Evaluation of Water Content in Soils of Žitný Ostrov from the Point of View of Its Exploitation for Biosphere

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Abstract. The lithospheric zone between the soil surface and the first ground water horizon, respectively the ground water table, has a character of three-phase system. It consists of solid phase having fine to rough disperse granularity. This creates a structure of porous environment with characters that can be physically determined. The water occurs in pores in different forms of state and its bond with solid phase. Its energetic bond is clearly quantified by means of moisture retention curve. The gas phase fills pores with the water up to the value of the full porosity, i.e. it fills the part of pores that is not saturated with water. Therefore, this lithospheric zone is called the soil aeration zone. The volume of water occurring in the soil aeration zone corresponds to the concentration of water in the framework of hydrological cycle components. This water serves as the water resource for the vegetation cover. The data used for calculation were particular soil types in the area, depth of ground water table, hydrolimits (wilting point, point of decreased availability, field water capacity) and aeration zone thickness. The water content in the soil aeration zone between hydrolimits field water capacity (FWC) and wilting point (WP) is the critical interval of water content for vegetation cover in a given locality. Water from this interval is available for the vegetation cover. This water has no properties of free water, and plants have to have a developed root system and such suction pressure, that is able to overcome the bond between water and soil. Calculated results were verified with the help of monitored water content. Both calculated and measured values of soil water content in the aeration zone show that the water content is affected by appurtenant soil type. The human activity in a landscape directly affects the dynamics of this water resource, either from quantitative or qualitative viewpoint. This affect is demonstrated by changes of the ground water regime, i.e. changes of ground water table and amplitude of its fluctuation. The paper brings results of water content evaluation in the soil aeration zone in the Žitný ostrov area.

1. Introduction
The lithospheric zone between the soil surface and the first ground water horizon, respectively the ground water table, has a character of three-phase system. It consists of solid phase having fine to rough disperse granularity. This creates a structure of porous environment with characters that can be physically determined. The water occurs in pores in different forms of state and its bond with solid phase. Its energetic bond is clearly quantified by moisture retention curve. The gas phase fills pores with the water up to the value of the full porosity, i.e. it fills the part of pores that is not saturated with water. Therefore, this lithospheric zone is called the soil aeration zone [1].
If the ground water table is not present, the lower border of the aeration zone is the turning point of the infiltrated water in the evapotranspiration process, respectively selected depth below the soil surface as a reference level [2].

The volume of water occurring in the soil aeration zone corresponds to the concentration of water in the framework of hydrological cycle components. This water serves as the water resource for the vegetation cover. The data used for calculation were particular soil types in the area, depth of ground water table, hydrolimits (wilting point / WP, point of decreased availability / PDA, field water capacity / FWC) and aeration zone thickness. The water content in the soil aeration zone between hydrolimits FWC and WP is the critical interval of water content for vegetation cover in a given locality, because only water from this interval is available for the vegetation cover [3]. This water resource is of renewable character as far as cyclicity of hydrological cycle components.

The human activity in a landscape directly affects the dynamics of this water resource, either from quantitative or qualitative viewpoint [4], [5], [6]. This affect is shown in changes of the ground water regime, i.e. changes of ground water table and amplitude of its fluctuation. This paper deals with quantification of water content in the soil aeration zone in Žitný ostrov.

The objective method of evaluation of water content in the soil aeration zone is based on its direct monitoring. The monitoring of water content course in the soil aeration zone in the whole agricultural land in the Slovak territory has not been established. Sporadic information was published in the framework of research projects in the field of irrigation management, ecology, hydrology, and soil science. Since 1989, quite systematic monitoring of water content in the soil aeration zone was organized in connection with construction and operation of Gabčíkovo hydropower plant (GHPP) [7], [8]. However, even this organized monitoring is not able to secure data for determination of water content in the soil aeration zone for the whole area of Žitný ostrov.

The water content quantification in the soil aeration zone can be done also indirectly [3], [9]. This methodology is based on the fact, that the moisture retention curve quantifies relation between volume moisture of soil and its bond with solid phase of soil, i.e. Θ = F(hw), where Θ is the volumetric moisture of soil expressed in (% vol.) and (hw) is soil moisture potential expressed by pressure head (cm). Particular points of the moisture retention curve can be used for analysis of the water state in soil as far as its physical, chemical and biological properties. Based on convention [10], there were selected characteristic points of the moisture retention curve for evaluation of the interaction of the vegetation cover with water content in the soil aeration zone:

- wilting point (WP), corresponding to the value pF = 4,18 (such soil moisture when the vegetation cover permanently suffers from lack of water from soil and withers),
- point of decreased availability (PDA), corresponding to the value pF = 3,3 (such soil moisture when physiological processes of the vegetation cover are limited due to lack of water),
- field water capacity (FWC), corresponding to the value from the interval 2,2 to 2,7 (such soil moisture that remains in a soil profile for a relative long period and the soil aeration is still satisfactory for vegetation cover development. Since this moisture state is not stable, we use the interval (pF = 2 for sandy soils, pF = 2,47 for loamy soils, pF = 2,7 for clay soils).

