UNIVERSITY OF MISKOLC
MIKOVINY SÁMUEL DOCTORAL SCHOOL OF EARTH SCIENCES
Head of the Doctoral School:
Dr. Mihály Dobróka, professor

WATER BUDGET CALCULATION AND DATA SERIES ANALYSIS ACCORDING TO DATA OF BÜKK KARST WATER MONITORING SYSTEM

THESIS BOOKLET

AUTHOR
Enikő Darabos
environmental engineer

SCIENTIFIC SUPERVISOR
Dr. László Lénárt,
r. associate professor

Institute of Environmental Management
Department of Hydrogeology and Engineering Geology
Miskolc, 2017.

I. RESEARCH WORK

My research topic is Bükk Mountain, in my PhD thesis after introduction of general geology and hydrogeology of the mountain I will review the actually workingmonitoring systems.

In my paper I will analyze the water level and precipitation data of Bükk Karst Water Monitoring System (BKWMS) which system means continuous qualitative monitoring since 1992.

My investigations based on daily data can be grouped into two topic (Figure 1.):

- Topic 1 is the water budget calculation. The aim of this research to determine the volume of storage and recharge in the mountain in case of different water levels with a new method.
- Topic 2 is spectral analysis of data series complement with source and well hydrograph analyses. The aim of this research to determine flow and karstifying properties and to develop the accuracy of water level forecast. Concrete aim in case ofdata series analyses to compare the result of recession curves analysis based on water level of karstic well of BKWMS and the result of spectral analysis. Anywhere is possible I defined the border of well karstified zone.

According to the results I give new information related to mountain and I develop new, useful methods which can help to make decisions for stakeholders of water supply companies.

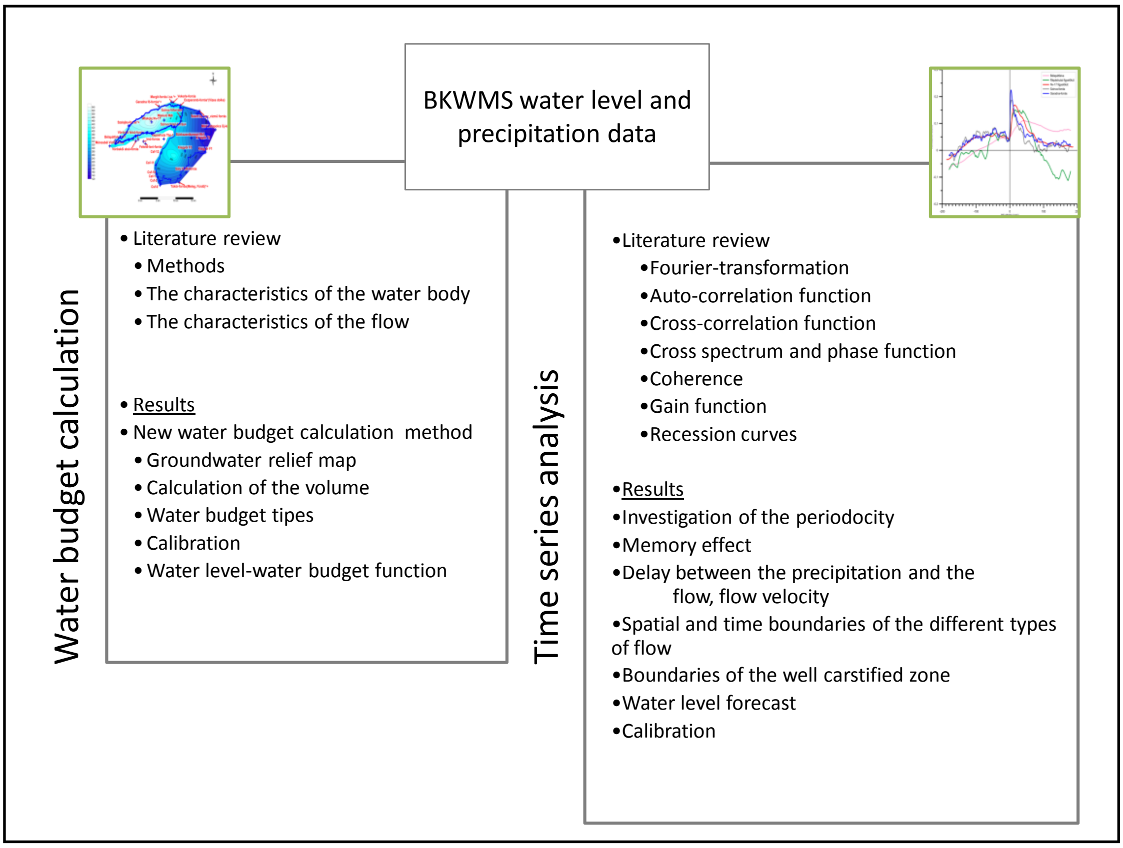

Figure 1. Main research areas in my dissertation

II. Data collection, applied methods

The aims of hydrogeological monitoring system are to know the actual state of water cycle, to satisfy the human water demand and to avoid the damaged caused by water. The basic of BKWMS was 5 well which were planned and carried out by Tivadar Böcker in 1983. The first automatic water level registers were installed in 1992 about the heavy water scarcity. In the BKWMS water level, temperature and conductivity are registered.

The time step of measurements generally 15-60 minutes, but in some special cases there is 1, 10 and 240 minutes between measurements. The accuracy of measuring equipment for every parameters is ± 0.1%.The data collection is performed monthly or in every 3 month and followed by manual measurements to validate the registered data. The collected data are archived in the original file format, but the data for analysis are attached in MS Excel format after occurrent correction according to manual measurement. The collected data are also upload into a MS Access database. In every investigation I used the mean daily water levels.

In the BKWMS there are more than 80 monitoring point but not all works in the last 25 years. For the investigations I used the monitoring points which have the longest data series. The water level change have different characteristic in wells and in springs so I performed the analysis in all the two type of measuring point. During selection of monitoring point another aspect was the position in the mountain because I wanted information from all important hydrogeological unit of it. To water budget calculation near the monitoring points of BKWMS I used spring exit point elevation data from the spring cadaster to determine the characteristic water level on the border of mountain.

The precipitation data are also collected in different part of the mountain. The Hungarian Meteorological Service, the North-Hungarian Water Directorate and BKWMS also provide data in our precipitation database. For analysis I used mean daily precipitation data of Jávorkút. This monitoring point is a best choice for investigations because it is in the center of the main recharge area. (Lénárt 2006, Darabos 2010)

Water budget calculation

The traditional water budget calculation methods based on the determination of parameters of hydrological budget equation. In this case the refill of system is determined. (Cheng-Haw et al. 2006)

Another group of water budget calculation methods is volume estimation of stored groundwater.The first step in this method to construct a geographical information system which makes possible to visualize and to manage the data. The following step is volume estimation which have two ways:

- calculation of total volume according to porosity and thickness of saturated zone
- estimation of exploitable volume by pumping according to specific yield, specific storage and the thickness of confined zone. Ending step is determination of estimation sensitivity on parameters. (Hinaman 2005, Kinzelbach 1986, Liedl et al. 2003, Reimann et al. 2011)

In the Hungarian practice there is three method to determine the volume of exploitable groundwater (Juhász 1987):

- experimental estimation
- calculation on physical base
- combination of previous methods

My water budget calculations is new in case of Bükk because the previous calculations based on hydrological budget equation (Kessler 1954, Csepregi 1985, Mező 1995, Gondárné et al. 2008). My new method is simple and based on more accurate measurements. The base of the calculation is geographical, geological information, water level from BKWMS and spring exit points from VIFIR spring cadaster.

In 2005 the Bükk Mountain hydrogeologically was divided into 3 main and several smaller units by György Less (Less 2005). According to that paper and after personal consultation with György Less a new hydrogeological category map were created. All geological formation in the mountain could be assorted into 5 groups: (1) well karstified rocks, n=0,0075, (2) poorly karstified rocks, n=0,0025, (3) non-karstified, fractured rocks: riolite tuff, dacite tuff, n=0,001, (4) non-karstified, fractured rocks: others, n=0,001, (5) aquitard rocks, n=0,0005.("n" means porosity) The category of rocks and measuring points of BKWMS are shown on Figure 2.

