THE ROLE OF ACCURATE RECHARGE ESTIMATION IN THE HYDRODYNAMIC ANALYSIS OF KARST AQUIFERS

POMEN NATANČNE OCENE NAPAJANJA V HIDRODINAMIČNIH ANALIZAH KRAŠKIH VODONOSNIKOV

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Izvleček

Metka Petrič: Pomen natančne ocene napajanja v hidrodinamičnih analizah kraških vodonosnikov

Za izbran študijski poligon kraškega vodonosnika v zaledju izvirov Vipave v jugozahodni Sloveniji je bil na osnovi metode bilance vode v tleh najprej postavljen model za oceno napajanja, v katerem so bili poleg merjenih padavin upoštevani še vplivi intercepcije na vegetacijskem pokrovu, snežnih padavin in taljenja snega, evapotranspiracije, uskladiščenja vode v tleh, neposrednega napajanja in sekundarne infiltracije. Po kalibraciji modela glede na primerjavo s pretoki izvirov Vipave so bile ocenjene dnevne vrednosti napajanja. Za testiranje pomena take natančne ocene napajanja za nadaljnjo analizo hidrodinamičnih značilnosti kraških vodonosnikov pa je bila uporabljena metoda črne skrinjice. Kot vhodni signal v predpostavljeni linearni sistem so bile najprej privzete kar merjene padavine, nato pa še ocenjene vrednosti napajanja. Primerjava rezultatov je pokazala, da prinese uvedba funkcije napajanja značilno izboljšanje modela. Na ta način je bil potrjen pomemben vpliv procesov v zraku, vegetaciji in tleh na količino in časovno razporeditev napajanja in s tem tudi na značilnosti hidrodinamičnega delovanja kraških vodonosnikov.

Ključne besede: kraška hidrologija, napajanje, bilanca vode v tleh, izviri Vipave, Slovenija.

Abstract

Metka Petrič: The role of accurate recharge estimation in the hydrodynamic analysis of karst aquifers

For the karst aquifer in the background of the Vipava springs in south-western Slovenia the first the model of the recharge estimation was set on the base of the method of soil moisture balance. Additional to precipitation, the influences of the interception on vegetation cover, snow and snowmelt, evapotranspiration, water storage in soil, rapid recharge and secondary infiltration were also considered in this model. It was calibrated by comparison with the discharges of the Vipava springs and then the daily values of recharge were estimated. To test the role of such accurate estimation of the recharge in further hydrodynamic analysis of karst aquifers, the black-box method was used. As the input signal in the supposed linear system the measured precipitation was first adopted, and then the estimated recharge values. It was demonstrated by comparison of results that the introduction of the recharge function significantly improves the model. In this way the important influence of the processes in the air, vegetation and soil on the amount and the time distribution of the recharge, and through this also on the hydrodynamic functioning of karst aquifers, was proved.

Key words: karst hydrology, recharge, soil moisture balance, Vipava springs, Slovenia.
INTRODUCTION

Karst aquifers are hydrodynamic systems with heterogeneous structure. Various research methods are applied to define their characteristics. Very important are different analyses of karst springs which reflect the functioning of the whole system. Also the study of the recharge-discharge relations can give some further information about the characteristics of the flow and the storage in karst systems. Very often the precipitation data are simply used as the input signal. In this way some important processes in the air, vegetation and soil and their influence on the infiltration are neglected. The main reason for such a decision is usually the lack of appropriate data, but the motive can also be the complex structure and functioning of karst systems. It can be assumed that already because of this the uncertainty of the used methods is so high that some additional error due to the simplification of the recharge estimation does not have a significant influence on the final result. For certain conditions this assumption can be confirmed, but still in many cases also the processes that influence the precipitation before and during the infiltration and can change the form of the input signal significantly must be considered. The aim of this study was to test this influence in the chosen research area and through this to estimate the role of accurate recharge estimation in the hydrodynamic analysis of karst aquifers.

