi}{\psi_a}\right)^{-\lambda} \qquad (8)$$

Where $\psi_a$ is the air-entry pressure and $\lambda$ is the pore distribution index. $S_e$ (effective saturation) which is defined as:

$$S_e = \frac{\theta - \theta_r}{\theta_s - \theta_r} \tag{9}$$

Where $\theta_s$ is the porosity and $\theta_r$ is the residual water content.

In order to get a good fit in the whole range, Eqs. (8) and (9) are fitted only to data corresponding to potentials above a threshold value $\psi_x$. The relation between water content and potential below this threshold is assumed log-linear:

$$\frac{\log\left(\dfrac{\psi}{\psi_x}\right)}{\log\left(\dfrac{\psi_{wilt}}{\psi_x}\right)} = \frac{\theta_x - \theta}{\theta_x - \theta_{wilt}} \qquad \psi_{wilt} < \psi < \psi_x \tag{10}$$

Where $\theta_x$ ($=\theta(\psi_x)$) is the threshold water content and $\theta_{wilt}$ is the water content at wilting point, defined as a water potential of -15 000 cm water.

In the range close to saturation, i.e. from $\theta_s$ to $\theta_m$ a linear expression is used for the $\theta$ - $\psi$ relationship.

$$\psi = \psi_m - \frac{(\theta - \theta_s - \theta_m)}{\theta_m}\psi_m \tag{11}$$

Where $\psi_m$ is the potential which corresponds to a water content of $\theta_s$ - $\theta_m$.

Following Mualem (1976), and using the analytical expressions according to Brooks & Corey (8) and (9), the unsaturated conductivity is given by:

$$k_w = k_{mat} S_e^{(n+2+\frac{2}{\lambda})} \tag{12}$$

And

$$k_w = k_{mat}\left(\frac{\psi_a}{\psi}\right)^{2+(2+n)\lambda} \tag{13}$$

$k_{mat}$ is saturated conductivity and n is parameter accounting for pore correlation and flow path tortuosity. Eqs. (8) and (9) are used for water contents in the matric pores.

To account for the contribution of macropores, an additional contribution to the matric pore hydraulic conductivity is considered when water content exceeds $\theta_s$ - $\theta_m$.

$$k_w = 10^{\left(\log(k_w(\theta_s-\theta_m)) + \frac{\theta-\theta_s+\theta_m}{\theta_m}\log\left(\frac{k_{sat}}{k_w(\theta_s-\theta_m)}\right)\right)} \tag{14}$$

where $k_{sat}$ is the saturated conductivity which includes the macropores and $k_w(\theta_s$ - $\theta_m)$is the hydraulic conductivity calculated from Eqs. (12 -13).

Regarding to the temperature effect on the viscosity of water, the hydraulic conductivity is given by equation.

$$k_w = (r_{A0T} + r_{A1T}T_s)\max(k_w^*, k_{\min uc}) \tag{15}$$

Where $r_{A0T}$, $r_{A1T}$ and $k_{minuc}$ are parameter values. $k_w^*$ is the conductivity according to Eqs. (12 - 14).

### 2.4.3 Groundwater flow

The ground water flows are considered as a sink term in the one-dimensional structure of the model. Based on the equations presented by Hooghoudt (1940), the total flow to drains is given by:

$$q_{wc} = \frac{4k_{s1}(z_{sat} - z_p)^2}{d_c^2} + \frac{8k_{s2}z_D(z_{sat} - z_p)r_{corr(z)}}{d_c^2} \tag{16}$$

Where $k_{s1}$ and $k_{s2}$ are saturated conductivity in the horizon above and below drainage canals respectively, $z_D$ is the thickness of the layer below the drains and $d_c$ is the spacing between parallel drain canals.

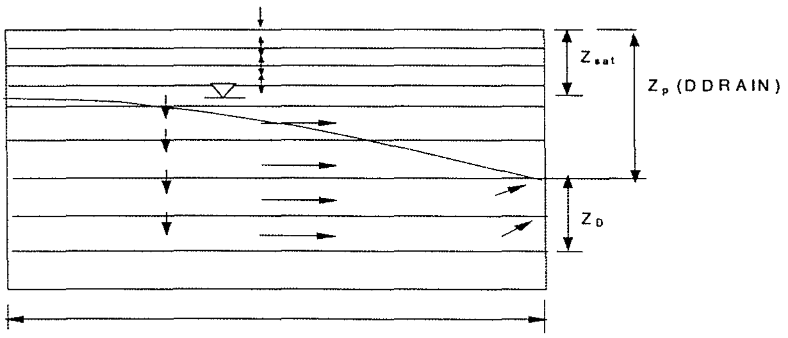



**Figure 2.5** The geometrical assumptions behind the groundwater flow towards a sink point in the saturated zone of the soil.

The correction factor $r_{corr}(z)$is based on estimated sums of the radial ($r_r$), horizontal ($r_h$) and vertical ($r_v$) resistance for each layer. The correction factor is then (GWFLOW 3 or 4 in the model) given as:

$$r_{corr}(z) = \frac{(r_v(z) + r_h(z) + r_r(z))\Delta z}{r_{href}\, z_D} \tag{17}$$

Where the $r_{href}$ is the horizontal resistance and $\Delta z$ is thickness of layer.

### 2.4.4 Boundary and initial conditions

*i. Upper boundary*

Water coming from precipitation infiltrates into the soils provided that the infiltration capacity is high enough. Otherwise a surface pool of water will be formed on the soils surface. Water in the surface pool can either infiltrate with a delay into the soils or be lost as surface runoff. The surface runoff, $q_{surf}$, is calculated as a first order rate process:

$$q_{surf} = a_{surf}\left(W_{pool} - w_{p\max}\right) \tag{18}$$

Where $a_{surf}$ is an empirical coefficient, $W_{pool}$ is the total amount of water in the surface pool and $w_{pmax}$ is the maximal amount, which can be stored on the soils surface without causing any surface runoff.

The fraction of the total soil surface that is covered with water ($f_{cspool}$) is given by

$$f_{cspool} = \frac{W_{pool}}{f_{w\mathrm{cov}\,tot}} \tag{19}$$

When the total amount a water is less then $f_{wcovtot}$ .

*ii. Lower boundary condition*

The vertical water flow from the lowest compartment may be calculated by a unit gradient i.e. by gravitational forces only or it may be assumed to be equal to zero. For the present application at Tan Thanh, it was assumed to be zero since the vertical hydraulic gradient is negligible for the Mekong Delta area.

*iii. Initial condition*

Initial values in the model include water content in each of the soil compartments, soils temperature, ground water level and drainage canal water level. Initial soil water content may be specified as a measured profile or as a constant value for the whole profile. Initial water contents may also be deduced from a soil water potential profile or from a constant, i.e., equilibrium potential in the whole profile.

## 2.5 Parameters of the simulation model

### 2.5.1 Soil hydraulic functions

The water retention curves for a 1 m deep soil profile (as described in Table 2.1) were obtained from soil cores taken from the field at Tan Thanh farm. The least-squares method was used to estimate the parameters $\lambda$, $\theta_r$ and $\psi_a$ in eqs. 8 & 9 of Brooks & Corey (1964) to experimental data. Good agreements with measured data were obtained (Figure 2.6). The porosity of soil samples was rather high in the top layer (0 -20 cm). The saturated hydraulic conductivity was estimated to 0.01cm $min^{-1}$ for the whole soil profile.

The saturated conductivity measured in the laboratory with two sample sizes of 5 cm and 16 cm diameter were assumed to represent the maximum vertical conductivity when macropores were taken into account. Data in Table 2.3 showed that the values of vertical $k_s$ including more macropores (in the larger sample size) were higher than that of smaller soil samples. The horizontal $k_s$ values were larger for 5 cm samples than for 16 cm samples in some cases. The variation between replicates was very large. An ANOVA was made so that means errors could be obtained from data (Table 2.4). The mean values of $k_s$ in the vertical direction from soil cores were about 0.02 cm/min for the whole profile. Note the low values of $k_s$ in the B1 layer (ploughed base layer) and C1 layer (impermeable).

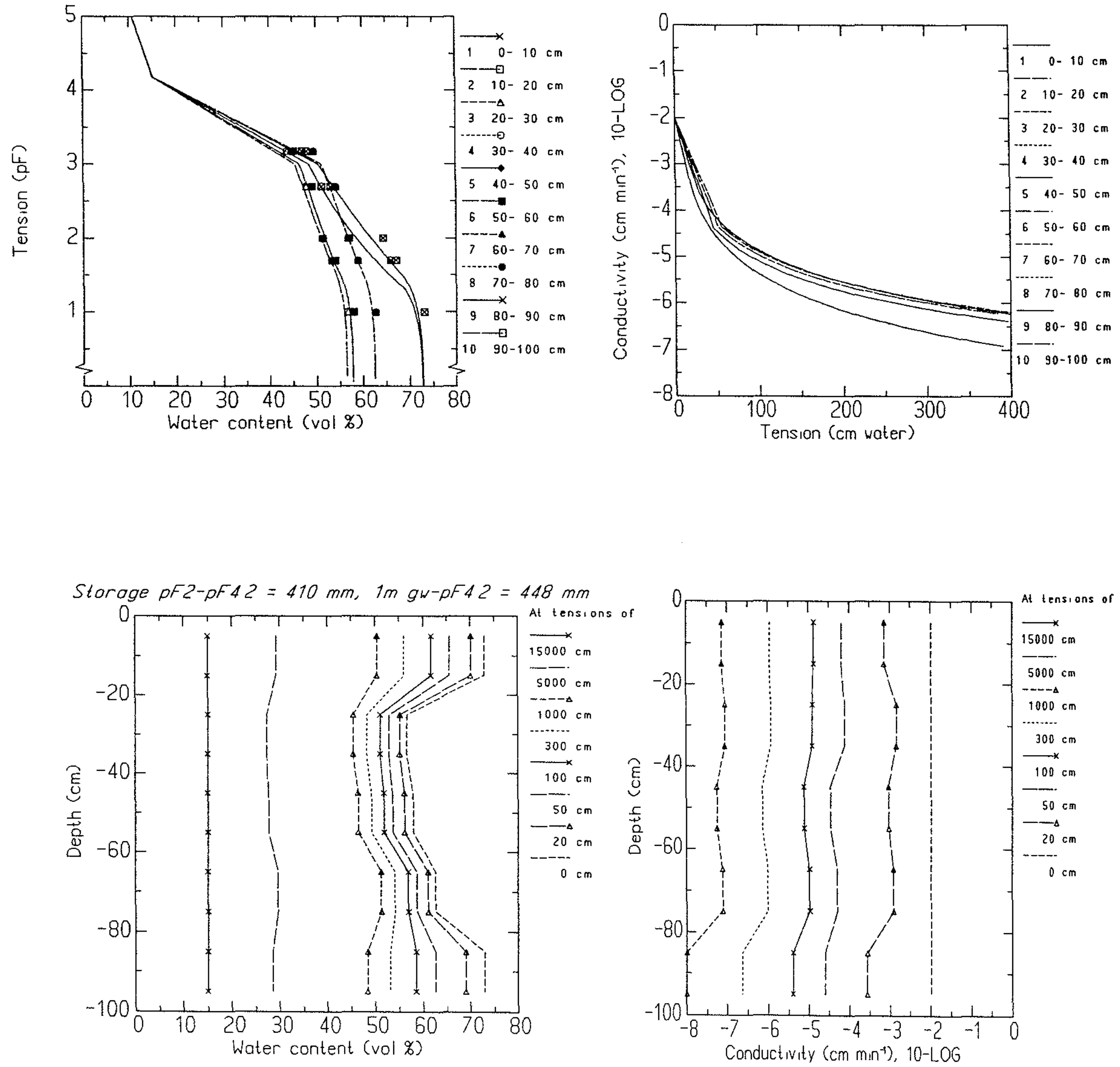



**Figure 2.6** Soil physical properties in Tan Thanh farm were made with measured data (symbols) and estimated functions (lines) according to Brooks and Corey (1964).

**Table 2.3** Saturated hydraulic conductivity using two sample sizes at Tan Thanh farm in vertical and horizontal direction

| **Soil sample sizes** (Φ cm) | **SOIL LAYERS** *($k_s$ : cm/ min)* A | B1 | B2 | B3 | C1 | **Repetition** |
|---|---|---|---|---|---|---|
| 5 cm | *0.00006* | *0.00009* | *0.15208* | *0.07888* | 0.00003 | *1* |
| Horizontal | *0.00041* | *0.00011* | *0.04444* | *0.00944* | 0.00006 | 2 |
| Direction | *0.00284* | *0.00013* | *0.00030* | *0.02865* | 0.00006 | *3* |
| **Average** | ***0.00110*** | ***0.00011*** | ***0.06560*** | ***0.03899*** | ***0.00005*** | |
| 5 cm | *0.00312* | *0.00001* | *0.00016* | *0.00018* | 0.00009 | *1* |
| Vertical | *0.00268* | *0.00001* | *0.00002* | *0.00018* | 0.00063 | 2 |
| Direction | *0.00073* | *0.00001* | *0.00018* | *0.00050* | 0.00091 | *3* |
| **Average** | ***0.00217*** | ***0.00001*** | ***0.00012*** | ***0.00028*** | ***0.00054*** | |
| 16 cm | *0.00323* | *.* | *.* | *0.00067* | *.* | *1* |
| Horizontal | *0.00131* | *0.00022* | *0.00385* | *0.01626* | 0.00009 | 2 |
| Direction | *0.00083* | *0.00033* | *0.00430* | *0.00140* | 0.00001 | *3* |
| **Average** | ***0.00179*** | ***0.00027*** | ***0.04526*** | ***0.00611*** | ***0.00005*** | |
| 16 cm | *0.00356* | *0.00095* | *0.01170* | *0.00102* | 0.00017 | *1* |
| Vertical | *0.03132* | *0.01399* | *0.05660* | *0.05040* | 0.01260 | 2 |
| Direction | *0.00330* | *0.00950* | *0.06760* | *0.04300* | 0.02990 | *3* |
| **Average** | ***0.01270*** | ***0.00814*** | ***0.04530*** | ***0.03147*** | ***0.01422*** | |