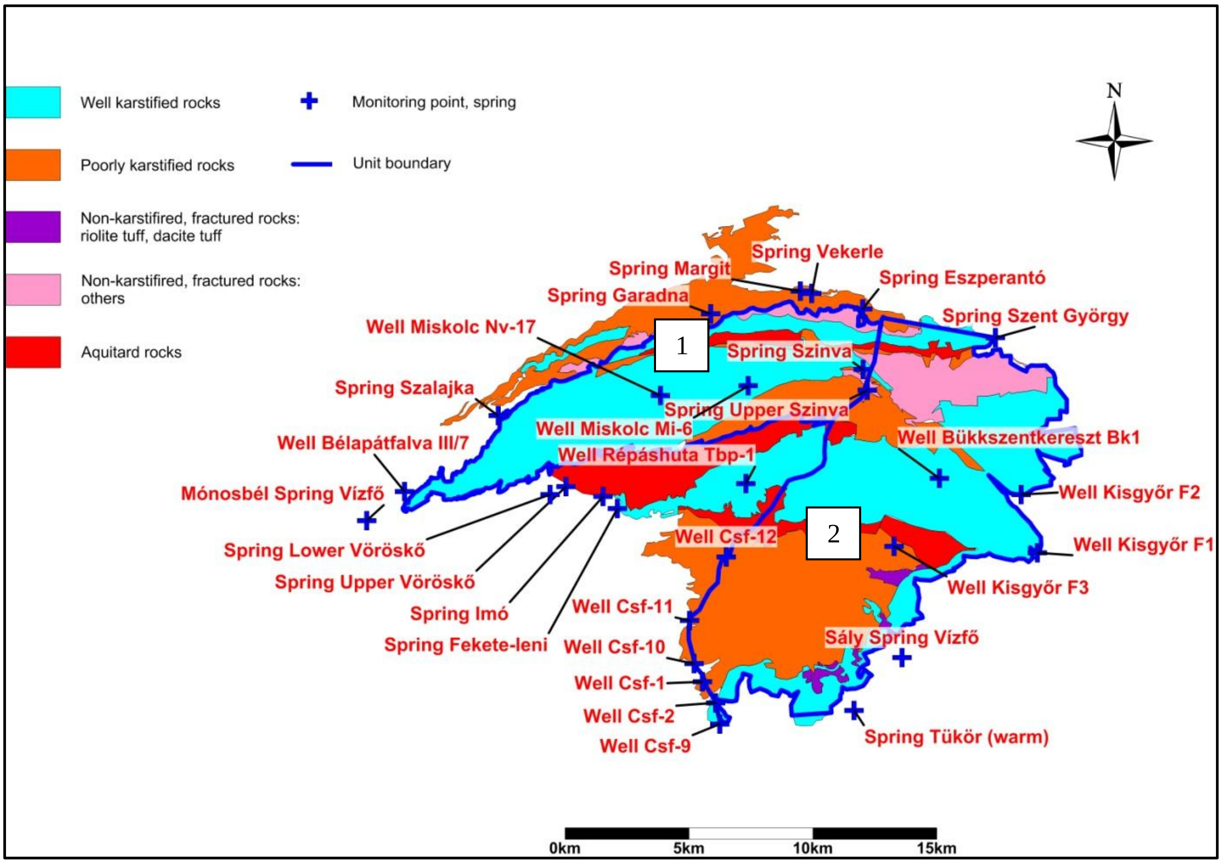

Figure 2. The category of rocks based on carstification in the Bükk, measuring points of BKWMS and the unit boundaries (1: central Bükk, 2: eastern Bükk) (base map: Less 2005)

From the mean water levels and spring exit points elevation a groundwater relief map were created by interpolation method of natural neighbor (the size of grid was 5 m x 5 m). The geological situation of Southwest Bükk is complex so I left it from calculation. The result (Figure 3.) is a surface with 2 maximum point which points can be found under the two non-contributing area of the mountain determined by Sásdi. (Sásdi 2005). The water level in well Nv-17 was found in the range of 529,84 ± 3 m with 55 % of absolute frequency during 25-years long investigation period. The characteristic flow direction can also be determined by isohypses of groundwater relief map. This map were also created in case of maximum and minimum water levels.

To calculate the saturated rock volume I had to determine the depth of it. About that I had to define new concept and technological border in the calculation: quickly refillable dynamic resource, slowly refillable dynamic resource and thermal karst water resource.

- ***Quickly refillable dynamic resource:*** the resource which can be calculated from decreasing water level caused by effective precipitation or precipitation group. The generated groundwater surface can be created from hydrographs of different monitoring points of BKWMS. I selected a decreasing period on the hydrograph of Nv-17. In the moment when the water level was on the maximum in Nv-17 I sorted the water level data of the different monitoring points. I used these data to create the upper groundwater surface. To create the lower groundwater surface I repeated this process with water levels related to the moment of the period when the water level was minimum in Nv-17. The water movement in this zone is governed by meteorology.
- ***Slowly refillable dynamic resource:*** the resource which can be found above the elevation of lowest spring in the water catchment. This is influenced by long-term meteorological conditions. In case of Bükk this resource is found above 127 m a.s.l., mean water level of Well Új in Miskolctapolca. This border is justified because the water level decrease below this elevation the cold water system of mountain cannot work gravitationally. According to that this elevation is the technological border between cold karst water and thermal karst water systems. This characteristic elevation can be determined to smaller water catchments. In case of central Bükk this lowest spring is the Spring Szinva with elevation of 310 m a.s.l..
- The sum of quickly and slowly refillable dynamic resources means ***the total, gravitationally working cold water resource***.
- Related to slowly refillable dynamic resources I delimited a technological border. This border is the elevation of lowest, cold water, flow off spring (in case of Bükk: 127 m a.s.l., Miskolctapolca, Well Új). Below this elevation can be found the zone of slow flow, this is the zone of ***thermal karst water resource.*** The lower border of this water body cannot be delimited, occurrent border could be the lowest water entering point of the deepest thermal well in front of the Bükk Mountain.

I calculated the quickly and slowly refillable dynamic resources in case of different water levels and I validated the results with 2 methods.

The first validation was based on comparison of volume of effective recharge and total volume of mean spring discharge in the center Bükk. I selected a decreasing period on hydrograph I calculated the volume of water between the upper and lower surface. Simultaneously, I summarized the mean volume of discharge of main springs in the center

Bükk. During a water level decreasing period the main volume of water are released by springs. The order of magnitude of calculated quickly refillable dynamic resources is comparable with the discharge of springs. The uncertainty of discharge of springs is high about the non-continuous monitoring of them so the discharge in the spring cadaster could be different from characteristic discharge.The results show the calculated and measured values are similar and they are inside of acceptable error margin (± 20%).

Another way to prove the correctness of calculation method is comparison with the result of a previous, different method. Katalin Székvölgyi (Smaragd GSH) made a resource calculation of the year 2008 (Gondárné et al. 2008). I compared my results with her calculation. The water catchment area is different in the two method so I normalized the values to unity area. According to my method I calculated all volume of all decreasing period. Total volume of that is equal with quickly refillable dynamic resource in the year of 2008. The result are similar.

All the two validation method verify the reliability of my calculation so this method can be used to calculate water resource of Bükk. Table 1 shows the volume of slowly refillable dynamic resource of the Center and East Bükk calculated by my method.

I calculated the slowly refillable dynamic resource in case of different water levels of Well Nv-17 and I get a linear dependency between water resource and water levels. Although, in this linear relationship I just use the water level of Well Nv-17, the volume of water resource is calculated from water relief created from data of all monitoring point. Function 1 can serves the easier application in practice:

$$Vk = 0{,}334 * Vsz - 120{,}7 \tag{1}$$

where

- Vk the slowly refillable dynamic resource(million m^3)
- Vsz the water level of Well Nv-17 (m.a.s.l.)

Table 1. The total, gravitationally working cold water in the Bükk Mountain based on average water levels (1: well karstified rocks, 2: poorly karstified rocks, 3: non-karstifired, fractured rocks: riolite tuff, dacite tuff, 4: non-karstifired, fractured rocks: others, 5: aquitard rocks)

	Rock category	1	2	3	4	5	Total
Central Bükk	Rock volume (million m3)	16152,1	2577,2	-	699,7	957,4	-
	Porosity	0,0075	0,0025	0,0005	0,001	0,001	
	Basic level (m.a.s.l)	127	127	127	127	127	
	slowly refillable dynamic resource (million m3)	121,1	6,4	-	0,7	1	129,2
Eastern Bükk	Rock volume (million m3)	6355,2	8357,5	274	1382,6	1481,1	-
	Porosity	0,0075	0,0025	0,0005	0,001	0,001	
	Basic level (m.a.s.l)	127	127	127	127	127	
	slowly refillable dynamic resource (million m3)	47,7	20,9	0,1	1,4	1,5	71,6
The total slowly refillable dynamic resource (million m3)		168,8	27,3	0,1	2,1	2,4	**200,8**

TIME SERIES ANALYSIS

The long time series like 25-years long time series of BKWMS could be used to perform autocorrelation, cross-correlation investigations. These investigations can serves information about working of karst system.

