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# Moisture conditions on a polder without an efficient drainage system. Case study

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A b s t r a c t. Many hectares of field culture changed not only ownership, but also the manner in which it was farmed in the last decade in Poland. This refers also to polders with compound soil profiles and complex water conditions. Alluvial soils and relatively high water tables occur often in such areas. These conditions are more suitable for grassland than for arable land farming. These rules are very often forgotten by new farmers. This causes conflicts between farmers and the holder of the melioration system or the water reservoir in the vicinity. An example of such a situation is a small polder where soil water conditions are influenced by the reservoir with retained water levels between about 0-1.5 m above the surface of the surrounding land.

The paper presents the results of measurements and mathematical simulation for such a polder in the depression. It is concluded that if the beginning of the vegetation season (April) is wet, the moisture conditions are unfavourable for crop production. But if April is dry, then even if the rest of the season is wet, the moisture conditions will still be satisfactory. This conclusion was derived from presented results of simulation. It is true only if farmers' activities are responsible and rational for such soil and water conditions.

K e y w o r d s: water flow, water uptake by plants, mathematical modeling

## INTRODUCTION

Alluvial soils of the polder are mostly silt deposits with a clay content of 15-30%, or heavy gley soils with about 30-50% of clay. The soils, generally, have low water permeability, poor aeration and very often too high a water content (Kowalik, 1986). Beneath these soils is often a sandy layer. The yield of agricultural crops can be high, but mainly in dry years, thanks to a favorable climate and good soil fertility. High yield needs appropriate drainage and irrigation systems (Kowalik, 1986).

The polder under consideration (Fig. 1) contacts with a water retention reservoir on the north side and the old branch of the Motława river in the south. Hypsometric classification shows it to be a depressive area with an altitude of 0-0.5 m below see level.

Water in the retention reservoir is about 1-1.5 m above the polder surface, but in the old branch of the river it is about 0-0.5 m below the polder surface. The polder is drained by two ditches, 140 m apart, the water being channelled to a pumping station. The average precipitation is about 500 mm per year, but varies greatly from 300 to 900 mm per year. Potential evapotranspiration is about 600-700 mm per year. Winds are strong and frequent, increasing the rate of evapotranspiration. The moisture conditions in soil profile depend greatly on the wetness of the vegetation season, as well as on farmers' activity.

The soil profile consists of heavy soils, sometimes very heavy soils or peat. Saturated hydraulic conductivity of the upper part of the profile is of the order of 23.9-46.3 cm day$^{-1}$ *ie* (2.76-5.36)10$^{-6}$ m s$^{-1}$. Further down, the values of this coefficient are lower and of the order of (4.94 – 9.78)10$^{-9}$ m s$^{-1}$.

The wide spacing of the drainage ditches conducting water from the polder to the pumping station was caused by so-called 'integration of small fields into a bigger whole', after the Second World War (after 1945). According to the custom of that time, the State Farms did not agree to run a farm on small plots of ground enclosed by a dense drainage ditches system: the Ministry of Agriculture at the time decided to carry out the above mentioned "integration" with farming as arable land. It was forgotten, however, that such 'integration' would be effective only when filled up ditches be properly drained. Beside this they forgot that the area

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discussed was used in the past as grassland, meaning soil profiles with shallow ground water. As we know, arable lands usually need a deeper water table (*ca* 0.3 m, *eg* (Fukuda, 1967; IMUZ, 1988).

Mathematical simulations were performed for cross section I – I, depicted in Fig. 1 and schematically shown in Fig. 2. Calculations were performed for 1996, as meteorological data, measurement results of water level in the retention reservoir, and the water table on the polder were available (from the holder of the reservoir) for that year. In 1996, from 14th May to 25th June, the retention reservoir held a variable but controlled water level. On 14th May, the water level reached a height of 0.96 m above sea level and later (on 17th June) receded to 0.3 m below sea level. From 17th June, the retention reservoir again rose quickly, reaching 1 m above sea level by 22nd June. This level was then held during the following days. It is these water levels that were applied as the boundary conditions in the simulation model.

The height of water table on the polder was evaluated in control wells Nos 10 and 11 on the foreland of the retention reservoir. These wells were placed as shown in Fig. 1. The measured results were used to verify those calculated.

