# WATER FLOW AND SOLUTE TRANSPORT IN THE KORENBURGERVEEN SITE

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**Abstract:** The present investigation was part of fen restoration project which deal with the rehabilitation of a cutaway peatland area Korenburgerveen (the Netherlands) that is a nature conservation reserve now. The paper describes the results of investigation of water flow and tracer transport to estimate the effect of different water management scenarios, climatic conditions and such restoration measure as turf stripping on the ground water table dynamics as well as percentage concentration of ground water mixed with precipitation in the soil profile of the Korenburgerveen site. An one –dimension model for coupled transport of water, heat and solutes in the soil- plant –atmosphere continuum (SWAP) was used for the purpose of this study.

## INTRODUCTION

Ground water and solute transport are the fundamental processes that govern the most geochemical and ecosystem functions in peatlands.

Transport of reactive chemicals in soils is affected by complex interactions involving biological, chemical and physical processes. Knowing how dissolved solid, dissolved gases and trace metals move vertically through peat is important to understand the complexity of nutrient, carbon and other cycles and the controls over the ecological changes in peatlands (Bair (1995)).

The mass transport of inorganic solute from mineral sources determines both the abundance and distribution of vegetation in peatlands (Glaser et al., 1981). According to the surface-water chemistry and vegetation peatlands are divided into two classes—fens and bogs. Fens have a flat or a bit sloping surface. The higher pH (usually pH > 4.2) and greater solute concentration (Ca> 2 mg $kg^{-1}$) in fen surface water stipulates more diverse plant communities with feather mosses as the dominant bryophyte. Bogs are topographic domes that contain acidic (pH< 4.2)

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surface waters with low concentration of inorganic solutes (e.g. Ca< 2 mg $kg^{-1}$) and vegetation is represented by few species and are dominated by *Sphagnum* (Gorham et al. (1985), Glaser et al. (1981), Glaser (1983)). The inorganic geochemistry of bog surface water similar to that of local precipitation, with minor deviations due to biological activity and evaporative concentration (Reeve et al. (1996), McNamara et al. (1992)). The chemistry of the fen waters is more similar to that of ground- water, although it becomes more dilute with increasing distance from a mineral source because of mixing with precipitation.

Pore-water of peat is dependent on the mineralogical composition of underlying geologic materials, inputs from precipitation, and other factors (Bromley & Robinson (1995), Ingram (1983)).

Superficial peat pore water in bogs and fens contains about 1 and 10 % ground-water, respectively (Reeve et al. (2001)).

Peatlands are very susceptible to human activities. In the last decades due to cultivation significant losses of typical fen plant species and phytocenoses took place in many regions (Patzelt et al (2001), Graham & Hutchings (1988), Rodwell (1991)).

Until 50 years of the 20 century, nutrient poor, base rich fen meadows were common in the Netherlands. Fen meadows are semi-natural ecosystems derived from fens by extensive agricultural exploitation for hay- making without fertilization and some degree of drainage. The typical plant communities in fen meadow have become endangered or extinct.

In addition to nature preservation, restoration projects are important to protect wet fen meadows for the future.

The present investigation was part of fen restoration project which deal with the rehabilitation of a cutaway peatland area Korenburgerveen that is a nature conservation reserve now. There used to be an upward seepage which brought water with a moderate pH buffering capacity in to the root zone, which caused a rather specific flora to develop. Today, the hydrological conditions have been changed as a result of groundwater extraction in the surroundings of the area. The development of the vegetation suggests an ongoing acidification of the topsoil. Instead of upward seepage of calcareous ground water, precipitation water is now infiltrating which has caused acidification.

To maintain and restore of the abiotic site conditions of degraded fen the special water management is needed. The restoration measure inside the nature reserve included turf striping and trench –cutting, which aimed to diminish eutrophication and acidification. (D. vad der Hoek (2000)).

In this study SWAP (Soil-Water-Atmosphere-Plant) model have been applied to analyse the effect of different water management scenarios, climatic conditions and such restoration measure as turf stripping on the ground water level fluctuations as well as percentage concentration of ground water mixed with precipitation in the soil profile of the Korenburgerveen site.