During Fourier transformation we convert our data from time domain to frequency domain which allow us to investigate the periodicity. I introduce the Fourier transformation by paper of Endre Turai (Turai 2005), the further applied methods will introduce according to books of Jenkins and Watts, Chatfield and Wei (Jenkins & Watts 1969, Chatfield 2005, Wei 2006), and determinative article of Alberto Padilla and Antonio Pulido-Bosch (Padilla & Pulido-Bosch 1995), and article of Larocque (Larocque et al. 1998).

The univariate autocorrelation investigation characterize the unique structure of time series. The autocorrelation means correlation of a data series and its time lagged series in time domain. If we convert it into frequency domain, it will be the spectral density function. The autocorrelation investigation characterize the memory effect of system which serves information about storage capacity and degree of karstification. Generally, there is a linear relation between memory effect and storage capacity. The lower the memory effect the lower the storage capacity. The velocity of flow in the low memory effect system is quick about well karstified aquifer. The low memory effect means higher vulnerability because there is no delay in spread of contamination. (Andreo et al. 2015)

The cross analysis serves information about transformation of input precipitation function into output water level function. The cross-correlation function is interpreted in time domain, the cross-amplitude, phase, coherence and gain function is interpreted in frequency domain. (Padilla & Pulido-Bosch 1995)

The cross-correlation gives the impulse response of aquifer to precipitation if the precipitation is considered to white noise. (Mangin & Pulido-Bosch 1983, Padilla & Pulido-Bosch 1995, Panagopoulos & Lambrakis 2006, Jukic & Denic-Jukic 2015)This function serves the input data to Fourier transformation.

To apply this method to hydrological time series, the cross-amplitude function $\alpha_{xy}(f)$ can be associated with the duration of the impulse response function, and indicates the filtering of the periodic components of the rainfall data. It characterize the short-, intermedier- and long-term modifying effect of aquifer on the sign caused by precipitation. (Padilla & Pulido-Bosch 1995)

In the karst hydrogeology, the phase function $\Phi_{xy}(f)$ shows the delay between precipitation and discharge, water level in case of different frequencies.The value of it change in range of 2π between $-\pi$ és $+\pi$. It should be taken into account that the values of $\Phi_{xy}(f) = \pi + c$ will give values of $\Phi_{xy}(f) = -\pi + c$ in the function; this ambiguity should be interpreted according to the tendency of the function.The attenuation of input data can be seen in the cross amplitude and gain function, the mean delay can be determined from phase function. (Padilla & Pulido-Bosch 1995)

We can use the cross amplitude function and spectral density function to create new functions called coherence and gain function. The coherence function shows how the output respond to changes of the input. The gain function shows the system amplification and attenuation effect on input data. (Padilla & Pulido-Bosch 1995, Panagopoulos & Lambrakis 2006, Jukic & Denic-Jukic 2015)

The general time series analysis is common in karst hydrogeology to know and to characterize the system. The main purpose of these analysis is the forecast, the data supplement. One part of it is the hydrograph analysis which can helps to differentiate the quick and base flow. (Plummer et al. 2007)

The recession curve analysis is general investigation in karst hydrogeology. I performed this analysis according to data of BKWMS and I compared the results with results of spectral analysis. These methods can be used to determine the boundary of well karstified zone. According to these investigations I can take several new establishment related to the karst system of Bükk.

III. THESES

Thesis 1.

According to registered, mean water level in monitoring points of BKWMS and spring exit point elevation by spring cadaster the mean water relief map of Bükk can be determined.(Figure 3.)

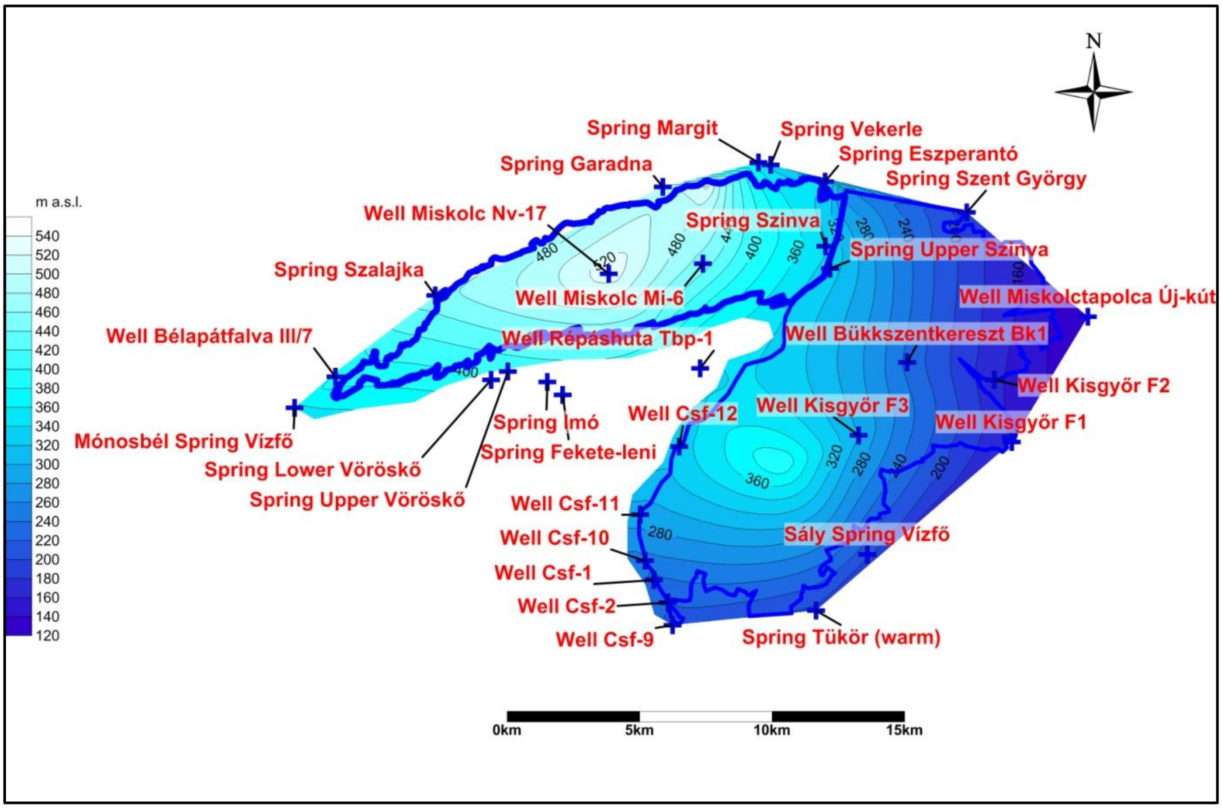

Figure 3. Groundwater relief map based on average water levels of BKWMS water level monitoring points and springs exit points elevations

Thesis 2.

The water resource of Bükk can be divided into 3 segment:quickly refillable dynamic resource, slowly refillable dynamic resource and thermal karst water resource.

Quickly refillable dynamic resource: *refillable resource related to water level change caused by precipitation event or precipitation group which can be calculated from water level data of BKWMS and spring exit point elevation of spring cadaster.*

Slowly refillable dynamic resource: *water resource above elevation of lowest flow-off spring, this can be calculated to a catchment or to the whole mountain*

The sum of slowly and quickly refillable dynamic resources gives ***the total, gravitationally working, cold water resource*** *of Bükk*

Thermal karst water resource *is the water resource below the elevation of lowest flow-off spring in Bükk Mountain. Lower boundary of this resource is the lowest entering point of the deepest well in front of the mountain.*

Thesis 3.

The quickly refillable dynamic water resource of Bükk can be calculated according to my water resource calculation method based on water level of BKWMS and spring exit point elevation.

I verified this statement on two different way. First, I calculated the quickly refillable dynamic water resource of the center Bükk and I compared this volume with the volume of main springs of the area. In the other verification method I compared my calculated volume of year 2008 with the resource calculation of another author. In all the two cases I got good results with error margin of ± 20 %.

Thesis 4.