RECHARGE ESTIMATION

Direct field measurements of the recharge in the regional sense are practically impossible, therefore different methods of estimation are used in practice. Vegetation, climatic conditions and hydrological characteristics of soil can have an important influence on the interception on vegetation cover, snow and snowmelt, evapotranspiration and water storage in soil. Described processes are considered in the method of the soil water balance. The source of water is the rainfall reduced by the amount of water intercepted by the vegetation cover and the water that flows out of the snow cover during melting at adequate climatic conditions. The consumption of water is connected mainly with evapotranspiration. The relation between the source and the consumption is influenced by the hydrological characteristics of soil, which define the amount of the water storage in soil.

These basic relations can be expressed by different more or less complex models (Rushton & Ward 1979, Sauter 1992, Jeannin & Grasso 1995), but it is often proved by their practical use that the differences between the models are less important for the final result than the accuracy of the estimation of the input parameters (Lerner 1997).

One of the possible equations of the soil water balance is the following:

\[ N = (P_g + M - ETR - \Delta S) + n_h + N_{nk} \]  

\( N \) is the recharge, \( P_g \) the precipitation that is not intercepted by the vegetation and actually reaches the ground, \( M \) the amount of snowmelt, \( ETR \) the actual evapotranspiration and \( \Delta S \) the change of the soil moisture. Parameter \( n_h \) describes the process of the rapid recharge where the infiltration is not conditioned by the replenishment of the soil moisture deficit and the rain water flows directly through the fissures in the soil. Listed parameters define the primary infiltration. In
karst areas also the secondary recharge by the sinking streams from non-karstic regions \( N_{sk} \) has an important role. If the discharge of the sinking streams is measured, these measured values can be considered as an additional parameter in the model of recharge estimation.

**DESCRIPTION OF THE PARAMETERS**

**Precipitation**

It is relatively easy to measure the amount of precipitation at the precipitation stations, but errors due to the influences of wind, evaporation and wetting of the rain gauge can significantly lower the accuracy of measurements. At a wind speed more than 5 m/s the measured values in the rain gauges of the Helmann type reach only 22 % of the actual snow fall and 87 % of the actual rain (Yang et al. 1994). According to Neff (1977) the total measured precipitation is 5 to 15 % lower that the actual values, and for individual rainfall events the error due to the wind can vary from 0 to 75 %. The wetting loss has a lower and more uniform effect.

Numerous correction methods have been suggested, but none gives entirely satisfying results. The adequate international standards of correction have not been defined yet, so in each individual research the solutions remain dependant on the subjective estimation of the researcher. Usually simplified forms are used which only consider the most important influences. Different equations were developed to correct the wind induced errors. The coefficient of correction for daily precipitation can be calculated by the one proposed by Allerup and Madsen (1979):

$$ k_v = \exp(-0.001 \cdot \ln i_{pd} - 0.0082 \cdot u_p \cdot \ln i_{pd} - 0.042 \cdot u_p + 0.01) $$  (2)

\( k_v \) is the wind correction coefficient, \( i_{pd} \) is the daily intensity of rain (mm/h) and \( u_p \) the wind speed at the height of 10 m above the surface (m/s).

Due to the wetting of the inner walls of the gauge collector the measured daily values should be increased for 0.3 mm for rain, 0.2 mm for mixed precipitation, and 0.15 mm for snow for each day with precipitation more than 1 mm. For precipitation less than 1 mm these factors should be decreased by the half.

Also the interception has an important influence on the recharge. It is defined as a process by which precipitation falls on vegetative surfaces, where it is subject to evaporation. It depends on vegetation type and stage of development, and the intensity, duration, frequency, and form of precipitation (Dingman 1994). Because these factors are very variable also the interception varies a lot.

Dingman (1994) reports measurements for 41 different forest types on 25 locations in different countries of the world in which the portion of the interception ranges between 5 and 49 %. After Rejic and Smolej (1988) this portion varies in dependence on the intensity of the precipitation in winter for coniferous trees between 80 and 28 %, for deciduous-coniferous forest between 52 and 14 %, for deciduous trees between 20 and 0 %, and in summer for coniferous trees between 85 and 30 %, for deciduous-coniferous forest between 60 and 18 %, for deciduous trees between 32 and 6 %.

