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**INVESTIGATION OF INTERACTION BETWEEN RIVER AND SHALLOW GROUNDWA-
TER**

THESES OF PhD DISSERTATION

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Miskolc, 2017.

INTRODUCTION

Rivers can gain water from groundwater or can lose water to groundwater, and depend on the strength of connection they can determine the groundwater flow system. Due to changes in river stages the groundwater head is constantly changing in a dynamic way. The hydraulic impact of a river is complex, not only the narrow coastal zone is influenced. The river affects the groundwater flow velocity, the flow gradient and flow direction even over long distances. In Hungary the river beds partially penetrates the shallow aquifers [Rózsa 2000], fully penetration is rare [Léczfalvy 2004]. The hydraulic connection generally exists between the river and groundwater. In natural state hungarian rivers are gaining rivers in most of the year, but during wet periods they lose water to groundwater.

A detailed study of the hydraulic effects of rivers, the effect distances and the relation to groundwater based on field tests, data evaluation, and numerical modeling can help the protection of bank-filtered water resources, and other groundwater resources too. In Hungary the daily water demand of 40% of population is satisfied by bank-filtered water. Most of the bank-filtered water resources is located along the Danube [Léczfalvy 2004]. As 75 % of the potential water resources are bank-filtered water resources, they play a big role in the future water resource management. To know exactly the flow system is also necessary for the better understanding of mass transport processes in the contact zone of surface and groundwater. The most part of industrial sites are located near surface water bodies, where potential or existing pollution of groundwater can contact the surface water.

BACKGROUND OF THE RESEARCH

Most of the current research on the relationship between rivers and groundwater in Hungary is closely related to bank-filtered water resources. During these researches such problems were analyzed that the proportion of river water and groundwater in the produced water, the quality changes in the produced water, the suitability of perspective bank-filtered water resources for production, the depression and flow conditions. For answering the questions, riverbed drilling [Kontur 1988], seismic geophysical measurements, leakage tests [Rózsa 2000], pumping tests on pilot sites [Völgyesi 1992], tracer tests [Karman et al. 2013, Deák et al. 1992, Kármán-Deak, 2012] were carried out. In the subject also some small-scale studies were performed, which have mostly used statistical tools to explore the river-groundwater relationship [Csoma-Gálós 2009, Csoma et al. 2012, Fejes 2014, Molnar - Hajdu 2003]. In addition, hydrological studies dealt with the questions of groundwater [Bezdán M. 2011].

Overall, the studies are typically valid only for a limited time period. Rarely reflect changes in the system over time. Small areas are investigated, typically at the riverbank. It doesn't define different hydraulic impacts and distances of effects. There is no information on groundwater flow velocity changes in space and time. In the modeling practice permanent approach is accepted and used, which do not take into account the changes in groundwater flow system, or just grab specific states of the system (average, low, or high water level conditions).

THE GOALS OF MY RESEARCH

First objective of the research is to examine how the dynamic changes in the interaction of river and groundwater can influence the groundwater flow conditions. Defining the hydraulic

impacts of the river is usually limited to determine an approximate distance in which the river influence the groundwater. Influence generally means only the changes in groundwater level. It is not clearly defined what kind of effects are present, and how it may change in time. During my research I studied the hydraulic effects of river for the groundwater flow conditions in detail, trying to find answers to questions that which kind of effects can be defined, how the distances of effects can be separated.

A further aim was the detailed investigation of the relationship between river and groundwater level, as the results showed that the linear relationship between two variables is not always valid, the relationship changes over time. During the research questions about the nature of the relationship, its changes in time during river floods were examined.

It was important to apply the gained skills from the topic of river-aquifer relationship in numerical modeling of such systems, improving representativeness of the models. In particular, I focused the problems of permanent modeling. I examined the differences in catchments of bank-filtered water resources resulting from the assumption of permanent and transient water flow conditions. Applying initially smaller, and later higher temporal resolution in the transient models I found further difficulties without satisfactory solutions. Thus, further research examined the effect of time resolution for the accuracy of the models and tested new tools in model calibration.

A review of research methodology illustrated in Figure 1.