Functional relationship was established between water level of Well Nv-17 and slowly refillable dynamic water resource in the Bükk. This function is $Vk = 0{,}334 * Vsz - 120{,}7$ *(Figure 4.), where Vk is volume of slowly refillable dynamic resource (million* m^3*), Vsz is water level of Well Nv-17 (m a.s.l)). According to this equation the volume of water resource can be calculated to an arbitrary moment.*

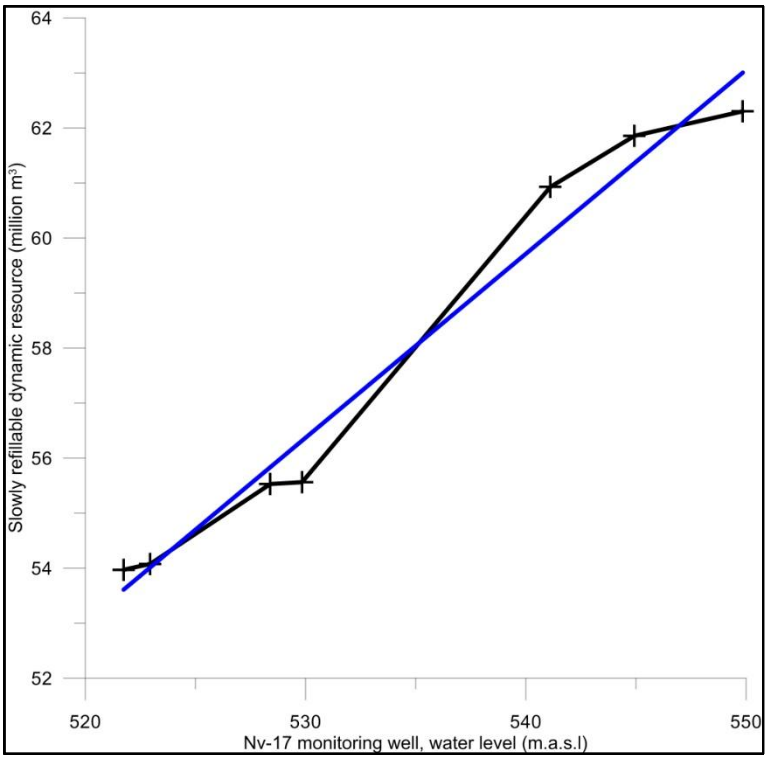

Figure 4. Slowly refillable dynamic resource depending on the water level of Nv-17 monitoring well

Thesis 5.

By periodicity investigation based on Fourier transformation of water level data of Well T10 Miskolctapolca and Well Thermal Miskolctapolca I proved the method applicable to identify which monitoring point belongs to which local water body.

I performed periodicity investigation on data of precipitation of Jávorkút and long time series of Spring Szinva, Spring Garadna, Well Nv-17, Well Bélapátfalva, Well T10 Miskolctapolca, and Well Thermal Miskolctapolca, respectively. According to precipitation data of Jávorkút I determined the characteristic periods in the Bükk. By Fourier-transformation I also determined the characteristic cycles in water level data. The characteristic longer periods can be found in time series of all cold water monitoring point. Not in case of Well Thermal where the most characteristic 1-year period neither cannot be found. (Figure 5. and 6.)

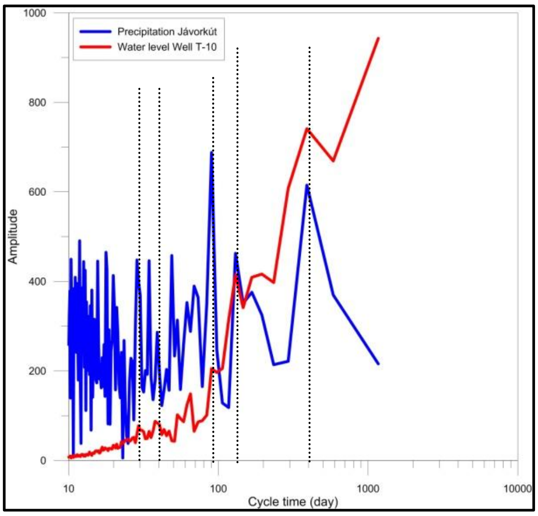

Figure 5. The periods of precipitation (Jávorkút) and water level of T10 monitoring well, analysed by Fourier-transformation (marked the significant common periods)

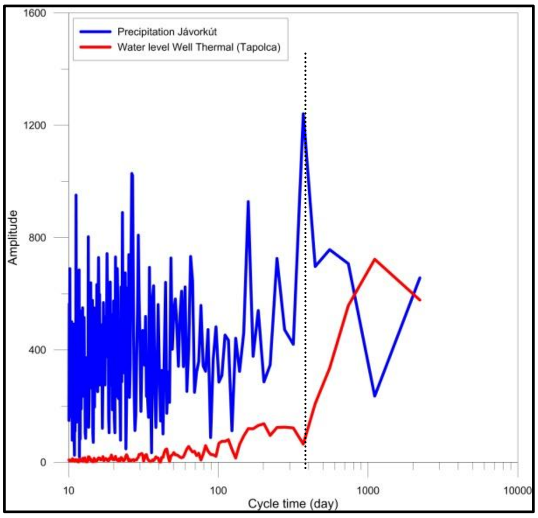

Figure 6. The periods of precipitation (Jávorkút) and water level of Thermal well, analysed by Fourier-transformation (marked the one year period, no common periods)

Thesis 6.

The autocorrelation investigation of water level time series can be used to interpret complex geological situations. I proved according to autocorrelation functions that hydraulic properties of Bükkfennsík Limestone Formation and Fehérkő Limestone Formation in the first 7 days of flow are congruent.

I also proved that Bükkfennsík Limestone aquifer of Well Répáshuta and Well Nv-17 despite of spatial segregation of them are congruent from aspect of hydraulic properties in the first 6 days of flow.

In karst hydrogeology memory effect of a karst system is the time where the value of autocorrelation of water level decrease below 0.2. The development of karst system can be also seen on the curves of autocorrelation (Table 2., Figure 7.). (Pulido-Bosch et al. 1995)

Table 2. The memory effect based on autocorrelation function

	Memory effect (day)
Spring Szinva	70
Spring Garadna	132
Well Rh-1(Répáshuta)	89
Well Nv-17	112
Well Bélapátfalva	206

I compared the characteristic autocorrelation curves of different monitoring points and I took farther statements related to geological formation.

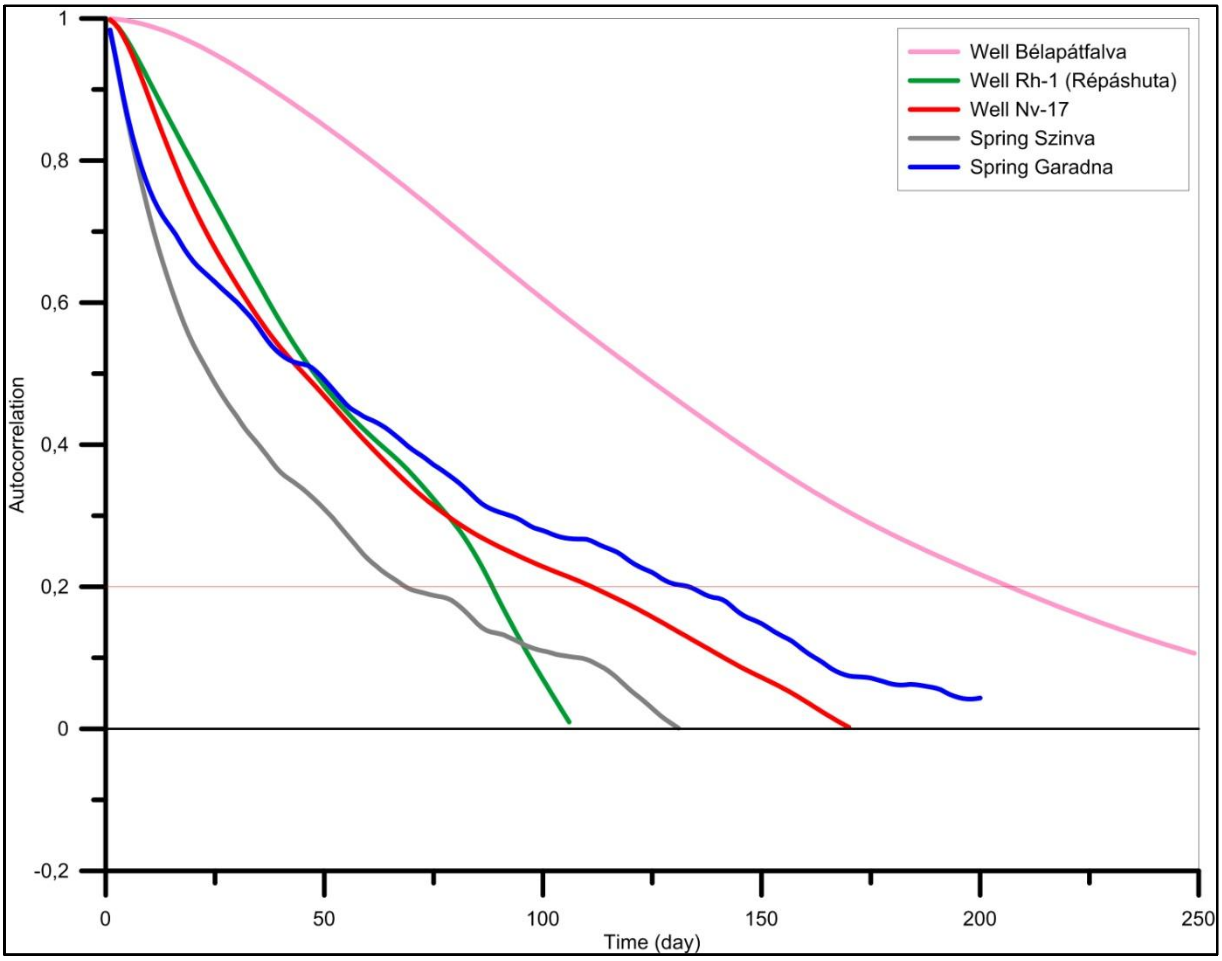

Figure 7. Autocorrelation functions of water levels

Thesis 7.