Direct measurements of the losses due to the interception are practically impossible. On well-equipped test sites with a dense network of raingauges the difference between the measured preci-
pitation on the one hand and the throughfall and the stemflow on the other is defined. But in hydrological researches usually different conceptual models are applied. The most often used is the Rutter model which computes a running water balance of the canopy and the tree trunks (Rutter et al. 1971).

The canopy and the trunk storages are filled by rainfall and emptied by evaporation and drainage. When the actual amount of water on the canopy $C_k$ exceeds the canopy capacity $S_k$, evaporation takes place at the rate given by the Penman equation (Dingman 1994). The quantity of water that drains to the ground is equal to the difference between $C_k$ and $S_k$. When $C_k$ is smaller than $S_k$ no drainage occurs and actual evaporation is decreased by a quotient between $C_k$ and $S_k$. Similar relations are characteristic also for the interception on the trunks.

The problem in hydrological practice is how to determine the canopy-structure parameters. Sometimes they are estimated by experimental measurements based on the comparison between the results of conceptual models and field measurements. But in the analyses of the water balance they are often adopted from the literature and then included in the calibration of the model of the recharge estimation.

**Snow melting**

At specific climatic conditions also the snow has an important role in the time distribution of the recharge. It accumulates on the surface as the snowpack, then at increased temperatures starts to melt and infiltrate into the ground with a certain time lag. Melting depends on meteorological conditions (sunshine hours, air temperature, humidity, wind speed, precipitation). The basic methods of estimation are the degree-day and the energy balance methods. Due to the lack of adequate data also different empirical equations are often used. They were defined on the basis of the field measurements in certain locations, therefore they can strictly be used only for these areas. But in practice they are widely applied. Such example are the equations of the U.S. Army Corps of Engineers (1960):

\[ M = (0.3 + 0.012 \cdot R) \cdot T + 1.0 \quad \text{and} \quad M = (0.1 + 0.12 \cdot R + 0.8 \cdot k \cdot v) \cdot T + 2.0 \] (3)

$M$ is the daily amount of the snowmelt (mm), $R$ the daily precipitation (mm) and $T$ the mean daily air temperature (°C). The second equation is valid for grassland and partly forested areas, where also the wind speed at the height of 10 m $v$ (m/s) and the basin parameter $k$ (between 0.3 for medium dense forest and 1.0 for open grassland) have to be considered.

For days without rain, melting is defined only in dependence on the air temperature. The first equation is used for forests and the second for open areas. $M$ is expressed in inches, and the mean daily air temperature $T_m$ in °F:

\[ M = 0.05 \cdot (T_m - 32) \quad \text{and} \quad M = 0.06 \cdot (T_m - 24) \] (4)

Taking into account the conditions of the precipitation and the distribution of the vegetation the adequate combination of these equations can be used.
Evapotranspiration

Evapotranspiration is a collective term for all the processes by which water in the liquid or solid phase at or near the earth’s land surface becomes atmospheric water vapour (Dingman 1994). Penman (1948) developed a formula for calculating open water evaporation based on fundamental physical principles, with some empirical concepts incorporated, to enable standard meteorological observations to be used. It combines the mass transfer method and the energy budget method:

\[
ETP = \frac{\delta \cdot H + Ea}{\gamma / \delta + 1}
\]  

(5)

ETP is the potential evapotranspiration (mm/day), \( \delta / \gamma \) the relation between the slope of the curve of the saturated vapour pressure plotted against the temperature and the hygrometric constant (-), H the available heat (mm/day) and Ea the aerodynamic evaporation (mm/day).

