CHANGES OF GROUNDWATER LEVEL IN THE GREAT HUNGARIAN PLAIN

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EMBERI ERŐFORRÁSOK MINISZTÉRIUMA

EMBERI ERŐFORRÁS TÁMOGATÁSKEZELŐ

Nemzeti Tehetség Program

INTRODUCTION

- On Earth approximately 400 000 km^3 volume of water is being transported annually in the water cycle.
- Which is affected by the changing climate and the meteorological extremities present in recent years.
- These changes in the behaviour of precipitation have an impact on the groundwater resources through the recharge, so we chose to investigate the precipitation and GW level together
- In Hungary most of the drinking-water is produced from GW resources (96%)

INTRODUCTION

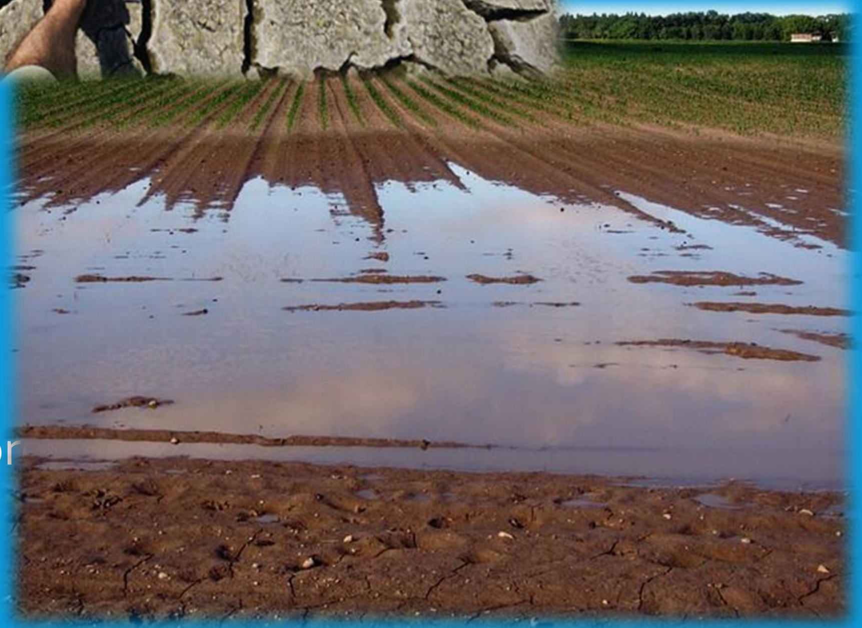
- Growing number of extreme weather conditions

- Connected to the hydrological cycle

- Huge amount of rainfall in a short time period
  - Meaning longer periods without any measurable rain
  - Fast floods increasing runoff only

- In Hungary these can cause several problems even in agricultural regions, such as the Great Plain

INTRODUCTION

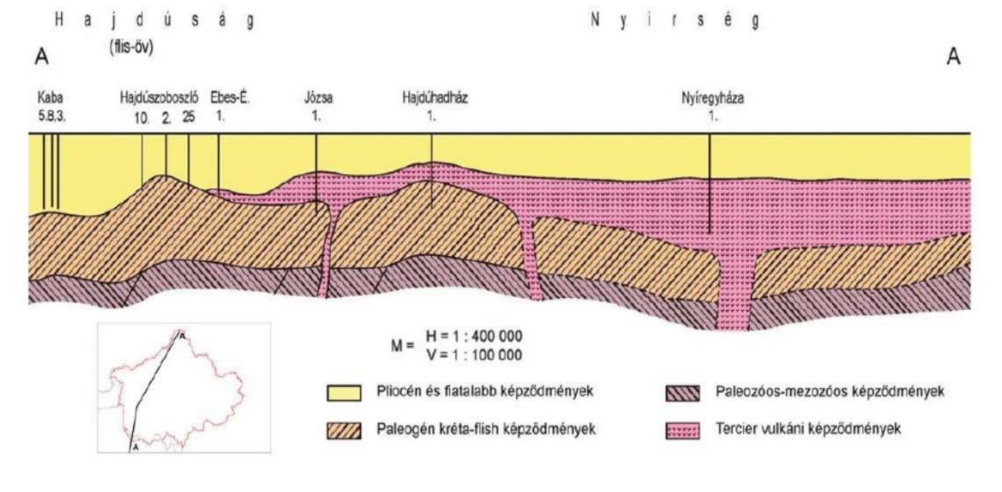


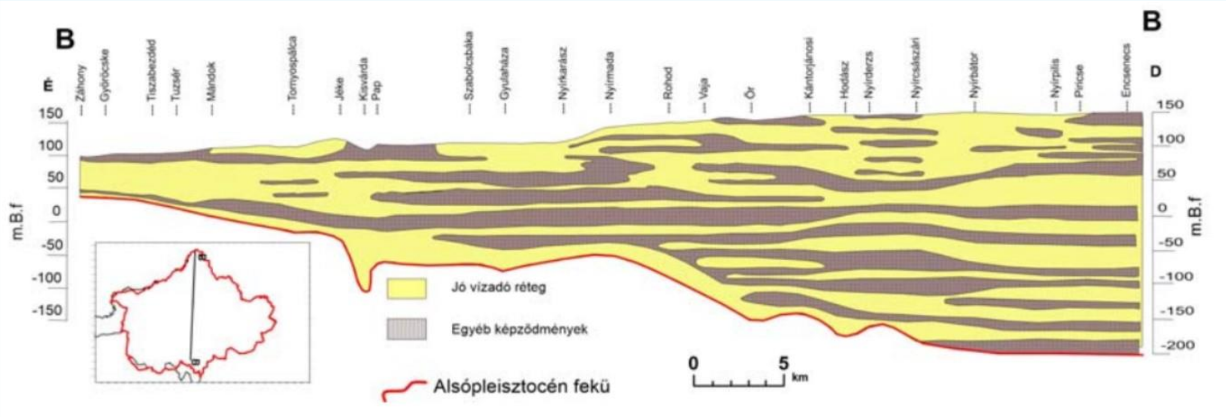
- In Hungary inland water and drought can be at the same place
- These extremities affect the agriculture, food industry and energy usage through irrigation
- Several mathematical methods to investigate these changes and connections
- Conceptual changes in groundwater management
  - Not to let the water surpluss go (floods) through fast, but to stor the large amount of water

WHERE ARE WE?


Észtország
Balti-tenger
Lettország
Egyesült Királyság
Írország
Dánia
Litvánia
Fehéroroszország
Lengyelország
Hollandia
Belgium
Németország
Luxemburg
Ukrajna
Csehország
Szlovákia
Moldova
Franciaország
Ausztria
Hungary
Svájc
Vizcayai-öböl
Szlovénia
Románia
Grúzia
Horvátország
Fekete-tenger
Monaco
Szerbia
Andorra
Portugália
Olaszország
Montenegró
Koszovó
Bulgária
Spanyolország
Macedónia (MVJK)
Törökország
Albania
Tirrén-tenger
Gibraltár
Görögország
Szíria
Irak
Térkép
Google
Ciprus
Libanon