It should be remembered that the water content in the soil aeration zone between the FWC and the WP is existential interval for the vegetation cover, because it can use only water within this interval. This water has no properties of free water, and plants have to have a developed root system and such suction pressure, that is able to overcome the bond between water and soil. This critical water content is called available moisture capacity.
Following methodology of water content quantification in the soil aeration zone of Žitný ostrov is oriented to these points on the moisture retention curve, i.e. WP, PDA, and FWC. The calculation of the water content in the soil aeration zone requires following parameters:

- cover layer thickness
- soil aeration zone thickness
- agricultural land area, forest land area, participation of different soil types on that area
- moisture retention curves for particular soil types and their hydrolimits FWC, PDA, WP

The water content in soil aeration zone of Žitný ostrov was identified with the help of two independent methodologies.

2. First methodology

The above mentioned parameters were taken from [11], [12] and used for calculation of water content in the soil aeration zone of 100 cm thickness in Žitný ostrov and hydrolimits FWC, PDA and WP (table 1) [13], [14].

Hydrolimits are presented for four soil types:

- light soils (sandy and loam-sandy soils),
- medium heavy soils (sand-loamy and loamy soils),
- heavy soils (clay-loamy soils),
- very heavy soils (clay soils).

| Soil type          | Hydrolimits [% vol.] |
|--------------------|----------------------|
|                    | FWC      | PDA      | WP       |
| 1. Light soils     | 27.31    | 14.87    | 8.90     |
| 2. Medium heavy soils | 32.03    | 21.21    | 14.77    |
| 3. Heavy soils     | 34.74    | 25.24    | 17.24    |
| 4. Very heavy soils | 42.77    | 34.02    | 24.41    |

Since retention properties belonging to particular soil types will be dealt with later, their area in Žitný ostrov is presented in the table 2 [15].

| Soil type          | Share [%] | Area [ha] |
|--------------------|-----------|-----------|
| 1. Light soils     | 5         | 7 198     |
| 2. Medium heavy soils | 66        | 95 009    |
| 3. Heavy soils     | 23        | 33 109    |
| 4. Very heavy soils | 6         | 8 637     |
| Total              | 100       | 143 953   |
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Figure 1. Area of particular soil types in % in Žitný ostrov.

The calculation of water content in soil aeration zone is based on soil volume moisture, i.e. 1 % of volume moisture = 1 mm of water column head.

Then, if we take the area of 1 m² (10 decimetre x 10 decimetre) with 1 mm thick water layer, the volume of water is equal to 1 dm³. Gradual calculation of water content in the soil aeration zone from soil surface z = 0 to selected depth with base 1 m² provides the water volume in litres. When we multiply the number of m² related to 1 ha and divide by 1000 litres, we obtain the water content in m³ per 1 ha. This way water content has been determined in the soil aeration zone for thickness Δz = 100 cm. Results are shown in the table 3.

Table 3. Water content in the soil aeration zone in Žitný ostrov for soil profile thickness 100 cm.

| Soil type             | Hydrolimits – moisture [% vol.] | Area [ha] | Water content in soil aeration zone for hydrolimits [thousands m³] |
|-----------------------|---------------------------------|-----------|------------------------------------------------------------------|
|                       | FWC    | PDA  | WP   | FWC    | PDA  | WP   |
| 1. Light soils        | 27.31  | 14.87| 8.90 | 7 198  | 19 657| 10 703| 6 406 |
| 2. Medium heavy soils | 32.03  | 21.21| 14.77| 95 009 | 304 314| 2 015 141| 140 328|
| 3. Heavy soils        | 34.74  | 25.24| 17.24| 33 109 | 115 021| 83 568| 57 080 |
| 4. Very heavy soils   | 42.77  | 34.02| 24.41| 8 637  | 36 941| 29 384| 21 083 |
| Total                 |        |      |      | 143 953          |       |       |       |

3. Second methodology
The second methodology comes out from the database of basic physical and hydro-physical parameters, both measured in a laboratory and under natural conditions [16]. That means that soil granularity, moisture retention curves, saturated hydraulic conductivity were measured in a laboratory and infiltration rate was measured in the field.

Datasets were statistically analysed. They were divided into groups according to granularity and depth from which was a soil sample taken. Afterwards, they were divided into subgroups according to soil horizon and soil type. With the help of analysis of hydro-physical and physical parameters of soil
from sample taking localities there was identified similarity among particular data groups. Based on this similarity the soils were distributed into five model soil profiles, shown in the table 4.