## MATERIALS AND METHODS

### Description of study site

The nature reserve the Korenburgerveen is a 310 ha remnant of a bog in the eastern part of the Netherlands. It is situated at the border of a glacier valley that is eroded in Tertiary clay. Within the reserve the height of surface is influenced by digging and dragging of peat and by reclamation activities in the 19th century. Many parallel dikes at the distance of about 25 m are dominated in the landscape. Nowadays the area between the dikes are terrestrialised for the greater part and fens have been developed.

In the transition zone between the bog and the brook lays a 14-ha remnant of formerly extensive communal hay field with nutrients- poor, special rich plant communities (*Cirsio- Molinietum*.) During the past twenty years a shift in the botanic composition of these fen- meadows has occurred. Some rare species like *Parnassia palustris* have decreased and mosses (*Sphagnum spec.* and later on *Polytrichum spec*.) became more and more abundant. The changes in the vegetation of the bog and fen- meadows are correlated with deterioration of environmental circumstances.

The Korenburgeen has been protected since 1918 as a nature reserve but its hydrological position has become increasingly problematic because it is surrounded by intensively used agricultural lands. Up till now only restoration measures inside a nature reserve could be carried out. They include turf-stripping and trench cutting which aim to diminish eutrophication and acidification. The question is how effective the measures are.

### Field measurements

In 1990 two experimental fields were constructed in the meadow to investigated the effect of trenches on the solute movement in the soil profile. The ditches in the area N have depth of 70 cm and the distance between them is 31 m. The area S has two levels drainage system- shallow ditches with depth of 20 cm and the distance between them is about 7 m, as well as deep ditches (70 cm) and distance between them is about 55 m.

A data set, including daily precipitation, ground and surface water level, quality ground and surface water was collected. The field program was covered a more than full year (from April, 1, 2001 till September, 30, 2002).

Samples to characterize the quality of the water in the saturated and the unsaturated zone are taken and analysed by the Department of Nature Conservation of the Wageningen University. Samples were taken two times a year (May, August) to determine the solute in the surface and groundwater (at the depth of 10, 20, 40 and 60 cm), soil (OA- horizon).

Soil sampling was made in each plot to a depth of 1 m and major soil horizons were described.

## Description of the model used

An existing one –dimension model for coupled transport of water, heat and solutes in the soil- plant –atmosphere continuum (SWAP) was used for the purpose of this study. A detailed description of the original SWAP model can be found in (Van Dam at al. (1997), Van Dam (2000)).

## Soil water movement

SWAP employs the Richards' equation for soil water movement in the soil matrix:

$$C(h)\frac{\partial h}{\partial t} = \frac{\partial\left[K(h)\left(\frac{\partial h}{\partial z}+1\right)\right]}{\partial z} - S_a(h), \tag{1}$$

where K is unsaturated hydraulic conductivity (cm $d^{-1}$), h is soil water pressure head (cm), z is the vertical coordinate (cm) taken positively upward, t is time (d) and S is soil water extraction by plant roots ($cm^3$ $cm^{-3}$ $d^{-1}$ ), C is the differential water capacity (cm $^{-1}$),$\theta$ is volumetric water content ($cm^3cm^{-3}$).

In SWAP the analytical functions of Van Genuchten (1978) and Mualem (1976) for $\theta$(h) and K(h) are implemented.

## Solute transport

In SWAP is used the transport equation, which is valid for dynamic, one –dimensional, convective- dispersive mass transport, including non-linear adsorption, linear decay and proportional root uptake in unsaturated/saturated soil:

$$\frac{\partial(\theta c+\rho_b Q)}{\partial t} = -\frac{\partial qc}{\partial z} + \frac{\partial}{\partial z}\left(\theta(D_{dif}+D_{dis})\frac{\partial c}{\partial z}\right) - \mu(\theta c-\rho_b Q) - K_r Sc, \tag{2}$$

where C is the solute concentration in soil water (g $cm^{-3}$), $D_{dif}$ is the solute diffusion coefficient($cm^2$ $d^{-1}$), $D_{dis}$ is the solute dispersion coefficient($cm^2$ $d^{-1}$), Q- the amount adsorbed solute (g $g^{-1}$), $\rho_b$-the dry soil bulk density (g $cm^{-3}$), S is the root water extraction rate ($d^{-1}$), $K_r$- the root uptake preference factor ($d^{-1}$).