NORTHERN HUNGARIAN GREAT PLAIN

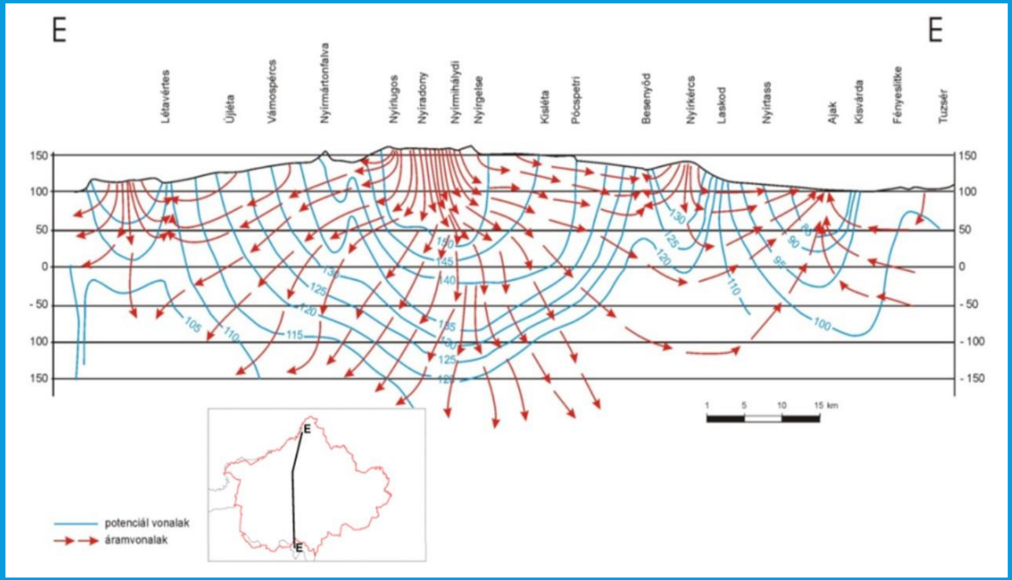




- The first near-surface aquifers of the Great Plain are built up by diverse quaternary formations formed in rivers and aeolian sediments.

- From the beginning of the Pleistocene (about 2.4 million years), the sinking basin areas were filled with alluvial rivers, and the foundations of today's water network were formed by the gradual contraction of the more or less contiguous Pannonian Inland.

NORTHERN HUNGARIAN GREAT PLAIN

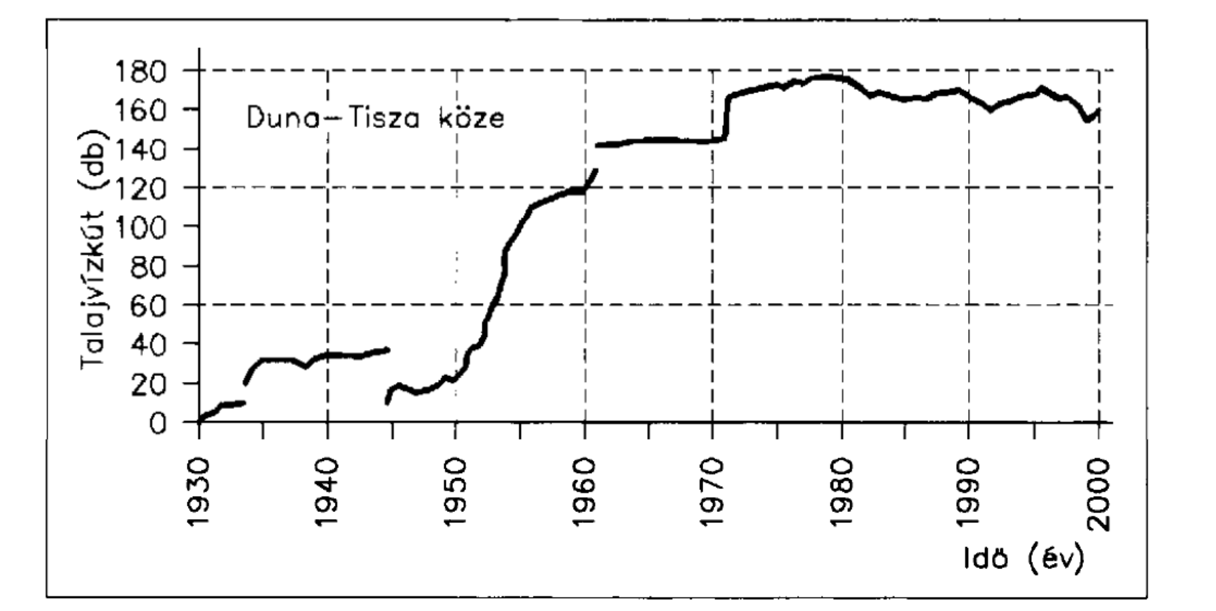


- In addition to the aeolian influences, the surface of the young plains was shaped by these freely migrating watercourses (rivers) until the completion of the flood control works. In general, mainly the alternation of sand-silt-clay layers, to a lesser extent gravel cords and (infusion) loess form the near-surface, which also forms the groundwater layers.

- The static water level is about 75-125 mBf above sea level, depending on the local topography and hydrogeological conditions.

MEASUREMENTS

- 1929, first complex network of 149 wells, in around 12 000 km2
- 1933, countywide network building,
  - in the D-T Interfluve: 25-40 wells in 1940, 140 in the 60's
  - In the Tiszántúl region 114 wells were established
- 1943: 363 observational well, in which 271 continuosly measured
- 1952-1971: 1020 wells in the country
- After that period: a stagnation of around 1500-1700 observational wells



SHALLOW GW IN THE HUNGARIAN GREAT PLAIN

- In the period between the beginning of the 1970s and the middle of the 1990s, there is a significant change in the groundwater flow in the area between the Danube and the Tisza, including the Hátság. In the Hátság area, on average, the groundwater level decreased by 250–300 cm, but in the north and south-west by 600–800 cm.
- The lowering of the groundwater level can be explained by the combined effect of several triggers, among which natural, social and economic factors can play a role.
- The exploration of the factors and background factors resulting in the decrease of the groundwater level has been addressed in several research workshops. Regarding the nature and magnitude of the background factors, the greatest agreement emerged around the following division in the early 1990s: meteorological factors: 50%, shallow GW extraction: 25%, deep GW extraction:6%, land use change (eg increase in forest area): 10%, water management: 7%, other (eg hydrocarbon extraction) 2%

SHALLOW GW IN THE PREVIOUS CENTURY

- Danube-Tisza Interfluve:
  - At the 60's, precipitation surplus, higher GW levels
  - More temporary lakes, construction of inland water canals
  - Between the 70's and 90's, more than 1000 mm precipitation deficit
    - Drying out of several lakes, inland water reservoirs
    - More GW wells for irrigation water
  - After the 90's, more precipitation, increase of GW levels (even in dm)
- Nyírség, Hortobágy, Hajdúság:
  - Precipitation surplus at the end of the 80's
  - After that deficit, decreasing GW levels
  - In the 90's: increasing levels

SHALLOW GW IN THE PREVIOUS CENTURY

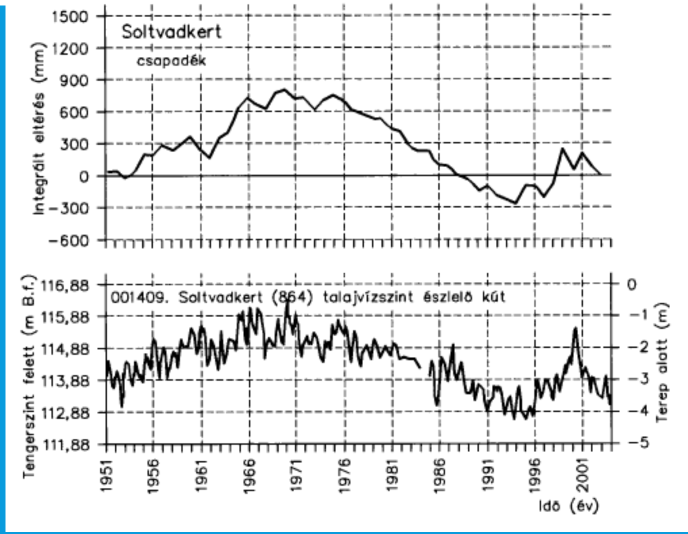
- Nagykunság, Sárrét:
  - Precipitation surplus in the 60's
  - Stagnation in the following decade
  - Since the 90's: precipitation deficit.