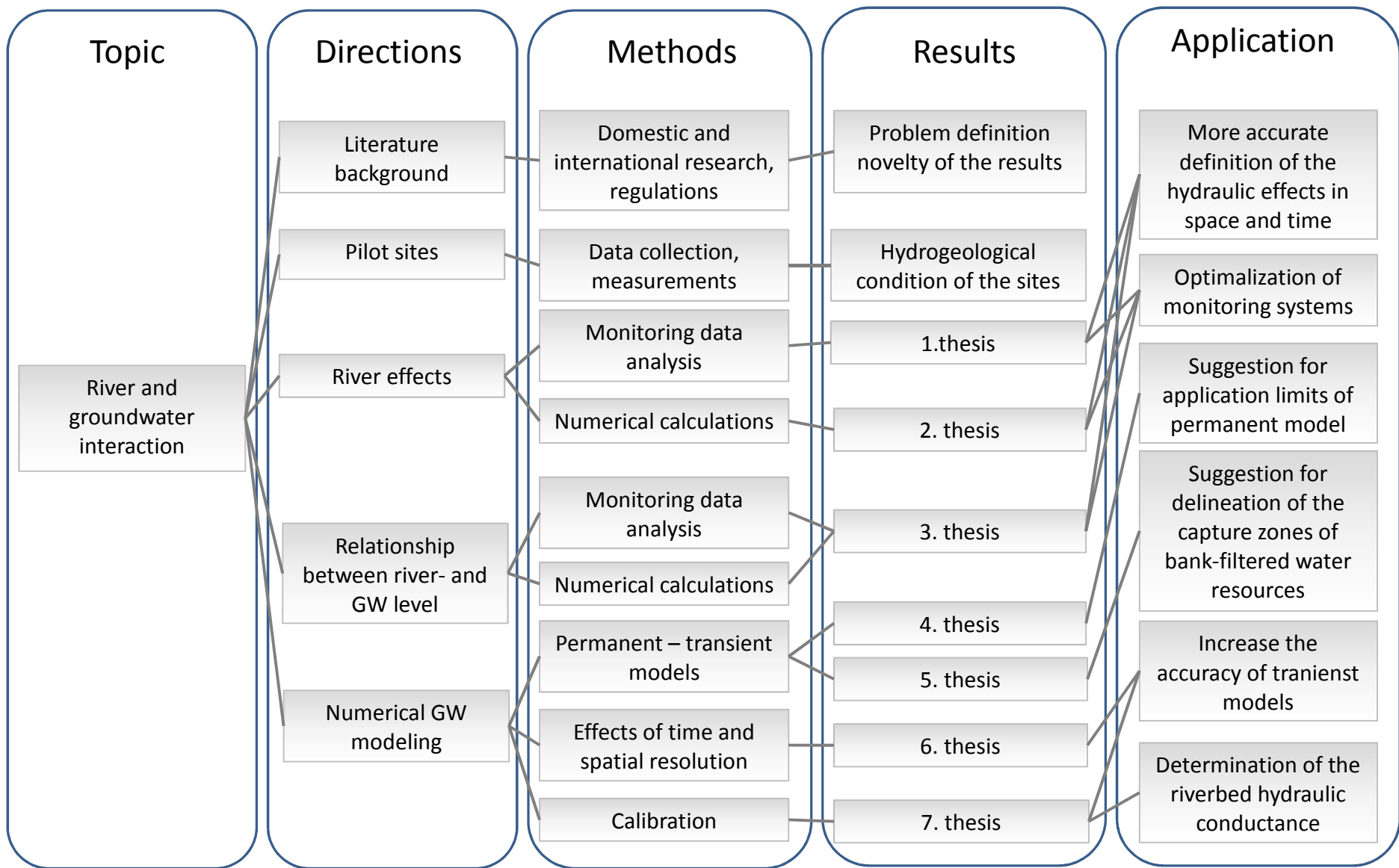


Figure 1: Methodology framework

INVESTIGATED SITES

The locations of pilot sites are shown in Figure 2. The first area is located along the riverside of Danube between Komárom and Neszémly, in south direction 7 km distance from the river. The other sites are along the Tisza River between Tiszadob and Ároktő, primarily located on the right side of the river. Initially, the available geological and hydrogeological information was collected and background research was performed. The data used in the research are originated from web and project databases [K.Tóth et al. 2015, K.Tóth-Madarász 2014].