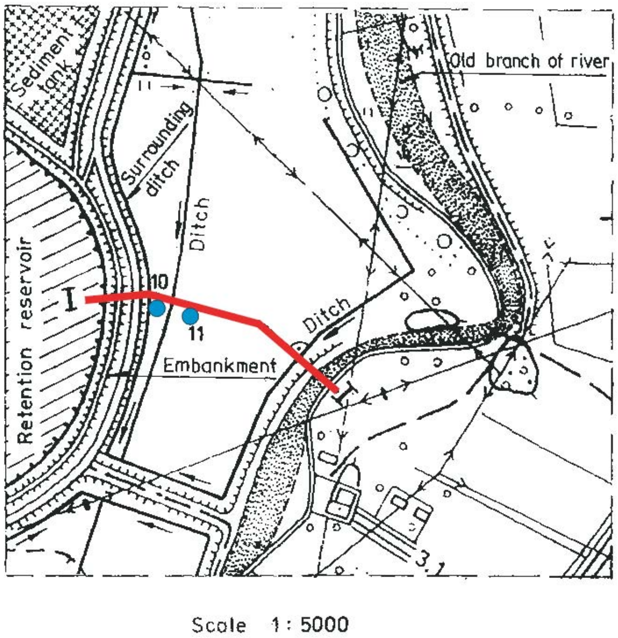



**Fig. 1.** A part of polder studied, showing the cross-section I-I.

## MATHEMATICAL MODEL

In most cases, for the simulation of moisture conditions on the polder, the two-dimensional model of soil water movement in x-z plane is optimal. This model enables faithful projection of essential elements of the polder system, such as streams, ditches, drainage systems *etc*., and first of all, soil arrangement, geometry of root zone, variety of the boundary conditions (BC) in time and space, and particularly those of the atmospheric type. The latter (BC) describe the current extortion of atmosphere for water transport into the soil profile (infiltration or soil evaporation) or water uptake from the root zone of the soil

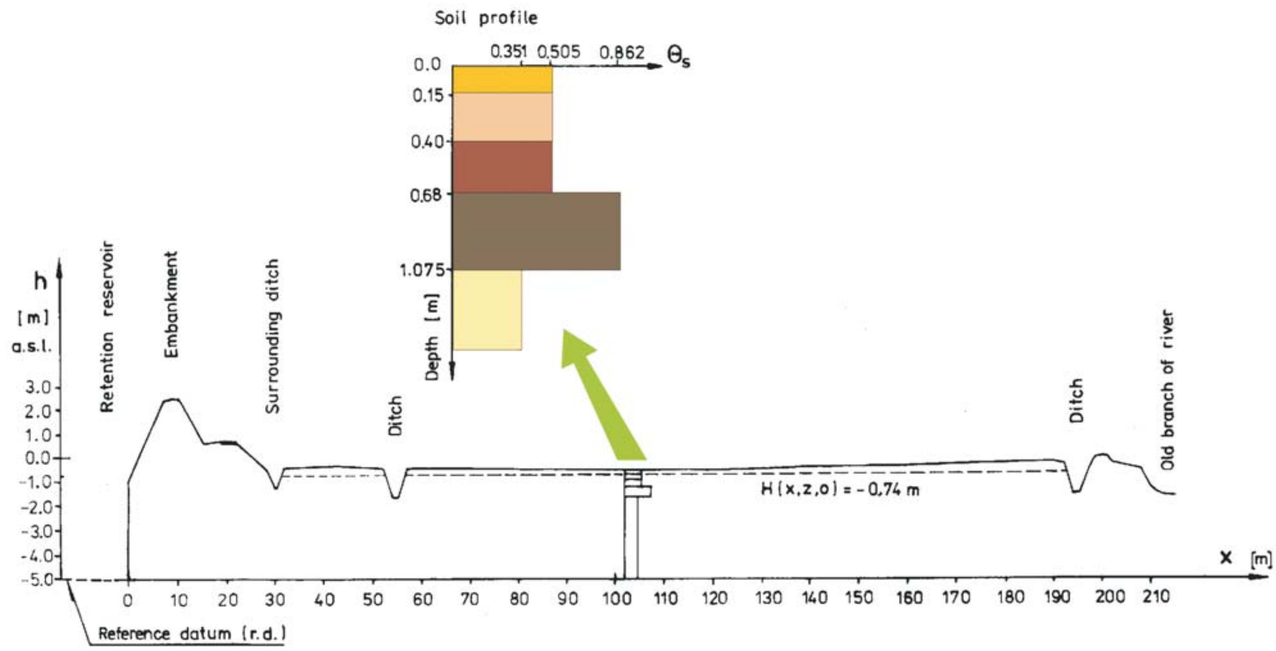



**Fig. 2.** Cross-section I-I taken for the mathematical simulation.

profile for transpiration. The response of the system (soil – plant) to such boundary conditions depends on actual distribution of the pressure of soil water and capabilities of the soil profile to transport water. Generally, the pressures of soil water should be suitable for work ability, traffic ability and for grazing; it should also be suitable for water uptake by transpiration on an optimal level (*ie* that the actual transpiration $ET^{act}$ should be equal, or close to the potential ones $ET^{pot}$ ).