## Modelling strategy

Numerical simulations were run in some steps: first, ground water flow rates and second solute transport were simulated.

Given the length of the data set, the period from July, 1, 2001 till June, 30, 2002 was used for the model calibration and estimation of unmeasured parameters. Field measurements of ground water level have been used during model calibration with experimental data.

Variability with respect to model input data is recognized as a potential source of uncertainty in model predictions. That is why the sensitivity of the ground water level to input data have been investigated. To optimise the parameters the PEST has been used.

The calibrated models were applied to simulate the tracer behaviour in the layered soil profile.

All mass transport simulations were run until steady –state conditions were achieved. Concentration can be considered the percent of ground water that has mixed with recharge from precipitation. Soil profile itself does not supply solutes to the water and the deep aquifer maintains a continuous and uniform concentration through time.

Finally, the model was used to quantify the effect of changes in meteorological conditions, different water management scenarios and such measure as turf stripping (top soil removal) to restore fen meadow at the cutaway peatland Korenburgerveen.

To estimate behaviour of tracer under different meteorological conditions 2 scenarios have been simulated—wet year (1966) and dry year (1976)

The comparison of water flow and tracer transport in area N and area S, as well as simulation scenario for area S without shallow ditches allowed to evaluate the effect of shallow ditches on the water quality in the soil profile. Simulation of scenario with removed of top soil layer have been done to evaluate the measure to restore favourable conditions for fen meadow at the site.

## RESULTS AND DISCUSSIONS

## Analysis of the monitoring data of the surface and ground water

The results of monitoring data have shown that ground water levels are fluctuated strongly as a functions of the intensity of the precipitation.

The ground water levels for both fields were shallow, between -30 and 0 cm, during most part of the period monitored (September- May) and sometimes, especially in the winter, have been reached the soil surface. During summer period the ground water levels at the both field drop down till –57 cm .

The behaviour of the groundwater levels was different for the different lateral distance from drains. Large fluctuations of ground water level were measured at the plots, midway at the deep drains and shallow ditches, as compare with the fluctuations of groundwater level at the plots which is located close to deep drains. It should be emphasized that for both investigated areas the ground water level

and surface water level are close and the difference between them is not exceeded 15cm during whole investigated period.
Surface water levels in the shallow ditches were a bit higher as compare with deep ditches during autumn-winter-spring seasons.

## SIMULATIONS OF GROUND WATER FLOWS

### Sensitivity analyses to physical properties affecting groundwater level

The calibration of the model based on the field measured data of ground water level for period of July, 1, 2001- June, 30, 2002. Measurements of ground water levels are relatively easy and often used during model calibration with experimental data (van Dam, 2000). Model simulated and monitored ground water levels were compared and model parameters were adjusted to bring simulated values with measured ones.
Important problem in simulation is the estimation of the sensitivity of model output to uncertainties concerning the variability of input parameters.
The sensitivity of the ground water level to drainage and infiltration resistance, bottom flux, as well as soil hydraulic functions of the both top and subsoil layers-saturated hydraulic conductivity, shape $\alpha$ and $n$ parameters in equations for soil hydraulic functions has been investigated. Given the uncertainties in the values of these parameters it is important to investigate how sensitive the ground water level is to these parameters.
The goodness of fit between calculated and measured ground water levels was express in terms of relative efficiency, RE .
Sensitivity of ground water level to varying the drainage resistance was found to be very high. Thus, increase of drainage resistance up to 100 d lead to RE=33%, whereas decrease of drainage resistance down to 10 d increase efficiency up to 80 %.
The results of simulation have shown much greater fluctuation in the predicted water ground levels than in the measured values particularly where the measured ground water level was within 20 cm of the surface. The slower dynamics of the field data indicates that the differential water capacity in the field was larger than in the simulation. So, sensitivity of the ground water level can be studied best by varying the water retention characteristics in zone. The shape of water retention curve for larger value of $\alpha$ resulted in larger differential water capacities in the region 100-0 cm.
Sensitivity analysis of ground water level to the shape parameters $\alpha$ and n in Mualem- Van Genuchten equations can been done. Increasing the $\alpha$ parameter by factor 10 to 0.176 in top layer resulted in increasing RE up to 90%, increasing $\alpha$ parameters by factor 10 to 0.242 in the 2nd layer resulted in increasing of RE up to 80%. The increased differential capacity results in a damping out of the changes in the ground water level.