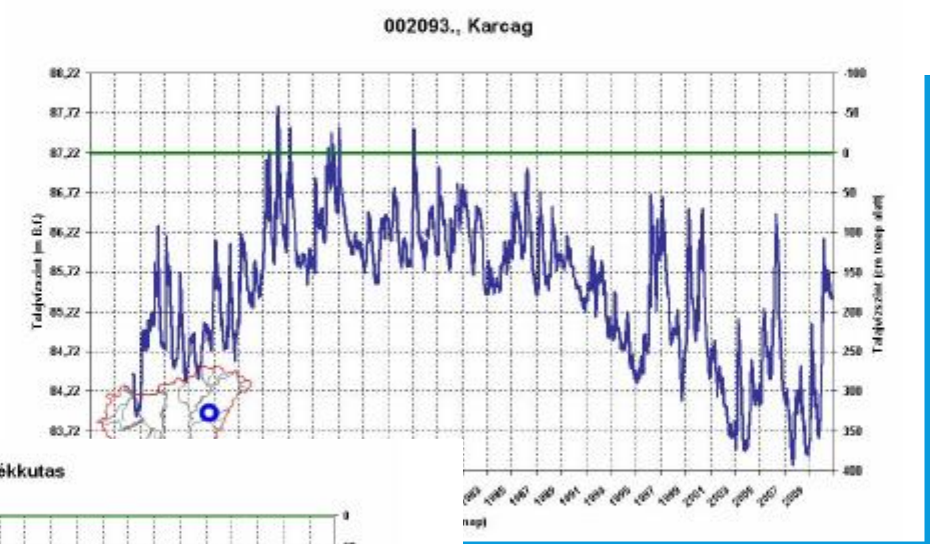
- In the 2000's:
  - In 2000: 140 mm deficit in the whole Country, 250-300 in the Southern Great-Plain
  - 2002: suplus and deficit in different areas, 2003 deficit (160 mm)
  - In case of GW:
    - Huge differencces only in regions whre GW level is colse to the surface
    - Below 3.5-4 m, stagnation was discovered

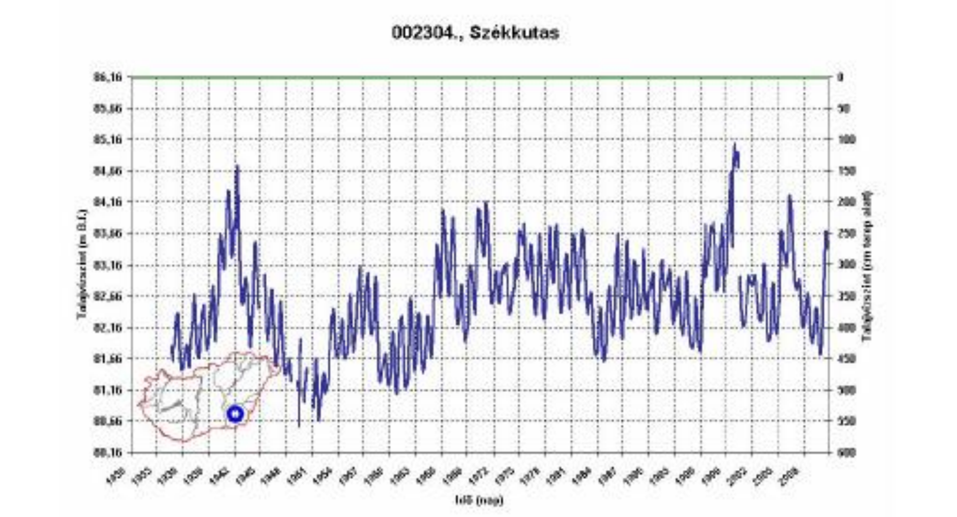
SHALLOW GW IN THE PREVIOUS CENTURY

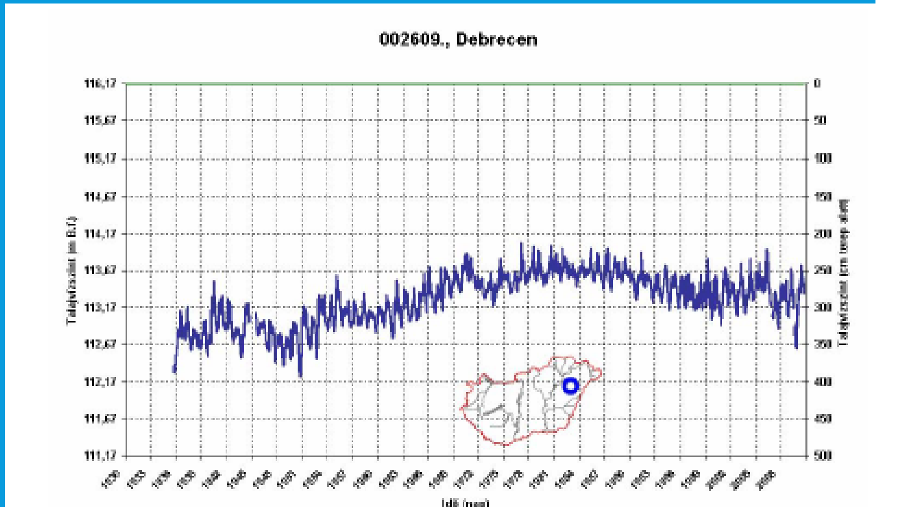
- In the 2000's
  - Danube-Tisza Interfluve:
    - The lowest ever recorded: 2000
  - Upper-Tisza Region:
    - Between 2000-2003: Decreasing levels
    - In 2003: Slow snowmelting caused increasing levels
  - Nagykunság, Körös-Maros
    - In 2000, huge decrease, 2001, some increasing, 2003: more stabilized increase

SHALLOW GW IN THE HUNGARIAN GREAT PLAIN









PREVIOUS STUDIES

- The study of periodic components began in Hungary in the 1950s, as data sets of sufficient length were available to perform the studies.
- The first cycle that researchers recognized was the 1-year period observed in the annual groundwater cycle (Ubell, 1953).
- (Rónai, 1956) (Rónai, 1961) found a uniform 14-17 year cycle, which he later extended to 14-16 and 28-30 years, using the moving average methodology.
- Periods of 12–14 and 25–26 years were determined by autocorrelation using 24 observation wells (Réthˇáti, 1977).
- Harmonic analysis (Kontur, 1985) were applied on Trans-Tisza water level time series, with the help of which he identified a period of about 12.5 years.