On this basis the Penman-Monteith equation was developed by Monteith (1965) in which also the mechanism of transpiration is considered. But due to the lack of adequate data it is not often applied in practice. Instead, the modified Penman equation with some changes of the coefficients can be used also for vegetated areas. Parameters H and Ea from the equation (5) are defined as (Shaw 1994):

\[
H = (1 - r) \cdot Ra \cdot (0,18 + 0,55 \cdot \frac{n}{N} - 0,95 \cdot \sigma \cdot T^4 \cdot (0,1 + 0,9 \cdot \frac{n}{N}) \cdot (0,56 - 0,092 \cdot \sqrt{e_d})
\]

\[
Ea = 0,35 \cdot (e_a - e_d) \cdot (1 + \frac{u_2}{100}) \cdot (1 + \frac{h}{20000})
\]

(6)

New parameters are the albedo r (-), the solar radiation Ra (mm/day), the measured sunshine hours n (h), the maximum possible sunshine duration N (h), the Stefan-Boltzmann constant \( \sigma \) (5,67·10⁻⁸ W/m²K⁴), the air temperature T (°K), the vapour pressure of air \( e_d \) (mm Hg), the saturated vapour pressure \( e_a \) (mm Hg), the mean wind speed at 2 m above ground \( u_2 \) (km/day) and the altitude h (m).

Soil-water storage

The process of the soil-water storage is connected with the changes of the soil moisture which depends on the relation between the water supply and the consumption, and the hydrological characteristics of soil. These are soil moisture, field capacity, root constant and wilting point. Groundwater recharge only occurs if the field capacity is exceeded. If the soil moisture drops below the field capacity and is still above the root constant, evapotranspiration can proceed at the full potential rate. Below the root constant and above the wilting point evapotranspiration is reduced according to the ratio between the present and the maximum soil moisture. At the wilting point, transpiration by plants ceases (Sauter 1992).

The problem in hydrological practice is how to determine the hydrological characteristics of soils. Measurements in the field are difficult and usually limited to the small test sites. Therefore often values from literature are adopted and then adequately corrected in the process of the calibration of the model for the recharge estimation.
**Rapid recharge**

Precipitation recharge water can bypass the soil moisture store via fissures and macropores without substantially reducing the soil moisture. Different methods can be used to estimate this rapid recharge. As suggested by Rushton and Ward (1979), the quantity of effective rainfall per day, exceeding some threshold is contributed directly to recharge. The rest is used to replenish the soil moisture deficit. The problem is how to define the threshold value. One possibility is to use values from the literature and then test them in the process of the model calibration.

**Secondary infiltration**

Secondary infiltration includes the sinking surface streams at the contact between karstic and non-karstic part of the recharge area. If the discharges are measured this parameter can be included separately as an additional input into the estimation of the total recharge.

**CASE STUDY**

**Characteristics of the study site**

The method of recharge estimation presented here was tested in the chosen study area in the background of the Vipava springs in south-western Slovenia (Fig. 1). Because the extent of the recharge area has a distinctive influence on the results of the recharge estimation the first step was to define the borders of this area as precisely as possible. Due to the special characteristics of karst aquifers (unknown directions of the groundwater flow, bifurcation, different extent of the recharge area at different hydrological conditions, hidden groundwater flow in covered karst) some simplifications have to be adopted in this procedure. Besides the data about the geological structure and the results of the tracing tests, also the method of hydrological balance was used. Based on comparison between the mean precipitation and the discharges in the period 1961 - 1990 as the recharge area was estimated 149 km$^2$ (Petrič 2000).

The central part is represented by the Nanos and Hrušica karst plateaux. They are mostly built of Cretaceous limestones; only in the border areas also Jurassic limestones and dolomites and Upper Triassic dolomites can be found. Characteristic of the whole area is the thrust structure which is dissected by numerous neotectonic faults. On three sides this karst background is bordered by impermeable Eocene flysch. Carbonate rocks are covered by a thin layer of rendzina soil and on the non-karstic ground a somewhat thicker eutric brown soil prevails. The most widely extended vegetation type is mixed beech-fir forest (57 %). Also grassland (15.9 %), shrubs (more than 15 %), deciduous (6.2 %) and coniferous forest (4.2 %) are important. Urban and arable land cover a little more than 1 % (Puncer et al. 1982).