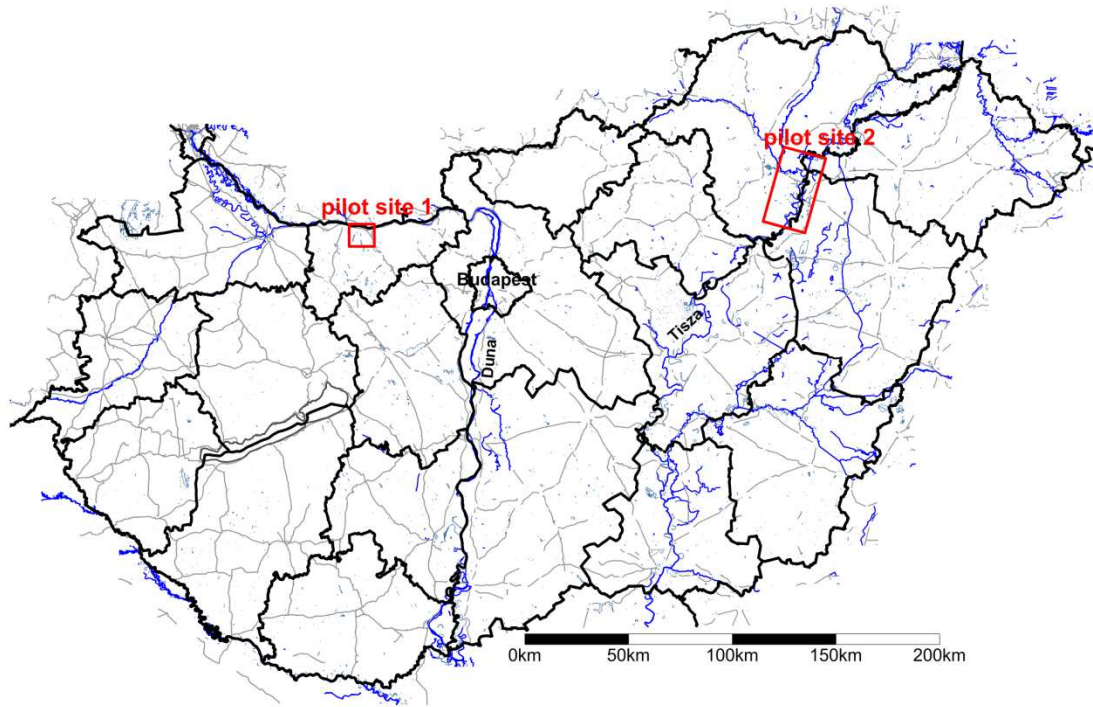


Figure 2.: The location of pilot sites

My studies started with monitoring data analysis, since the problem statement itself is derived from water level observations of the research sites, and first I wanted to draw conclusions from measured data. Data analysis means graphical representations of data, descriptive statistics, kriging, and other interpolations, correlation and regression calculations, and other database management, filtering, etc.. Determination and evaluation of river-groundwater relationship, and river effects can be only as accurate as dense the available monitoring network is in space and time. Therefore, the data gaps were filled with numerical calculations, which could also show the spatial and temporal variation of the hydraulic changes.

Numerical calculations were used in two approaches. In the first case "schematic" models were built, which can not be linked to a specific site. I examined the effects of river for groundwater flow conditions with different parameters, scenarios, spatial and temporal resolution. In the other the calibrated numerical models of study sites were used, and targeted tests were performed.

THESES

1. thesis

The effects of river for groundwater flow condition and its distances were examined on measured and calculated datasets. Based on the effects **three hydraulically effective distances were defined:**

- the distance in which the river influence the groundwater flow velocity, and the groundwater head; this is called **distance of flow gradient**,
- the distance in which the groundwater flow direction is reversed during rising river stage, the flow is towards the aquifer from the river; this is called **distance of flow direction**,
- and finally the distance which the entering water particles reach in the aquifer during the rising river stage; this is called **distance of bank storage**.

I determined that the defined distances are increasing at all times in the following order: the distance of bank storage, flow direction and flow gradient.