The problem under consideration (in two-dimensional x–z system), in slightly compressible unsaturated or partly-saturated soils, with water taken up by plant roots, can be described by Richards equation (Zaradny, 1990; 1993):

$$\frac{\partial}{\partial x}\left[k_r(h)\left(k_{xx}\frac{\partial H}{\partial z}\right)\right]+\frac{\partial}{\partial z}\left[k_r(h)\left(k_{zx}\frac{\partial H}{\partial x}+k_{zz}\frac{\partial H}{\partial z}\right)\right]$$

$$S=\left[C(h)+S_w S_s\right]\frac{\partial h}{\partial t} \tag{1}$$

where: H = h + z – total hydraulic head of soil water (m), h – pressure head (m), x, z – spatial coordinates ( z – the vertical) (m), $k_r(h)$ – relative hydraulic conductivity: $0 \le k_r(h) = \frac{k(h)}{k_s} \le 1$, k(h) – hydraulic conductivity at the pressure head h (k(h) = $k_s$ for h≥0), $k_s$ – hydraulic conductivity (m $d^{-1}$) at full saturated soil, in the general case it is a tensor:

$$k_s = \begin{vmatrix} k_{xx} & k_{xz} \\ k_{zx} & k_{zz} \end{vmatrix} \tag{2}$$

where: S – sink term ($d^{-1}$), $S_w = \theta / \theta_s$ – saturation ratio (fraction), $S_s$ – specific capacity ((retention), elastic capacity ($m^{-1}$)), C(h) = d$\theta$/dh – differential water capacity (C(h) = 0 for h≥ 0) ($m^{-1}$), t – time, day (d).

The Richards equation is a non-linear second-order partial differential equation which can be of the following types: parabolic for C(h)≠0 (unsaturated medium) or $S_s \neq 0$ (saturated medium), or elliptic if C(h) = 0 and $S_s$ = 0 (saturated medium).

From a numerical study of Zaradny (1990), there appears a practical conclusion that by taking an adequate small value $S_s \neq 0$ (*eg* $S_s < 10^{-5}$ $m^{-1}$) one can preserve the parabolic type of the Richards equation in both zones of saturation. If the medium were perfectly incompressible, the assumption as to the adequately small value of $S_s$ during computations (necessary to maintain the parabolic type of the equation) would be of no practical impact on the results.

Considering the moisture conditions on the polder, the problem lies in time and in space, which is - among other things - a result of varying height of water level in the canals, varying weather conditions, and varying stage of plant growth: depths and densities of root systems, leaf area index, height of the plants, *etc*. From the practical point of view for the problem under consideration, the variability mentioned refers in most cases to the day and night cycle, with the values averaging for this period (Feddes *et al*., 1978).

For a complete definition of the problem, one must determine the boundary and initial conditions. The initial conditions are due to the fact that the independent variable (time, t) also intervenes. To solve such a problem one must apply a function h(x,z,t) which satisfies the Richards equation (Eq. (1)) in the whole flow area under consideration Ω (the area in Fig. 2) for t > 0, and known function $h(h,z,t_0) = h_0(x,z)$ for $t = t_0 = 0$.

The source function S permits simulation of water uptake from soil by plant roots. This kind of water uptake is referred to as transpiration ET (water passes from the liquid to the gaseous phase by plant metabolism, contrary to evaporation ES which is referred to as direct transition from liquid to the gaseous phase). Water uptake by roots depends, on the one hand, on the forcing called potential transpiration $ET^{pot}$, and – on the other hand – on the energy status of soil water in the root zone. Using the source function, one can estimate the actual transpiration $ET^{act}$, that is the real uptake of water from soil. For this, one must first determine the potential transpiration $ET^{pot}$ and appropriately describe the source function S. The methods for determining the first value can be found in the pertinent literature (Feddes *et al*., 1978; Zaradny, 1993). The method of describing the source function S is given below.

As one knows, there are several models describing the flow of liquid water through the rooted soil zone in terms of Ohm's law. The rate of water uptake is then assumed to be directly proportional to the difference in pressure head between soil and the root interior, to the hydraulic conductivity of soil, and to some empirical 'root effectiveness' or 'root density' function. This 'root density' function, depending on the investigator, is interpreted and evaluated differently (Molz, 1981; Zaradny and Maciejewski, 1986). Such models have a serious shortcoming, consisting in the necessity of using numerous input data which is difficult to establish. Also, such data as 'root effectiveness' and 'root density' depend for the same plant on the external conditions, soil profile, plant growth stage, *etc*.

In view of the above uncertainties, Feddes *et al*., (1978) constructed a fairly simple model of water uptake by plants, which permits the source term S to be found as a function of the field of soil water pressure (h) in the root zone. The essence of this model, slightly modified by Zaradny (1990; 2004), is depicted in Fig. 3.

The primary task, for given soil and atmospheric conditions, consists in finding $h_1$, $h_2$, $h_3$, $h_3$' and $h_4$, of which $h_1$ and $h_4$ are most easy to define. One can choose $h_1$ as $h_1$ = $h(\theta - \Delta\theta)$, in which $\theta_s$ is water content at saturation and $\Delta\theta_1$ stands for a certain small water content about 0.01-0.02 $cm^3cm^{-3}$. Larger quantities should be taken for soils of worse structure (sandy soil).