The results of varying of soil physical properties revealed that the most sensitive parameters are saturated moisture content of the both layers as well as $\alpha$ parameter in hydraulic function equations of the top soil layer.
The range and dynamics of the simulated ground water level correspondent reasonably to measured ones as illustrated in Figure 1.

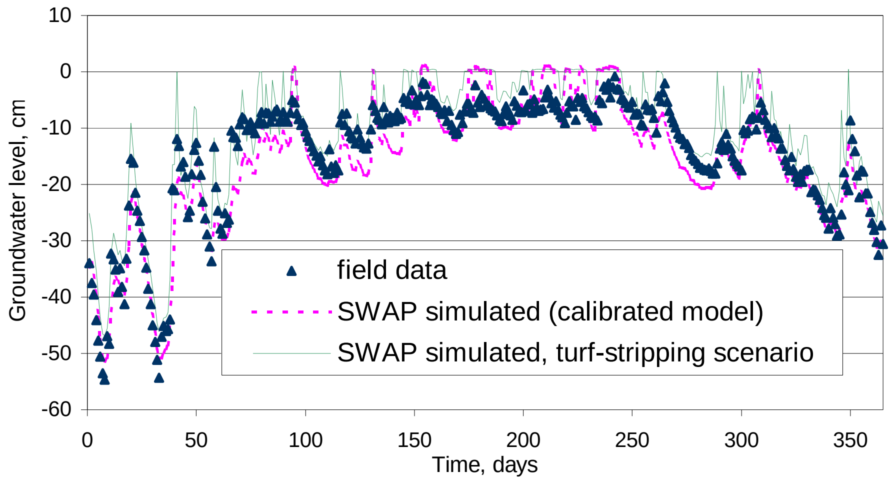


Fig.1. SWAP simulated and field measured ground water level for plot 7 (area N) in the period July, 1, 2001- June, 30, 2002

## Simulation of the tracer transport

Tracer have been used as the indicator of ground water to define the relative fraction of ground water in soil pore-water.
The calibrated model for water flow has been used to simulate the tracer behaviour in the soil profile. In the simulation experiments we applied tracer to ground water in the concentration of 100 mg/cm$^3$ which maintains a continuous and uniform concentration through time in soil column. Tracer has been added at the July, 1, 2002 and its transport have been simulated through the year in the monitoring period (July, 1, 2001—June, 30, 2002). In the conditions considered solute diffusion is much less than solute dispersion therefore diffusion have been neglected. To calculate the dispersion coefficient we assumed that a field dispersion length of 5 cm. Adsorption, decomposition and root uptake of the tracer were assumed to be negligible.
All mass transport simulations were run until steady –state conditions were achieved. In this case the percentage concentration of tracer in soil layer allows to judge about the fraction of ground water in soil pore water at the certain depth.