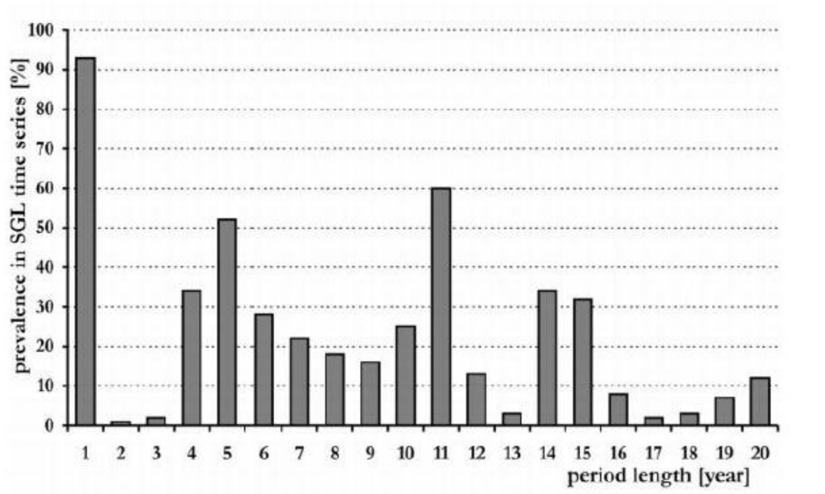
PREVIOUS STUDIES

- In the areas between the Danube and the Tisza, 140 data sets more than 30 years old were studied using the method of Lomb-Scargle periodogram and Wavelet analysis.
- Here, the 5-year cycle was detected in 87% of the studied wells, and the 12-year cycle was detected in 60% of the wells in the presence of the natural annual period (Kovács, et al., 2004).
- Several other local periods were also identified in the sample area, and it was shown that annuals, those around three years, and those around 5 years were not detectable in many periods.
- To study the fluctuations of shallow groundwater levels in the Trans-Tisza region (Kovács, et al., 2010) (Kovács, et al., 2011), the existence and dominance of 1, 11, and 5-year cycles was determined in 120 wells studied, along with several other locally detectable cyclic components.

PREVIOUS STUDIES

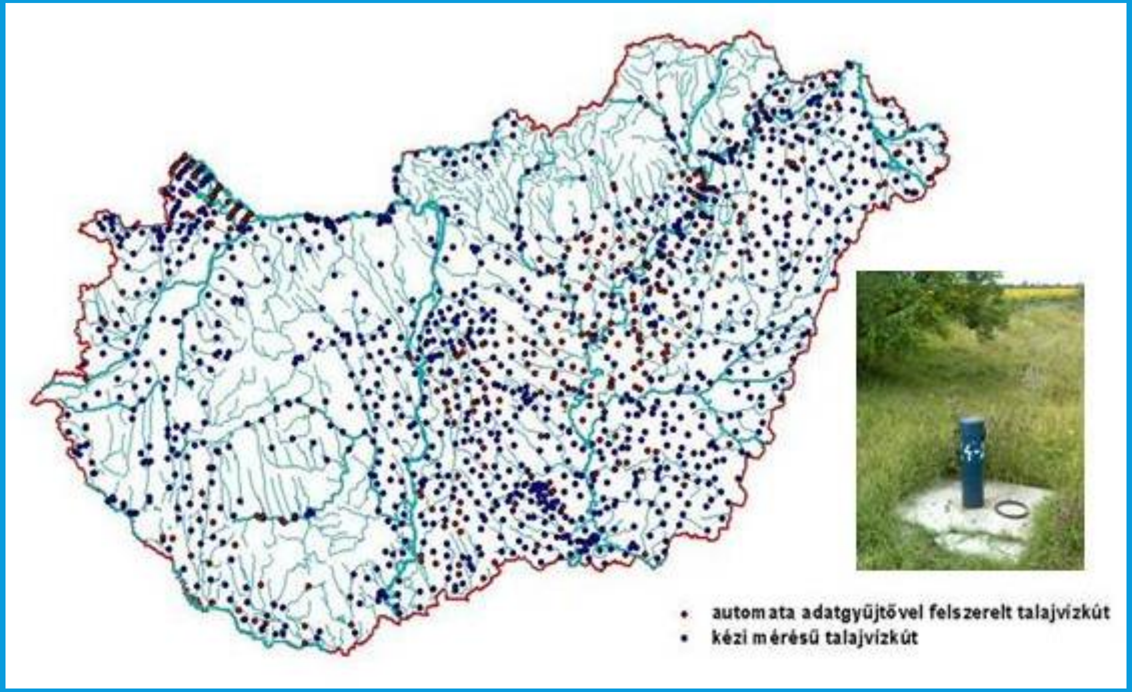
A Duna – Tisza köze néhány észlelőkútjának becsült periódusidői

kút	Periódus											
	1	2	3	4	5	7	8	10	11	12	15	>15
	év											
1137	1,00		2,72		5,07							
1141	1,00				5,23		8,05					
1145	1.00				5,64				11,00		14,45	
1148	1,00	1,92			5,56							
1356	1.00				4,89	6,71					13,84	19,02
1360	1,00						7,76					
1361	1,00			3,51	5.45	6,83						
1365	0,98			3,94	4,62						14,88	
1369	1,00				5,12			10,54			15,22	
1370	1,00		2,55		5.07		8.18	10,62				
1373	0.98				4.80			9,78			14,81	
1374	0.98							9,48		12,53		
1375	1.00				5,07			9,45			13,63	18,26



MATERIALS

- Hungarian Meteorological Service Online Database – official rainfall measurements
- Water Directorates – official shallow GW monitoring wells
- Spectral analysis
- Cross-correlation and cross-spectral analysis



METHODS – DFT

$$\cos(t) = \cos\left(\frac{2\pi}{2\pi}t\right) = \cos\left(\frac{2\pi}{T}t\right) = \cos\left(2\pi\frac{1}{T}t\right) = \cos\left(2\pi f t\right)$$

$$f = \left(\frac{1}{T}\right)$$

Where, f :frequency,
$T=2\pi$: period length

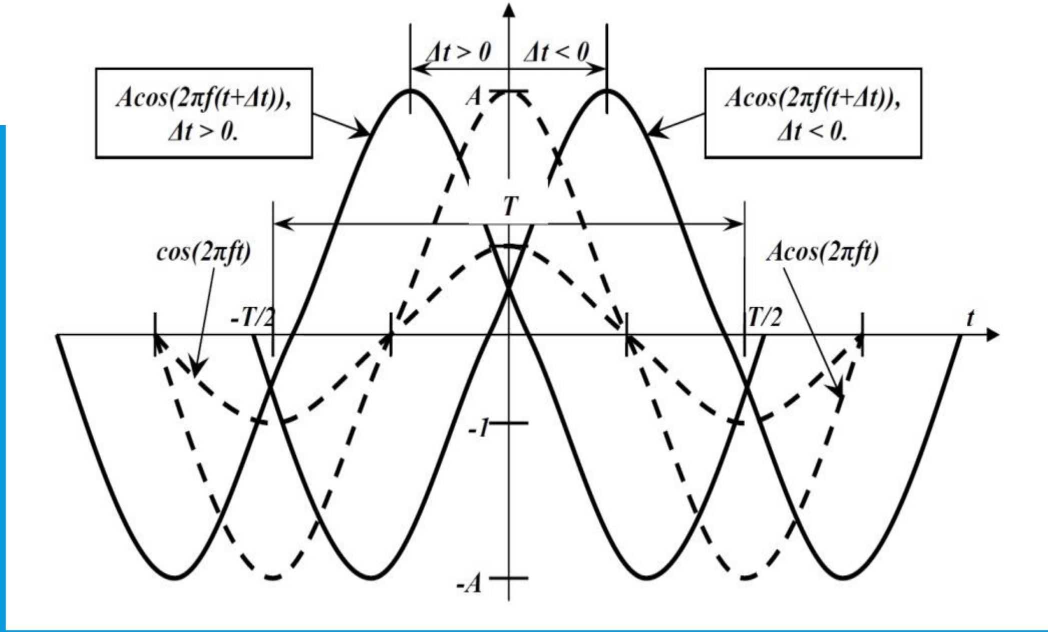
$$A * \cos\left(2\pi f t + \varphi\right)$$

Where, A :amplitude,
φ: phase angle

$$Re[F(f)] = \int_{-\infty}^{+\infty} f(t)\cos(2\pi f t)\,dt$$

$$Im[F(f)] = \int_{-\infty}^{+\infty} f(t)\sin(2\pi f t)\,dt$$

The real and imaginary spectrum gives the weights of the sin-cos components.



$$F(f) = A(f)e^{j\Phi(f)}$$

Fourier-spectrums based on the *cos(2πft)* and *sin(2πft)* functions.

