Hydropedological Data Necessary for Computing Drain Spacings in a Gleysol

Adia Grozav, Gheorghe Rogobete

1 Polytechnic University Timisoara, Hydrotechnical Engineering Department, George Enescu 1A, Romania

adiagrozav@yahoo.com

Abstract. Gleysols comprise soils saturated with groundwater for long enough periods to develop reducing conditions resulting in gleic properties. Gleysols occupy more than 720 million ha worldwide, on low positions in landscapes with high groundwater table. Evidence of reduction processes with segregation of Fe compounds starting in the first 40 cm of the soil surface. For many gleyso a main obstacle to utilization is the necessity to install a drainage system to lower the groundwater table. With a particle-size distribution clayey-loamy (44.8-42.9% clay), a great bulk density (1.50-1.57g/cm³), and SAR 12.5, these soils have a poorly natural drainage, from which water is removed very slowly. The volume of all pores, namely porosity, is very small in the second horizon, 38.3%. The primary function of a drainage equation is the computation of drain spacings for drainage design. An analysis reveals the influence of the various factors, as permeability, thickness of the soil layers, depth of drains, discharge rate in surface, effective porosity, drainage intensity etc; namely geohydrological investigations. In order to determine the drain spacing on the Gleysols we have used a similar method with the auger-hole method (1970, van Beers) but with 4 holes. The water was removing from the central auger-hole with a bailer, the time interval was 20 minutes. The analytical data of measurements are in the tables 2 and 3. Knowing the pumped and extracted water volumes from central auger hole which has perforated tube, we have obtained the final values of effective (or drained) porosity (0.0197-0.0208). For the drain space calculation, we recommend to use 0.0208, the finally value.

1. Introduction
In accordance with WRB-Reference Group (2014), the soil saturated by groundwater near the surface for long periods, are Gleysols, which develop reducing conditions resulting in gleic properties, including underwater and tidal soils.

This pattern is essentially made up of reddish, brownish or yellowish colors at aggregate surfaces and / or in the upper soil layers, in combination with greyish / bluish colors inside the aggregates and / or deeper in the soil. Redox processes may also cause upmoving gases, like CO₂ or CH₄.

Gleysols occupy more than 720 million ha worldwide (4.79%). In Romania, Gleysols occupy 595000ha, predominantly in the western part of the country (2.5%).

The main obstacle to utilization Gleysols is the necessity to install a drainage system to lower the groundwater table [1]
A reduced soil is one in which redox reactions, have caused reduced forms of O, N, Mn, Fe or S to be present in soil solution. Common reduced forms found in Hydric Soils include: H₂O, N₂, Mn⁴⁺, Fe³⁺ and H₂S; their oxidized forms are: O₂, NO₃⁻, Mn⁵⁺, Fe⁴⁺ and SO₄²⁻, and, respectively [2].

Oxidation occurs when bacteria decompose organic matter and produces electrons (e⁻) and protons (H⁺). Oxidation is the norm; however, when a soil becomes wet and saturated, reduction reactions begin at microsites if the soil is wet enough for a long period (some weeks or months) spread through the soil. [3]

For a proper diagnosis of drainage problems, one must have the appropriate soils information. The required soil data have to be of physical and chemical nature to relate to the hydrological problems, but they must also allow interpretation in agronomical terms in connection with the increased yields that can be expected after drainage improvements have been made. For a drainage plan, the following soil data will be required: infiltration rate, unsaturated or saturated hydraulic conductivities, effective or drainable porosity, moisture storage in the soil, data on salinity and alkalinity, degree of ripening of the soil, special problems of peat soils, geographical distribution of soil units, and external factors [4].

The principle of evaluating field data on water table elevations and drain discharge is based on the application of the formulas describing the flow of groundwater to drains.

In drain spacing calculation it is usually justified to simplify the actual, non-steady” conditions to, steady conditions”.

When using equations based on steady-state conditions, one should realize that such conditions seldom occur in practice. Nevertheless, the equations are extremely useful because they make to design a drainage system which has the same intensity everywhere even through quite different hydrological conditions (effective porosity and transmissivity values) occur in the area.

In the opinion of the authors of this paper, the equation Glover – Dumm is appropriate to use.

\[ L^2 = \frac{10 \cdot KD \cdot t}{p \cdot \ln\left(\frac{h_0}{h}\right)} \]  

(1)

where:
L = drain spacing (m)
KD = transmissivity (m²/day)
p = effective porosity
h = hydraulic head (m) – the height of the water table above drain level midway between drains

The effective porosity may be found directly – during tail recession – from the volume of water released by the soil when the watertable drops from positions h₀ to position h in a known time interval.