Concentrations in all simulations can be considered the percent of ground-water that has mixed with recharge from precipitation.
Anizotropy factor of saturated hydraulic conductivity was assumed to be a factor controlling the tracer pattern in soil profile.
The simulation of the tracer transport with addition of factor anisotropy of 0.2 for middle soil layer allow us to get pattern of tracer dynamic in soil profile close to measured data. Therefore under these conditions a significant fraction of ground water from the base of the profile would be transported to the surficial layers.
The tracer concentration (equally ground water fraction) shows clear seasonal fluctuation with the highest value in summer period and the lowest value in winter period. Thus at the depth of 20 cm percentage of ground water in soil pore water was 7.56 % on February 28 and 55 % on June 30. The fraction of ground water that was transported to the soil layer 0-9.5 cm ranged from 1.27 % on January, 1 to 24.8 % on July, 31m (Fig.2).

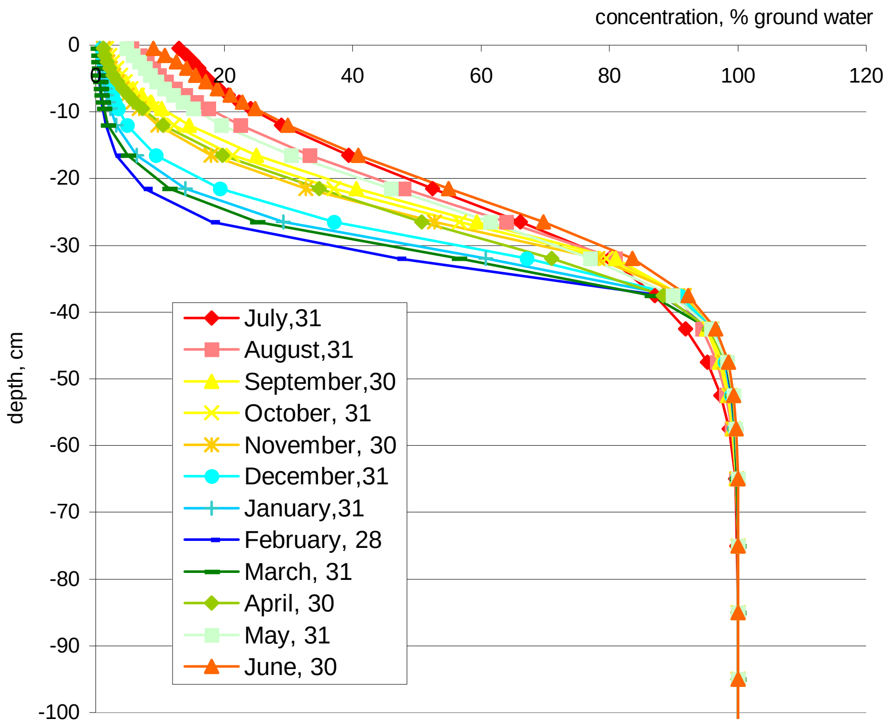


Fig. 2. Percentage of ground water which mixed with precipitation in the soil profile in the period July,1,2002- June,30,2002

All pore soil water at the depth 60 cm entirely consists from ground water during whole year, at the depth 42.5 cm pore water contains about 96 % of ground water during whole year.

Short term changes in soil pore water content during year obviously is stipulated by seasonal dynamics of water flow in soil profile. During summer period upward water flow increases of the tracer concentration in the soil profile whereas in winter time downward water flow decreases it.

## Tracer behavior in the wet year

As example of wet year we used 1966 year at which the sum of precipitations was 1166 mm. Under this extremely wet conditions soil profile is nearly saturated during whole year. The interception is 11.73 cm, transpiration is 44.11 cm, runoff is 7.08 cm and drainage is 67.04 cm.
The percentage concentration of ground water in soil pore water is decrease in root layer and the pattern is shifted to more deep soil layer. Thus, the tracer concentration at the depth of 9.5 cm was only 1 % in period December, 31 – February, 28 and about 10 % in the period of September, 30 -October, 31 whereas at the depth 21.5 cm was changed from 3 % on April, 30 till 32 % on October, 31 that is considerably lower than concentration for the average year.