Search for periodic components in *y(t)* precipitation functions.

METHODS – CROSS-CORRELATION & CROSS-SPECTRAL

Cross-correlation analysis:

- $r_{+k} = r_{xy}(k) = \frac{C_{xy}(k)}{\sqrt{C_x^2(0)C_y^2(0)}}$
- $r_{-k} = r_{yx}(k) = \frac{C_{yx}(k)}{\sqrt{C_x^2(0)C_y^2(0)}}$

where:

- $C_{xy}(k) = \frac{1}{n}\sum_{t=1}^{n-k}(x_t - \bar{x})(y_{t+k} - \bar{y})$
- $C_{yx}(k) = \frac{1}{n}\sum_{t=1}^{n-k}(y_t - \bar{y})(x_{t+k} - \bar{x})$
- $C_x(0) = \frac{1}{n}\sum_{t=1}^{n}(x_t - \bar{x})^2$
- $C_y(0) = \frac{1}{n}\sum_{t=1}^{n}(y_t - \bar{y})^2$

where $\bar{x}$ *and* $\bar{y}$ are the averages of the two dataset.

Cross-spectral analysis:

Because of the asymmetry of the spectral density function, the equation needs to be interpreted in the complex numbers as well:

- $\Gamma_{xy}(f) = |\alpha_{xy}(f)| exp[-i\Phi_{xy}(f)]$

where i is $\sqrt{-1}$,the $\alpha_{xy}(f)$, $\Phi_{xy}(f)$ the value of the cross-amplitude and phase functions:

- $\alpha_{xy}(f) = \sqrt{\Psi_{xy}^2(f) + \Lambda_{xy}^2(f)}$
- $\phi_{xy}(f) = arctan\frac{\Lambda_{xy}(f)}{\Psi_{xy}(f)}$

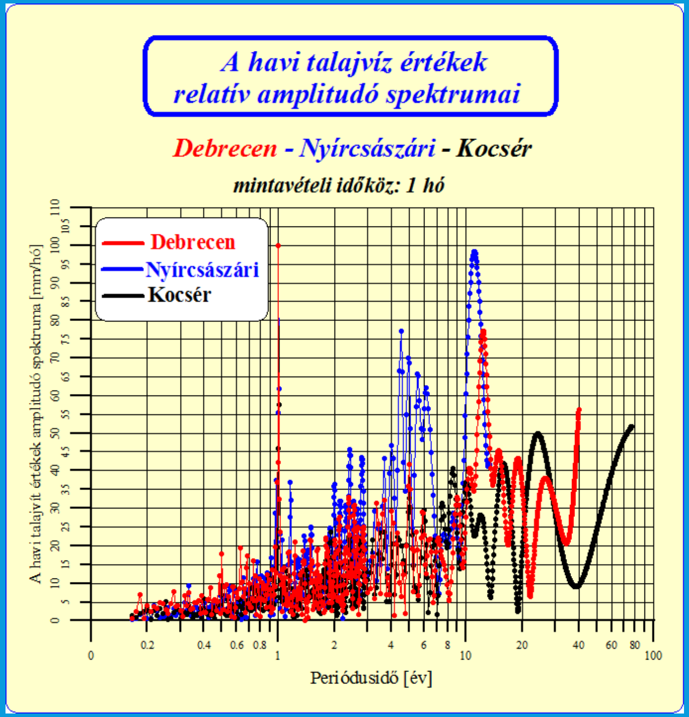
where the creoss-spectrum is, $\Psi_{xy}(f)$ and the squared spectrum is, $\Lambda_{xy}(f)$ the following:

- $\Psi_{xy}(f) = 2\{r_{xy}(0) + \sum_{k=1}^{m}[r_{xy}(k) + r_{yx}(k)]D_k\cos(2\pi fk)\}$
- $\Lambda_{xy}(f) = 2\{\sum_{k=1}^{m}[r_{xy}(k) - r_{yx}(k)]D_k\sin(2\pi fk)\}$

where D_k is a weight function, which Ψ_{xy}(f) and theΛ_{xy}(f) to eliminate bias in the coefficient.

SPECTRAL ANALYSIS – SHALLOW GW

No.	Debrecen (relative weight)	Nyírcsászári (relative weight)	Kocsér (relative weight)
1.	1 year (100%)	1 year (100%)	1 year (100%)
2.	12.3 year (77.3%)	11.1 year (98.3%)	24.2 year (49.9%)
3.	15 year (45.4%)	4.5 year (77.2%)	15.8 year (41.9%)
4.	18.9 year (43.2%)	4.9 year (70.1%)	8.5 year (40.6%)
5.	5 year (41.7%)	5.5 year (65.8%)	10.1 year (37.2%)
6.	10.5 year (40.7%)	6.2 year (62.1%)	5 year (32.6%)
7.	26.6 year (38.1%)	4 year (46.8%)	7.5 year (31.4%)
8.	9 year (32.9%)	2.4 year (45.5%)	6 year (29.5%)
9.	2.4 year (32.9%)	2.8 year (43.5%)	12 year (28.3%)
10.	3.7 year (32.2%)	3.7 year (43.2%)	1.9 year (23.7%)
11.	3.3 year (31.4%)	0.98 year (37.4%)	3.7 year (23.6%)