Daily precipitation is measured in the precipitation stations Nanos-Ravnik, Hrušica and Podkraj. For the estimation of the spatial distribution of precipitation the whole recharge area was divided in 3 precipitation zones on the base of the precipitation map prepared by Pristov (1997). Measured precipitation in all 3 precipitation stations was compared with this map and the extent of precipitation zones was defined (Fig. 1). For each zone the measured values from the adequate precipitation station were accepted as representative.
Estimation of the recharge

Described parameters of the soil water balance were linked together into the model of the recharge estimation. As the input, daily meteorological data measured by the Hydrometeorological Survey of Slovenia in the period of two hydrological years from 25 August 1993 to 23 August 1995 were used. For the parameters of the vegetation cover and the hydrological characteristics of
soil, values from the literature were adopted and then in the process of the model calibration adjusted to the conditions in the studied system. Calibration was based on the assumption that the total amounts of recharge and discharge within individual hydrological years are approximately the same. For such comparison measured daily discharges of the Vipava springs in the same period of two hydrological years were used.

In the first phase the measured values of precipitation were corrected. Based on the measurements in the period from 1961 to 1990 and considering the influence of the wind, wetting loss and configuration of the surrounding area different correction coefficients were defined for 3 precipitation stations (Pristov 1998). The biggest are the deviations for the station Nanos-Ravnik with the correction factor for yearly precipitation \( k=1.14 \). Smaller coefficients were suggested for Podkraj \( (k=1.04) \) and Hrušica \( (k=1.02) \). Since these deviations are significant, the method of correction was applied in spite of its imperfection. First the correction factor was calculated for each day according to equation (2), and additionally the wetting loss was considered. Based on these two factors the corrected daily values of precipitation were defined. Gathered results were tested in two ways. The coefficient \( k=1.14 \) was obtained by the comparison of the yearly values and is in agreement with the value proposed by Pristov (1998). For the comparison of the monthly values the Sevruk method (1986) was additionally used. The agreement between the results of both methods is good and only for two monthly values the difference exceeds 5 \%. Such testing is useful to exclude some big errors, but can not give an objective evaluation of the gathered results. For the stations Hrušica and Podkraj the measurements of the wind speed are not available therefore simply the reduced correction coefficients of the Nanos-Ravnik station were used.

Interception was estimated based on the Rutter model. After calibration the following values were adopted: the canopy capacity for the period from April to September 2.8 mm and for the period from October to March 2 mm (due to the calibration nature of this parameter no separation between deciduous and coniferous forest was considered), the throughfall capacity 0.014 mm and the precipitation on trunks 1.6 \%. Based on these values the mean interception loss for two hydrological years was estimated as 16.5 \%. Daily values range between 2 and 68 \% according to the intensity of the precipitation and the time of the year. This is a relatively low percentage in comparison with the literature values, but can be explained by the high intensities of rain in the studied area.

Considering both correction and interception the daily values of precipitation that actually reach the ground were estimated. Due to the assumption that the snow accumulates temporarily on the surface as the snowpack and infiltrates with a certain time lag, only the rain was included in this estimation. Then the snowmelt was examined separately. According to the known values of the daily precipitation and the spatial distribution of the vegetation the adequate combination of described empirical equations (3) and (4) was used. For each day with registered snow cover and the air temperature above 0°C the quantity of melted snow was calculated.

Gathered results were compared with some field data. During an intensive melting event in April 1996 special plates were placed at different altitudes in the background of the Vipava springs. The amount of melted snow was measured and the average daily value in this short period was estimated as 20 mm (Armbruster & Leibundgut 1997). For the same interval the value of 18.3 mm/day was determined by the empirical equations. The comparison of the data for just one event is certainly not enough for the evaluation of the adequacy of the used method. Also the measurement errors cannot be ignored. But since no other data were available to compare the
methods over a longer period and at different meteorological conditions the results of the described calculation were accepted.