Flow velocities were determined based on cross-correlation and phase function analysis. In case of Well Nv-17 that is vertical flow velocity (17-22 m/day) because it is in the center of non-contributing area of Bükk. In case of Well Tbp-1 Répáshuta it is a mean flow velocity with value 8,5-10 m/day.

The distance to maximum value of cross-correlation function from the initial point shows the delay of water level peaking (Figure 8.). It is evident the springs have the quickest reaction to precipitation event.

The slope of fitted linear on initial part of phase function can give the mean delay of different periods. When the initial part of phase function is short it is possible to fit on intermedier frequencies (in that case the coherence also makes it possible).

Both methods were used to determine delay and flow velocity.

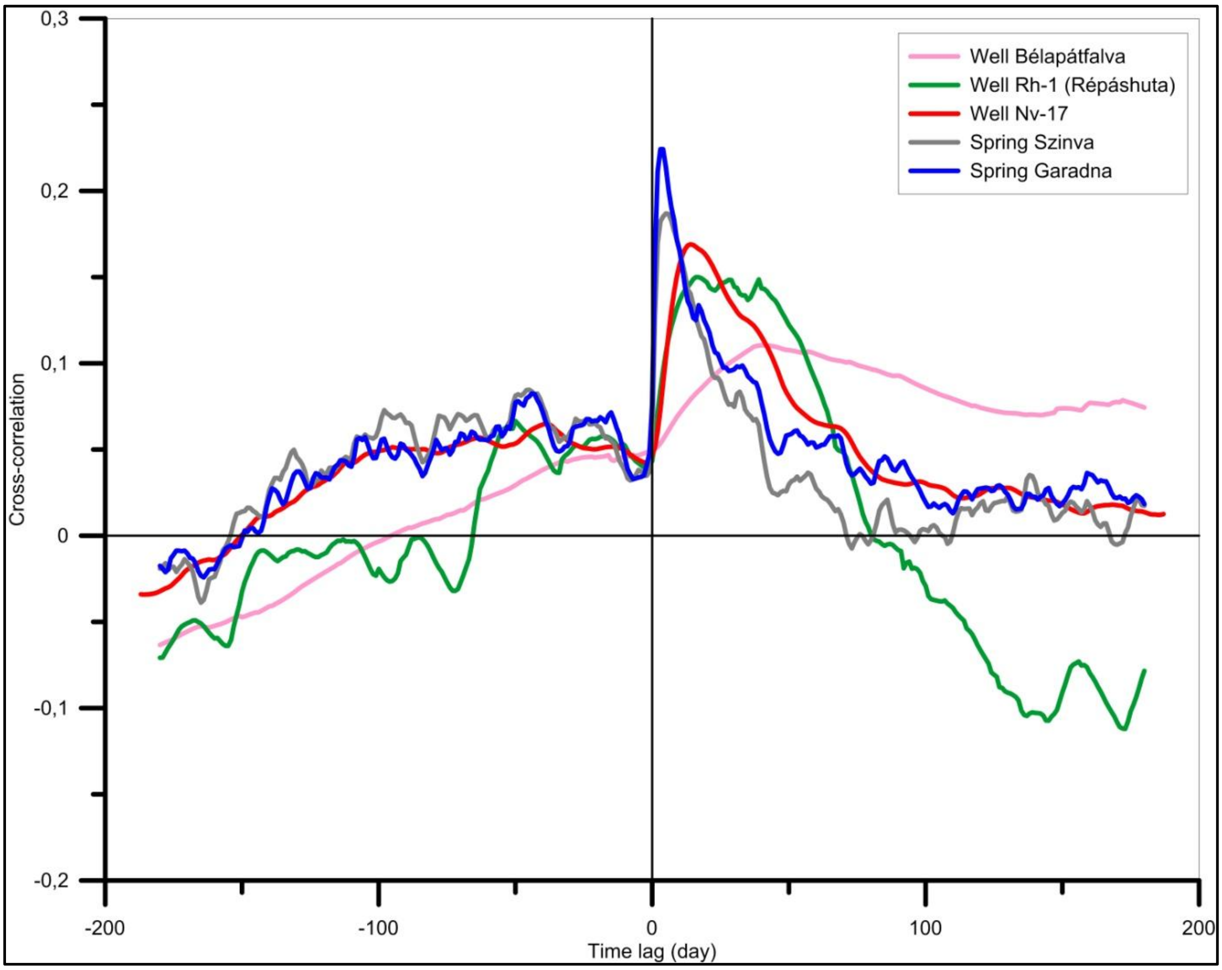

Figure 8. Cross-correlation function between water levels and precipitation (Jávorkút)

Theis 8.

I determined the lowest depth of well karstified zone by analysis of water level characteristic curve of non-edge wells in center Bükk. I appointed the possible depth of cave forming. These depths are 250 m below the non-contributing areaof Great-plateau by Well Nv-17 and 100 m in case of Well Tbp-1 Répáshuta.

The lowest depth of well karstified zone can be determined by water level characteristic curve of non-edge wells in center Bükk. These depths are equivalent with baseflow starting depths by gain function. By data of Well Nv-17 in the Great-plateau the depth of well karstified zone is 250 m, in case of Well Répáshuta this depth is 100 m. Previous cave end point investigations shows the same result on the Great-plateau. (Hernádi et al. 2012)

Theis 9.

I proved that in arid periods the characteristic curves of Well Nv-17 can be used to forecast the decreasing water levels and to forecast the change of the quickly and slowly refillable dynamic resources.

Continuous work of our institute to perform water resource calculation to water supply companies who provide drinking water from the karst water of Bükk. During calculations we always presume that in the following period there will not be recharge from precipitation. It means the undisturbed decreasing of water levels. So we always determine the worst case scenario in case of water resource. To the calculations the forecast of decreasing water level is needed which can be done with characteristic curves easily.

I validated the characteristic curves in periods where we had measured water levels. The difference between measured and calculated water levels was 22 cm which is the 0.8 % of the total water level fluctuation.

APPLICATION OPPORTUNITIES OF THE RESEARCH RESULTS

The Bükk Karst Water Monitoring System (BKWMS) was established in 1992 by pushing of three water supply companies which are produced the karst water of Bükk. For the companies, the water resource estimation was the main requirement from the beginnings. This is the reason why the first research topic of my dissertation is the water resource calculation.

The 25-years data of water level and precipitation enable to develop new calculation methods. The previous method used data of only one monitoring point (Well Nv-17) and it calculated the exploitable water volume from one porosity value with neglect of relief and water relief.

The water relief in my work was determined according to geological and hydrogeological data, furthermore I used water levels from BKWMS and spring exit point elevation from spring cadaster. According to this database the water relief can be calculated to an arbitrary moment. By application of different porosity and technological border (quickly and slowly refillable dynamic resources and thermal water resource) from the water relief, the water resource can be calculated. The created water level-water resource function makes it easier to determine volume of water resourcefor water supply companies. The results can be used directly during water resource estimations which are made in the Institute of Environmental Management at University of Miskolc. With this method the companies can plan the daily water production, they can prepare to providing drinking water from alternative sources. The results of water resource calculation can also serves basics for governments.For example they can evaluate the effect of new water withdrawals.

The flow direction and expectable hydraulic heads can be determined according to water relief map. This can help well planning or contamination transport modeling. Indirectly, my investigations of interpolation and grid sizing can help the farther hydrodynamic and transport modeling. In this investigations I proved that 5 m x 5 m grid size and the application of natural neighbor method for interpolation can result the more accurate water relief map.

The time series analysis is the second research topic of my paper. The aim of this investigation is the better understanding of karst system of Bükk Mountain. I have made several comparable investigations. According to these, the geological formations can be ranked by hydraulic conductivity and storativity.

The periodicity investigations based on Fourier-transformation can help to separate local water systems. The autocorrelation investigation can serves information about memory effect of different part of mountain. This could be useful when the movement of a contamination is monitored. In karstic aquifer the water can flow quickly, the small fractures do not work during quick flow so the filtering effect of rocks is negligible.