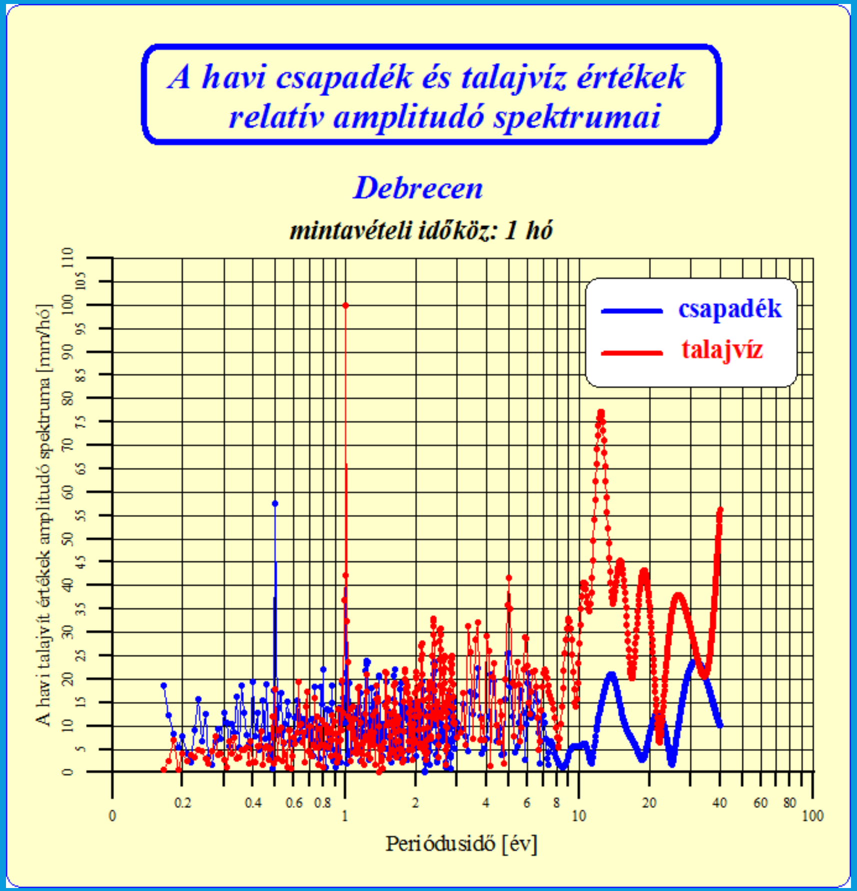


SPECTRAL ANALYSIS – SHALLOW GW

- The spectra of the monthly sampled shallow groundwater level time series were calculated.
- The interval of 110 years between 1901 and 2011 in two neighboring (Debrecen, Nyírcsászári) and a far (Kocsér) location.
- 1 year, 3.7 years, 5 years and 11-12 years can be detected in the time series of the groundwater level in all three location.
- In the case of Debrecen and Nyírcsászár which are close to each other, a cycle of 2,4 years is also appeared as a common cycle, but this cycle is no longer visible in Kocsér area.

SPECTRAL ANALYSIS - DEBRECEN

- From the precipitation and the change of ground water level data a 1 year, 2.4 years, 3.67 and 5 year cycles can be detected (shown with red color).
- The 12.3 year cycle in the groundwater spectrum can be detected in the precipitation timeline of 13.7 years, while the 26.6 year groundwater cycle is also higher at 31.5 years.



SPECTRAL ANALYSIS - DEBRECEN

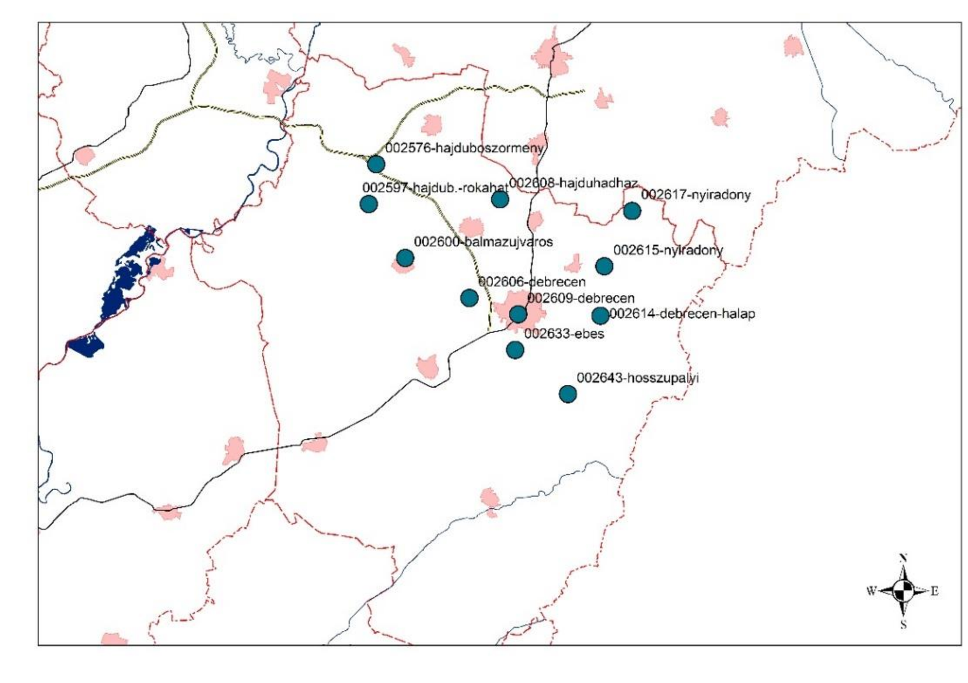
- Two long-term cycles can be detected in the time series of both parameters, but they do not occur exactly with the same period of time.
- The 12.3 year cycle in the groundwater spectrum can be detected in the precipitation timeline and a cycle of 13.7 years in the shallow GW,

- While the 26.6 year precipitation cycle in the groundwater levels is also higher at 31.5 years.

Debrecen No.	precipitation (relative weight)	shallow GW (relative weight)
1.	1 year (100%)	1 year (100%)
2.	0.5 year (57.6%)	12.3 year (77.3%)
3.	4.92 year (25.5%)	15 year (45.4%)
4.	1.23 year (24%)	18.9 year (43.2%)
5.	31.5 year (23.8%)	5 year (41.7%)
6.	2.39 year (23.6%)	10.5 year (40.7%)
7.	3.67 year (22.4%)	26.6 year (38.1%)
8.	1.62 year (22.2%)	9 year (32.9%)
9.	0.8 year (22.1%)	2.38 year (32.9%)
10.	6.08 year (21.4%)	3.67 year (32.2%)
11.	13.7 year (21.1%)	3.33 year (31.4%)