For the estimation of the rapid recharge the threshold method was used, and the threshold value was set at 6 mm in the process of calibration. The quantity exceeding the threshold is contributed directly to the recharge, and the rest is used as the input value to the model of the soil moisture balance.

Potential evapotranspiration was calculated by the Penman equation. Meteorological parameters were measured at the station Nanos-Ravnik.

All described parameters were then linked in the soil water balance. For the karst part of the recharge area there are no field data about the hydrological characteristics of soils, but some basic values were adopted from the in-situ measurements in the area of Trnovski gozd which has similar characteristics of soils and climate (Vrevc 1994). Based on the calibration the following values were applied: 100 mm for the field capacity, 95 mm for the root constant, and 85 mm for the wilting point.

In the final model also the secondary recharge by the sinking streams from the surrounding flysch area was included. The most important are Lokva and Belšiča at the eastern border of the aquifer. Also some smaller, temporary streams sink in this area. The discharges of Lokva and Belšiča were measured in the period of two hydrological years by the Hydrometeorological Survey of Slovenia. For smaller streams just separate estimations of the discharge exist and based

![Graph showing comparison between recharge and discharge for 2 hydrological years.](image)

**Fig. 2: Comparison between recharge and discharge for 2 hydrological years.**

**Sl. 2: Primerjava med napajanjem in praznjenjem za 2 hidrološki leti.**
on these their share can be valued to around 25% of the Belščica discharge. A special case is the Bela stream in the north-western part of the studied area. At low and medium waters it sinks near the village Vrhpolje and presumably recharges the Vipava springs. But at high water levels several temporary springs are activated northern from Vipava and they flow into the Bela stream. Still less is known about the extent of the recharge area of the Vipava springs in the Pivka valley and the Javorniki mountain. The underground water connection was proved by the tracing tests (Habič 1989, Kogovšek et al. 1999), but there is not enough data to quantify the amount and the time distribution of this inflow. Based on the described characteristics and the estimation that the share of the secondary recharge only comes up to 6% of the total recharge some simplifications were adopted for the determination of the secondary recharge. To include the influence of the small sinking streams at the eastern border of the aquifer the measured discharges of Belščica were increased by 25%. The influence of the Bela stream was considered in the correction of the measured discharges of the Vipava springs. The correction was based on the comparison between the measured discharges of Bela in two different gauging stations Sanabor and Vipava (Fig. 1). And due to the lack of the adequate data the inflows from the Pivka river were neglected.

The calibration of the model of the recharge estimation was based on the assumption that the total amounts of recharge and discharge within individual hydrological years are approximately the same. So the estimated recharges for hydrological years 1993/94 and 1994/95 were compared with the discharges of the Vipava springs in the same time period and with the adequate changes of the calibration parameters the above mentioned condition was fulfilled (Fig. 2). Finally daily values of the recharge were calculated by the calibrated model.

THE ROLE OF THE ACCURATE ESTIMATION OF THE RECHARGE

To test the role of the described accurate estimation of the recharge in the analysis of the hydrodynamic functioning of karstic aquifers the black-box method was used. Here the karst system is presented as a centre of dynamic processes determined by input and output signal. These two have physical meaning, and the relation between them is defined by empirical or mathematical functions which only reflect the physical processes in the system. They are called transfer functions. This principle of linear systems is in certain discord with the findings about the non-linearity of the karst systems, but assuming that it is not too big the method has been applied in many karst studies.

Equations that link input and output functions in lumped, time-invariant linear systems are well known from the hydrological literature. The basic convolution integral can be written in discrete form for two isolated, finite series (Dreiss 1989):

$$Q(j) = \Delta t \cdot \sum_{k=0}^{j} Z(j - k) \cdot N(k)) + \varepsilon(j)$$

$$Q$$ is the discharge and $$N$$ the recharge of the aquifer, $$\Delta t$$ the time between the data points, $$Z$$ the transfer function and $$\varepsilon$$ are the errors due to the model assumptions that are not strictly met and the errors in input and output data. Each measured value of daily discharge in the observation period can be defined as a function of the estimated recharge values and the corresponding trans-
fer functions. In this way a system of linear equations is set in which the unknown quantities are the components of the transfer function. The least squares method can be used to solve this system of linear equations.