By cross-correlation and phase function I determined the delay and flow velocity. These results can also be applied in hydrodynamic modeling.

The gain function and characteristic curve can also serves information about the water system of Bükk. I determined the duration of basic and quick flow by gain function. These periods could be converted into depth by aid of characteristic curves. In practice this is more useful and easier to understand. I appointed the boundary of well-karstified zone which means the possible lowest depth of cave forming. Below these depths can found the zone of slow flow.

Another important application of characteristic curves is the water level forecast. To forecast water resources we use forecasted water levels. In my investigations I proved, my characteristic curve can forecast the water level with uncertainty of 1%.

I also investigated how the precipitation of different registers can influence result of spectral analysis and what are the most sensitive parameters of analysis. In generally, I could say the low frequencies in gain functions where we can find significant differences. It can cause problems to establish the border between quick and intermedier flow. In practice we have to use data of that precipitation monitoring station which have the highest coherency in lower frequency domain.

This year is 25th anniversary of BKWMS. On this event there were several companies which are interested in working of monitoring system. The workers of Miviz Ltd., Waterworks of Heves County Co., Regional Waterworks of North Hungary Co., North-Hungarian Water Conservancy Directorate, Bükk National Park, Zsóry Medicinal and Open bath, PannErgy Co. can use the results of my dissertation during their daily work.

REFERENCES IN THE THESIS BOOKLET

- Andreo et al. (2015). *Andreo, B.; Carrasco, F.; Durán, J. J.; Jiménez, P.; LaMoreaux, J.: Hydrogeological and Environmental Investigations in Karst Systems.* Springer. pp. 1-638.
- Bakalowicz, M. (2005). Karst groundwater: A challenge for new resources. *Hydrogeology Journal. 13.*, pp. 148-160.
- Bonacci, O. (1987). *Karst hydrology.* Springer. New York, pp. 1-184.
- Böcker, T. (1975). A barlangi csepegés és a beszivárgás kapcsolata a Bükk-hegység keleti részén. *Karszt és Barlang, I-II. füzet, Budapest*, pp. 5-8.
- Chatfield, C. (2005). *The analysis of time series.* USA, New York: Chapman & Hall.
- Cheng-Haw et al. (2006). Cheng-Haw, L.; Wei-Ping, C.; Ru-Huang, L.: Estimation of groundwater recharge using water balance coupled with base-flow-record estimation and stable-base-flow analysis. *Environmental Geology 51.*, pp. 73-82.
- Csepregi, A. (1985). A karsztos beszivárgás számítási módszereinek összehasonlítása a vízszintváltozások elemzése alapján. *Hidrológiai Közlöny III. szám*, pp. 130-133.
- Darabos, E. (2010). Examining relationships is data recorded with the Bükk Karst Water Monitoring System. *Karst Development Volume 1., Issue 1., Szombathely* , pp. 6-12.
- Darabos et al. (2014). Darabos, E.; Miklós, R.; Tóth, M.; Lénárt, L.: Hydrogeological investigation of the Garadna catchment area. *Geoscience and engineering: A publication of the University of Miskolc 3*, pp. 119-127.
- Darabos et al. (2015). Darabos, E.; Lénárt, L.; Hernádi, B.: Forrásokban és kutakban mért vízszintcsökkenések jellegzetességeiből kinyerhető információk a bükki karszt példáján. In S. Bodzás, *Műszaki Tudomány az Észak-kelet Magyarországi Régióban,* Debrecen. pp. 169-174.

- Drogue, C. (1972). Statistical analysis of hydrographs of karstic springs. *Journal of Hydrology 15.*, pp. 49-68.
- Eisenlohr, L. (1997). Eisenlohr, L; Király, L.; Bouzelboudjen, M; Rossier, Y.: Numerical simulation as a tool for checking the interpretation of karst spring hydrographs. *Journal of Hydrology 193.*, pp. 306-315.
- Florea, L., & Vacher, H. L. (2006). Springflow hydrographs: Eogenetic vs. telogenetic karst. *Ground Water 44, no. 3.*, pp. 352-361.
- Ford, D., & Williams, P. (2007). *Karst Hydrogeology and Geomorphology,* England. Wiley.pp.103-144.
- Goldschieder, N., & Drew, D. (2007). *Methods In Karst Hydrogeology.* London, UK. Taylor & Francis.
- Gondárné et al. (2008). Gondárné, K.; Székvölgyi, K.; Gondár, K.; Gyulai, T.; Könczöl, N.; Kun, É.: Egy új módszer az utánpótlódó felszín alatti vízkészlet számítására hegyvidéki víztestek területén. *Magyar Hidrológiai Társaság, XXVI. Országos vándorgyűlés, 4. szekció*) Budapest. pp. 667-681.
- Gunn, J. (1986). Modelling of conduit flow dominated karst aqifers. *Gunay G. & Johnson A. I. (szerk.) Karst Water resources. IAHS, Publications 161.* Wallington. pp. 587-596.
- Hartmann et al. (2014). Hartmann, A; Goldschieder, N; Wagener, T; Lange, J; Weiler, M: Karst water resources in a changing world: Review of hydrological modeling approaches. *Reviews of Geophysics Vol. 52 (3)*, pp. 218-242.
- Hernádi et al. (2012.). Hernádi, B.; Lénárt, L.; Horányiné Csiszár, G.; Tóth, K.: A bükki nyílt karszt vertikális karsztosodottsága. *Karsztfejlődés XVII.* Szombathely: Nyugat-magyarországi Egyetem. pp. 63-78.
- Hinaman, K. (2005). *Hydrogeologic Framework and Estimates of Ground-Water Volumes in Tertiary and Upper Cretaceous Hydrogeologic Units in the Powder River Basin, Wyoming.* USA, Virginia: U.S. Geological Survey.pp. 6-11.
- Jenkins, G., & Watts, D. (1968). *Spectral analysis and its applications.* San Francisco: Holden Day.
- Jenkins, G. M., & Watts, D. G. (1969). *Spectral analysis and its applications.* USA: Holden-Day.
- Juhász, J. (1955). Felszínalatti vízkészletünk. *Hidrológiai Közlöny 35. évf. 1-2. szám, Budapest* , pp. 21-34.
- Juhász, J. (1973). A kitermelhető sztatikus vízkészlet. *Hidrológiai Közlöny 53. évf. 4. szám, Budapest*, pp. 187-195.
- Juhász, J. (1987). *Hidrogeológia.* Budapest: Akadémiai Kiadó, pp. 1-917.
- Jukic, D., & Denic-Jukic, V. (2015). Investigating relationships between rainfall and karst-spring discharge by higher-order partial correlation functions. *Journal of Hydrology, Vol. 530*, pp. 24-36.
- Kessler, H. (1954). A karsztból tartósan kitermelhető vízmennyiség és a beszivárgási százalék megállapítása. *Hidrológiai Közlöny 34. évf. 5-6. szám, Budapest*, pp. 213-222.
- Kessler, H. (1954). A beszivárgási százalék és a tartósan kitermelhető vízmennyiség megállapítása karsztvidéken. *Vízügyi közlemények, 2. szám, Budapest* , pp. 117-123.
- Kinzelbach, W. (1986). *Groundwater Modelling.* Amsterdam, N. Y.: Elsevier.
- Kovács et al. (2016). Kovács, A.; Darabos, E.; Perrochet, P.; Miklós, R.; Lénárt, L.: Forrás és kút hidrogram elemzések eredményei a Bükk hegységben. *Debreceni Akadémiai Bizottság Műszaki Szakbizottsága*, Debrecen. pp. 261-268.
- Kresic, N., & Bonacci, O. (2010). Spring discharge hydrograph. In N. Kresic, & Z. (. Stevanovic, *Groundwater hydrology of springs. Engineering, theory, management and sustainability.* Amsterdam: Elsevier Inc. pp. 129-163.
- Kresic, N., & Stevanovic, Z. (2010). *Groundwater Hydrology of Springs.* USA: Elsevier.