*Note: (*.*) missing data*

**Table 2.4** Result of ANOVA for $k_s$ in cm/min

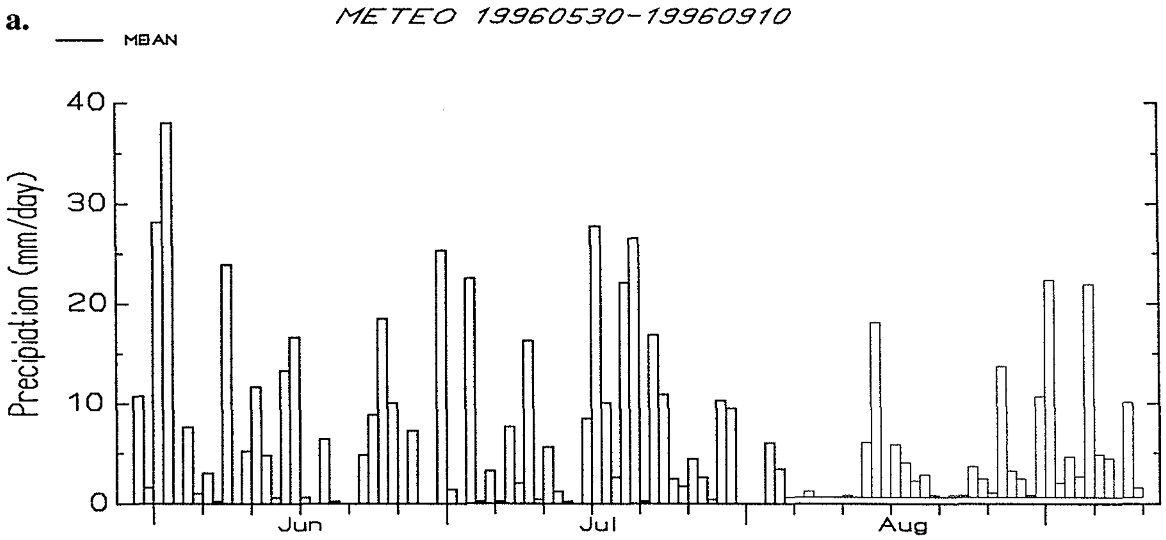
| **Source** | **Sum of squares, SS** | **d.f.** | **Mean square, MS** | **F** | **p-value** |
|---|---|---|---|---|---|
| Differences - layers | 0.006240 | 4 | 0.001560 | 3 | 0.05 |
| Differences - sizes | 0.002058 | 3 | 0.000686 | 1.31 | 0.25 |
| Residual errors | 0.006240 | 12 | 0.000520 | | |

Some other experiments were carried out at Tan Thanh farm aim to determine $k_s$ values in the field. The mean value of the saturated hydraulic conductivity in the horizontal direction was determined by the pumping test in the field to about 1.6 cm/min according to Uppenberg et al (1997). The large difference in $k_s$ between field and lab experiment may be explained by the small size of the soil sampling cores, which do not include the same degree of fissures and cracks as the field soil.

### 2.5.2 Local meteorological measurements

Meteorological variables for the period 1996-05-30 to 1996-09-10 were collected at Tan Thanh station. During this period, total precipitation was about 600 mm. Rainfalls with high intensity and frequency caused water flows in deeper soil layers. However, dry spells of 7 - 15 days normally take place during the period from June to August. During 1996 one longer dry spell occurred in the middle of June (7 days) and one in August (15 days). The frequency of 30 minute-mean precipitation higher than 20 mm per hour was about 5% of all rainfalls (Fig. 2.7). The corresponding frequency of daily mean precipitation larger than 10 mm per day was 20%.

a.

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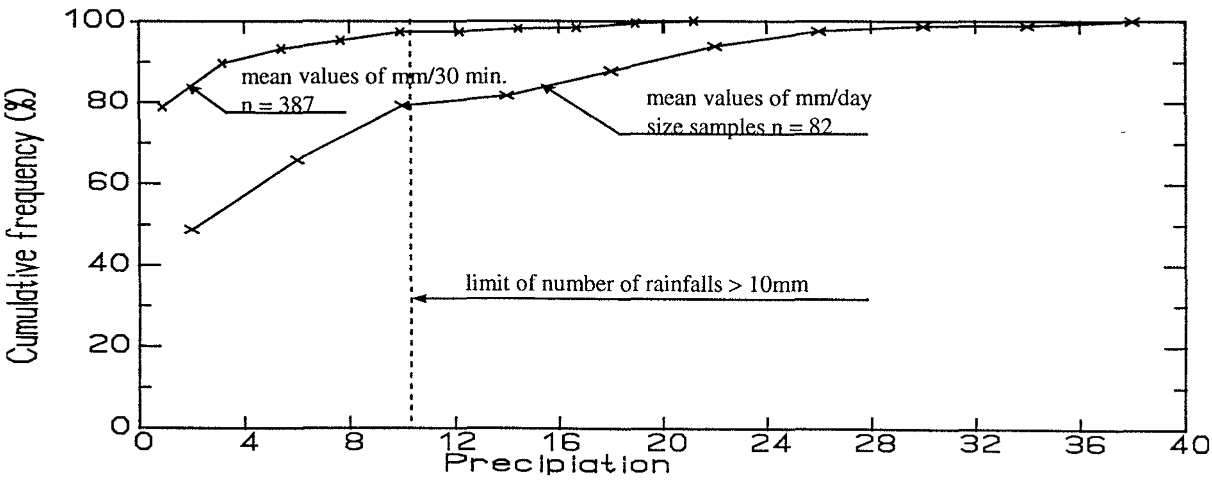



**Figure 2.7** a) The daily mean precipitation at Tan Thanh weather station. b) Frequency of 30 min. mean values and daily mean values of precipitation during the period of 19960530 - 19960910.

Some values of other variables were recorded. Air temperature varied in the range 24 to 36° with a mean value of 29° (Fig. 2.8a). Relative humidity varied strongly at low value (Fig. 2.8b) and its mean value was 85%. Daily mean value of global radiation was 190 w/m$^2$ (Fig. 2.8.c).

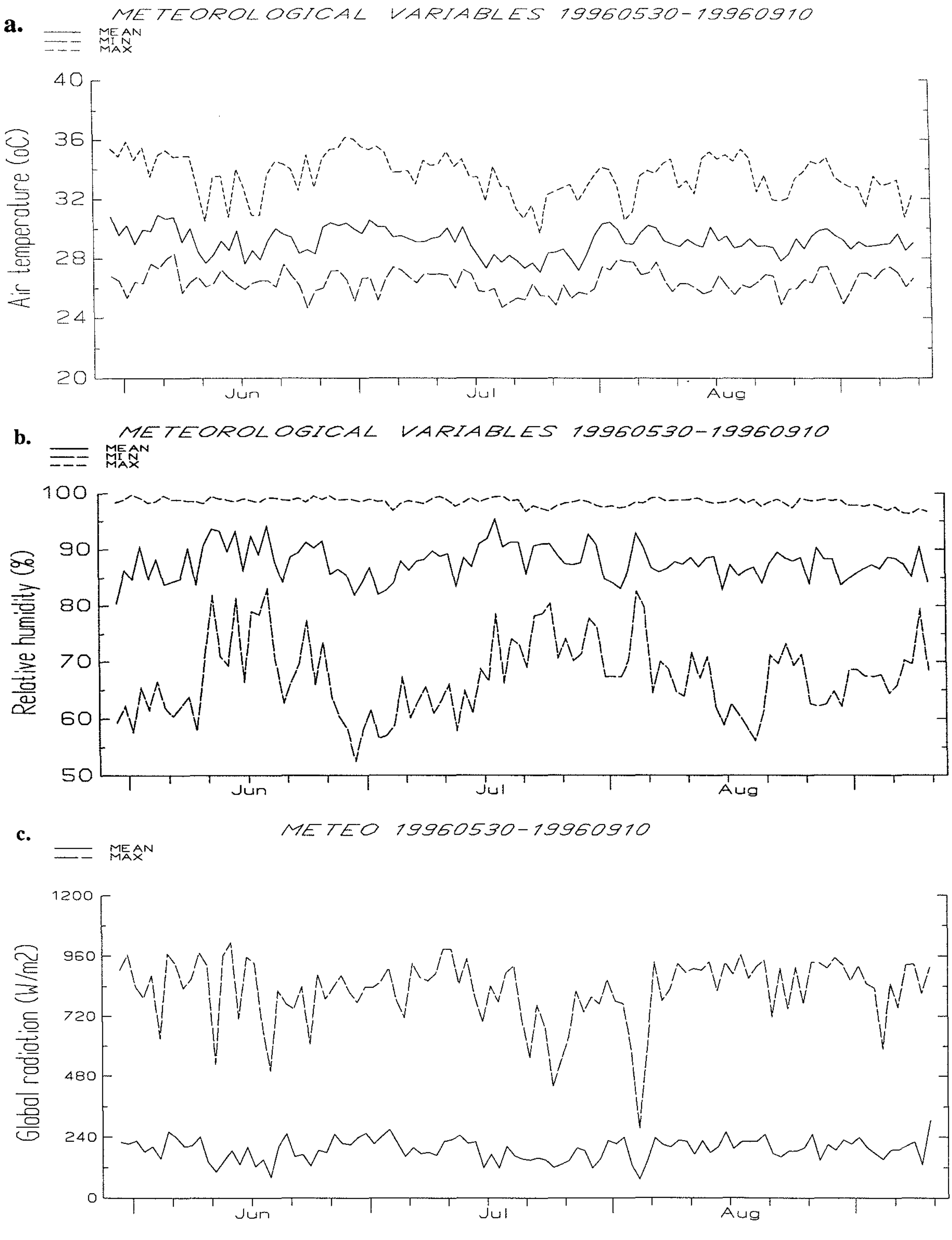
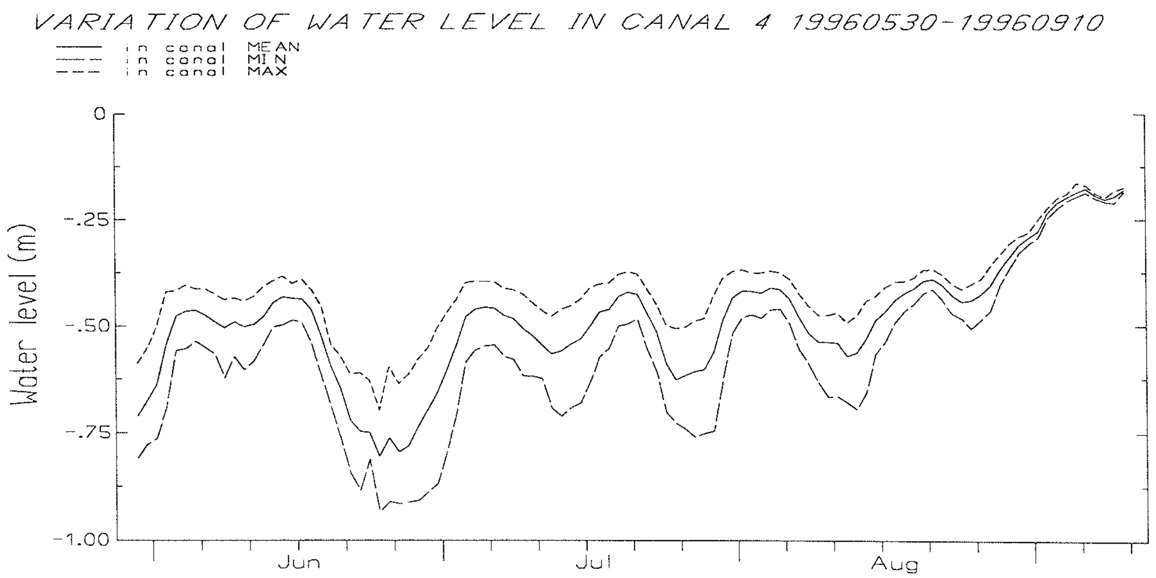



**Figure 2.8** Meteorological variables at Tan Thanh station. a) Air temperature: max., mean and min. value. b) Relative humidity: max., mean and min. value and c) Total radiation: max. and mean value.

### 2.5.3 Variation of water level in canal

Following precipitation, the water level in the canal was a major factor controlling water flow path in soil (Fig. 2.9a). Variation in water level in canals was affected by the semi-diurnal tide of the East Sea with 2 peaks and 2 feet in a day (Fig. 2.9b). The amplitude of the daily tide was about 20 - 25 cm, but the tidal frequency contains two tidal floods and two tidal falls in a month with a mean amplitude of about 50 cm. The canal water was at the lowest level at the end of June (Fig. 2.9a). After that, it increased until September when the flood of the Mekong River upstream appeared, covering the entire Plain of Reeds. The maximum inundation level at Tan Thanh farm was about 1.5 m above the soil surface.

**a.**




**b.**

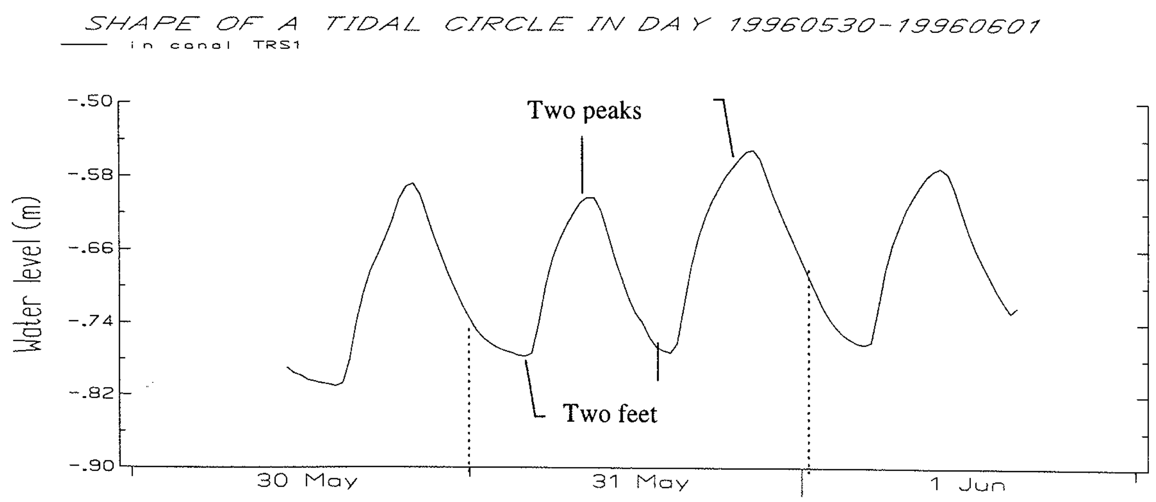



**Figure 2.9** a) Water level in the canal no.4 at Tan Thanh during the rainy season of 1996. b) Variation of the daily tide.