## Tracer behavior in the dry year

As example of dry year we have taken for simulation the 1967 year. In the dry year sum of precipitation was particularly low and consisted 438 mm. So the minimum of water table was maintained for a long period.
Under this extremely dry conditions during summer period root water extraction causes considerable increasing of the solute concentrations in the surface layer. So, in the scenario we included the tracer uptake by roots with coefficient of the relative uptake of 1.
In the dry year the highest concentration of tracer at the depth of 9.5 cm is assumed to be in summer period and will be changed from 61 % on May, 31 till 93 % on July, 31. But in the winter it will be have maximum 35 % on December, 31 and minimum 11% on January, 31.
Figure 3 illustrates the ground water content in soil pore water at the depth 9.5 cm and 21.5 cm for wet year, dry year and the reference situation.
The results indicate that climatic conditions have a strong effect on tracer transport in soil profile. Under this dry conditions during summer period soil pore water at the depth of 10 cm will be consist up to 93 % of ground water whereas in winter period up to 30%.

## Scenario with removal of top soil layer

Turf –stripping removes the eutrophicated topsoil and the measure had been used at the area N to create the favourable conditions for restoration of fen meadow (Van Der Hoek, 2000).
Calibrated model have been applied to simulate the effect of the top organic layer removal on the ground water flow to the soil surface.

By lowering the surface level more wet conditions are created in the remaining top soil. The simulation results have shown that this measure increase the water discharge by runoff up to 20 cm, by drainage up to 23 cm and was resulted in upward of ground water level during whole investigated period.
The turf stripping of the top soil layer with high differential water capacity changes not only hydrological field conditions but soil profile properties. These factors are stipulated the considerable increase of fraction of ground water in top layers as compare with the reference situation. The seasonal fluctuation of the fraction of the ground water at the certain depth was decreased in the changing conditions also. It allows to judge about a turf stripping as a effective measure to create more favourable conditions for regeneration of vegetation typical for fen meadow.
Comparison of scenarios for calibrated models at the area N and S revealed that ground water in the area S is transported to more upper soil layer as compare with area N and at the depth of 10 cm the difference changes from 1% on January, 31 till 12% on May, 31.

## Tracer transport in the scenario without shallow ditches

Changing of the two level drainage system on one level (without shallow ditches) had considerable impact on the groundwater level fluctuation.
Simulation of the scenario have shown that the removal of shallow ditches leads to redistribution of water balance component in soil profile. For the situation with shallow ditches the mail part of water (36 cm) have been discharged from soil profile by the shallow ditches and lower part (8.39 cm) by deep ditches and runoff was absent. The removal of the shallow ditches will lead to the increase of water discharged by runoff till 11.19 cm and discharge of water by deep ditches till 31 cm.
This was stipulated the increase of fluctuation of ground water level in the soil profile - downward of ground water level during March, July –August and to upward to close to the surface during the winter period as compare with two level drainage situation.
Comparison of the simulated data for scenarios with and without shallow ditches have shown that shallow ditches did not effect on pattern of the tracer distribution (percentage of ground water) in soil profile deeper than 50 cm.
At the depth of 10 cm the percentage of ground water in soil pore water was higher on value of about 3- 10 % during period from May to November and or a little bit lower in the winter time (January, February) at the two level drainage system as compare with one level drainage system. The same regularity is for depth of 21.5 cm. These data allowed to say that shallow ditches cause the tracer transport to the soil surface especially in spring- summer- autumn season, it means increasing of percentage of ground water in pore soil water in top layers. So, the shallow ditches are quite effective measure to decrease acidification of top soil layer because they discharge atmotrophic water during the wet periods with high ground water level and stipulate the upward flow of the lithotrophic water from soil base. The system is very sensitive to the drainage resistance and the

efficiency of the measure will obviously depend on the distance between shallow ditches as well as the depth of ditches.

## CONCLUSIONS

The agrohydrological model SWAP has been used to analyse the effect of different water management scenarios, climatic conditions and the restoration measures as turf stripping on the ground water level fluctuations as well as percentage concentration of ground water mixed with precipitation in the soil profile of the Korenburgerveen site.