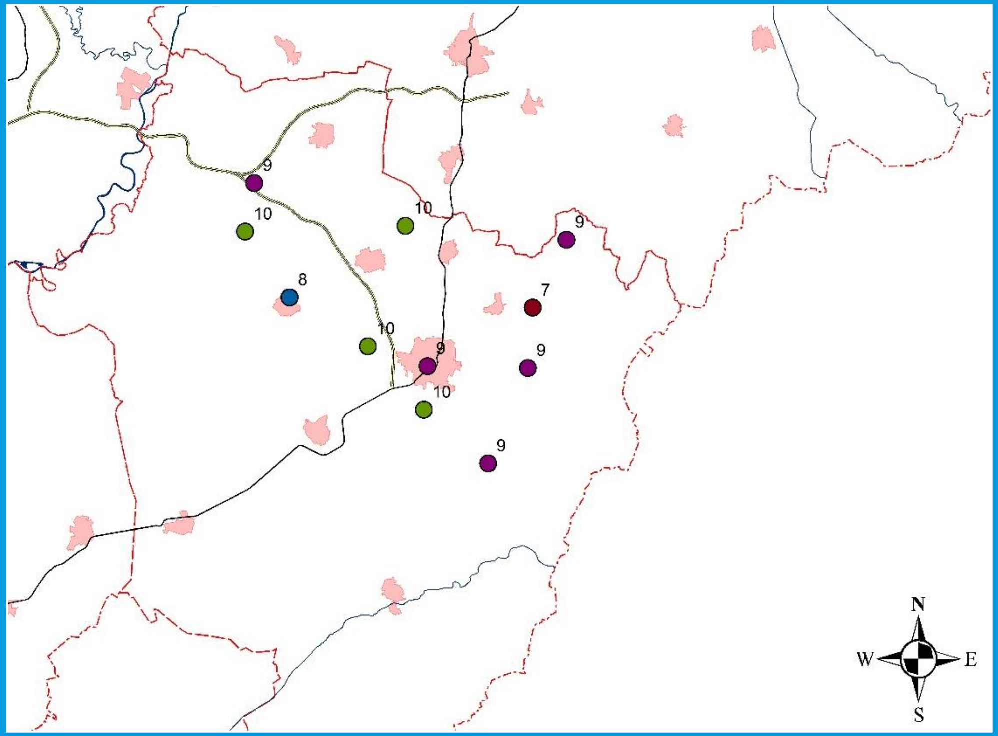
CROSS-CORRELATION - MONTHLY

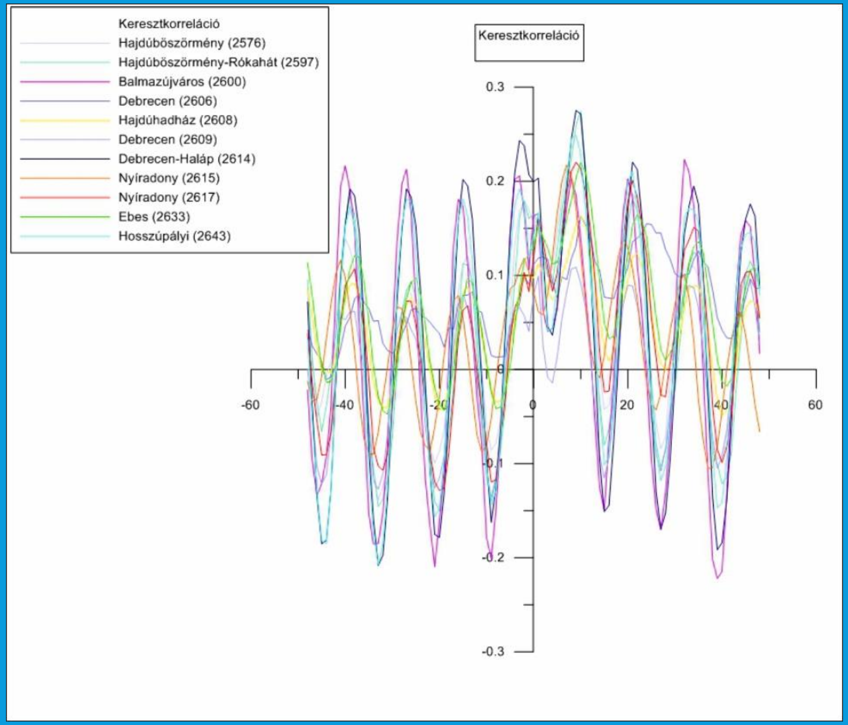
- The incorporated wells come from both the southern part of Nyírség and the northern area of Hajdúság, so areas with different geological structures can be examined, as well as the possible difference between the inflow and outflow areas.
- Area of Hajdúság near the city of Debrecen
  - 11 monitoring sites of shallow groundwater levels



CROSS-CORRELATION- MONTHLY

- Shallow GW:
  - Time lag of 7-10 month, mostly influenced by the depth of the well.

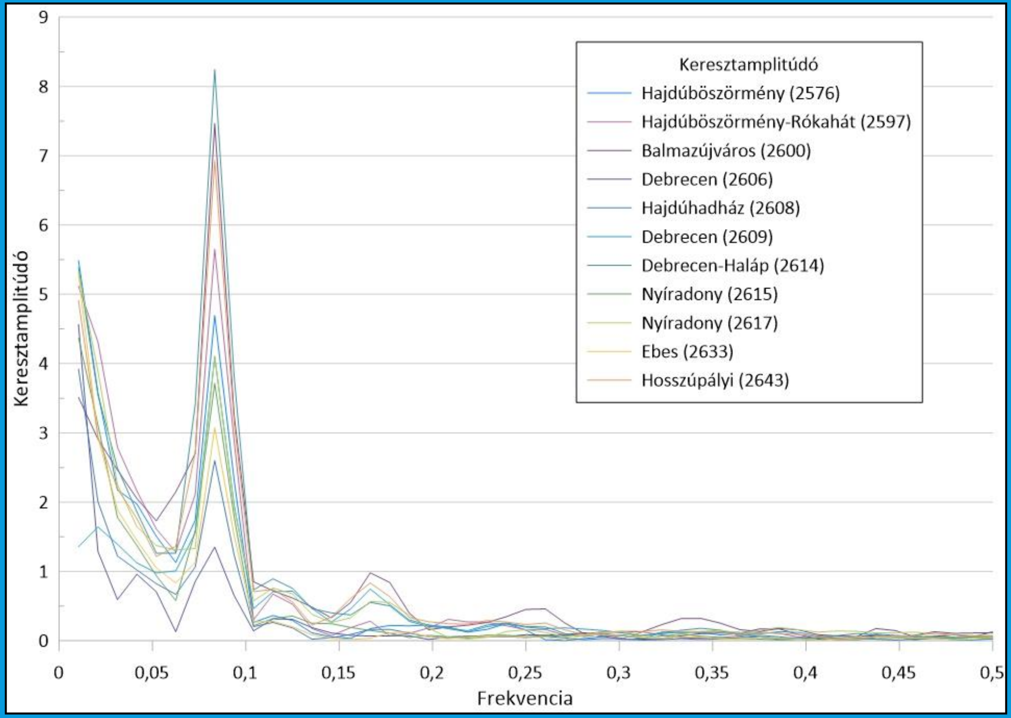




CROSS-SPECTRAL ANALYSIS - MONTHLY

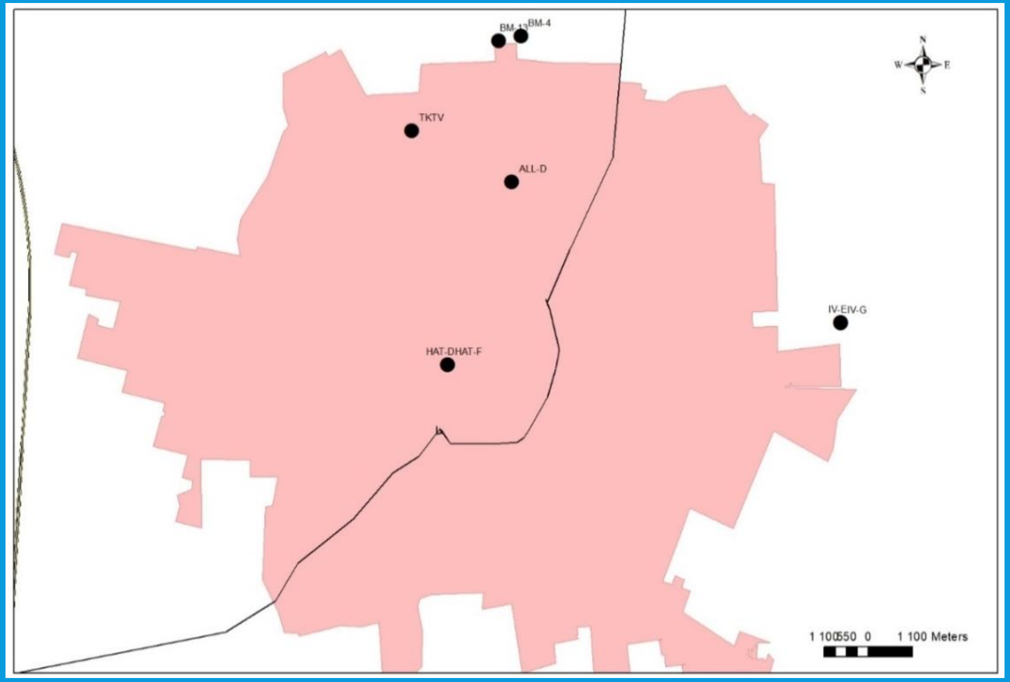
Kút No.	Periódusok (hónap)				
Hosszúpályi (2643)		12	8,72	6	4,3
Ebes (2633)		12	8,72	5,33	
Nyíradony (2617)		12	8,72	6	4
Nyíradony (2615)		12	8	5,05	
Debrecen-Haláp (2614)		12	8,72	6	
Debrecen (2609)	48	12	8	6	4,18
Hajdúhadház (2608)		12	8,72	5,64	
Debrecen (2606)	24	12	8,72		
Balmazújváros (2600		12		6	3,84
Hajdúböszörmény - Rókahát (2597)		12	8,72	6	4,8
Hajdúböszörmény (2576)		12	8,72	5,05	4,18