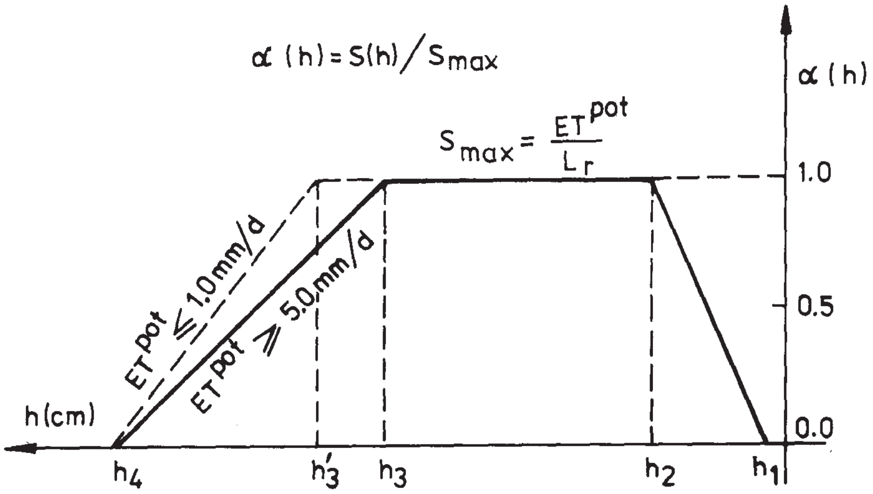



**Fig. 3.** Plant root uptake function S versus pressure height of soil water h.

The other of the two quantities, $h_4$, is proposed as the point of permanent wilting. Most frequently, this point is understood as the stage of soil moisture with pF = 4.2, which corresponds to $h_4$ = - 15850 cm.

The quantity $h_2$ can be estimated from the soil's capability of gas diffusion (soil air), depending on the water content. From this capability one can determine the transport of oxygen from soil to roots. If the coefficient of oxygen diffusion is less than 1.5 $10^{-4}cm^2\ s^{-2}$, then the growth of plants is limited (Feddes *et al*., 1978). The above coefficient of diffusion corresponds to the air content $\Delta\theta_2 \approx$ 0.05 $cm^3cm^{-3}$ in soil of good structure and $\Delta\theta_2 \approx$ 0.10 $cm^3cm^{-3}$ for worse structured soils. One can then take $h_2 = h(\theta_s - \Delta\theta_2)$ in which $\Delta\theta_2$ depends on the structure of soil and can be taken between 0.05 and 0.10 $cm^3\ cm^{-3}$.

It is proposed that other two quantities, $h_3$ and $h_3$', be selected from the range of pF = 2.6-3 *ie* from -400 cm to -1000 cm.

It is also proposed to use $h_3$ = - 400 cm for $ET^{pot} \geq 5$ mm $d^{-1}$ and $h_3$' = - 1000 cm for $ET^{pot} \leq 1$ mm $d^{-1}$ with the linear changes in h = h* at intermediate values of $ET^{pot}$:

$$h^* \quad \begin{array}{l} h_3' \text{ dla } ET^{pot} \quad 1 \text{ mm d}^{-1} \\ h_3 \text{ dla } ET^{pot} \quad 5 \text{ mm d}^{-1} \\ h_3 \quad 5 \quad ET^{pot} \quad h_3' \quad h_3 \ /4 \text{ for } 1 \quad ET^{pot} \quad 5 \text{ mm d}^{-1} \end{array} \qquad (3)$$

For this formulation of the source term it appears that the uptake of water by plants will be maximum only if the soil pressure head h in the root zone is in the range $h^* \leq h \leq h_2$. Then one has:

$$ET^{pot} = ET^{act} = S_{max} \int_0^{L_r} \alpha(h) RDF(z) dz =$$
$$S_{max} \int_0^{L_r} 1 RDF(z) dz = S_{max} L_r \qquad (4a)$$

thus:

$$S_{max} = \frac{ET^{pot}}{L_r} = \frac{ET^{pot}}{DRZ - DRZ^{na}} \qquad (4b)$$

where: $S_{max}$ – maximum value of the sink term, RDF(z) – root density function: $\int_0^{L_r} 1 RDZ(z) dz = L_r$, $L_r$ = DRZ- $DRZ^{na}$ – length of root zone, DRZ – depth of root zone, $DRZ^{na}$ – inactive (upper part) root zone ($0 \leq DRZ^{na} \leq 5$ cm), $\alpha$(h) – quantity depending on the actual value of h ($0 \leq \alpha(h) \leq 1$). The quantity $\alpha$(h) will read:

$$(h) \quad \begin{array}{l} 0 \text{ for } h \quad h_1 \text{ and } h \quad h_4 \\ \dfrac{h_1 \quad h}{h_1 \quad h_2} \text{ for } h_2 \quad h \quad h_1 \\ \dfrac{h_4 \quad h}{h_4 \quad h^*} \text{ for } h_4 \quad h \quad h^* \\ 1 \quad \text{for } h^* \quad h \quad h_2 \end{array} . \qquad (5)$$

By analogy to the results of investigation (Zaradny, 1986b) on the Bielnik polder in the Delta area of the Vistula River (northern part of Poland, latitude $54^0$10'N and average altitude about 0 m), for the polder under consideration: $h_1$ = - 0.3 m, $h_2$ = - 1 m, $h_3$ = - 4 m, = -10 m and $h_4$ = -159 m were applied.