When a (drainage intensity factor) and p are known, the transmissivity can be calculated.

\[ a = \frac{\pi^2 \cdot KD}{pL^2} \]  

(2)

or

\[ KD = \frac{a \cdot p \cdot L^2}{\pi^2} \]  

(3)
2. Materials and methods
The required soil data have to be gley systems, groundwater level, particle-size distribution, bulk density and particle density, total porosity tension – free porosity or effective porosity, field capacity, permeability, water content, pH, humus content, salinity (EC) and exchangeable sodium percentage.

The determinations have been made in the Timis Plain, near the Timisoara town, in a Chernic – Sodic Gleysol. The soil profile was studied to a depth of 2 m and the soil samples have been analyzed on the Soil Science Laboratory from the Hydrotechnical Department.

For hydromorphic properties, like hydraulic conductivity and effective porosity, have been 4 auger-holes. The required depth of the holes was about 60 to 70 cm below the water table, respectively 2 m depth. In order to determine hydraulic conductivity (K) and effective porosity (p) in the central auger hole a perforated pipe has been placed. Gravel or coarse sand is inserted between the pipe and wall of the auger hole.

Water table fluctuations are measured by means of a float. For the effective porosity are necessary 4 auger holes (figure 1).

![](image.png)

Figure 1. Computing drain spacings in a nonsteady-state flow system

3. Results and discussions
It would be ideal, from the point of view of the drainage planning engineer, if a soil survey, with its accompanying maps and report, contained all the kinds of information for the area in question.

Soil survey has to provide data which can be interpreted in a technical way for drainage project. The soil profile was studied in a dug pit of 2 m depth, and in 4 auger holes. Based on the profile investigations it was concluded that the soil type is Chernic – sodic Gleysol, in accordance with WRB – 2014 [5], soils having a layer ≥ 25 cm thick, and starting ≤ 40 cm from the mineral soil surface, that has:
- gleyic properties throughout, and
- reducing conditions in some parts of every sublayer,

with principal qualifiers – Chernic, and supplementary qualifiers – Sodic.

The chernic horizon is a relatively thick, well – structured, blackish surface horizon, with a high base saturation, a high biological activity and a moderate to high content of organic matter.

The natric (sodic) horizon has an exchangeable Na percentage (ESP) of ≥ 15 throughout the entire natric horizon or its upper 40 cm.
Table 1 Analytical data

| Horizon        | A chernic-gleic oximorphic | AC gleic reductimorphic | C relictogleic |
|----------------|----------------------------|-------------------------|--------------|
| Depth, cm      | 0-35                       | 35-51                   | 51-100       |
| Clay, %        | 44,8                       | 42,9                    | 37,5         |
| Density, g/cm³ | 2,38                       | 2,43                    | 2,56         |
| Bulk density, g/cm³ | 1,20                  | 1,50                    | 1,57         |
| Total porosity, % | 49,6                   | 38,3                    | 38,7         |
| Field capacity, % | 33,78                  | 33,19                   | 32,14        |
| pH H₂O         | 8,60                       | 9,50                    | 9,70         |
| Humus, %       | 3,60                       | 2,85                    | -            |
| Na/T *100      | 6,4                        | 12,5                    | 6,8          |
| Soluble salts, % | 0,043                  | 0,115                   | 0,128        |

Figure 2. Gleysol

The measurement properly consists in determining the rate at which the water rises in the central hole. The observations are made either with a constant time interval Dt or with fixed intervals for the rise of the water (DYt). The time interval depends on the permeability of the soil, and for our soil type was 30 seconds because the permeability is very low (K is 0.01.m/day).

It has been determined the volume of removing water and the soil volume in which the hydraulic level was modified. The ratio of the two volumes represented the average value of effective porosity.
The equation of the median curve from the piezometric surface will be:

\[ d_1 = -\alpha \log r_1 + \beta \]
\[ d_2 = -\alpha \log r_2 + \beta \]

where:
- \( d_1 \) is the decrease from the piezometric surface to the distance \( r_1 \) from the well axis (cm)
- \( d_2 \) is the decrease from the piezometric surface to the distance \( r_2 \) from the well axis (cm)
- \( \alpha \) and \( \beta \) is determined at the mean value of the piezometric elevations (cm)

from:

\[ \alpha = \frac{d_1 - d_2}{\log(r_2 / r_1)} \]
\[ \beta = d_1 + \alpha \log r_1 \]

The appropriate range of action will be:

\[ \log R = \frac{\beta}{\alpha} \rightarrow R \]

and the volume of the drop cone is:

\[ V = \pi \alpha \left( \frac{R^2 - r_0^2}{2} - r_0^2 \log \frac{R}{r_0} \right) \]

In these formulas \( \alpha, \beta \) and \( R \) are a time function.

