ARTIFICIAL RECHARGE – MEASUREMENT OF SOIL INFILTRATION IN ROŽNOV POD RADHOŠTĚM

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Abstract

The purpose of this study is to evaluate the potential for infiltration in a study area – Rožnov pod Radhoštěm, the Czech Republic. The results are important for the future design of an artificial recharge structure as a method to store water underground in times of water surplus. A total of six measurements of infiltration were made using a double ring infiltrometer on selected prospective sites for the future application of artificial recharge. The results of infiltration tests were analysed based on the Philip`s model. The steady soil infiltration rates ranged from 28 cm·h^{-1} to 70.38 cm·h^{-1} and the cumulative soil infiltration ranged from 58 cm to 68 cm.

Keywords: infiltration rate, surface water, groundwater, infiltrometer, hydraulic conductivity

1 INTRODUCTION

For the Czech Republic, similarly to a number of other EU countries, it is necessary to propose many adaptation measures to ensure water supplies in the course of dry and average periods. Artificial recharge is one of the adaptation measures. We could define such artificial recharge as an engineering system where surface water is conducted on or in the ground, infiltrates and subsequently moves to an aquifer to augment groundwater resources [1, 2]. Other objectives of artificial recharge may be an improvement to the quality of water through soil-aquifer treatment.

We can divide the artificial recharge into three main groups: direct injection, vadose zone infiltration and surface infiltration [3]. Surface infiltrations are divided into in-channel and off-channel systems. Vadose zone infiltration is used for unconfined aquifers, where surface material is impermeable or has a low permeability [1]. Surface infiltration techniques are suitable for moderately to highly transmissive, unconfined aquifers [1].

Before determining the artificial recharge technique, prospective sites are commonly selected to measure the likely infiltration rate. Infiltration rates can be measured using an infiltrometer. Several types of infiltrometers are available – tests ponds, tension-disc infiltrometer, single-ring and double-ring infiltrometers [3, 5].

The most widely used field vadose zone methods use tension-disc infiltrometers and double-ring infiltrometers [4]. In this work, we obtained direct measurements of infiltration rates using a double-ring infiltormeter. The double-ring infiltrometer consists of inner and outer rings. The rings are inserted into the soil and filled with water, and the rate of infiltration is measured. The measurement is conducted until the infiltration rate becomes steady. The steady infiltration rate is often equal to the saturated hydraulic conductivity.

Hydraulic conductivity (K) is one of the most important soil properties controlling the rainfall partition into infiltration and surface runoff. The saturated hydraulic conductivity, together with the gradient in hydraulic potential, controls the upper limit of water flow in soils. It is a critical piece of information required to evaluate the aquifer performance – to calculate the water transmitting and storage capacities of the aquifer. Saturated hydraulic conductivity depends strongly on soil texture and structure. Of course, it also shows a variability that depends on different factors (soil nature, climate, land use).

The purpose of this study is to evaluate the potential for infiltration in a study area – Rožnov pod Radhoštěm. Specifically, measuring and evaluating the infiltration rates in selected sites.

2 STUDY AREA

The study area is located in Rožnov pod Radhoštěm – premises of a water treatment plant (WTP) in Rožnov pod Radhoštěm. This is a site having regular problems with groundwater supplies in dry periods of time. The study sites were selected based on possible locations for the future application of artificial recharge in cooperation with Vodovody a Kanalizace Vsetín a.s. (Fig. 1).

Fig. 1: Map of the study area.

According to the **geological condition**, the area belongs to the Carpathian flysch zone represented by the facial-tectonic units – Podslezská, Slezská, Předmagurská and Magurská. The floodplain of Rožnovská Bečva is filled with fluvial coarse-grained gravel and gravel of Pleistocene to Holocene age [11].