Values of the hydraulic conductivity in the model discussed can be given as a table or a function. The second manner is more convenient, as it needs less data. For this the formulae of van Genuchten (1979) and Mualem (1976) are best, as they need only 6 parameters, namely $k_1$, $k_2$, $\theta_s$, $\theta_r$, alpha and n, where: $k_1$, $k_2$, $\theta_s$ – the parameters earlier discussed,

$\theta_r$ – residual water content, alpha and n – coefficients in the van Genuchten and Mualem formulae.

Using the formulae mentioned (Zaradny, 2004) one can easily estimate the values of k(h) and C(h) needed in the model discussed.

CHARACTERISTICS OF THE FLOW AREA Ω

The flow area Ω consists of the cross-section I – I illustrated in Fig. 2. Total length of the cross-section is 211 m. For the right border, the old branch of the river Motława, with a constant water level h = -1 m above sea level, is assumed. The upper border consists of the soil surface of diversified ordinates, whereas a horizontal impervious layer on the ordinate 5 m below sea level limits the flow area at the bottom. The reference datum was taken for the ordinate mentioned *ie* $z_{pp}$ = -5 m above sea level.

Characteristics of the soil profile is given in Table 1. Besides:

soil No. 7, $k_s = 0.00864$ m $d^{-1}$ and $\theta_s = 0.465$ $cm^3$ $cm^{-3}$, was attributed to the dike body of the retention reservoir

soils Nos 8, 6 and 5 were attributed to the fragments of the flow area that contain roads (hardened, with concrete plate surfacing), *etc*.

The daily values of $ES^{pot}$, $FLUX^{pot}$ = PREC – EI and SGL as well as $ET^{pot}$ were computed using the programme EVAPOT elaborated by the Author.

COMPUTATIONS FOR ADEQUATE FARMING ON THE POLDER

For the polder under consideration, the most effective way of farming would be grasslands, because of the relatively shallow root system and relatively small sensitivity to excessive water content in the soil profile. A uniform root system (RDZ(z) = 1 = constant) was assumed, with the constant values of DRZ = 0.4 m and $DRZ^{na}$ = 0.02 m for the whole growth season. For lack of exact values of the initial conditions, it was decided to assume:

H(x, z, 0) = 4.26 m (*ie* - 0.74 m above sea level), for x, z$\geq$ 0 and t = 0, and

starting with the computation at the beginning of the vegetation season for the area under consideration (1st April).

This assumption is made during the mathematical simulation, as practiced by the Author, as it minimises the influence of the initial conditions on the calculated results; *ie* at least on or after 14th May, as this is when the computation and measurements were taken for the simulated model.

**T a b l e 1.** Characteristics of the soil profile

| Soil | No. | Depth (m) | $k_s$ (m $d^{-1}$) | $\theta_s$ | n | alpha | $\theta_r$ |
|---|---|---|---|---|---|---|---|
| Heavy soils (fen soil, loamy clay or clay mud) | 1<br>9<br>2 | 0-0.15<br>0.15-0.40<br>0.40-0.68 | 0.350<br>0.00631<br>0.000631 | 0.505<br>0.505<br>0.505 | 1.16424 | 0.00482 | 0.119 |
| Peat | 3 | 0.68-1.075 | 0.001097 | 0.862 | 1.34671 | 0.00598 | 0.098 |
| Middle or silt sand | 4 | >1.075 | 1.296 | 0.351 | 1.85792 | 0.02307 | 0.007 |