# 3 RESULTS AND DISCUSSION

## 3.1 The results of measured and simulated data

### 3.1.1 Groundwater level

Simulated ground water level (GWL) was calibrated against measurements. The total saturated hydraulic conductivity (KSATC) with the original value ($k_s$ = 0.01cm.min$^{-1}$) was varied in the range from 0.016 to 1.6 cm.min$^{-1}$ (ASCALE = 0.2 to 2.2) to find out a suitable value. The reasonable values were found in the range of 1.4 to 1.8 cm min$^{-1}$ for distances to canal in the range of 1 to 5m. These values resulted in the stable fluctuation of GWL. They were rather close to $k_s$ = 1.6 cm.min$^{-1}$ which was indicated by the measurement of Uppenberg et al (1997).

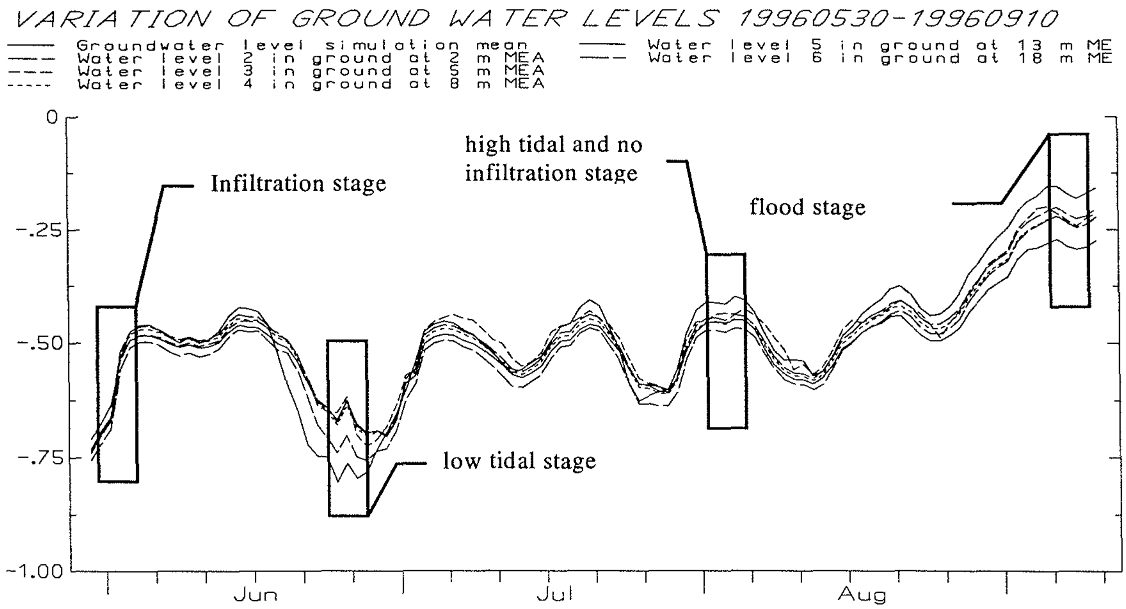



**Figure 3.1** Simulated and measured daily mean ground water levels

The observed ground water levels were strongly influenced by variation in canal water level following the same pattern with the lowest level at the end of June during the beginning of rainy season (Fig 3.1). The fluctuation in daily GWL was about 10 - 15 cm and the mean variation was about 40 cm.

In general the simulated values agreed rather well with observed data. The simulated result demonstrated that the GWL was nearly equal to canal level because there were short distances between canal and GWL. However the simulation showed discrepancies compared to observed data at some stages: during the infiltration stage (Fig 3.2a) the simulated level increased to higher values than the observed levels. The simulated GWL was more sensitive to large infiltration quantities compared to the observed During the low tidal stage (Fig 3.2b) the observed GWL was higher than the simulated level and the canal water level. A possible explanation in this stage may be increasing capillary rise. The non-infiltration or high tidal stage and the beginning of flood stage (Fig. 3.2c, d) were rather reasonable.

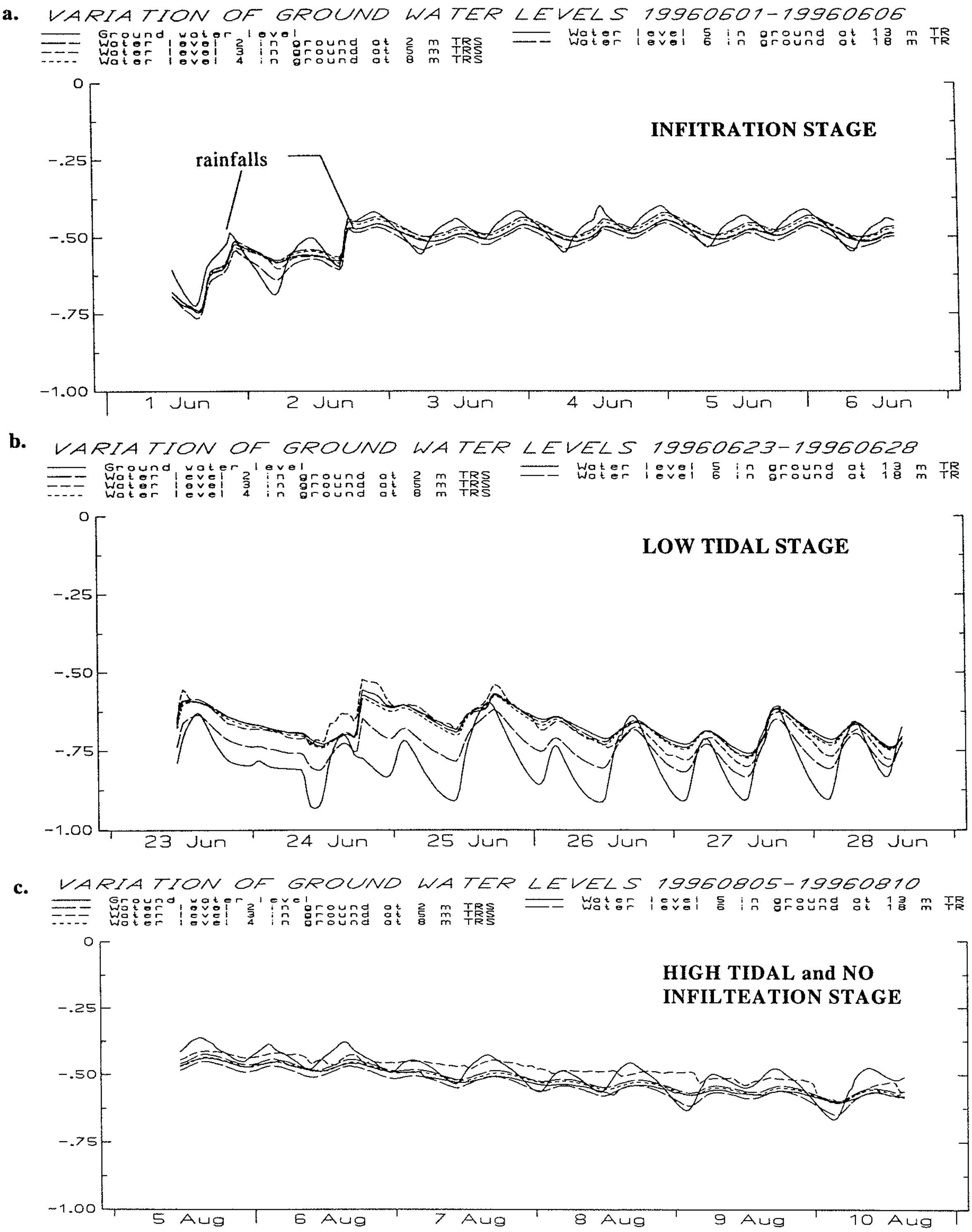



**Figure 3.2** a) Infiltration stage; b) low tidal stage, c) high tide and non-infiltration stage

d.

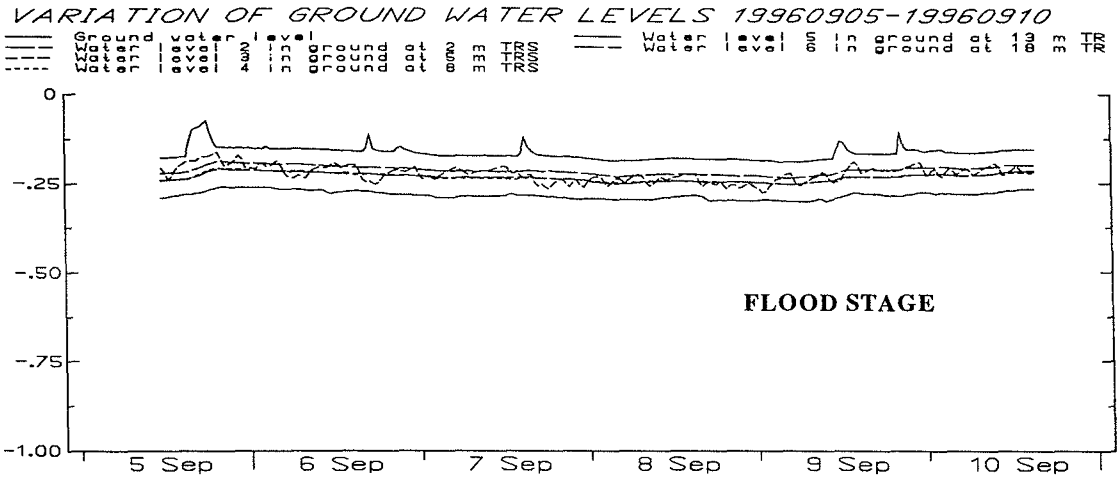



**Figure 3.2** d) saturated stage by flood inundation.

### 3.1.2 Soil temperature

Although soil temperature does not affect the water flow in soils very much since the variation is small. Nevertheless the soils temperature simulated by the SOIL model may indicate interesting phenomena when they do not agree with measurements. The variation of soil temperature within a day at different depth may be used as an indicator of soils water conditions.

a.

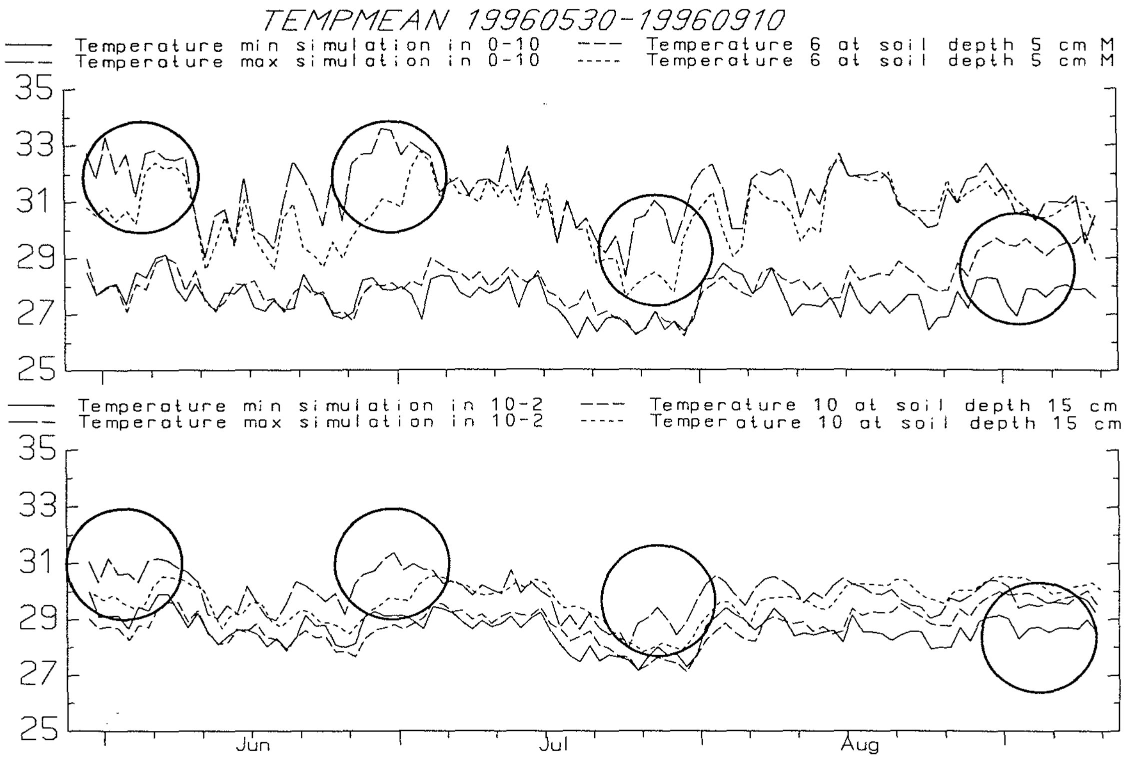



**Figure 3.3** a) Comparison between simulated and observed values of soil temperature in 0-10 cm depth and b) soils temperature in 10-20 cm depth.

The results of simulated soils temperatures at depth agreed well with observed values although they also showed some differences (Figs. 3.3 a and b). Differences occurred in the low tidal periods when simulated daily maximum values were overestimated and in the flood period when the simulated daily minimum values were overestimated.

### 3.1.3 Soil water contents and soil water pressure heads

Unfortunately there were no comparisons with observed data to test the model. However, based on the results of the model, the simulated values of the water content shows the soil water content to have been strongly affected by rainfall, air temperature and groundwater level. The values of water content at the soil surface oscillated from 60% up to a saturated value at 70% vol. In the lower depths of 30 – 40 cm layers, values were near saturation values during the period studied (Fig.3.4a).