According to the **hydrogeological condition**, the area belongs to the quarter of Horní Bečva. It is an area formed by fluvial sediments. In the area of interest, it is mainly the valley gravel accumulation about 1-4 m deep below the river bed. An important role for the accumulation and circulation of shallow groundwater is played by the pass-through incoherent deposits [11].

The underground water is located in the collector with free surface of quaternary gravel Rožnovská Bečva. The thickness of the collector is 3–4 m. The groundwater level is approximately 2 to 3 m high below the ground level. The direction of groundwater flow is influenced by high permeability of the quaternary and the course of the gravel subsoil [11].

From the point of view of groundwater, there is a free aquifer with groundwater type Ca-Mg-HCO$_3$-SO$_4$. The total mineralization of the waters ranges from 0.3 to 1 g·l^{-1}. It is also characterized by low concentrations of chlorides, sulphates and nitrates.

The climate of this area is cold and temperate. The average annual temperature is 7.7°C. According to the Water Balance of the Morava Estuary, the hydrological situation in the study area is not favourable. The average monthly precipitations are under normal. This state corresponds to the water levels of groundwater and watercourse. Especially in summer, the water level is below the drought limit.

3   MATERIALS AND METHODOLOGY

3.1 Infiltration tests

Six measurements points were selected for the experiment. Each point was determined using a GPS unit. The scheme of the measurements points is shown in Fig. 2.
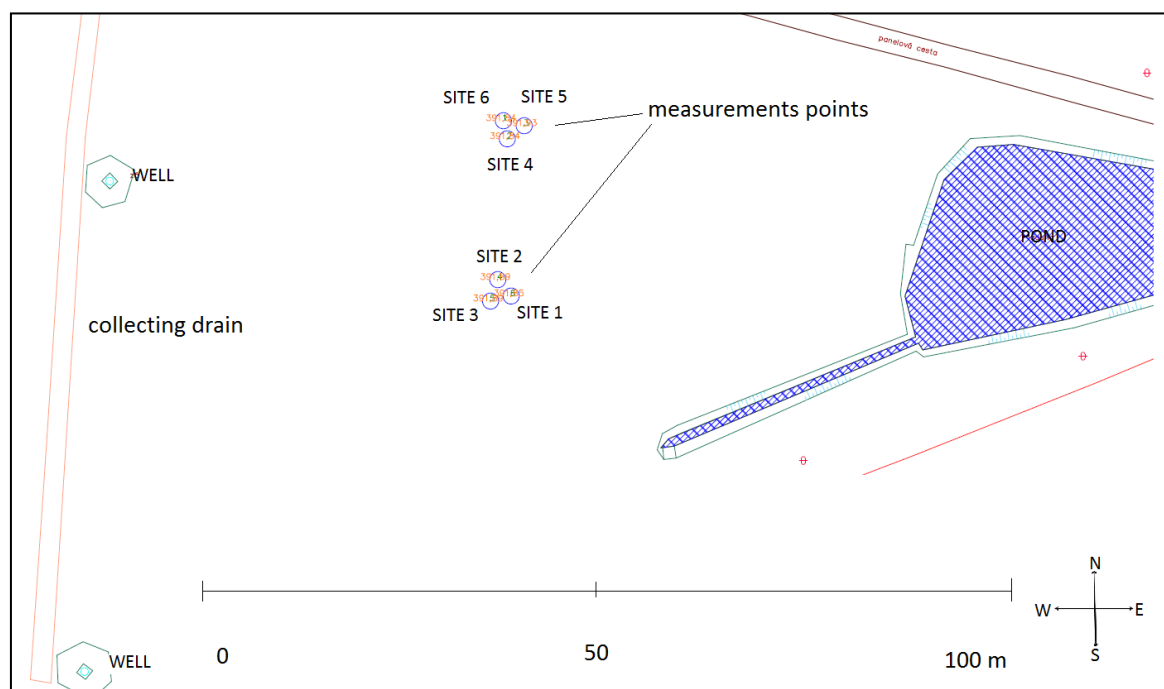

Fig. 2: Sites of infiltration measurements.