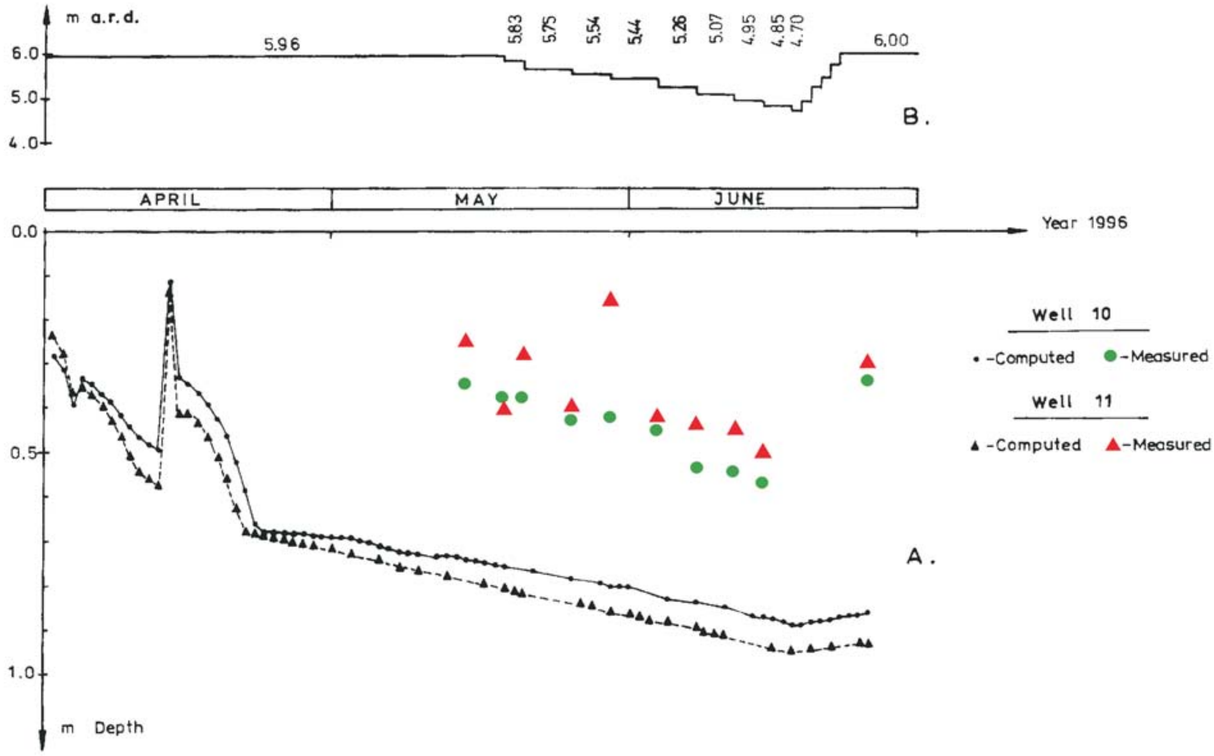
Because of its dimensions, the area of motion in Fig. 2 is shown in a reduced and discriminated scale without drawing the computational grid. In total, 1349 elements were used (triangles or quadrangular), with 1397 nodes. For 115 nodes on the soil surface, the potential flux $E^*$ = (PREC – EI) – $ES^{pot}$ was prescribed, where EI – plant interception (EI = f(PREC); EI = 0 if precipitation PREC = 0). For each daily value of $E^*$ one must estimate so-called limiting value of h = SGL which describes the conditions when the pressure head of water at soil surface is in equilibrium with the atmosphere. SGL can be derived from the well-known relationship (Zaradny, 1990):

$$SGL = \frac{RT}{M} \ln(RH) \tag{6}$$

where: R is the universal gas constant (hPa $cm^3$ $mole^{-1}$ $°K^{-1}$), T is the absolute temperature, (°K), RH is the relative humidity of the air (fraction), M is the mole volume of water ($cm^3$ $mole^{-1}$).

The results obtained are presented graphically in Figs 4 and 5. In Fig. 4A, calculated ground water tables and the results of measurements in control wells Nos 10 and 11 are shown. In the upper part (Fig. 4B), the water heights in the retention reservoir are shown. It is easy to conclude that the calculated results are pronouncedly below the measured ones. For the profile of well No. 10, the differences were 0.3-0.52 m, while for well No. 11 about 0.41-0.64 m. Due to this fact, the results of verification of the calculated versus the measured results must be evaluated as negative.

From the meteorological data it is known that April 1996 was deemed dry because of low precipitation (less than 11 mm). For that month the potential values of evaporation and transpiration were estimated as $ES^{pot}$ = 26.19 mm and $ET^{pot}$ = 42.36 mm. From simple calculation (PREC-EI-ES-ET) it results that the soil profile, as a consequence of evapotranspiration process in that period, should theoretically (*ie* potentially) decrease its water capacity by about 57.6 mm. In reality it was less, because moisture conditions


m a.r.d.
6.0
5.0
4.0
5.96
5.83
5.75
5.54
5.44
5.26
5.07
4.95
4.85
4.70
6.00
B.
APRIL
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0.0
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Well 10
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A.

in the soil profile were unsatisfactory for water transmission from below to the soil surface and for water intake by plants on the optimal level (then $ES^{act} < ES^{pot}$ and $ET^{act} < ET^{pot}$). The last partly resulted from the ratio $ET^{act}/ET^{pot}$, illustrated in Fig. 5.

Generally, a drawing down of the water table in the profile is seen. Only on 13th April, the precipitated water suddenly lifted the water table (about 0.4 m). At that point, the soil profile had a low capability to retain water.