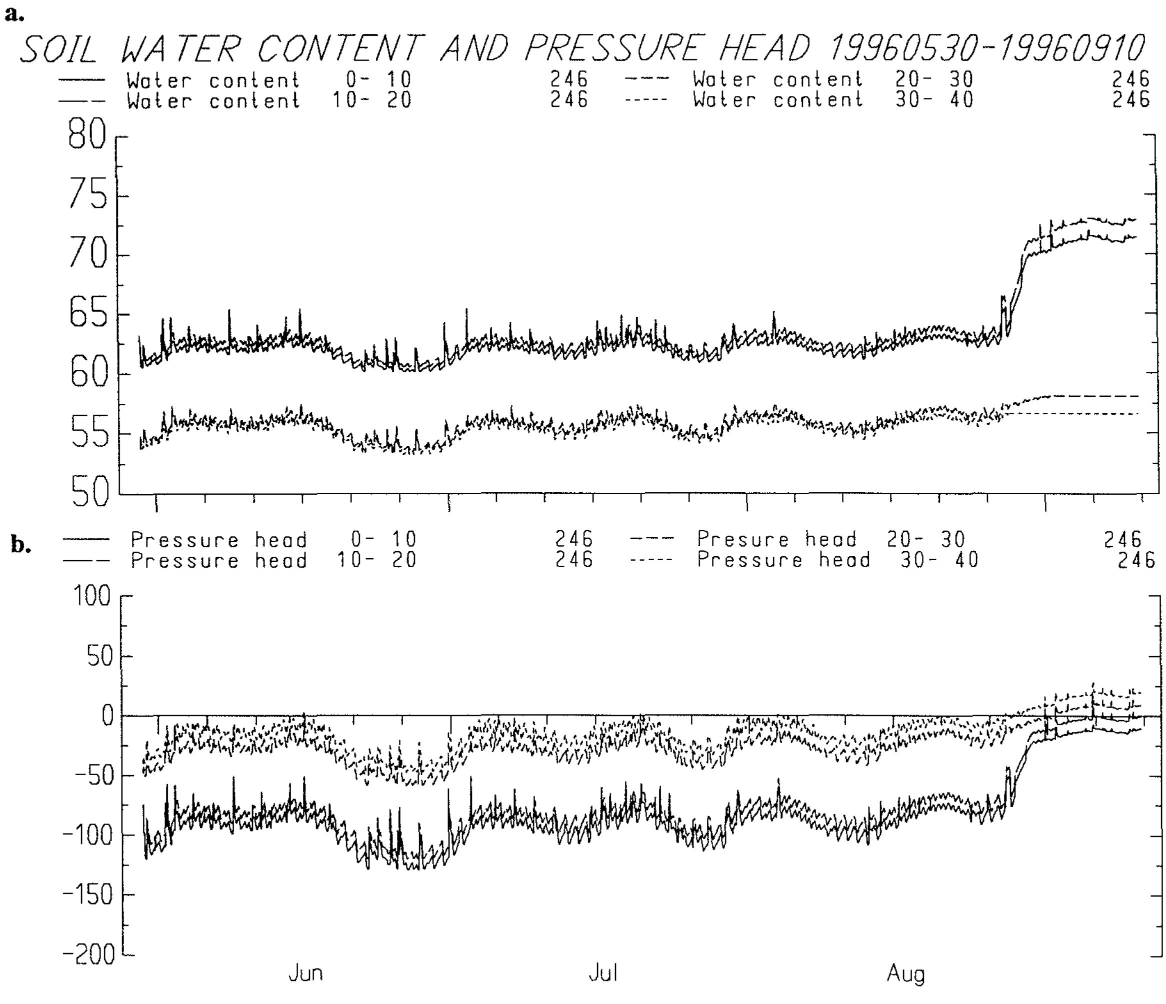



**Figure 3.4** a) Simulated water contents and b) soils pressure heads in depths from 10cm to 40 cm.

Similarly to soil water content, the values of pressure heads at soil depths were simulated during the period of June to August. Soil pressure heads decreased strongly at the end of August. The range of soil pressure head was from -100 to 0-cm water for the two top layers (Fig.3.4b).

## 3.2 Partitioning of water flows by using SOIL model

### 3.2.1 Water balance between field and canal

Figures 3.5 a and b demonstrates the water exchange between canal and soil. The gradients of canal water level and groundwater level ((CANLEV - GWLEV)/DIST) were computed (the positive value for inflow and the negative value for outflow). The simulation gave similar fluctuations as the observed values. However the gradients were very small. The measured gradients were mostly positive indicating a net flow from the canal to the soil.

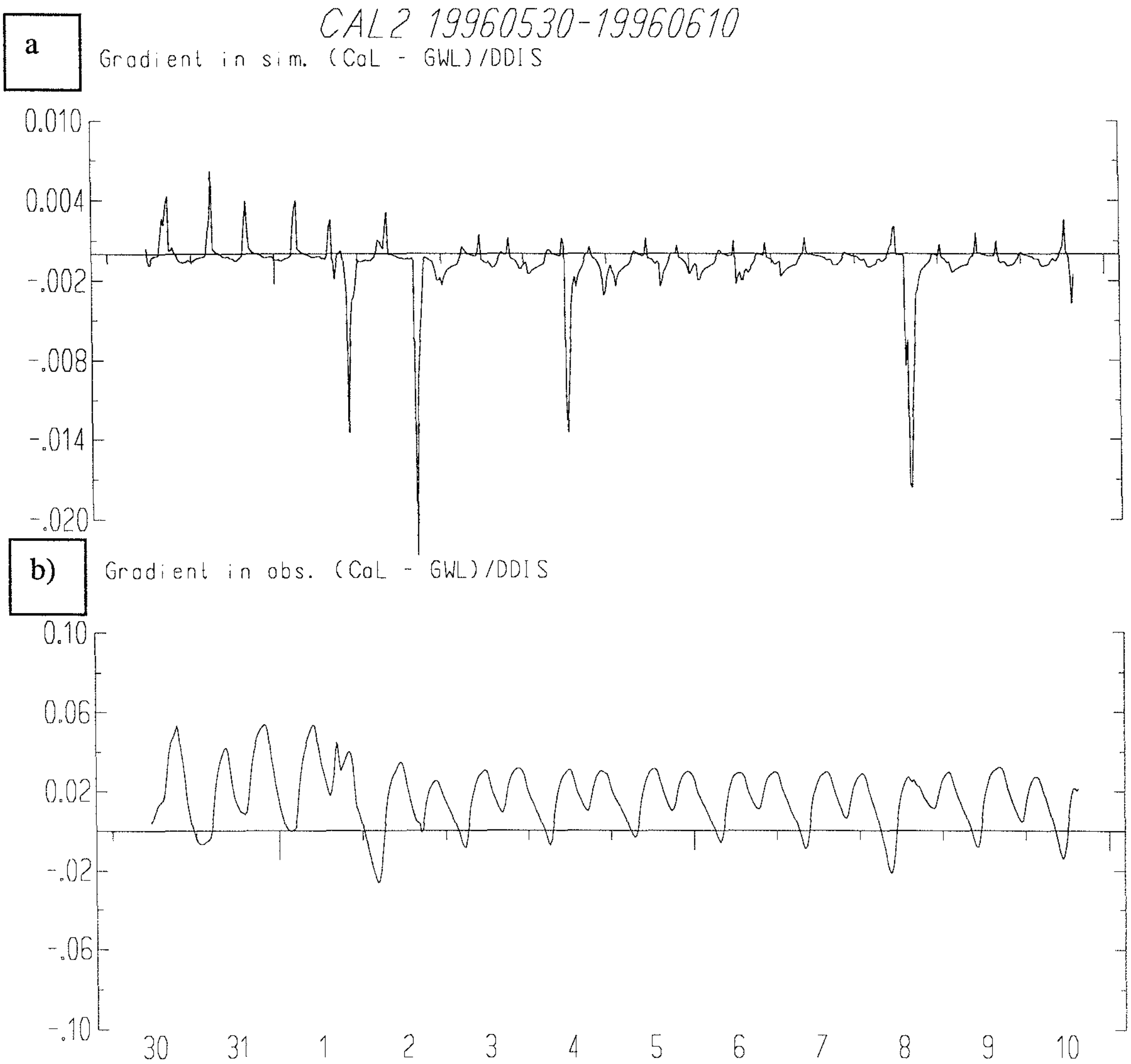



**Figure 3.5:** The hydraulic gradients between canal level and ground water level as calculated from a) simulation results and b) measurement data.

The ratio between accumulated inflow gradients and outflow gradient was about 4.5 in the measurements. These values imply the outflow to canal was less than inflow from canal.

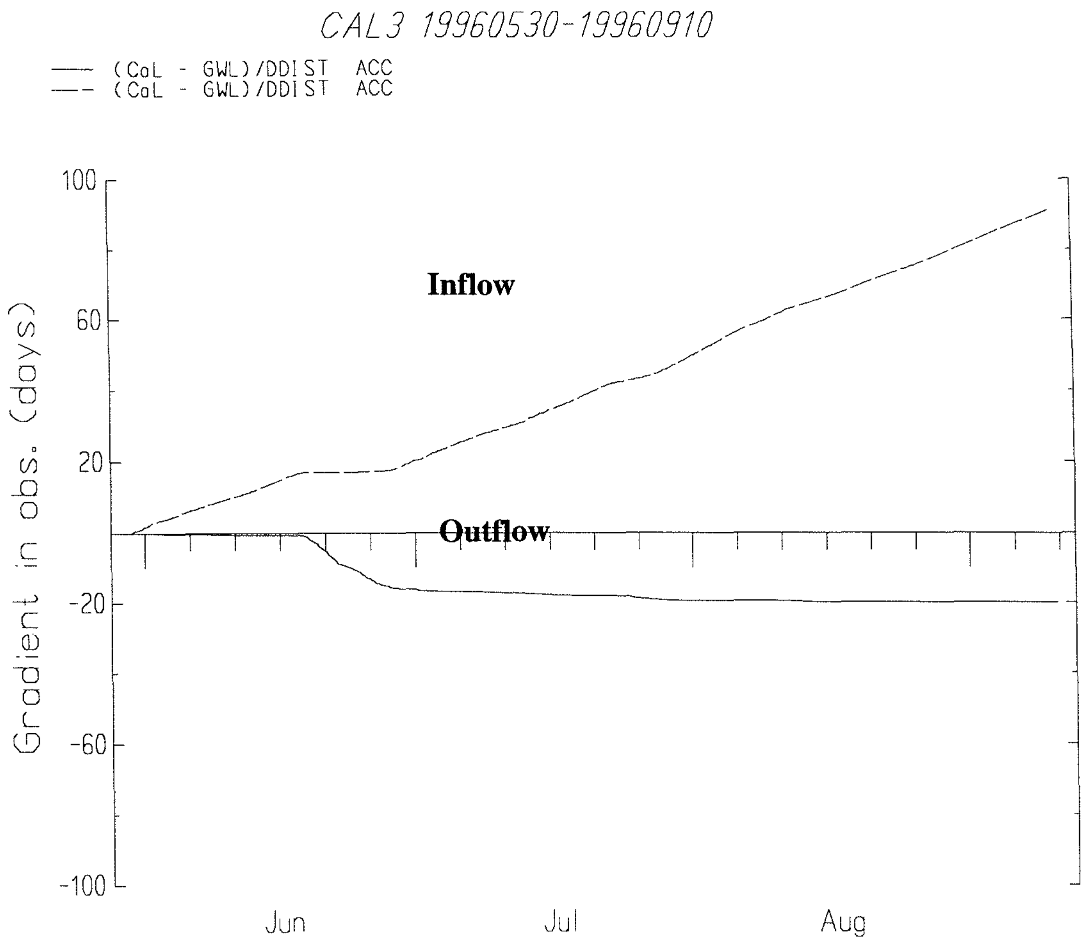



**Figure 3.6** The cumulative values of in flow gradients and outflow gradients. Water exchange between canal water and ground water.

### 3.2.2 Distribution of Water flow path

The partition of water flow in soils depended mainly on precipitation and the tidal regime in canals during the study period. In other words, it depends on the infiltration rate and the water exchange by horizontal water flow. In the area investigated, the saturated hydraulic conductivity in the horizontal direction was higher than that in the vertical direction because almost all fissure structures are in the horizontal direction. From the start of the rainy season in June, early rainfalls were only able to saturate a part of the uppermost layers and infiltrate into the groundwater layer and finally drain to the canal. At the end of June, canal water penetrated into soils and elevated the groundwater level during dry spells. This water exchange was a result of the high saturated hydraulic conductivity of acid sulphate soils, especially in B soils layers with high porosity and horizontal fissures. The water inflow consisted of matric flows and bypass flows in the soil. Water flow paths were complicated in layers that were affected by the fluctuation of groundwater level. The water flow quickly responded to changes in the tidal level. The fractions of the simulated bypass flows in the three top layers (unsaturated) to the total water flow for each layer were about 50 %, 35 %, and 20 % respectively (Fig. 3.7).

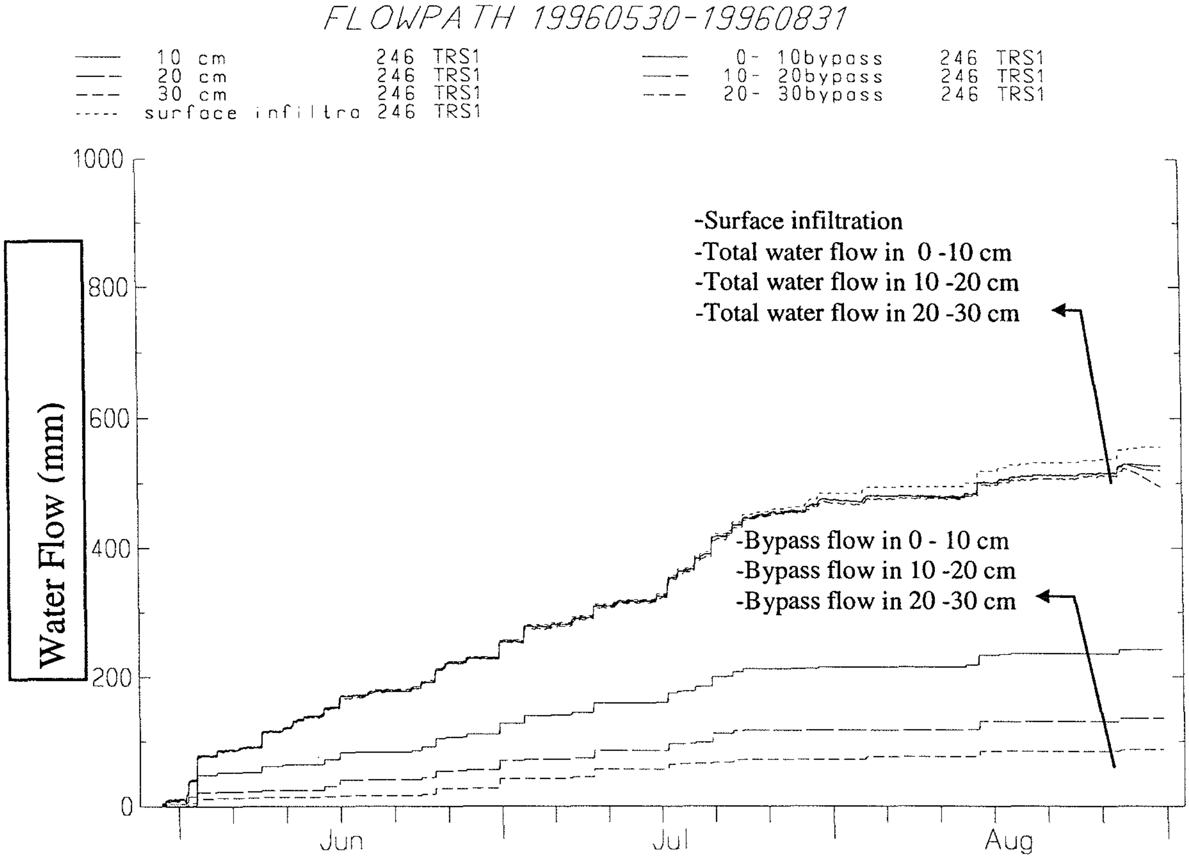



**Figure 3.7** Accumulation of the partition of water flow in vertical direction represented by bypass flows during the rainy season.