The infiltration measurements were carried out by using three pairs of rings for synchronic measuring. They consist of inner and outer rings with diameters: 28/53 cm, 30/55 cm and 32/57 cm. The rings were inserted 10 cm into the soil using a rubber hammer. The ring remained horizontal during the insertion. The picture of a double-ring infiltrometer is illustrated in Fig. 3.

Fig. 3: Double-ring infiltrometer.

The surface water from the pond was used for conducting the infiltration test and was added inside the inner and outer ring. The quality of surface water is shown in Tab. 1.

Tab. 1: Quality of surface water.

pH	Conductivity	COD$_{Cr}$	BOD	TDS	P	N-NH$_4$	N-NO$_3$	N-NO$_2$
	[mS.m^{-1}]	[mg.l^{-1}]	[mg.l^{-1}]	[mg.l^{-1}]	[mg.l^{-1}]	[mg.l^{-1}]	[mg.l^{-1}]	[mg.l^{-1}]
8.29	21.7	11.8	1.4	110	0.11	<0.05	1.7	0.036

The infiltration rate was measured in the inner ring with a pressure logger. The outer ring minimizes lateral water movement from the inner ring. The time durations for the water level to drop 2 cm in the inner ring were being recorded with a stopwatch until the infiltration time was constant.

The measured data were analysed based on the Philip`s infiltration model. This model was chosen because it is based on empirical parameters. Empirical models are generally preferred over theoretical ones because they reflect in-site conditions. This model predicts infiltration rates for sandy soil more accurately than for clayey soil. The vertical infiltration was calculated according to [6, 7, 8]:

$$i(t) = St^{\frac{1}{2}} + At \qquad (1)$$

where:

$i(t)$ - cumulative infiltration [cm]

t - time [s]

A - steady-state infiltration rate [cm.s^{-1}]

S - sorptivity [cm.s$^{-1/2}$]

The infiltration rate is therefore [6, 7, 8]:

$$v(t) = \frac{1}{2}St^{-\frac{1}{2}} + A \qquad (2)$$

where:

$v(t)$ - infiltration rate [cm.s^{-1}]

t - time [s]

A - steady-state infiltration rate [cm.s^{-1}]

S - sorptivity [cm.s$^{-1/2}$]

For the evaluation of measured data, it was necessary to determine the parameters S and A. One of the widely used approximation method – the method of the "least squares" – was used to find the parameters.

The steady-state infiltration rate after long time of infiltration remains constant and its values are close to the values of saturated hydraulic conductivity [6, 7]:

$$K_s = \frac{A}{m} \qquad (3)$$

where:

K_s - hydraulic conductivity [m.s^{-1}]

A - steady-state infiltration rate [cm.s^{-1}]

m - constant, 0.6667

Hydraulic conductivity was then used to soil classification according to the valid Czech standard ČSN CEN ISO/TS 17892-11 [9].

3.2 Soil sampling

The soil information for each site was obtained from analyses of soil samples that were collected from each test site. Immediately before each infiltrometer application, an undisturbed soil core was collected from the soil surface after removing the first 10 mm of soil. The soil samples were weighed and dried at 105°C for 24 h and then re-weighed to determine the gravimetric water content.