Later, *ie* after 21st-22nd April, the draw down of the water table was slower, mainly as a result of reaching the peat layer that was characterized by a high water content ($\theta_s = 0.862$ m$^3$m$^{-3}$). At the end of April, the water table was already sufficiently low (about 0.7 m bellow surface). Also at a low level were the heads of soil water pressure; even higher than normal, precipitation in May (81.12 mm) was not able to negatively influence the water table and the water pressures in the root zone. The high values of ratio $ET^{act}/ET^{pot}$ presented in Fig. 5 illustrate the above.

From the presented results for the analyzed soil profile, the most optimal conditions for water intake by plants (grass) are when the water table falls to a depth of about 0.7 m bellow the surface. For a deeper water table, the ratio $ET^{act}/ET^{pot}$ was less, as seen in Fig. 5 for 20th June ($ET^{act}/ET^{pot} = 0.33$). June 1996 was a dry month (PREC = 29.16 mm).

One can also see that fast rising of the water level in the retention reservoir (from 4.7 to 6 above reference datum *ie* from -0.3 to 1.0 m above sea level) for the period of 17th-22nd June, had no pronounced influence on the rise of the water table on the polder. The rise was actually about 0.015 m. However, in that period, over 50% of monthly rainfall PREC (15.12 versus 29.16 mm) had fallen and could have contributed to the rise of the water table mentioned. This higher water table, in turn, then caused higher transpiration, which can be seen in Fig. 5. One can conclude, therefore, that in June 1996, when the soil profile showed a water deficit, irrigation was necessary to increase crop yield.

The average value of the ratio $ET^{act}/ET^{pot}$ was equal to 0.73, on the other hand, the contribution of the transpiration in the budget, contrary to evaporation and infiltration, was crucial (181.9 towards 29.79 mm).

The ability of soil to retain water in the profile of well No. 10, according to the calculations for 25th June, was relatively high, which can be seen in Fig. 6 presenting the computed water content distributions. Colours are used – blue to mark the water content, grey - the air content, and other colours mark the solid phase (soil layers Nos 1, 9, 2, 3 and 4 respectively).

The results of simulation prove that for grassland farming on the analyzed polder with low effective existing drainage system (because of the pronounced overestimated spacing of the drainage ditches), for the meteorological conditions in the first three months of the growing season in 1996, it was possible to obtain a relatively high crop yield. These prove the calculated results of $ET^{act}/ET^{pot}$.

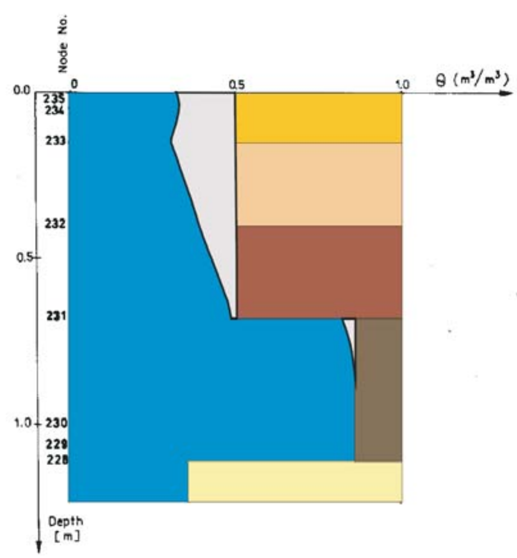


**Fig. 6.** Soil water content distribution at the profile of well No. 10 ($ET \neq 0$).

Such a situation is in conformity with the known Polish folk proverb: 'a dry April and wet May then a rye will be as a grove'. In 1996, April perfectly suited the proverb mentioned, as the precipitations in relation with monthly rainfall – averaged over a long term – were only about 23-32%, in May 1996 it was wet; then precipitation values were 191% for Elbląg and 237% for Gdynia (according to data presented in IMGW (1997).

## COMPUTATIONS FOR FORBEARANCE FROM AGRICULTURAL FARMING ON THE POLDER

As it was written, in the last decade in Poland many hectares of field culture changed not only ownership, but also the manner of farming. This also refers to the polders with complex compound soil profile and water conditions. Often in such areas, alluvial soils and relative water tables occur. These conditions are preferable for grassland, as opposed to arable land farming. New farmers often forget this and stop farming or they use their land for other activities due to bad crop yield; turning it to – for example – storing grasses and weeds from mowed ditches, dikes, *etc.*

If the land is then used as mentioned above, for storing grasses, we can assume for a non- active root system; ET = 0. In this case, for the calculations we will retain the previous values of the conditions *ie* the initials and boundaries as mentioned earlier.