The decrease of simulated bypass flow with depths was rather strong. It seems to be related to the horizontal ground water flow, the high sorptivity capacity of the soil aggregates and the decrease of vertical flow rate with depth. However, the total simulated amounts of vertical water flow through unsaturated layers were very similar.

# 4 CONCLUSIONS

The driving variables used in the SOIL model were measured at Tan Thanh farm. The measured values such as the ground water level and soil temperatures were used to compare the simulated values during the study period. The simulated results were reasonable. However, it some discrepancies were identified, especially during infiltration at high rainfall intensities were identified. Some important characteristics are given below:

- The total saturated hydraulic conductivity used in the SOIL model was in the range from 1.4 to 1.8 cm $min^{-1}$.
- Water flows directly from drainage canal to saturated soils was estimated to be about 4 times as large as the water flow from plot to the drainage canal.
- The fractions of the bypass flows in the three top layers (unsaturated) to the total flow for each layer were estimated to 50 %, 35 %, and 20 % respectively.
- The high-saturated hydraulic conductivity reduced the time lag of water exchange between canal and soils. The major part of the rain infiltrated. The surface runoff was small because of high storage capacity and high infiltration capacity of the acid sulfate soil.

It is too early to draw general conclusions about the general hydrological behavior of soils in the Mekong delta. It will be necessary to carry out more experiments to provide information on the distribution of water flow paths in tidal affected areas.

# 5 ACKNOWLEDGMENT

I would like to thank my supervisors, Professor Per-Erik Jansson and Professor Erik Eriksson, for teaching me the model simulation and for their good advice concerning experiments as well as writing my thesis. Many thanks to all the people in the Department of Soil sciences have helped me during my studying time at the Swedish University of Agricultural Sciences. Practical helps with installations was provided by Jennie Andersson and Anna Lindahl among others.

I also send my thanks Prof. Nguyen An Nien, Director of Southern Institute of Water Resources Research, Associate Prof. Cu Xuan Dong and my colleagues have assisted in experiments within the Management of Acid Sulfate Soils project. Thanks especially to my wife, Ngoc Dung P.T, and my children who have heartened me so much in my works.

# 6 REFERENCES


Anon. 1990. Tan Thanh soils physical characteristics, report from MASS project. Southern Institute of Water Resources Research, Ho Chi Minh City, Vietnam.

Bouma, J., and L.W.Dekker. 1978. A case study on infiltration into dry clay soil. I. Morphological observation. Geoderma 20:27-40.

Brooks, R.H., and Corey, A.T. 1964. Hydraulic properties of porous media. Hydrology paper No.3. Colorado State Univ., Ft.Collins, Colorado.

Houghoudt, S.B. 1940. Bijdragen tot de kennis van enige natuurkundige grootheden van de ground No.7 Versl. Landb. Onderz. 42:449 –541.

Jansson, P-E. 1994. SOIL model (ver. 7.5). User´s Manual 3rd Edition Swedish University of Agricultural Sciences, Uppsala. Division of Agricultural Hydrotechnics, Communication 94: 3., 66p.

Jansson, P-E. 1996. PLOTPF User's manual. Swedish University of Agricultural Sciences, Uppsala. Department of Soil Science, Division of Agricultural Hydrotechnics, internal paper. 63 pp.

Jansson, P-E. 1998. Simulation Model for Soil Water and Heat Conditions.Swedish University of Agricultural Sciences, Uppsala. Division of Agricultural Hydrotechnics. Communications 98:2, 81pp.

Larsson, C. 1996. Infiltration Capacity and Tidal Influence on Groundwater Motion in Acid Sulfate Soils. A minor field study in Vietnamese Mekong delta. Swedish University of Agricultural Sciences, Uppsala. Division of Hydrotechnics. Communication 96: 3.

Minh, L.Q., M.E.F. van Mensvoort, T.P. Tuong, and J.Bouma. 1996. Aluminum transport by surface runoff and bypass flow in acid sulfate soil raised beds, Mekong delta, Vietnam. Ph. D. Thesis, Wageningen Agricultural University.

Mualem, Y. 1976. A new model for predicting the hydraulic conductivity of unsaturated porous media. Water Resour. Res. 12, 513-522.

Nielsen, D.R., Van Genuchten, M.TH and Biggar, J.W. 1986. Water flow and solute transport processes in the unsaturated zone, Water Resources Research, vol.22, No.9, Pages 89-108.

Sen, L.N. 1988. Influence of water management and agronomic packages on the chemical changes and growth of rice in acid sulfate soils. Ph. D. Thesis, Wageningen Agricultural University.

Uppenberg, S., Wallgren, O. & Ahman, M. 1997. Saturated hydraulic conductivity in an acid sulfate soils. A minor field study in the Vietnamese Mekong delta. Swedish University of Agricultural Sciences, Uppsala. Division of Hydrotechnics. Communication 97: 1.

# APPENDIX 1 - LIST OF SYMBOLS

| Symbol | Description | Unit | equation | Name in model | Value |
|---|---|---|---|---|---|
| (1) | (2) | (3) | (4) | (5) | (6) |
| $\psi$ | Soil water potential | cm water | (1,3,8,10,11,13) | PSIE | |
| $\psi_a$ | Soil water potential at air entry | cm water | (8, 13) | | |
| $\psi_m$ | Soil water potential at the lower boundary of Brooks & Corey's expression used | cm water | (11) | | |
| $\psi_x$ | Soil water potential at the upper boundary of Brooks & Corey's expression used | cm water | (10) | | |
| $\psi_{wilt}$ | Soil water potential at wilting point | cm water | (10) | | -15,000 |
| $\theta$ | Soil water content | vol % | (2,3,9,10,11,14) | THETA | |
| $\theta_m$ | Macropore volume | vol % | (11,14) | BLB | |
| $\theta_r$ | Residual soil water content | vol % | (9) | RESIDAL | |
| $\theta_s$ | Water content at saturation | vol % | (9,11,14) | PORO | |
| $\theta_x$ | Water content at the upper boundary of the Brooks & Corey's expression | vol % | (10) | | |
| $\theta_{wilt}$ | Water content at wilting point (15,000 cm water) | vol % | (10) | WILT | 15 |
| $\lambda$ | Pore size distribution index | | (8,12,13) | LAMDA | 0.05 - 0.1 |
| $\Delta_z$ | Thickness of soil layer | m | (16) | THICK | 0.1 |
| $a_r$ | Ratio between layer thickness and unit horizontal area | | (7) | see THICK | |
| $a_{scale}$ | Scaling coefficient accounting for the geometry of aggregates | | (7) | ASCALE | 0.1 - 1 |
| $a_{surf}$ | First order coefficient in surface runoff equation | $day^{-1}$ | (17) | SURDEL | |
| $d_c$ | Space between parallel drain canal | m | (15) | DDIST | 1 - 8 |
| $f_{cspool}$ | Area fraction of surface pool | | (18) | | |
| $f_{wcovtot}$ | Amount of water corresponding to complete area cover | mm | (18) | SPCOVTOT | |
| $k_{mat}$ | Saturated conductivity of soil matrix, excluding effects of macropores | $mmday^{-1}$ | (7,12,13) | SATC | 144 |
| $k_{sat}$ | Saturated conductivity of soil including the macropores | $mmday^{-1}$ | (14) | SATCT | 14,400 |
| $k_{s1}$ | Saturated conductivity in the horizon above drainage canal | $mmday^{-1}$ | (15) | GFLOW(1) | |
| $k_{s2}$ | Saturated conductivity in the horizon below drainage canal | $mmday^{-1}$ | (15) | GFLOW(2) | |
| $k_w$ | Unsaturated conductivity of soil | $mmday^{-1}$ | (1,3,12,13,14) | | |
| N | Tortuosity coefficient | | (12, 13) | ISTOREL | |
| PF | Water tension express as $\log(\Psi)$ | | (7) | | |
| $q_{bypass}$ | Soil water flow in macropores | $mmday^{-1}$ | (4,5,6) | BYPASS | |

**APPENDIX 1: LIST OF SYMBOLS ( Continuation)**

| (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|
| $q_{mat}$ | Soil water flow in micropores | $mmday^{-1}$ | (3,5,6) | | |
| $q_{in}$ | Soil water flow to a soil layer in macropores or as infiltration rate | $mday^{-1}$ | (3,4,5,6) | WFLOW | |
| $q_{sof}$ | Constant rate of ground water source flow | $mmday^{-1}$ | | GWSOF | |
| $q_{sol}$ | Layer for the ground water source flow | $mmday^{-1}$ | | GWSOL | |
| $q_{surf}$ | Surface runoff from surface pool | $mmday^{-1}$ | (17) | SURR | |
| $q_w$ | Soil water flow, between layers | $mmday^{-1}$ | (1,2) | WFLOW | |
| $q_{wc}$ | Total water flow to drainage canal | $mmday^{-1}$ | (16) | PIPEQ | |
| $r_{corr}$ | Correction factor for each layer | | (17) | | |
| $r_{href}$ | total horizontal resistance | $sm^{-1}$ | (17) | | |
| $r_r$ | radial resistance | $sm^{-1}$ | (17) | | |
| $r_h$ | horizontal resistance | $sm^{-1}$ | (17) | | |
| $r_v$ | vertical resistance | $sm^{-1}$ | (17) | | |
| Se | Effective saturation in Brooks & Corey's expression | | (8,9) | | |
| $S_{mat}$ | Sorptivity capacity of aggregate | $mmday^{-1}$ | (3,4,5,6,7) | | |
| $S_w$ | Net water source flow in soil (by rain or evaporation) | $mm^2day^{-1}$ | (2) | | |
| $w_{pool}$ | Amount of water in surface pool | mm | (17,18) | SURPOOL | |
| $w_{pmax}$ | Maximal water storage on soil surface without causing surface runoff | mm | (18) | SPOOMAX | 5.0 |
| Z | Depth | m | (1,2,3,17) | DEPTH | |
| $z_D$ | Thickness of the layer below the drainage canal | m | (15,16) | DLAYER | 0.5 |
| $z_P$ | Level of drainage canal | m | (16) | DDRAIN | |
| $z_{sat}$ | Depth of ground water table | m | (15) | GFLEV | |