4 RESULTS AND DISCUSSION

The infiltration curves for the different sites as well as the cumulative infiltration curves are presented in Fig. 4. As mentioned above, the measured data were analysed based on the Philip`s model. The comparison of the experimental data of cumulative infiltration and the modelled values gave the determination coefficients R^2 in the range from 0.96 to 0.99.
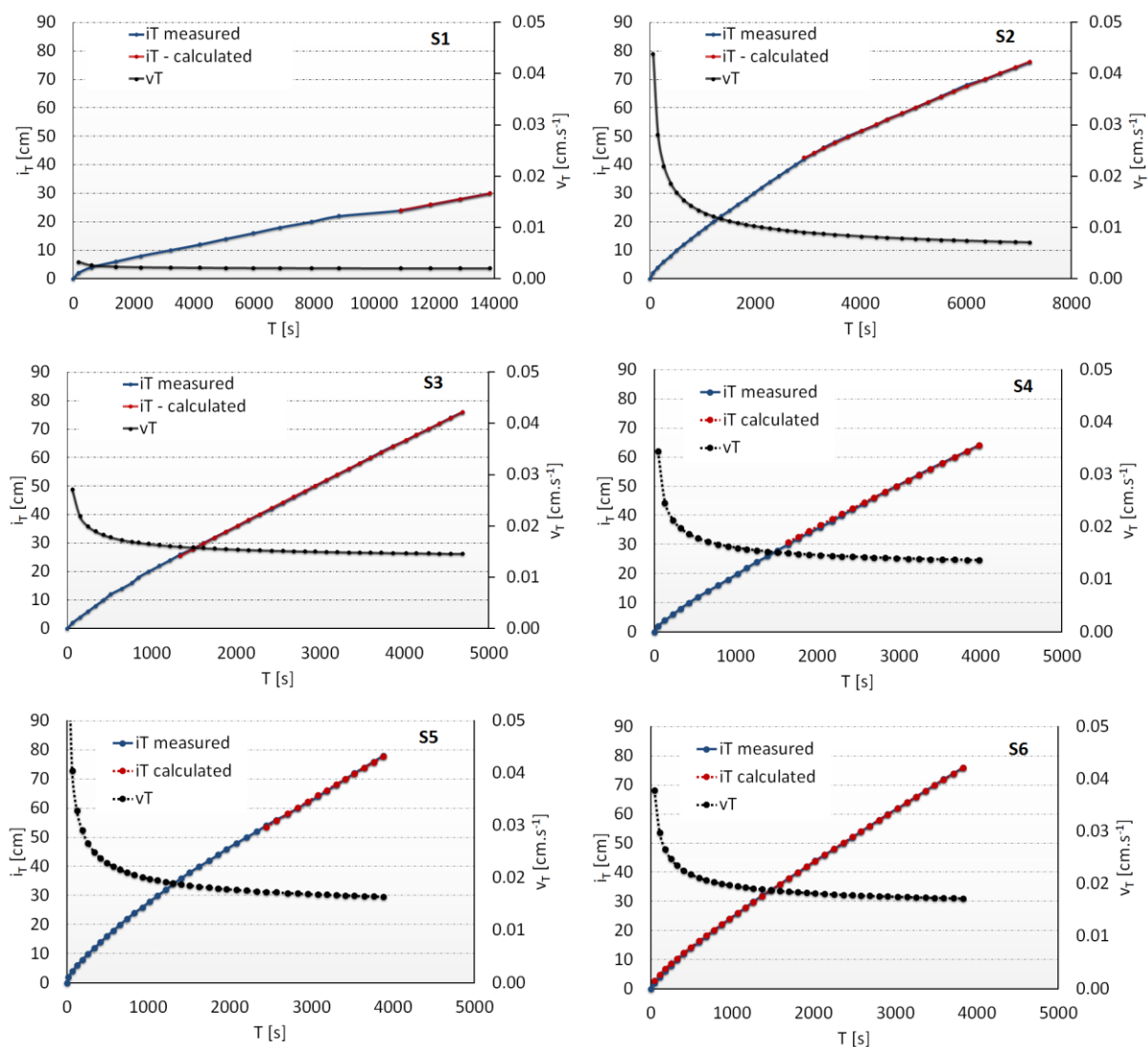
Fig. 4: Cumulative infiltration and infiltration rate for infiltration measurements.

At the beginning, the infiltration rates were high and decreased to reach the steady state. The high initial infiltration rate could be possible due to the influence by the surface sealing of the double-ring infiltrometer. The initial infiltration rate tended to increase with the initial soil water content (compare Fig. 4 and Fig. 5).