The computed values of water table heights are illustrated in Fig. 7. Compared with the results depicted in

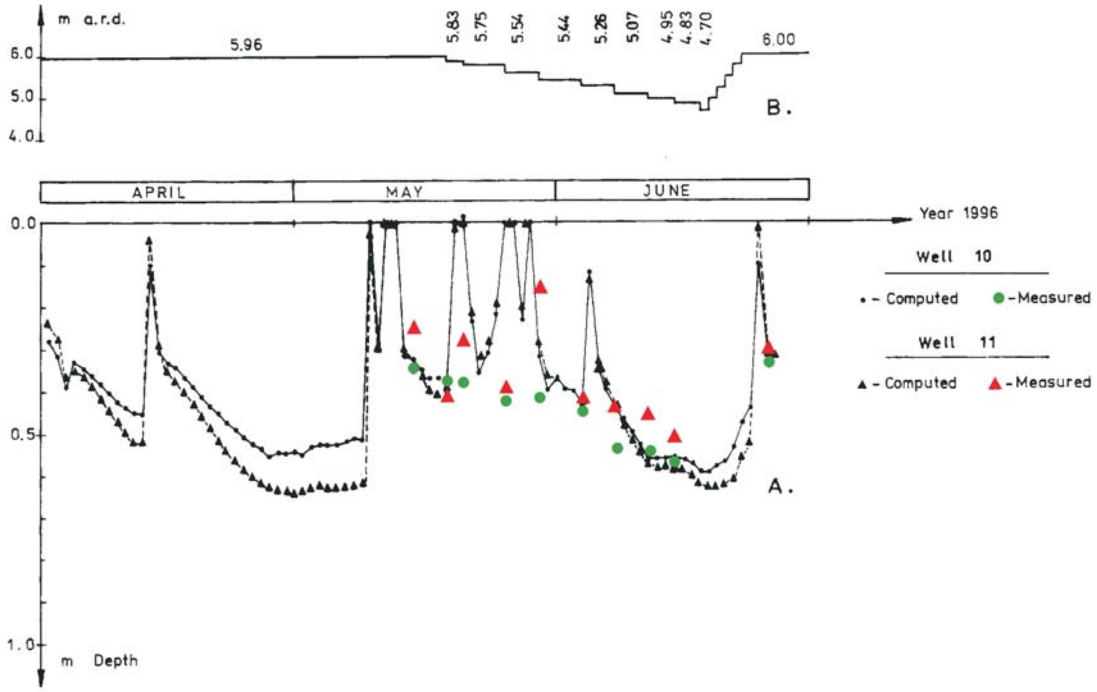


**Fig. 7.** Computted (solid lines) and measured (marked in green or red) water table depths at profiles of control wells Nos 10 and 11 (case

Fig. 4, the differences in the heights of water table from the second half of April are clearly visible. At the end of April the water table is at a depth of about 0.5-0.55 m for the profile of well No. 10 and about 0.1 m deeper for well No. 11. From 8th May, the water table fluctuates more and more, eventually reaching full saturation in the profiles analyzed. It was due to the low capability of the soil profile to retain rain water at that time.

However, this improves in June, when increased rainfall had no pronounced influence on the depth of water table. But, by comparison, June rainfall was considerably less than in May (29.16 mm in June compared with 81.12 mm in May), hence the changes in water table depths were smaller. At the beginning of the fourth week of June, somewhat higher rainfall caused a visible rise in the water table – about 0.62 m for well No. 11 and 0.47 for well No. 10. At this stage the computed depths of the water table reflect the measured depths accurately. On the last day of the field experiment (25th June), the differences between calculated and measured results were no bigger than 0.02 m.

From the results presented, we conclude that the soil profile had a very small capability to retain rain water. As a result, a run-off situation occurred (RUN OFF) – this was first seen in May. Also for the rest of the period the mentioned capability was very small – this can be clearly seen in Fig. 8, where the calculated water content distributions on the 25th June are depicted. This is in contradiction to the results depicted in Fig. 6, where the results for previous calculations are presented. The last results have been obtained for grass-land farming (ET≠0).

## CONCLUSIONS

1. Appropriate moisture conditions can be preserved, without highly efficient drainage, for grass-land farming in depressive areas for a relatively dry period in the first month of the vegetation season.

2. The existing moisture conditions result in good grass yields – the conclusion is derived from the relatively high values of the calculated ratio $ET^{act}/ET^{pot}$.

3. For other meteorological conditions for middle periods, and more so for wet ones, the existing drainage system should be appropriately modernized. Such modernization demands either significantly denser drainage ditches or supplementing the existing ditches with drainage pipes, placed at least 1 m bellow th e surface. The pipes should be deeper if the soil profile is less pervious to water.

4. Agricultural farming on the depressive areas with heavy soils should be carefully-considered, since in other cases such areas tend to suffer degradation due to excessive and long-lasting soil water saturation, worsening of soil structure, *etc*.

5. The proposed mathematical model with the assumed root-water uptake term seems to be a good tool for simulation, which was verified by the results of the calculated data against the measured data.

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