# APPENDIX 2 – LIST OF PARAMETER FILE

```
# ------------------------------------------------------------------------------
# SOIL_250.SUM Wed Aug 20 19:30:49 1997
# ------------------------------------------------------------------------------
# ------------------------------------------------------------------------------
# Switches
# ------------------------------------------------------------------------------
  ADDSIM              OFF   ALBEDOV             ON   ATIRRIG              OFF
  AVERAGED             ON   AVERAGEG            ON   AVERAGET              ON
  AVERAGEX             ON   CHAPAR             OFF   CRACK                 ON
  DDAILY              OFF   DRIVDRAIN           ON   DRIVPG                 1
  EVAPOTR               4   FRINTERA            ON   FRLIMINF               1
  FRLIMUF              ON   FRLOADP             ON   FRPREFL              OFF
  FRSWELL             OFF   FURROW               0   GWFLOW                 4
  HEATEQ               ON   HEATPUMP             0   HEATWF                ON
  HYSTERES              0   INHEAT               0   INSTATE              OFF
  INTERCEPT            ON   INWATER              1   LISALLV               ON
  NETLSURF            OFF   NUMMETHOD          OFF   OUTFORN              OFF
  OUTSTATE            OFF   PLANTDEV           OFF   ROOTDIST               1
  ROUGHNESS             0   RSCALC               0   SALT                 OFF
  SNOW                  1   SUREBAL              0   UNITG                  3
  UNITPOT             OFF   VALIDPG            OFF   VAPOUR                 0
  WATEREQ              ON   WUPTAKE              2
# ------------------------------------------------------------------------------
# Parameters
# ------------------------------------------------------------------------------
# Initial conditions ------------------------------------------------------------
  IGWLEV             -0.8   IPOT               100   ITEMPS                30
# Soil profile ------------------------------------------------------------------
  NUMLAY               14   THICK(1)           0.1   THICK(2)             0.1
  THICK(3)            0.1   THICK(4)           0.1   THICK(5)             0.1
  THICK(6)            0.1   THICK(7)           0.2   THICK(8)             0.2
  THICK(9)            0.2   THICK(10)          0.2   THICK(11)            0.2
  THICK(12)           0.2   THICK(13)          0.2   THICK(14)            0.2
  UNUM                  1   UPROF              600   UTHICK(1)              0
  VC                    1
# Soil properties ---------------------------------------------------------------
  A0T                0.54   A1T              0.023   ASCALE               0.1
  ASCALEL             0.4   MINUC           1e-012   SCALE(1)               0
  SCALE(2)              0   SCALE(3)             0   SCALE(4)               0
  SCALE(5)              0   SCALE(6)             0   SCALE(7)               0
  SCALE(8)              0   SCALE(9)             0   SCALE(10)              0
  SCALE(11)             0   SCALE(12)            0   SCALE(13)              0
  SCALE(14)             0   SCALECOND            2
# Numerical ---------------------------------------------------------------------
  XADIV                 2   XINFLI               5   XLOOP                  1
  XNLEV                 2
# Driving variables -------------------------------------------------------------
  ANGSTR(1)          0.22   ANGSTR(2)          0.5   BRUNT(1)            0.56
  BRUNT(2)        0.00779   BRUNT(3)           0.1   BRUNT(4)             0.9
  CNUMD                 2   HEIGHT               2   PRECA0               1.1
  PRECA1             0.08   SIFRAC               0   SOILCOVER              0
  YCH                 365   YPHAS                0   YTAM                  29
  YTAMP                 6
# Evapotranspiration ------------------------------------------------------------
  ALBVEG(1)            25   ALBVEG(2)           25   ALBVEG(3)             25
  ALBVEG(4)            25   CFORM(1)           0.5   CFORM(2)               2
  CFORM(3)              2   DAYNUM(1)            1   DAYNUM(2)             40
  DAYNUM(3)            70   DAYNUM(4)           85   DAYNUM(5)              0
  DISPLV(1)          0.01   DISPLV(2)          0.1   DISPLV(3)            0.1
  DISPLV(4)             0   INTLAI             0.2   INTRS                  5
  LAIV(1)             0.2   LAIV(2)              7   LAIV(3)                5
  LAIV(4)             0.2   LATID             10.5   ROUGHV(1)           0.01
  ROUGHV(2)          0.03   ROUGHV(3)         0.02   ROUGHV(4)           0.01
  RSV(1)              100   RSV(2)              50   RSV(3)                70
  RSV(4)              200
# Water uptake ------------------------------------------------------------------
  ROOTDEP(1)         -0.1   ROOTDEP(2)        -0.8   ROOTDEP(3)            -1
  ROOTT(1)              1   ROOTT(2)            60   ROOTT(3)             100
  ROOTT(4)            150   UPMOV              0.5   WUPATE               0.8
  WUPBTE              0.4   WUPCRI             400   WUPCRISAT              1
  WUPF                0.2   WUPFB                0   WUPREDSAT              0
# Ground water and surface pool -------------------------------------------------
```

```
 DDIST                  2   DDRAIN              -1   DLAYER            0.5
 GFLEV(1)              -1   GFLEV(2)            -2   GFLOW(1)            0
 GFLOW(2)               0   GWSOF                0   GWSOL               0
 RPIPE                  1   SPCOVTOT            50   SPOOLMAX           50
 SURDEL               0.8
# Surface E-balance ---------------------------------------------------------
 ALBDRY                30   ALBKEXP              1   ALBWET             15
 ARICH                 16   MAXNEGEG          -0.5   RALAI              50
 RNTLAI               0.5   SURFDEF             -2   SURFEXC             1
# Thermal properties --------------------------------------------------------
 GEOTER                14   HUMUS                0   THSCALE(1)        2.4
 THSCALE(2)             2   THSCALE(3)         1.8   THSCALE(4)        1.4
 THSCALE(5)           1.2   THSCALE(6)           1   THSCALE(7)          1
 THSCALE(8)             1   THSCALE(9)           1   THSCALE(10)         1
 THSCALE(11)            1   THSCALE(12)          1   THSCALE(13)         1
 THSCALE(14)            1
# Frost ---------------------------------------------------------------------
 FCOND                  0   FDF                 20   FDF0                0
 FWFRAC               0.5
# Snow ----------------------------------------------------------------------
 Asnow1                50   Asnow2           -0.05   Asnow3           -0.1
 AsnowMin              40   CCSNOW            0.03   PRLIM               2
 PSLIM                 -2   SAGEM1               2   SAGEM2            0.1
 SAGEZP                 5   SAGEZQ             0.9   SD1OL             200
 SD2OM                0.5   SDENS              100   SLWL0               3
 SMAFR                0.1   SMELTG               1   SMRIS         1.5e-007
 SMTEM                  2   SRET              0.07   STCON        2.86e-006
# Plotting on line ----------------------------------------------------------
 PMAX                  60   XTGD                80
# ---------------------------------------------------------------------------
# Control variables
# ---------------------------------------------------------------------------
 STARTDAT       "1996-05-30 11:00"
 ENDDAT         "1996-09-10 15:30"
 OUTINTD               0
 OUTINTM              30
 NUMITER            1024
 RUNID          ""
# ---------------------------------------------------------------------------
# Selected output variables
# ---------------------------------------------------------------------------
# State variables -----------------------------------------------------------

 HEAT          [1-22]
 HSNOW         [1]
 PLANT         [1]
 SALTSUR       [1]
 SALTX         [1-22]
 STREAM        [1]
 SURPOOL       [1]
 WATER         [1-22]
 WATP          [1-22]
 WSNOW         [1]
# Flow variables ------------------------------------------------------------
 DEEPCONV      [1]
 DEEPPERC      [1]
 DFLOW         [1-22]
 DRIVF         [1]
 EFLOW         [1-21]
 EVAG          [1]
 HEATSINK      [1-22]
 INFBYPASS     [1]
 INFBYPREC     [1]
 INFIL         [1]
 INFREEZE      [1-22]
 PUMP          [1]
 SALTDEEP      [1]
 SALTDF        [1-22]
 SALTFL        [1-21]
 SALTIN        [1]
 SALTPIN       [1]
 SALTPOUT      [1]
 SALTSURR      [1]
 SPOOLA        [1]
 SPOOLINF      [1]
 SURR          [1]
 WFLOW         [1-21]
```

```
  WFLOWNP        [1-21]
  WFLOWP         [1-21]
  WFLOWPN        [1-21]
  WUPRATE        [1-10]
# Auxiliary variables ---------------------------------------------------------
  ALBEDOG        [1]
  BYPASS         [1-21]
  DENSS          [1]
  DINFIL         [1]
  DISPL          [1]
  EACT           [1]
  EACTI          [1]
  EBAL           [1]
  EGAVAIL        [1]
  EGPOT          [1]
  EINTPOT        [1]
  ETR            [1]
  ETRPSI         [1]
  ETRTEM         [1]
  EVAPO          [1]
  FROSTBL        [1-2]
  FROSTBU        [1-2]
  GTHICK         [1-22]
  HCANOPY        [1]
  HYSEFF         [1-22]
  INTCAP         [1]
  INTERC         [1]
  ISTORE         [1]
  LAI            [1]
  LATENT         [1]
  PAI            [1]
  PERC           [1]
  PFSOIL         [1-22]
  PIPEQ          [1]
  PREC           [1]
  PSI            [1-22]
  RA             [1]
  RAC            [1]
  RICH           [1]
  RNTG           [1]
  ROOTDEPTH      [1]
  ROUGH          [1]
  RS             [1]
  RSSOIL         [1]
  SAGE           [1]
  SALTCONC       [1-22]
  SATLEV         [1]
  SENS           [1]
  SPOOLCOV       [1]
  SURFMOS        [1]
  SWATS          [1]
  SWELL          [1]
  TDSNOW         [1]
  TEMP           [1-22]
  THETA          [1-22]
  THETATOT       [1-22]
  THQUAL         [1-22]
  TOTQ           [1]
  TQUALP         [1]
  TTSTEP         [1]
  VAPOURF        [1-21]
  VAPOURFS       [1]
  VPA            [1]
  VPD            [1]
  VPS            [1]
  WUPPOT         [1]
# Driving variables  ----------------------------------------------------------
  CLOUDN         [1]
  DRAINLEV       [1]
  EPOT           [1]
  HR             [1]
  IRIG           [1]
  PRECMM         [1]
  RIS            [1]
  RNT            [1]
  SALTDEPC       [1]
  SPSOURCE       [1]
```

```
  TA            [1]
  TD            [1]
  WS            [1]
  WSOURCE       [1-22]
# ---------------------------------------------------------------------------
# Files
# ---------------------------------------------------------------------------
# Driving variable file -----------------------------------------------------
  FILE(1)  TATHACLI.BIN
# Parameter file ------------------------------------------------------------
  FILE(2)  TRI.PAR
# Translation file ----------------------------------------------------------
  FILE(3)  SOIL.TRA
# Hydraulic soil properties -------------------------------------------------
  FILE(8)  TT_SOIL.DAT
# Thermal soil properties ---------------------------------------------------
  FILE(9)  THCOEF.DAT
# Drainage depth (DDRAIN) file  ---------------------------------------------
  FILE(15)  CANAL4M.BIN
 Driving variable file : CANAL4M     1 variables in  4951 records
 From 19960530-1100  to  19960910-1530
Water level         m        in canal             TRS1
 Driving variable file : TATHACLI     8 variables in  4952 records
 From 19960530-1100  to  19960910-1530
Air temperature     C                             TRS1
Relative humidity   %
Wind speed          m/s
Precipitation       mm/day                        TRS1
Total radiation     W/m2
Dummy
Dummy
Dummy
No soil parameters found in file : TT_SOIL.DAT
The data file contains profile:   1:  1Your profile was:600:  1
Values of UPROF and UNUM has changed to:  1:  1

 Distribution of groundwater flow to pipes within D-layer
 Depth - Horisontal Radial Vertical & total resistances (days)
 -------------------------------------------------------
```

| Depth | Horisontal | Radial | Vertical | total |
|---|---|---|---|---|
| 90. | 3.9 | -3.1 | 1.4 | 2.2 |
| 110. | 3.9 | -3.1 | 2.8 | 3.6 |
| 130. | 3.9 | -3.1 | 4.2 | 5.0 |

```
 The Brooks & Corey equation will be used for soil properties

      SOIL IDENTIFICATION: New profile       1       1                0

      SOIL PARAMETERS AT BOUNDARIES BETWEEN LAYERS
```

| DEPTH | N | SATC | SATCT | LAMBDA | RESIDAL | PORO | PSIE | BLB | TCON | TCONF |
|---|---|---|---|---|---|---|---|---|---|---|
| 10.0 | 1.0 | 144.0 | 14400.0 | .09 | .5 | 73.0 | 14.8 | 4.0 | 1.3 | 2.7 |
| 20.0 | 1.0 | 144.0 | 14400.0 | .07 | .5 | 65.5 | 13.9 | 4.0 | 1.4 | 2.9 |
| 30.0 | 1.0 | 144.0 | 14400.0 | .05 | .4 | 57.3 | 12.9 | 4.0 | 1.3 | 2.4 |
| 40.0 | 1.0 | 144.0 | 14400.0 | .05 | .4 | 57.2 | 11.7 | 4.0 | 1.2 | 2.1 |
| 50.0 | 1.0 | 144.0 | 14400.0 | .05 | .4 | 57.8 | 10.4 | 4.0 | 1.0 | 1.7 |
| 60.0 | 1.0 | 144.0 | 14400.0 | .05 | .5 | 59.5 | 10.7 | 4.0 | .9 | 1.7 |
| 80.0 | 1.0 | 144.0 | 14400.0 | .07 | .5 | 65.6 | 11.0 | 4.0 | .8 | 1.6 |
| 100.0 | 1.0 | 144.0 | 14400.0 | .10 | .4 | 68.8 | 10.3 | 4.0 | .7 | 1.6 |
| 120.0 | 1.0 | 144.0 | 14400.0 | .10 | .4 | 69.0 | 10.3 | 4.0 | .7 | 1.6 |
| 140.0 | 1.0 | 144.0 | 14400.0 | .10 | .4 | 69.0 | 10.3 | 4.0 | .7 | 1.6 |
| 160.0 | 1.0 | 144.0 | 14400.0 | .10 | .4 | 69.0 | 10.3 | 4.0 | .7 | 1.6 |
| 180.0 | 1.0 | 144.0 | 14400.0 | .10 | .4 | 69.0 | 10.3 | 4.0 | .7 | 1.6 |
| 200.0 | 1.0 | 144.0 | 14400.0 | .10 | .4 | 69.0 | 10.3 | 4.0 | .7 | 1.6 |
| 220.0 | 1.0 | 144.0 | 14400.0 | .10 | .4 | 69.0 | 10.3 | 4.0 | .7 | 1.6 |

```
      SOIL PARAMETERS IN THE MIDDLE OF LAYERS
```

| DEPTH | ROOTF | LAMBDA | RESIDAL | PORO | PSIE | WILTP | BUB | BLB | HCAP | HCAPI |
|---|---|---|---|---|---|---|---|---|---|---|
| 5.0 | .19 | .09 | .5 | 73.0 | 14.8 | 15.0 | 1000. | 4. | 3.19 | 1.74 |
| 15.0 | .17 | .09 | .5 | 73.0 | 14.8 | 15.0 | 1000. | 4. | 3.23 | 1.75 |
| 25.0 | .15 | .05 | .4 | 58.1 | 13.0 | 15.0 | 1000. | 4. | 3.10 | 1.86 |
| 35.0 | .13 | .05 | .4 | 56.6 | 12.9 | 15.0 | 1000. | 4. | 3.11 | 1.88 |
| 45.0 | .11 | .05 | .4 | 57.8 | 10.5 | 15.0 | 1000. | 4. | 3.14 | 1.88 |
| 55.0 | .09 | .05 | .4 | 57.9 | 10.3 | 15.0 | 1000. | 4. | 3.18 | 1.90 |
| 70.0 | .12 | .05 | .5 | 62.6 | 11.7 | 15.0 | 1000. | 4. | 3.34 | 1.92 |
| 90.0 | .04 | .10 | .4 | 68.7 | 10.3 | 15.0 | 1000. | 4. | 3.51 | 1.93 |
| 110.0 | .00 | .10 | .4 | 69.0 | 10.3 | 15.0 | 1000. | 4. | 3.52 | 1.93 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 130.0 | .00 | .10 | .4 | 69.0 | 10.3 | 15.0 | 1000. | 4. | 3.52 | 1.93 |
| 150.0 | .00 | .10 | .4 | 69.0 | 10.3 | 15.0 | 1000. | 4. | 3.52 | 1.93 |
| 170.0 | .00 | .10 | .4 | 69.0 | 10.3 | 15.0 | 1000. | 4. | 3.52 | 1.93 |
| 190.0 | .00 | .10 | .4 | 69.0 | 10.3 | 15.0 | 1000. | 4. | 3.52 | 1.93 |
| 210.0 | .00 | .10 | .4 | 69.0 | 10.3 | 15.0 | 1000. | 4. | 3.52 | 1.93 |