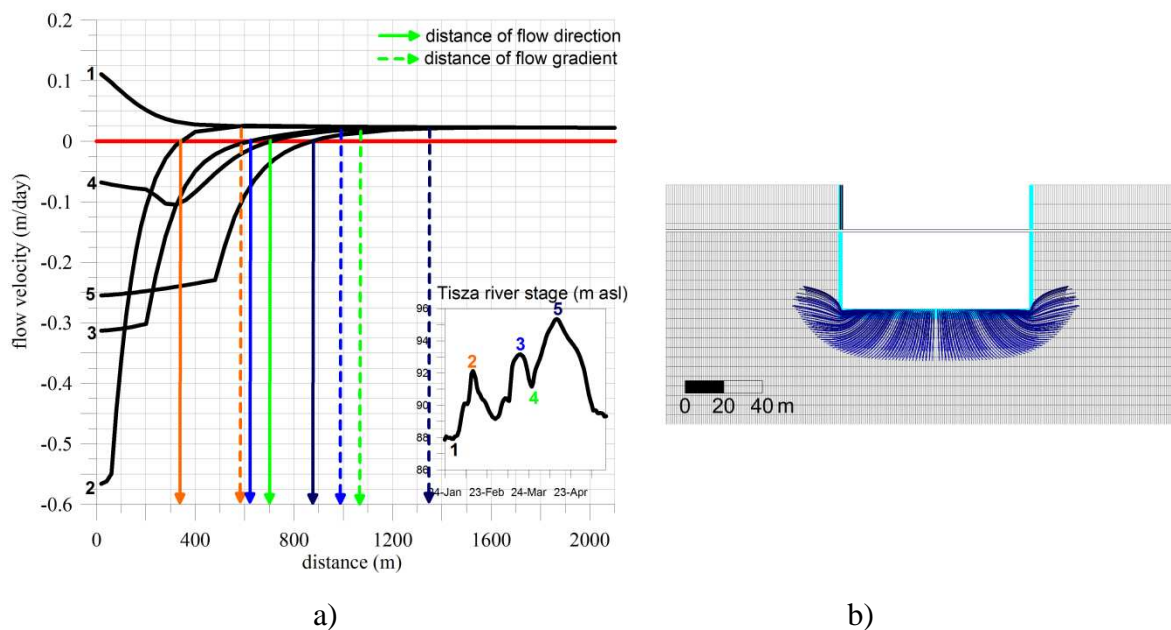


Figure 3. a) calculated flow velocities during a flood of Tisza river with indication of effective distances, b) particles pathes during the flood

2. thesis

I studied the groundwater flow velocity vector space in time and space with numerical calculations. I concluded that the absolute values of **velocities** in various river stages and in different distances from the river and also the defined **direction- and gradient distances are increasing logarithmically with increasing hydraulic conductivity of aquifer and riverbed's hydraulic conductance**. For riverbed's hydraulic conductance this dependence disappears when the flow velocity reaches the maximum value belongs to the resistance-free state between the river and aquifer.