1 year long, 8-9 month, 5-6 month long cycles in every monitoring point
3-4 month long ones on 1/3 of the wells.
In Debrecen: 24 nd 48 month long ones



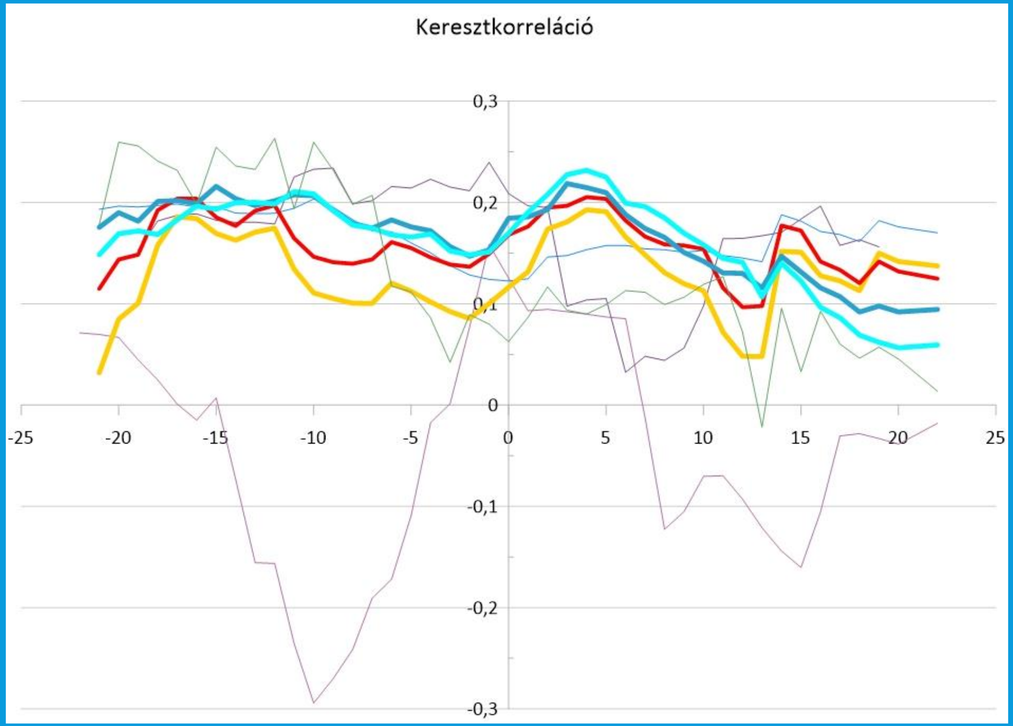
CROSS-CORRELATION - DAILY

- In order to perform the tests with daily data, the data sets of several groundwater monitoring wells from the area of Debrecen were compared.
- Wells ÁLL-D, HAT-D, HAT-F, IV-D, IV-E will be used from 25/04/2019 to 16/08/2019 and BM-4 from 02/05/2019 to 28/08/2019. BM-13 from 16.05.2016 to 13.08.2013. while TKTV also conducts research in two time intervals, from 22.12.2015 to 03.05.2016, and from 07.05.2019 to 28.08.2018.



CROSS-CORRELATION - DAILY

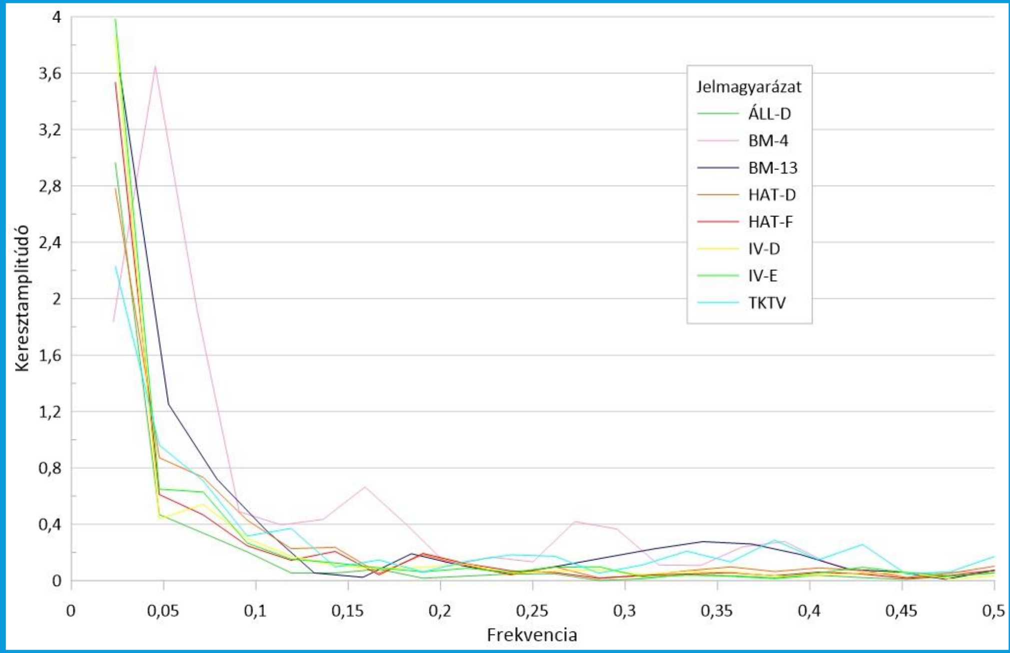
- In the case of the wells, where a clear maximum was detected in the examination of the connection, a difference of 3-4 days could be calculated.



CROSS-SPECTRAL ANALYSIS - DAILY

KÚT	Periódusok (nap)				
ALL-D	6			3,8	3
HAT-D	7	5,25		3,81	
HAT-F	7	5,25			2,8
BM-4	6,28		4,4	3,66	2,58
BM-13		5,42			2,92
IV-D	14		4,66	3,5	
IV-E	14		4,66	3,5	3
TKTV	8,4	6	4,2	3	
TKTV-15	11,5		4,18	3,06	2,42

Based on the period times, most of the wells also have a periodicity of around 5.2-4.6 days and something around 2.5-3.5 days. The 4.5-day cycle was also detected in two-thirds of the wells. For the measurement points in the pair, the similarity may be given by the proximity of the geography.



CONCLUSIONS

- Shallow GW levels:
  - 1 year, 3.7 years, 5 years and 11-12 years can be detected in all three GW location, so presumably there are regional deterministic reasons behind it.
- Debrecen rainfall and GW level:
  - 1-year, 2.5-year, 3.7-year and 5-year cycles appear in the time series of both parameters, therefore these cycles are caused by deterministic effecting both the periodic changes in the precipitation and ground water levels.
- Connection of monthly precipitaiton and GW:
  - 7-10 month long time lags in case of monthly sampling.
  - Main factors behind the differences are the geographycal position of the well.
- Connection of daily precipitation and GW:
  - HAT-D, HAT-F in Hatvan Street, and the results from the observational wells of waterworks IV. D, E, clear connection can be defined.

THANK YOU FOR YOUR ATTENTION!