-------------------- State Variables -----------------------------------

| Number | Variable | Initial | Final | Min | Max | Mean | Cumulated |
|---|---|---|---|---|---|---|---|
| 1 | WATER(1) | 6.31E+01 | 7.12E+01 | 6.05E+01 | 7.21E+01 | 6.31E+01 | 6.51E+03 |
| 2 | WATER(2) | 6.39E+01 | 7.26E+01 | 6.09E+01 | 7.31E+01 | 6.37E+01 | 6.58E+03 |
| 3 | WATER(3) | 5.38E+01 | 5.81E+01 | 5.38E+01 | 5.83E+01 | 5.62E+01 | 5.80E+03 |
| 4 | WATER(4) | 5.34E+01 | 5.66E+01 | 5.34E+01 | 5.68E+01 | 5.56E+01 | 5.74E+03 |
| 5 | WATER(5) | 5.46E+01 | 5.78E+01 | 5.46E+01 | 5.80E+01 | 5.71E+01 | 5.90E+03 |
| 6 | WATER(6) | 5.56E+01 | 5.79E+01 | 5.51E+01 | 5.83E+01 | 5.76E+01 | 5.95E+03 |
| 7 | WATER(7) | 1.23E+02 | 1.25E+02 | 1.21E+02 | 1.25E+02 | 1.25E+02 | 1.29E+04 |
| 8 | WATER(8) | 1.37E+02 | 1.37E+02 | 1.36E+02 | 1.38E+02 | 1.37E+02 | 1.42E+04 |
| 9 | WATER(9) | 1.38E+02 | 1.38E+02 | 1.38E+02 | 1.38E+02 | 1.38E+02 | 1.42E+04 |
| 10 | WATER(10) | 1.38E+02 | 1.38E+02 | 1.38E+02 | 1.38E+02 | 1.38E+02 | 1.42E+04 |
| 11 | WATER(11) | 1.38E+02 | 1.38E+02 | 1.38E+02 | 1.38E+02 | 1.38E+02 | 1.42E+04 |
| 12 | WATER(12) | 1.38E+02 | 1.38E+02 | 1.38E+02 | 1.38E+02 | 1.38E+02 | 1.42E+04 |
| 13 | WATER(13) | 1.38E+02 | 1.38E+02 | 1.38E+02 | 1.38E+02 | 1.38E+02 | 1.42E+04 |
| 14 | WATER(14) | 1.38E+02 | 1.38E+02 | 1.38E+02 | 1.38E+02 | 1.38E+02 | 1.42E+04 |
| 15 | HEAT(1) | 9.58E+06 | 1.08E+07 | 8.25E+06 | 1.10E+07 | 9.30E+06 | 9.60E+08 |
| 16 | HEAT(2) | 9.68E+06 | 1.05E+07 | 8.56E+06 | 1.09E+07 | 9.40E+06 | 9.70E+08 |
| 17 | HEAT(3) | 9.29E+06 | 9.49E+06 | 8.71E+06 | 9.81E+06 | 9.36E+06 | 9.65E+08 |
| 18 | HEAT(4) | 9.33E+06 | 9.43E+06 | 8.86E+06 | 9.81E+06 | 9.39E+06 | 9.68E+08 |
| 19 | HEAT(5) | 9.42E+06 | 9.56E+06 | 9.02E+06 | 9.91E+06 | 9.52E+06 | 9.82E+08 |
| 20 | HEAT(6) | 9.53E+06 | 9.61E+06 | 9.14E+06 | 9.89E+06 | 9.58E+06 | 9.89E+08 |
| 21 | HEAT(7) | 2.00E+07 | 1.99E+07 | 1.93E+07 | 2.03E+07 | 1.99E+07 | 2.05E+09 |
| 22 | HEAT(8) | 2.11E+07 | 2.08E+07 | 2.04E+07 | 2.11E+07 | 2.07E+07 | 2.14E+09 |
| 23 | HEAT(9) | 2.11E+07 | 2.10E+07 | 2.06E+07 | 2.11E+07 | 2.09E+07 | 2.15E+09 |
| 24 | HEAT(10) | 2.11E+07 | 2.11E+07 | 2.08E+07 | 2.11E+07 | 2.09E+07 | 2.16E+09 |
| 25 | HEAT(11) | 2.11E+07 | 2.13E+07 | 2.08E+07 | 2.13E+07 | 2.10E+07 | 2.17E+09 |
| 26 | HEAT(12) | 2.11E+07 | 2.14E+07 | 2.08E+07 | 2.14E+07 | 2.11E+07 | 2.18E+09 |
| 27 | HEAT(13) | 2.11E+07 | 2.16E+07 | 2.07E+07 | 2.16E+07 | 2.12E+07 | 2.18E+09 |
| 28 | HEAT(14) | 2.03E+07 | 2.17E+07 | 2.03E+07 | 2.18E+07 | 2.13E+07 | 2.19E+09 |
| 29 | PLANT | 4.89E-05 | 6.45E+00 | 4.89E-05 | 6.45E+00 | 2.95E+00 | 3.04E+02 |
| 30 | STREAM | -2.38E-02 | 6.08E+02 | -2.91E+00 | 6.08E+02 | 3.60E+02 | 3.71E+04 |

-------------------- Flow Variables -----------------------------------

| Number | Variable | Initial | Final | Min | Max | Mean | Cumulated |
|---|---|---|---|---|---|---|---|
| 34 | WFLOW(1) | -3.72E-06 | -2.50E+00 | -3.22E+01 | 1.04E+03 | 5.97E+00 | 6.16E+02 |
| 35 | WFLOW(2) | 1.92E-05 | -2.12E+00 | -1.20E+02 | 1.04E+03 | 5.36E+00 | 5.53E+02 |
| 36 | WFLOW(3) | -2.00E-05 | -1.63E+00 | -3.06E+02 | 1.03E+03 | 5.10E+00 | 5.26E+02 |
| 37 | WFLOW(4) | 1.17E-05 | -1.12E+00 | -2.98E+02 | 1.64E+03 | 4.60E+00 | 4.75E+02 |
| 38 | WFLOW(5) | -5.51E-05 | -6.23E-01 | -4.95E+02 | 1.50E+03 | 4.78E+00 | 4.93E+02 |
| 39 | WFLOW(6) | 2.17E-05 | 0.00E+00 | -4.20E+02 | 1.50E+03 | 5.52E+00 | 5.69E+02 |
| 40 | WFLOW(7) | -3.79E+01 | 0.00E+00 | -3.67E+02 | 1.50E+03 | 6.94E+00 | 7.16E+02 |
| 41 | WFLOW(8) | -1.84E+01 | 0.00E+00 | -8.47E+01 | 2.46E+02 | 3.04E-01 | 3.14E+01 |
| 42 | WFLOW(9) | 0.00E+00 | 0.00E+00 | -2.04E+01 | 2.68E+01 | 5.75E-03 | 5.94E-01 |
| 47 | EFLOW(1) | -4.69E-01 | 1.27E+06 | -3.98E+06 | 1.44E+08 | 6.90E+05 | 7.12E+07 |
| 48 | EFLOW(2) | 2.41E+00 | 1.13E+04 | -1.44E+07 | 1.34E+08 | 6.17E+05 | 6.37E+07 |
| 49 | EFLOW(3) | -2.52E+00 | -3.17E+05 | -3.73E+07 | 1.31E+08 | 5.88E+05 | 6.07E+07 |
| 50 | EFLOW(4) | 1.47E+00 | -2.93E+05 | -3.64E+07 | 2.06E+08 | 5.30E+05 | 5.47E+07 |
| 51 | EFLOW(5) | -6.94E+00 | -1.80E+05 | -6.11E+07 | 1.88E+08 | 5.54E+05 | 5.72E+07 |
| 52 | EFLOW(6) | 2.73E+00 | -6.52E+04 | -5.19E+07 | 1.89E+08 | 6.47E+05 | 6.68E+07 |
| 53 | EFLOW(7) | -4.77E+06 | -5.65E+04 | -4.54E+07 | 1.89E+08 | 8.27E+05 | 8.53E+07 |
| 54 | EFLOW(8) | -2.32E+06 | -6.05E+04 | -1.05E+07 | 3.04E+07 | 4.27E+03 | 4.41E+05 |
| 55 | EFLOW(9) | 0.00E+00 | -6.32E+04 | -2.55E+06 | 3.31E+06 | -3.15E+04 | -3.25E+06 |
| 56 | EFLOW(10) | 0.00E+00 | -6.58E+04 | -7.96E+04 | 3.74E+04 | -3.24E+04 | -3.34E+06 |
| 57 | EFLOW(11) | 0.00E+00 | -6.86E+04 | -8.10E+04 | 5.47E+04 | -3.40E+04 | -3.51E+06 |
| 58 | EFLOW(12) | 0.00E+00 | -7.08E+04 | -8.84E+04 | 9.35E+04 | -3.71E+04 | -3.83E+06 |
| 59 | EFLOW(13) | 3.60E+05 | -6.58E+04 | -1.23E+05 | 3.60E+05 | -4.18E+04 | -4.31E+06 |
| 60 | WUPRATE(1) | 1.00E-01 | 4.40E-01 | 9.48E-04 | 5.37E-01 | 6.25E-02 | 6.45E+00 |
| 70 | DRIVF | 5.61E+06 | 4.00E+06 | -1.18E+07 | 1.33E+08 | 7.20E+05 | 7.43E+07 |
| 71 | INFIL | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.05E+03 | 6.44E+00 | 6.65E+02 |
| 72 | EVAG | 1.92E-02 | 2.04E+00 | -5.00E-01 | 3.06E+00 | 1.87E-01 | 1.93E+01 |
| 73 | DFLOW(1) | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.38E+02 | 1.45E-01 | 1.50E+01 |
| 74 | DFLOW(2) | 0.00E+00 | -3.81E-01 | -4.96E-01 | 3.96E+02 | 5.27E-01 | 5.44E+01 |
| 75 | DFLOW(3) | 0.00E+00 | -4.99E-01 | -9.89E-01 | 1.91E+02 | 2.18E-01 | 2.25E+01 |
| 76 | DFLOW(4) | 0.00E+00 | -5.00E-01 | -1.37E+00 | 3.18E+02 | 4.67E-01 | 4.82E+01 |
| 77 | DFLOW(5) | 0.00E+00 | -5.02E-01 | -1.18E+01 | 1.98E+02 | -2.06E-01 | -2.12E+01 |
| 78 | DFLOW(6) | 0.00E+00 | -6.23E-01 | -1.54E+01 | 3.04E+01 | -7.61E-01 | -7.85E+01 |
| 79 | DFLOW(7) | -1.08E+01 | 0.00E+00 | -6.83E+01 | 7.25E+00 | -1.44E+00 | -1.49E+02 |
| 80 | DFLOW(8) | -1.95E+01 | 0.00E+00 | -6.74E+01 | 1.50E+03 | 6.64E+00 | 6.85E+02 |
| 81 | DFLOW(9) | -1.84E+01 | 0.00E+00 | -6.43E+01 | 2.46E+02 | 2.98E-01 | 3.08E+01 |
| 82 | DFLOW(10) | 0.00E+00 | 0.00E+00 | -2.04E+01 | 2.68E+01 | 5.75E-03 | 5.94E-01 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 90 | HEATSINK(1) | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.71E+07 | 1.83E+04 | 1.88E+06 |
| 91 | HEATSINK(2) | 0.00E+00 | -4.67E+04 | -6.10E+04 | 4.99E+07 | 6.52E+04 | 6.73E+06 |
| 92 | HEATSINK(3) | 0.00E+00 | -6.07E+04 | -1.21E+05 | 2.37E+07 | 2.70E+04 | 2.79E+06 |
| 93 | HEATSINK(4) | 0.00E+00 | -6.10E+04 | -1.69E+05 | 3.82E+07 | 5.71E+04 | 5.89E+06 |
| 94 | HEATSINK(5) | 0.00E+00 | -6.15E+04 | -1.46E+06 | 2.49E+07 | -2.53E+04 | -2.61E+06 |
| 95 | HEATSINK(6) | 0.00E+00 | -7.68E+04 | -1.90E+06 | 3.84E+06 | -9.40E+04 | -9.70E+06 |
| 96 | HEATSINK(7) | -1.36E+06 | 0.00E+00 | -8.45E+06 | 8.95E+05 | -1.78E+05 | -1.84E+07 |
| 97 | HEATSINK(8) | -2.45E+06 | 0.00E+00 | -8.33E+06 | 1.89E+08 | 8.25E+05 | 8.51E+07 |
| 98 | HEATSINK(9) | -2.32E+06 | 0.00E+00 | -7.97E+06 | 3.05E+07 | 3.70E+04 | 3.82E+06 |
| 99 | HEATSINK(10) | 0.00E+00 | 0.00E+00 | -2.53E+06 | 3.33E+06 | 7.14E+02 | 7.37E+04 |