For the studied karst aquifer two basic input-output models were tested. First simply measured precipitation and discharges were compared, and then the estimated recharge function was adopted as the input signal. The idea was to test whether the introduction of the recharge estimation contributes to a significant improvement of the model.

For both models first the transfer functions were defined (Fig. 3), and then used together with the estimated recharge values for the simulation of the spring discharges. As a criterion for the adequacy of the model the accuracy of the simulation was set, which refers to the capability of the transfer functions to reproduce discharges from which they were derived. So the correspondence between measured and calculated discharges was tested (Fig. 4).

For the comparison also two statistical coefficients were calculated: the coefficient of efficiency $E$, which reflects the capability of the model to reproduce the measured values, and the coefficient of cumulative residual curve $R$, which enables also the estimation of the systematic error (Tab. 1). For both coefficients ideal correspondence between the compared parameters is
Fig. 4: Comparison between measured and calculated discharges for both models.
Sl. 4: Primerjava merjenih in izračunanih pretokov za oba modela.

Table 2: Comparison of statistical coefficients.

<table>
<thead>
<tr>
<th>input - output model</th>
<th>E</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td>precipitation - discharge</td>
<td>0.65</td>
<td>0.50</td>
</tr>
<tr>
<td>recharge - discharge</td>
<td>0.87</td>
<td>0.82</td>
</tr>
</tbody>
</table>
defined with the value 1, but in the real systems this value is adequately lower according to the degree of agreement.

The improvement in the second model is significant and it confirms the importance of the introduction of the recharge function in the described models, especially in the periods of low water when the influence of different processes in the air and soil on infiltration is the largest. Still some deviations are present in the comparison of the results as a consequence of the assumption of the linearity of the system, or the errors in the estimation and measurement of the input and output data.

CONCLUSIONS

For the recharge estimation the model based on the soil water balance was set up and then tested on the karst aquifer in the background of the Vipava springs in south-western Slovenia. Due to the complexity of the processes that influence the infiltration and due to the lack of the adequate field data different indirect methods were used for the estimation of individual parameters. The calibration of the model was based on the presumption that in individual hydrological years the total recharge equals the total discharge of the Vipava springs.

It takes a lot of time and a lot of additional field data to set up and calibrate this model. But as it was proved by the presented study such accurate estimation of the recharge has an important role in further hydrodynamic analysis of karst aquifers. This proves an important influence of the interception on vegetation cover, evapotranspiration, snow and snowmelt, and water storage in soil on the amount and the time distribution of the recharge and through this also on the functioning of karst water systems. Although karst aquifers have special characteristics of groundwater flow and storage is characteristic for karst aquifers due to their heterogeneous structure, the role of the described processes in the vegetation, air and soil on the recharge function must also be emphasised and considered in researches. Without precise estimation of the recharge already the error in the values of the input function can have a significant negative influence on the results of further analysis of the hydrodynamic characteristics of karst water systems.

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POMEN NATANČNE OCENE NAPAJANJA V HIDRODINAMIČNIH ANALIZAH KRAŠKIH VODONOSNIKOV

Povzetek


Postavitev in kalibracija opisanega modela ocene napajanja prav precej zamudni in potrebnih je veliko dodatnih terenskih podatkov. Vendar pa je opravljena študija potrdila pomen natančne ocene napajanja pri nadaljnjih hidrodinamičnih analizah kraških vodonosnikov. Čeprav imajo ti vodonosni sistemi že zaradi heterogene zgradbe posebne značilnosti podzemnega toka in uskladiščenja, je potrebno v raziskavah upoštevati tudi pomemben vpliv opisanih procesov v zraku, vegetaciji in tleh na napajanje. Če ocena napajanja ni dovolj natančna, lahko že napake v vrednostih vhodne funkcije negativno vplivajo na rezultate nadaljnje analize hidrodinamičnih lastnosti kraških vodonosnih sistemov.