Two measurements (1, 2) differed from each other. In the case of measurement no. 1, the test was performed incorrectly.

The steady-state infiltration rate for the measurements sites 3, 4, 5 and 6 was balanced (around 70 cm·h^{-1}).
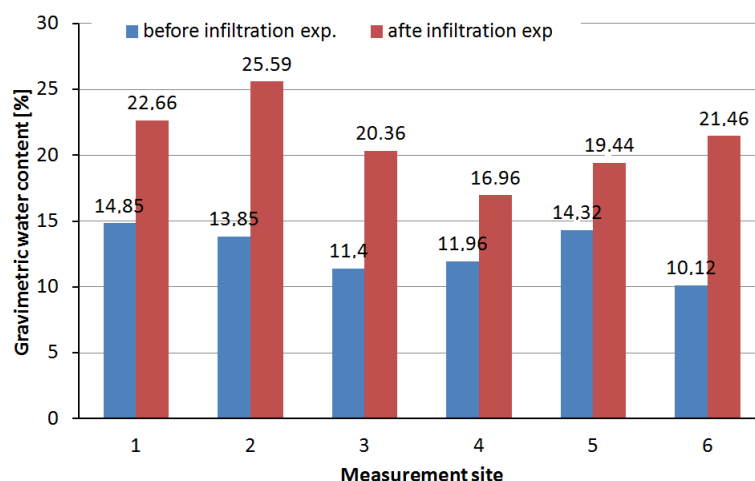
Fig. 5: Gravimetric water content measurements at the beginning and at the end of infiltration experiments.

The constants used for the Philip`s infiltration model are shown in Tab. 2. Tab. 2 also shows the values of calculated saturated hydraulic conductivity and soil classification according to the valid Czech standard CSN 721020.

Table 2 Models relating infiltration

Site	S	A	K_s	Soil permeability	Soil type
			m/s		
1	0.0360	0.0019	$1.789*10^{-5}$	permeable	Sand and gravel, containing fine-gradient fraction (5-15 %)
2	0.5916	0.0036	$5.390*10^{-5}$	permeable	Sand and gravel, containing fine-gradient fraction (5-15 %)
3	0.2188	0.0130	$1.948*10^{-4}$	highly permeable	Sand and gravel without or with very low fine-gradient fraction (< 5 %)
4	0.3043	0.0113	$1.689*10^{-4}$	highly permeable	Sand and gravel without or with very low fine-gradient fraction (< 5 %)
5	0.4440	0.0129	$1.935*10^{-4}$	highly permeable	Sand and gravel without or with very low fine-gradient fraction (< 5 %)
6	0.3182	0.0147	$2.203*10^{-4}$	highly permeable	Sand and gravel without or with very low fine-gradient fraction (< 5 %)

5   CONCLUSIONS

The artificial recharge is one way how to store water underground in times of water surplus. For the successful application of the measure, it is necessary to know the hydrogeological conditions.

In our study, infiltration rates of soil in Rožnov pod Radhoštěm were evaluated. The infiltration measurements were carried out by using a double-ring infiltrometer. The measured data were analysed based on the Philip`s infiltration model. The Philip`s infiltration model predicts infiltration rates for sandy soil more accurately than for clayey soil. The results showed that this model is usable for the study area. This model modelled the experimental data well, as indicated by the high coefficient of determination. The steady soil infiltration rate ranged from 28 cm·h^{-1} to 70.38 cm·h^{-1} and the cumulative soil infiltration ranged from 58 cm to 68 cm. The results show a high potential of surface artificial recharge in the study area.

The next step of the research consists in a pilot-based verification with the proposal of surface artificial recharge technology, the description of the impact of infiltrated water on the quality of groundwater and possible design of a water treatment plant.

Acknowledgements

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