--------------------Auxiliary Variables ----------------------------------

| Number | Variable | Initial | Final | Min | Max | Mean | Cumulated |
|---|---|---|---|---|---|---|---|
| 105 | TEMP(1) | 3.00E+01 | 3.06E+01 | 2.61E+01 | 3.36E+01 | 2.92E+01 | 3.01E+03 |
| 106 | TEMP(2) | 3.00E+01 | 2.92E+01 | 2.72E+01 | 3.15E+01 | 2.92E+01 | 3.02E+03 |
| 107 | TEMP(3) | 3.00E+01 | 2.90E+01 | 2.77E+01 | 3.06E+01 | 2.93E+01 | 3.02E+03 |
| 108 | TEMP(4) | 3.00E+01 | 2.91E+01 | 2.80E+01 | 3.04E+01 | 2.93E+01 | 3.02E+03 |
| 109 | TEMP(5) | 3.00E+01 | 2.92E+01 | 2.83E+01 | 3.03E+01 | 2.93E+01 | 3.03E+03 |
| 110 | TEMP(6) | 3.00E+01 | 2.93E+01 | 2.85E+01 | 3.02E+01 | 2.94E+01 | 3.03E+03 |
| 111 | TEMP(7) | 3.00E+01 | 2.95E+01 | 2.88E+01 | 3.01E+01 | 2.94E+01 | 3.04E+03 |
| 112 | TEMP(8) | 3.00E+01 | 2.96E+01 | 2.90E+01 | 3.00E+01 | 2.95E+01 | 3.05E+03 |
| 113 | TEMP(9) | 3.00E+01 | 2.98E+01 | 2.93E+01 | 3.00E+01 | 2.96E+01 | 3.06E+03 |
| 114 | TEMP(10) | 3.00E+01 | 3.00E+01 | 2.95E+01 | 3.00E+01 | 2.98E+01 | 3.07E+03 |
| 115 | TEMP(11) | 3.00E+01 | 3.02E+01 | 2.96E+01 | 3.02E+01 | 2.99E+01 | 3.08E+03 |
| 116 | TEMP(12) | 3.00E+01 | 3.05E+01 | 2.95E+01 | 3.05E+01 | 3.00E+01 | 3.09E+03 |
| 117 | TEMP(13) | 3.00E+01 | 3.07E+01 | 2.94E+01 | 3.07E+01 | 3.01E+01 | 3.10E+03 |
| 118 | TEMP(14) | 2.88E+01 | 3.09E+01 | 2.88E+01 | 3.10E+01 | 3.02E+01 | 3.12E+03 |
| 133 | THETA(1) | 6.31E+01 | 7.12E+01 | 6.05E+01 | 7.21E+01 | 6.31E+01 | 6.51E+03 |
| 134 | THETA(2) | 6.39E+01 | 7.26E+01 | 6.09E+01 | 7.31E+01 | 6.37E+01 | 6.58E+03 |
| 135 | THETA(3) | 5.38E+01 | 5.81E+01 | 5.38E+01 | 5.83E+01 | 5.62E+01 | 5.80E+03 |
| 136 | THETA(4) | 5.34E+01 | 5.66E+01 | 5.34E+01 | 5.68E+01 | 5.56E+01 | 5.74E+03 |
| 137 | THETA(5) | 5.46E+01 | 5.78E+01 | 5.46E+01 | 5.80E+01 | 5.71E+01 | 5.90E+03 |
| 138 | THETA(6) | 5.56E+01 | 5.79E+01 | 5.51E+01 | 5.83E+01 | 5.76E+01 | 5.95E+03 |
| 139 | THETA(7) | 6.17E+01 | 6.26E+01 | 6.06E+01 | 6.27E+01 | 6.25E+01 | 6.45E+03 |
| 140 | THETA(8) | 6.87E+01 | 6.87E+01 | 6.80E+01 | 6.88E+01 | 6.87E+01 | 7.09E+03 |
| 141 | THETA(9) | 6.90E+01 | 6.90E+01 | 6.90E+01 | 6.90E+01 | 6.90E+01 | 7.12E+03 |
| 142 | THETA(10) | 6.90E+01 | 6.90E+01 | 6.90E+01 | 6.90E+01 | 6.90E+01 | 7.12E+03 |
| 143 | THETA(11) | 6.90E+01 | 6.90E+01 | 6.90E+01 | 6.90E+01 | 6.90E+01 | 7.12E+03 |
| 144 | THETA(12) | 6.90E+01 | 6.90E+01 | 6.90E+01 | 6.90E+01 | 6.90E+01 | 7.12E+03 |
| 145 | THETA(13) | 6.90E+01 | 6.90E+01 | 6.90E+01 | 6.90E+01 | 6.90E+01 | 7.12E+03 |
| 146 | THETA(14) | 6.90E+01 | 6.90E+01 | 6.90E+01 | 6.90E+01 | 6.90E+01 | 7.12E+03 |
| 147 | PSI(1) | 7.50E+01 | 1.27E+01 | 6.13E+00 | 1.21E+02 | 8.17E+01 | 8.43E+03 |
| 148 | PSI(2) | 6.50E+01 | 2.46E+00 | -8.87E+00 | 1.11E+02 | 7.34E+01 | 7.57E+03 |
| 149 | PSI(3) | 5.50E+01 | -7.54E+00 | -1.89E+01 | 5.50E+01 | 2.34E+01 | 2.41E+03 |
| 150 | PSI(4) | 4.50E+01 | -1.75E+01 | -2.89E+01 | 4.50E+01 | 1.24E+01 | 1.28E+03 |
| 151 | PSI(5) | 3.50E+01 | -2.75E+01 | -3.89E+01 | 3.52E+01 | 3.30E+00 | 3.41E+02 |
| 152 | PSI(6) | 2.50E+01 | -3.75E+01 | -4.89E+01 | 3.00E+01 | -6.70E+00 | -6.91E+02 |
| 153 | PSI(7) | 1.00E+01 | -5.25E+01 | -6.39E+01 | 2.25E+01 | -2.16E+01 | -2.22E+03 |
| 154 | PSI(8) | -1.00E+01 | -7.25E+01 | -8.39E+01 | 3.29E+00 | -4.16E+01 | -4.29E+03 |
| 155 | PSI(9) | -3.00E+01 | -9.25E+01 | -1.04E+02 | -1.67E+01 | -6.16E+01 | -6.35E+03 |
| 156 | PSI(10) | -5.00E+01 | -1.13E+02 | -1.24E+02 | -3.67E+01 | -8.16E+01 | -8.42E+03 |
| 157 | PSI(11) | -7.00E+01 | -1.33E+02 | -1.44E+02 | -5.67E+01 | -1.02E+02 | -1.05E+04 |
| 158 | PSI(12) | -9.00E+01 | -1.53E+02 | -1.64E+02 | -7.67E+01 | -1.22E+02 | -1.25E+04 |
| 159 | PSI(13) | -1.10E+02 | -1.73E+02 | -1.84E+02 | -9.67E+01 | -1.42E+02 | -1.46E+04 |
| 160 | PSI(14) | -1.30E+02 | -1.93E+02 | -2.04E+02 | -1.17E+02 | -1.62E+02 | -1.67E+04 |
| 161 | INTCAP | 4.00E-02 | 4.00E-02 | 4.00E-02 | 4.00E-02 | 4.00E-02 | 4.13E+00 |
| 162 | INTERC | 0.00E+00 | 0.00E+00 | 0.00E+00 | 4.00E-02 | 1.81E-02 | 1.86E+00 |
| 163 | EINTPOT | 1.18E-01 | 8.32E-01 | 1.00E-03 | 1.18E+00 | 1.45E-01 | 1.50E+01 |
| 164 | EACTI | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.07E+00 | 4.56E-02 | 4.70E+00 |
| 165 | ISTORE | 0.00E+00 | 0.00E+00 | 0.00E+00 | 4.00E-02 | 1.80E-02 | 1.86E+00 |
| 166 | RA | 2.83E+02 | 4.34E+01 | 2.38E+01 | 3.34E+02 | 1.87E+02 | 1.93E+04 |
| 167 | ROUGH | 1.00E-02 | 1.00E-02 | 1.00E-02 | 1.00E-02 | 1.00E-02 | 1.03E+00 |
| 169 | RS | 2.00E+02 | 2.00E+02 | 2.00E+02 | 2.00E+02 | 2.00E+02 | 2.06E+04 |
| 170 | WUPPOT | 1.05E-01 | 4.60E-01 | 1.00E-03 | 5.60E-01 | 6.53E-02 | 6.74E+00 |
| 171 | EACT | 1.00E-01 | 4.40E-01 | 9.48E-04 | 5.37E-01 | 6.25E-02 | 6.45E+00 |
| 172 | ETR | 9.56E-01 | 9.57E-01 | 9.48E-01 | 9.62E-01 | 9.54E-01 | 9.84E+01 |
| 173 | EVAPO | 1.19E-01 | 2.48E+00 | -4.98E-01 | 3.97E+00 | 2.95E-01 | 3.04E+01 |
| 174 | VPD | 1.56E+03 | 1.56E+03 | 1.14E+01 | 2.98E+03 | 5.82E+02 | 6.01E+04 |
| 175 | RNTG | -3.68E+05 | -3.82E+05 | -1.62E+06 | -2.17E+05 | -4.48E+05 | -4.63E+07 |
| 176 | LAI | 2.00E-01 | 2.00E-01 | 2.00E-01 | 2.00E-01 | 2.00E-01 | 2.06E+01 |
| 177 | SATLEV | -8.00E-01 | -1.75E-01 | -9.33E-01 | -6.13E-02 | -4.84E-01 | -5.00E+01 |
| 178 | PREC | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.05E+03 | 6.49E+00 | 6.70E+02 |
| 179 | TOTQ | -4.87E+01 | -2.51E+00 | -1.10E+02 | 1.78E+03 | 5.89E+00 | 6.08E+02 |
| 180 | PIPEQ | -4.87E+01 | -2.51E+00 | -1.10E+02 | 1.78E+03 | 5.89E+00 | 6.08E+02 |
| 191 | TTSTEP | -3.31E+00 | -3.31E+00 | -3.31E+00 | -3.01E+00 | -3.30E+00 | -3.41E+02 |
| 192 | DINFIL | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.05E+03 | 6.44E+00 | 6.65E+02 |
| 193 | RAC | 1.31E+03 | 5.34E+01 | 3.38E+01 | 1.31E+03 | 1.97E+02 | 2.04E+04 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 195 | ROOTDEPTH | -1.00E-01 | -1.00E-01 | -1.00E-01 | -1.00E-01 | -1.00E-01 | -1.03E+01 |
| 196 | ETRPSI | 1.00E+00 | 1.00E+00 | 1.00E+00 | 1.00E+00 | 1.00E+00 | 1.03E+02 |
| 197 | ETRTEM | 9.56E-01 | 9.57E-01 | 9.48E-01 | 9.62E-01 | 9.54E-01 | 9.84E+01 |
| 198 | THETATOT(1) | 6.31E+01 | 7.12E+01 | 6.05E+01 | 7.21E+01 | 6.31E+01 | 6.51E+03 |
| 199 | THETATOT(2) | 6.39E+01 | 7.26E+01 | 6.09E+01 | 7.31E+01 | 6.37E+01 | 6.58E+03 |
| 200 | THETATOT(3) | 5.38E+01 | 5.81E+01 | 5.38E+01 | 5.83E+01 | 5.62E+01 | 5.80E+03 |
| 201 | THETATOT(4) | 5.34E+01 | 5.66E+01 | 5.34E+01 | 5.68E+01 | 5.56E+01 | 5.74E+03 |
| 202 | THETATOT(5) | 5.46E+01 | 5.78E+01 | 5.46E+01 | 5.80E+01 | 5.71E+01 | 5.90E+03 |
| 203 | THETATOT(6) | 5.56E+01 | 5.79E+01 | 5.51E+01 | 5.83E+01 | 5.76E+01 | 5.95E+03 |
| 204 | THETATOT(7) | 6.17E+01 | 6.26E+01 | 6.06E+01 | 6.27E+01 | 6.25E+01 | 6.45E+03 |
| 205 | THETATOT(8) | 6.87E+01 | 6.87E+01 | 6.80E+01 | 6.88E+01 | 6.87E+01 | 7.09E+03 |
| 206 | THETATOT(9) | 6.90E+01 | 6.90E+01 | 6.90E+01 | 6.90E+01 | 6.90E+01 | 7.12E+03 |
| 207 | THETATOT(10) | 6.90E+01 | 6.90E+01 | 6.90E+01 | 6.90E+01 | 6.90E+01 | 7.12E+03 |
| 208 | THETATOT(11) | 6.90E+01 | 6.90E+01 | 6.90E+01 | 6.90E+01 | 6.90E+01 | 7.12E+03 |
| 209 | THETATOT(12) | 6.90E+01 | 6.90E+01 | 6.90E+01 | 6.90E+01 | 6.90E+01 | 7.12E+03 |
| 210 | THETATOT(13) | 6.90E+01 | 6.90E+01 | 6.90E+01 | 6.90E+01 | 6.90E+01 | 7.12E+03 |
| 211 | THETATOT(14) | 6.90E+01 | 6.90E+01 | 6.90E+01 | 6.90E+01 | 6.90E+01 | 7.12E+03 |
| 212 | BYPASS(1) | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.04E+03 | 5.49E+00 | 5.66E+02 |
| 213 | BYPASS(2) | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.03E+03 | 4.69E+00 | 4.84E+02 |
| 214 | BYPASS(3) | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.04E+03 | 4.47E+00 | 4.61E+02 |
| 215 | BYPASS(4) | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.03E+03 | 2.80E+00 | 2.89E+02 |
| 216 | BYPASS(5) | 0.00E+00 | 0.00E+00 | 0.00E+00 | 9.93E+02 | 1.13E+01 | 1.16E+03 |
| 217 | BYPASS(6) | 0.00E+00 | 0.00E+00 | 0.00E+00 | 6.90E+02 | 2.60E-01 | 2.68E+01 |
| 225 | ALBEDOG | 1.60E+01 | 1.73E+01 | 1.60E+01 | 2.49E+01 | 2.36E+01 | 2.44E+03 |
| 226 | EGPOT | 1.92E-02 | 2.04E+00 | -5.00E-01 | 3.06E+00 | 1.87E-01 | 1.93E+01 |
| 227 | EGAVAIL | -3.68E+05 | -4.39E+06 | -1.33E+08 | 0.00E+00 | -2.19E+06 | -2.26E+08 |
| 228 | TDSNOW | 1.00E-04 | 1.00E-04 | 1.00E-04 | 1.00E-04 | 1.00E-04 | 1.03E-02 |

-------------------- Driving Variables -----------------------------------

| Number | Variable | Initial | Final | Min | Max | Mean | Cumulated |
|---|---|---|---|---|---|---|---|
| 229 | EPOT | 1.05E-01 | 4.60E-01 | 1.00E-03 | 5.60E-01 | 9.61E-02 | 9.92E+00 |
| 230 | PRECMM | 0.00E+00 | 0.00E+00 | 0.00E+00 | 9.55E+02 | 5.90E+00 | 6.09E+02 |
| 231 | TA | 3.26E+01 | 3.24E+01 | 2.47E+01 | 3.62E+01 | 2.91E+01 | 3.01E+03 |
| 232 | TD | 3.26E+01 | 3.24E+01 | 2.47E+01 | 3.62E+01 | 2.91E+01 | 3.01E+03 |
| 233 | HR | 6.96E+01 | 6.92E+01 | 5.26E+01 | 9.97E+01 | 8.78E+01 | 9.06E+03 |
| 234 | WS | 5.91E-01 | 3.85E+00 | 5.00E-01 | 7.01E+00 | 1.39E+00 | 1.43E+02 |
| 235 | RNT | -4.06E+05 | -4.22E+05 | -1.78E+06 | -2.39E+05 | -4.96E+05 | -5.11E+07 |
| 236 | CLOUDN | 1.00E+00 | 1.00E+00 | 7.00E-01 | 1.00E+00 | 9.60E-01 | 9.91E+01 |
| 237 | RIS | 2.19E+02 | 4.63E+02 | 0.00E+00 | 6.57E+05 | 2.01E+02 | 2.07E+04 |
| 239 | DRAINLEV | -7.89E-01 | -1.74E-01 | -9.33E-01 | -1.64E-01 | -4.86E-01 | -5.01E+01 |

The simulation occupied the computer during:

TIME USED 0 h 18 m 46 sec

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