Knowing the volume of pumped water and the volume of water extracted from the well during \( t \):

\[ V_p = \pi \cdot r_0^2 \cdot d_0 \]

Is deducted the volume of water extracted from the soil:

\[ V = V_p - V_p \]

The average drainage porosity value is calculated with the relationship:

\[ p = \frac{V}{V} \]

For a better understanding the mechanism of the method is given an example of calculation.
The values of the deviations in the well and in the 3 piezometers, as well as the volume of pumped water $V_p$, are given in table 2

### Table 2 Water pumped volume

| Time (min) | $d_0$ (well) (cm) | $d_1$ (cm) ($r_1=50$cm) | $d_1$ average (cm) | $d_2$ (cm) ($r_2=200$cm) | the pumped volume (cm$^3$) |
|------------|------------------|--------------------------|--------------------|--------------------------|---------------------------|
| 60         | 20               | 3                        | 6                  | 4.5                      | 0.2                       | 5.760                     |
| 80         | 22               | 4                        | 7                  | 5.5                      | 0.4                       | 7.680                     |
| 100        | 25               | 5                        | 8                  | 6.5                      | 0.8                       | 9.600                     |
| 120        | 30               | 6                        | 10                 | 8.0                      | 1.0                       | 11.520                    |

With data from table 2, the other elements can be calculated: $\alpha$, $\beta$, $R$, $V$, $v_p$, $v$ and finally, the drainage porosity that is centralized in table 3

### Table 3 Effective porosity

| Time (min) | $\alpha$ (cm) | $\beta$ (cm) | $R$ log | $R$ (cm) | $V$ (cm$^3$) | $V_p$ (cm$^3$) | $v_p$ (cm$^3$) | $v$ (cm$^3$) | $p=v/V$ |
|------------|---------------|--------------|---------|----------|--------------|---------------|----------------|-------------|---------|
| 60         | 3.10          | 16.60        | 5.36    | 210      | 213.517      | 5.760         | 1.570          | 4.190      | 0.0196  |
| 80         | 3.67          | 19.85        | 5.41    | 223      | 285.203      | 7.680         | 1.727          | 5.953      | 0.0208  |
| 100        | 4.10          | 22.50        | 5.48    | 241      | 372.345      | 9.600         | 1.963          | 7.637      | 0.0205  |
| 120        | 5.03          | 27.65        | 5.50    | 243      | 464.757      | 11.520        | 2.355          | 9.165      | 0.0197  |

Detailed calculation example for time = 120 minutes

$r_0 = 5$cm $\quad r_1 = 50$cm $\quad r_2 = 200$cm

$q = 1.6cm^3/s \quad r_1 = 50$ cm

$$\alpha = \frac{d_1 - d_2}{\log_e (r_2 / r_1)} = \frac{8 - 1}{\log_e (200/50)} = 5.03cm$$

$$\beta = d_1 + \alpha \log_e r_1 = 8 + 5.03 \cdot \log_e 50 = 27.65cm$$

$$R = \frac{\beta}{\alpha} = \frac{27.65}{5.03} = 5.5 \rightarrow R = 243$cm

$$V = \pi \alpha \left( \frac{R^3 - r_0^3}{2} - r_0^2 \log_e \frac{R}{r_0} \right) = 3.14 \cdot 5.03 \left( \frac{243^3 - 5^3}{2} - 5^2 \log_e \frac{243}{5} \right) = 464.757$cm$^3$

$$v_p = \pi r_0^2 d_0 = 3.14 \cdot 5^2 \cdot 30 = 2.355$cm$^3$

$$v = V_p - v_p = 11.520 - 2.355 = 9.165$cm$^3$

$$p = \frac{v}{V} = \frac{9165}{464757} = 0.0197$$

For the calculation of the distance between drains it is preferable to use the final value of the drainable porosity, which marks the transition to a pseudo-permanent regime.
4. Conclusions

Gleysols with a total area of 720 million hectares occur in northern Russia, Siberia, Canada, Alaska, in humid temperate latitude and low-land inter-tropical regions.

Gleysols comprise soils saturated with groundwater for long periods and develop reducing conditions resulting in gleyic properties.

The main obstacle to utilization for arable cropping is the excess of water which produces anaerobiosis. This means the reduction of $\text{NO}_3^{-}$ to $\text{N}_2$, $\text{Mn}^{4+}$ to $\text{Mn}^{2+}$, $\text{Fe}^{3+}$ to $\text{Fe}^{2+}$, $\text{SO}_4^{2-}$ to $\text{H}_2\text{S}$ and $\text{CO}_2$ to form methane ($\text{CH}_4$).

It is necessary to install a drainage system to lower the groundwater table with deep drainage ditches.

In Timis county Gleysols occupies alongside with Solonet 85.622 ha (12.19% from the total agricultural land of 702,398 ha).

The soil survey has to provide the planning engineer with soil data which can be used for computing drain spacings.

The equations for design a drainage system need hydropedological data as hydraulic conductivity, effective porosity, transmissivity.

For this reason, we have used the auger-hole method and for effective porosity with four holes. It has been determined the volume of removing water and the soil volume in which the hydraulic level was modified. The ratio of the two volumes represented the average value of effective porosity.

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