- Larocque et al., (1998). Contribution of correlation and spectral analyses to the regional study of a large karst aquifer (Charente, France). *Journal of Hydrology 205* , pp. 217-231.
- László, A. (2013). Idősor elemzési modellek gyakorlati alkalmazása újszülött malac aEEG adatain (url: http://www2.szote.u-szeged.hu/dmi/downloads/nepszeru_tud/alap_aEEG_idosorelemzes_RefW_LA_2013-09-09.pdf, letöltés dátuma: 2017. 07. 18). Szeged.
- Lénárt, L. (2006). A Bükk-térség karsztvízpotenciálja – A hosszú távú hasznosíthatóságának környezetvédelmi feladatai. *Észak-magyarországi Stratégiai Füzetek, III. évfolyam 2. szám* , pp. 17-28.
- Lénárt L., Darabos E. (2012): The hydrogeological relations of the thermalkarst of Bükk mountains (Northern Hungary). In: Schweizerische Gesellschaft für Höhlenforschung . Kommission für Wissenschaftliche Speläologie Proceedings of the 13th National Congress of Speleology. pp. 209-214.
- Less, G. (2005). In: Pelikán, P.: A Bükk hegység földtana. Magyar Állami Földtani Intézet, Budapest.
- Liedl et al. (2003). Liedl, R; Sauter, M; Hückenhaus, D; Clemens, T; Teutsch, G: Simulation of the development of karst aquifers using a coupled continuum pipe flow model. *Water Resour. Res., 39(3), p 1057.*
- Maillet, E. (1905). Essais d'hydraulique souterrain et fluviale. *Librairie, A. Hermann,* p 218.
- Mangin, A. (1975). Contribution à l'étude hydrodynamique des aquifères karstiques. *Thèse Univ. Dijon. Annales de spéléologie, 29/3: 283-332, 29/4: 495-601, 30/1.* pp. 21-124.
- Mangin, A., & Pulido-Bosch, A. (1983). Aplicación de los análisis de correlación y espectral en el estudio de los acuíferoskársticos. *Tecniterrae, 51,* p 55.
- Mangin, A. (1984). Pour une meilleure conaissance des systémes hydrologiques á partir des analyses corrélatoire et spectrale. *Journal of Hidrology 67.* pp. 25-43.
- Maucha, L. (1987). Jósvafő környéki karsztforrások kiürülési folyamatainak vizsgálata. In G. Péczeli, *Karsztvízháztartás.* Budapest. pp. 174-177.
- Mező, G. (1995). Távlati vízbázisok biztonságba helyezésének programja, A bükki karszt-rendszer földtanivízföldtani és szimulációs modellje. *BKMI Kutatási jelentés, kézirat,* Miskolc.pp. 1–32.
- Mijatovic, B. (1968). A method of studying the hydrodynamic regime of karst aquifers by analysis of the discharge curve and level fluctuations during recession. *Bull. of Inst. For Geol. and Geophys. Res. Serbia,* pp. 43-81.
- Milanovic, P. (1967). Water regime in deep karst: case study of Ombla spring drainage area. *V. Yevjevich (szerk.) Karst Hydrology and Watre resources, vol. 1 Karst Hydrology, Water resources Publications,* Colorado.pp. 165-191.
- Padilla, A., Pulido-Bosch, A., & Mangin, A. (1994). Relative importance of baseflow and quickflow from hydrographs of karst spring. *Ground Water, 32* , pp. 267-277.
- Padilla, A., & Pulido-Bosch, A. (1995). Study of hydrographs of karstic aquifers by means of correlation and cross-spectral analysis. *Journal of Hydrology*, pp. 73-89.
- Panagopoulos, G., & Lambrakis, N. (2006). The contribution of time series analysis to the study of the hydrodynamic characteristics of the karst systems: Application on two typical karst aquifers of Greece (Trifilia, Almyros Crete). *Journal of Hydrology*, pp. 368-376.
- Pintér, J. (2007). A spektrálanalízisről. *Statisztikai Szemle 85. évfolyam*, 2/130.
- Plummer et al. (2007). *Imes, J. L; Plummer, N. L; Kleeschulte, J. M; Schumacher, J. G: Recharge Area, Base-Flow and Quick-Flow Discharge Rates and Ages, and Genera lWater Quality of Big Spring in Carter County, Missouri, 2000–04.* USA, Virginia: U.S. Geological Survey.
- Pulido-Bosch et al. (1995). Pulido-Bosch, A; Padilla, A; Dimitrov, D; Machkova, M:. *Hydrological Sciences*, pp. 517-532.

- Reimann et al. (2011). Reimann, T; Rehrl, C; Shoemaker, W.B; Geyer, T; Birk, S: The significance of turbulent flow representation in single-continuum models. *Water Resour. Res. 47(9).*
- Sásdi, L. (2005). In: Pelikán, P.: A Bükk hegység földtana. Magyar Állami Földtani Intézet, Budapest.
- Schoeller, H. (1965). Qualitative evaluation of groundwater resources. *Methods and techniques of ground-water investigations and development,* UNESCO.pp. 54-83.
- Tallaksen, L. (1995). A review of baseflow recession analysis . *Journal of Hydrology 165.* pp. 349-370.
- Turai, E. (2005). Spektrális adat- és információ feldolgozás. Egyetemi jegyzet. Miskolci Egyetem, Miskolc.
- Wei, W. W. (2006). *Time series analysis. Univariate and multivariate methods.* USA, Philadelphia: Pearson.

IV. LIST OF PUBLICATIONS RELATED TO THE TOPIC OF THE RESEARCH AREA

1. Miklós Rita , Tóth Márton , SzegedinéDarabosEnikő , Lénárt László
   Vízkémiaiadatokfelhasználásakarsztvízdomborzatitérképpontosítására
   In: BodzásSándor (szerk.)
   MŰSZAKI TUDOMÁNY AZ ÉSZAK-KELET MAGYARORSZÁGI RÉGIÓBAN 2015 . 591 p.
   Konferenciahelye, ideje: Debrecen ,Magyarország , 2015.06.11
   Debrecen: DebreceniAkadémiaiBizottságMűszakiSzakbizottsága, 2015. pp. 71-76.
   (ISBN:978-963-7064-32-6)
   Link(ek): Teljesdokumentum
   Befoglalómű link(ek): Egyéb URL
   Könyvrészlet /Konferenciaközlemény /Tudományos

2. SzegedinéDarabosEnikő , Lénárt László , HernádiBéla
   Forrásokbanéskutakbanmértvízszintcsökkenésekjellegzetességeibőlkinyerhetőinformációk a bükkikarsztpéldáján: Featueres of recession curves of wells
   In: BodzásSándor (szerk.)
   MŰSZAKI TUDOMÁNY AZ ÉSZAK-KELET MAGYARORSZÁGI RÉGIÓBAN 2015 . 591 p.
   Konferenciahelye, ideje: Debrecen ,Magyarország , 2015.06.11
   Debrecen: DebreceniAkadémiaiBizottságMűszakiSzakbizottsága, 2015. pp. 169-174.
   (ISBN:978-963-7064-32-6)
   Link(ek): Teljesdokumentum
   Befoglalómű link(ek): Egyéb URL
   Könyvrészlet /Konferenciaközlemény /Tudományos

3. SzegedinéDarabosEnikő , Lénárt László , Tóth Márton , Miklós Rita , HernádiBéla , CzesznakLászló
   A Bükk karsztvizei: Hosszúadatsorokalkalmazásilehetőségei
   MÉRNÖK ÚJSÁG 22:(7-8) pp. 17-19. (2015)
   Link(ek): Teljesdokumentum
   Folyóiratcikk /Szakcikk /Ismeretterjesztő

4. SzegedinéDarabosEnikő , Lénárt László , Tóth Katalin , HernádiBéla , Kovács Péter
   A BükkiKarsztvízszintÉszlelőRendszerkeretébengyűjtötthidrometeorológiaiadatokelemzése
   In: VeressMárton ,ZentaiZoltán (szerk.)
   Karsztfejlődés XIX. . Konferenciahelye, ideje: Bük ,Magyarország , 2014.05.30 -2014.06.01. Szombathely: Nyugat-magyarországi Egyetem (NYME), pp. 137-146.
   Link(ek): Teljesdokumentum
   Egyébkonferenciaközlemény /Konferenciaközlemény /Tudományos

5. SzegedinéDarabosEnikő , Tóth Márton , CzesznakLászló , Lénárt László , HernádiBéla
   Újtípusúvízkészletmeghatározás a Bükkben
   In: VeressMárton ,ZentaiZoltán (szerk.)
   Karsztfejlődés XIX. . Konferenciahelye, ideje: Bük ,Magyarország , 2014.05.30 -2014.06.01. Szombathely: Nyugat-magyarországi Egyetem (NYME), pp. 125-136.
   Link(ek): Teljesdokumentum
   Egyébkonferenciaközlemény /Konferenciaközlemény /Tudományos

6. SzegedinéDarabosEnikő , Tóth Márton , Lénárt László , CzesznakLászló , HernádiBéla , Tóth Katalin
Vízszintekenalapulókarsztvízkészletmeghatározásimódszerelsőeredményei a Bükkben
ELEKTRONIKUS MŰSZAKI FÜZETEK pp. 343-350. (2014)
Link(ek): Teljesdokumentum
Folyóiratcikk /Szakcikk /Tudományos