Table 4. Distribution of particular soil types combination into model soil profiles

| Model soil profile | Soil type                                      | Area [ha] | Percentage from area [%] | Soil kind          |
|--------------------|------------------------------------------------|-----------|--------------------------|--------------------|
| 1                  | Light soils                                    | 6062      | 4.90                     | Every soil kind    |
| 2                  | Medium heavy and heavy soils                   | 18856     | 15.26                    | Fluviosoils        |
| 3                  | Medium heavy and heavy soils on a light substrate | 40578     | 32.83                    | Chernozems         |
| 4                  | Medium heavy and heavy soils                   | 50984     | 41.25                    | Mollic Fluviosoils |
| 5                  | Very heavy soils                               | 7120      | 5.76                     | Every soil kind    |
|                    | Total                                          | 123600    | 100                      |                    |

When comparing soil types categorized in model soil profiles in table 4 with soil types used in the first methodology (table 1 and table 2) we can see identity of selected light soils and very heavy soils with model soil profile 1 and model soil profile 5. While in the first methodology medium heavy soils and heavy soils are calculated separately, in model soil profiles according to the second methodology are calculated in three modified model soil profiles, i.e. 2, 3, 4.

Water content according to the second methodology was calculated from the soil profile thickness 100 cm and hydrolimits FWC, PDA and WP. Thus the total water content in Žitný ostrov area was about 554 million m³ for the FWC, 386 million m³ for the PDA and 286 million m³ for the WP.

The comparison of the results obtained from the first methodology and the second methodology shows that the water content obtained according to the Second methodology is higher by ca. 15-20 % than the one obtained according to the first methodology.

3.1. Determination of the water content in the soil aeration zone in selected localities of Žitný ostrov with the help of direct monitoring

In the period 1990 – 1997 there was organized a systematic monitoring of Žitný ostrov environment in order to quantify impacts of GHPP [17]. The water content was monitored in 10 cm horizons from soil surface up to depth of usually 200 cm. If the amplitude of ground water table fluctuation (or the interface between cover layer and water bearing water horizon) interfered with 200 cm gravel horizon of the soil aeration zone, the water content would be measured up to ground water table, or up to gravel horizon. There were selected monitored localities in order to verify obtained values of water content in Žitný ostrov soil aeration zone that correspond with selected points of the moisture retention curve, i.e. WP, PDA and FWC. These localities are relevant to soil types where the water content was calculated according to presented methodology. It has to be noted that the verification of calculated and monitored water content values was carried out for the soil aeration zone thickness 100 cm.

Representative localities of particular soil types are listed below:

- light soils (sandy and loam sandy soils) – locality Zlatná na Ostrove,
- medium heavy soils (sand –loamy a loamy soils) – locality Trstená,
- heavy soils (clay-loamy soils) – locality Kľúčovec and
- very heavy soils (clay soil and clay) – locality Kráľovská lúka.
The locality Trstená corresponds with the model soil profile 1 and the locality Kráľovská lúka corresponds with the model soil profile 5. The localities Zlatná na Ostrove and Kľúčovce can be related with model soil profiles 2, 3 and 4.

Monitored average month water contents in the soil aeration zone were statistically processed and thus there were obtained average annual water contents for 4 relevant soil types represented by above mentioned localities (see Figures 2 – 5).

**Figure 2.** Month average water content in the locality Zlatná na Ostrove (light soils).

**Figure 3.** Month average water content in the locality Trstená (medium heavy soils).
Figure 4. Month average water content in the locality Kľúčovec (heavy soils).

Figure 5. Month average water content in the locality Kráľovská lúka (very heavy soils).

4. Results and discussions

Water content in the soil aeration zone in Žitný ostrov was determined by calculation with the help of two methodologies, and by direct monitoring. The study takes into account soil types. Results of the first methodology for the soil aeration zone of thickness 100 cm are presented in the table 3 and in figures 2,3,4,5. The second methodology brought results of total integral water content in the soil aeration zone of 100 cm thickness 554 million m$^3$ of water under condition of reached FWC, 386 million m$^3$ of water under condition of reached PDA, and 286 million m$^3$ of water under condition of reached WP. The comparison of the two methodologies showed that the water contents obtained from the Second methodology is by 15 – 20 % higher than the one obtained from the First methodology.

Average month water contents in the soils aeration zone of 100 cm thickness were directly monitored in four localities relevant with the soil types for which the calculation was made. Results that are presented on figures 2 – 5, show that the cyclicity of water content creation during hydrological year is in principle maintained. The comparison of integral water contents in the 100 cm thick soil aeration zone that were calculated with the help of the first methodology for hydrolimits WP, PDA and FWC, and data from direct monitoring in four relevant localities, is shown on figure 6.
Values calculated according to the second methodology better correspond with monitored data than the values calculated according to the first methodology.

Figure 6. Calculated average annual water contents and monitored water contents in four localities in Žitný ostrov.

5. Conclusions
Both presented methodologies of calculation of water content in the soil aeration zone in Žitný ostrov were verified and they were found usable. Their special importance is underlined by fact that the monitoring of water content in the soil aeration zone has not been organized yet and the quantification of water balance in river basins is not possible without that balance component.

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