Modelling efficiency (as indicator of agreement between simulated and measured data) was 86% and 81% for N and S areas respectively. The agreement between simulated and monitored results is satisfactory considering the complexity of field conditions.

Given the uncertainties in the physical parameters, number parameters of the model, it was important to understand how sensitive the estimates of ground water level are to these parameters. Sensitivity analyses of ground water flow has been done to determine the parameters having the greatest effect on estimates of ground water level. The results of varying the drainage parameters and soil physical properties were analysed. Sensitivity to the parameters of soil moisture characteristics particularly to the shape parameters $\alpha$ and n of Mualem- Van Genuchten equations and drainage and infiltration resistance was found to be very high for both areas.

Based on the results of sensitivity analysis it should be notice that it is important to take into account the order of adjustment of parameters —first of all the drainage/ infiltration resistance, after that the bottom flux and after that the soil physical properties should be adjusted.

The calibrated models were applied to simulate the tracer behaviour in the layered soil profile. At the tracer transport simulations at the steady –state conditions tracer concentration can be considered the percent of ground water that was mixed with rescharge from precipitations.

Sensitivity analysis has shown the tracer behaviour ( as well as the fraction of ground water mixed with precipitation in soil pore water) is mainly affected by the relation between horizontal and vertical saturated hydraulic conductivity of soil layers especially for middle layer. The increase of factor anisotropy of top1$^{st}$ and 2$^{nd}$ layers shifts the pattern of tracer distribution upward of soil profile and increasing a fraction of ground water transported to soil surface.

The climatic conditions have a strong effect on tracer transport in soil profile and the fraction of lithotrophic ground water in soil pore water in the investigated system. Under extremely dry conditions during a summer period the soil pore water at the depth of 10 cm will be consist up to 93 % of ground water and up to 30% in the winter period whereas in the wet year 10 % and 0.5 % respectively.

Thus it should be noted that the results may only apply to the climatic conditions typified by the meteorological data used.

The turf stripping of the top soil layer with high differential water capacity changes not only hydrological field conditions but soil profile properties. These factors are stipulated the considerable increase of fraction of ground water in top layers as compare with reference situation. The seasonal fluctuation of the fraction of the ground water at the certain depth was decreased in the changing conditions also.
Comparison of scenarios for calibrated models at the area N and S revealed that ground water in the area with two levels drainage is transported to more upper soil layer as compare with area N in the summer –autumn period and at the depth of 10 cm the difference is up to 10% in some data.
Changing of the two level drainage system on one level (without shallow ditches) had considerable impact on the groundwater level fluctuations.
Shallow ditches cause the tracer transport to the soil surface especially in spring-summer- autumn season, it means increasing of percentage of ground water in pore soil water into top layers. The results have demonstrated that the shallow ditches are quite effective measure to decrease acidification of top soil layer because they discharge atmotrophic water during wet periods with high ground water level and stipulate the upward flow of the lithotrophic water from soil base. The system is very sensitive to the drainage resistance and the efficiency of the measure will obviously depend on the distance between shallow ditches as well as the depth of ditches.
The simulation of simulation have shown quite high sensitivity of the ground water level at the site to bottom flux. Due to there are not reliable methods to measure the ground water flux in situ the parameter can be used as fitting one. A central role in soil water movement and transport of tracer is played by the soil hydraulic functions. Taking in account high sensitivity of ground water flow and tracer transport in the site to the functions, especially ones in top layers, it should be very important to make experimental investigations of water retention functions and vertical and horizontal hydraulic conductivities of the top soil layers.
Father investigations should be aimed at the simulation of transport of inorganic solutes from underlying mineral base to the fen surface to evaluate the hydrological processes influencing pore-water chemistry within Korenburgerveen site. The simulation of behaviour of calcium in the system will allow to get more reliable data about water quality in soil profile and conditions for abundance and distribution of vegetation in the site.

## ACKNOWLEDGEMENT

This work was founded by the NATO and the Netherlands Sciences Foundation. The author wish to express thanks to Dr. S. van der Schaaf Dr. J. van Dam for field data collection and many useful discussions.

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