7. SzegedinéDarabosEnikő , Lénárt László , CzesznakLászló , HernádiBéla , Tóth Katalin
Jelleggörbékelőállítása a Bükkiés Bükk-térségivízszintadatokból
ELEKTRONIKUS MŰSZAKI FÜZETEK pp. 319-327. (2014)
Link(ek): Teljesdokumentum
Folyóiratcikk /Szakcikk /Tudományos

8. SzegedinéDarabosEnikő , Tóth Márton , Lénárt László
Karsztvízkészlet-meghatározásmódszertanifejlesztése a Bükk példáján
In: WanekF , Prokop Z (szerk.)
XVI. Bányászati, KohászatiésFöldtaniKonferencia: 16th Mining, Metallurgy and Geology Conference .Konferenciahelye, ideje: Székelyudvarhely ,Románia , 2014.04.03 -2014.04.06. Kolozsvár: Erdélyi Magyar MűszakiTudományosTársaság (EMT), pp. 248-252.
Link(ek): Teljesdokumentum
Egyébkonferenciaközlemény /Konferenciaközlemény /Tudományos

9. Lénárt László , Kovács Péter , CzesznakLászló , HernádiBéla , SűrűPéter , SzegedinéDarabosEnikő
A BükkiKarsztvízszintÉszlelőRendszer (BKÉR) létrejötte (1992), céljai, a mérőrendszerüzemeltetése, a kutatásfőbberedményei 2013-ig
MŰSZAKI FÖLDTUDOMÁNYI KÖZLEMÉNYEK 84:(1) pp. 133-140. (2013)
Folyóiratcikk /Szakcikk /Tudományos

10. SzegedinéDarabosEnikő , Lénárt László
Karsztvízszintelőrejelzés a Bükk hegységben
In: SzlávikLajos , Kling Zoltán , Szigeti Edit (szerk.)
XXXI. OrszágosVándorgyűlés : Magyar HidrológiaiTársaság . Konferenciahelye, ideje: Gödöllő ,Magyarország , 2013.07.03 -2013.07.05. Budapest: Magyar HidrológiaiTársaság (MHT), 2013. pp. 1-12.
(ISBN:963-8172-31-0)
Befoglalómű link(ek): Teljesdokumentum
Könyvrészlet /Konferenciaközlemény /Tudományos

11. Darabos E , Szucs P , Németh Á
Application of the ACE Algorithm on Hydrogeological Monitoring Data from the Bükk Mountains.
ACTA GEODAETICA ET GEOPHYSICA HUNGARICA 47:(2) pp. 256-270. (2012)
Link(ek): DOI, WoS, Scopus
Folyóiratcikk /Szakcikk /Tudományos
Függőidéző: 1 Összesen: 1
1 * *Kovacs Attila, Perrochet Pierre, DarabosEniko, Lenart Laszlo, Szucs Peter*
Well hydrograph analysis for the characterisation of flow dynamics and conduit network geometry in a karst aquifer, Bukk Mountains, Hungary
JOURNAL OF HYDROLOGY (ISSN: 0022-1694) 530: *pp. 484-499. (2015)*
Link(ek): DOI, WoS
Folyóiratcikk /Szakcikk /Tudományos

12. DarabosEnikő
Analysis of precipitation groups and related water level peak times in Bükk Mountains
GEOSCIENCES AND ENGINEERING: A PUBLICATION OF THE UNIVERSITY OF MISKOLC 1:(1) pp. 103-112. (2012)
Folyóiratcikk /Szakcikk /Tudományos

13. DarabosEnikő , Lénárt László
Pontosításilehetőségek a miskolcihidegkarsztvízszintés a kitermelhetőkészleteknagyságánakelőrejelzéséhez a termálkarsztvizekvédelménekfigyelembevételével
In: SzékelyGabriella ,MáthéIstván (szerk.)
A Kárpát-medenceasványyvizei IX. NemzetköziTudományosKonferencia . 176 p.
Konferenciahelye, ideje: BaileHerculane ,Románia , 2012.08.30 -2012.09.02. BaileHerculane: HargitaKiadóhivatal, 2012. pp. 43-52.
(ISBN:978-973-7625-37-3)
Befoglalómű link(ek): Egyébkatalógus
Könyvrészlet /Konferenciaközlemény /Tudományos

14. DarabosEnikő , Lénárt László
Vertikálisvízmozgásokvizsgálata a BükkiKarsztvízszintÉszlelőRendszeradataialapján (Különöstekintettel a vízszintcsökkenésekre)
KARSZTFEJLŐDÉS XVII: pp. 47-61. (2012)
Folyóiratcikk /Szakcikk /Tudományos

15. Lénárt L , SzegedinéDarabos E
The hydrogeological relations of the thermal karst of Bükk mountains (Northern Hungary)

In: SchweizerischeGesellschaftfürHöhlenforschung. KommissionfürWissenschaftlicheSpeläologie
Proceedings of the 13th National Congress of Speleology .Konferenciahelye, ideje: Muotathal ,Svájc , 2012.09.01 -2012.11.01. Muotathal: Bibliothèque de la société suisse de spéléologie, 2012. pp. 209-214.
(ISBN:978-2-88374-021-1)
Befoglalómű link(ek): WorldCat
Könyvrészlet /Konferenciaközlemény /Tudományos

16. Lénárt László , DarabosEnikő
A bükkikarsztvízkészletekmeghatározásiproblémái
ELEKTRONIKUS MŰSZAKI FÜZETEK pp. 231-240. (2012)
Folyóiratcikk /Szakcikk /Tudományos

17. Lénárt László , DarabosEnikő
Karsztvízszintelőrejelzés a BükkiKarsztvízszintÉszlelőRendszer (BKÉR) adataialapján
DEBRECENI MŰSZAKI KÖZLEMÉNYEK 2: pp. 27-34. (2012)
Folyóiratcikk /Szakcikk /Tudományos

18. Lénárt László , SzegedinéDarabosEnikő
IMPACT OF PRECIPITATION DISTRIBUTION CHANGE ON KARST WATER REGIME IN THE REGION OF MISKOLC: VPLYV ZMENY ROZDELENIA ZRÁŽOK NA VODNÝ REŽIM KRASOVEJ OBLASTI V REGIÓNE MISKOLC
In: 11. Zdravotno-TechnickeStavbyMaléVodnéDiela – Krajina a Voda, VysokéTatry .Konferenciahelye, ideje: StaráLesna ,Szlovákia , 2012.11.19 -2012.11.21. pp. 179-188.
Egyébkonferenciaközlemény /Konferenciaközlemény /Tudományos

19. Darabos E , Szűcs P
A miskolciegyetemikútparamétereinekelemzése modern geomatematikaimódszerekkel.
KARSZTFEJLŐDÉS XVI: pp. 247-260. (2011)
Link(ek): Teljesdokumentum
Folyóiratcikk /Szakcikk /Tudományos

20 DarabosEnikő
Examining relationships is data recorded with the Bükk Karst Water Monitoring System
KARST DEVELOPMENT 1:(1) pp. 6-12. (2010)
Folyóiratcikk /Szakcikk /Tudományos

21. DarabosEnikő
A BükkiKarsztvízszintÉszlelőRendszeráltalszolgáltatottadatokkapcsolatainakvizsgálata
HIDROLÓGIAI TÁJÉKOZTATÓ 2010: pp. 26-27. (2010)
Folyóiratcikk /Szakcikk /Tudományos

22. DarabosEnikő
BükkiKarsztvízszintÉszlelőRendszer (BKÉR) általszolgáltatottadatokkapcsolatainakvizsgálata
In: KrizsánJózsef (szerk.)
XV. NemzetköziKörnyezetvédelmiésVidékfejlesztésiDiákkonferencia .Konferenciahelye, ideje: Mezőtúr ,Magyarország , 2009.07.01 -2009.07.03. Mezőtúr: SzolnokiFőiskolaMűszakiésMezőgazdaságiFakultás, 2009. p. 9.
(ISBN:978-963-06-3726-8, CD 978 963 87874 3 9)
Könyvrészlet /Konferenciaközlemény /Tudományos

23. DarabosEnikő , Lénárt László , NémethÁgnes
A BükkiKarsztvízszintÉszlelőRendszermatematikaiösszefüggéseinekvizsgálata
In: MócsyI ,Szacsvai K , Urák I , Zsigmond A (szerk.)
V. Kárpát-medenceiKörnyezettudományiKonferencia .Konferenciahelye, ideje: Kolozsvár ,Románia , 2009.03.26 -2009.03.29. Kolozsvár: ÁbelKiadó, pp. 387-393.
Befoglalómű link(ek): OSZK
Egyébkonferenciaközlemény /Konferenciaközlemény /Tudományos