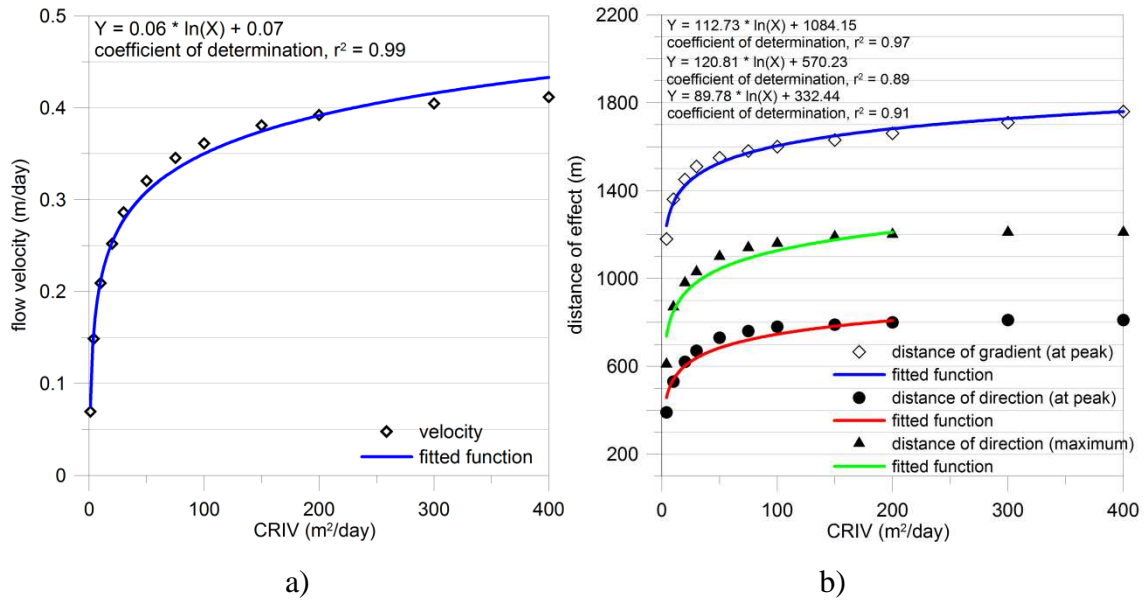


Figure 4. a) flow velocities at the starting stage of river flood, b) the distance of flow gradient and flow direction as a function of riverbed hydraulic conductance

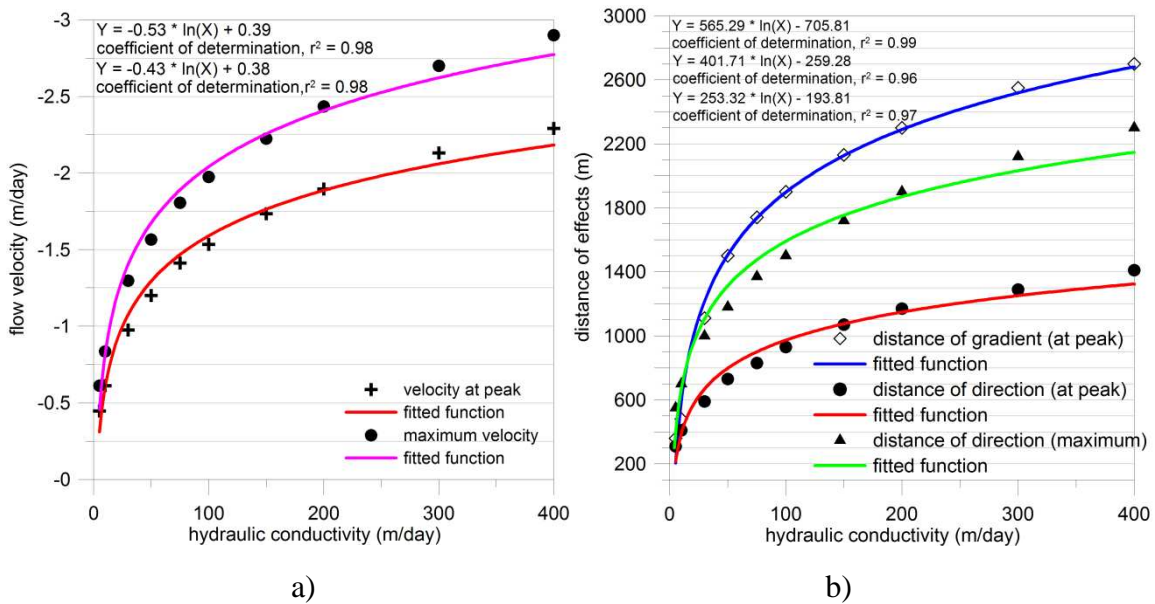


Figure 5. a) flow velocities at the peak of river flood and the maximum velocities during river flood, b) the distance of flow gradient and flow direction as a function of the aquifer's hydraulic conductivity

3. thesis

I examined the nature of hysteresis formed in the relation between river and groundwater daily water levels on measured and calculated data and concluded that:

- (1) the slope of rising and falling curves decreases, while the hysteresis width increases with decreasing riverbed conductance. It means that during a river flood lower the groundwater level and higher the time delay with decreasing riverbed conductance.
- (2) the changes of slope of rising and falling curves and the hysteresis width with hydraulic conductivity of aquifer is dependent on the distance from the river and riverbed conductance. Closer to the river the curve's slopes decrease and width increases, while farther from the river the slopes increase and width decrease with increasing hydraulic conductivity.
- (3) the slope of the rising and falling part of the looping curve are not necessarily identical, indicating that the discharge and recharge process in the aquifer take place with not the same delay.
- (4) for different floods the slopes of rising part of the looping curves are the same indicating that the linear relationship between river and groundwater levels is not influenced by the flood wave properties.

I observed that during flood there is also hysteresis between the river or groundwater level and the river recharge. It means that the river stage and groundwater level reach its maximum later, than the flow rate.

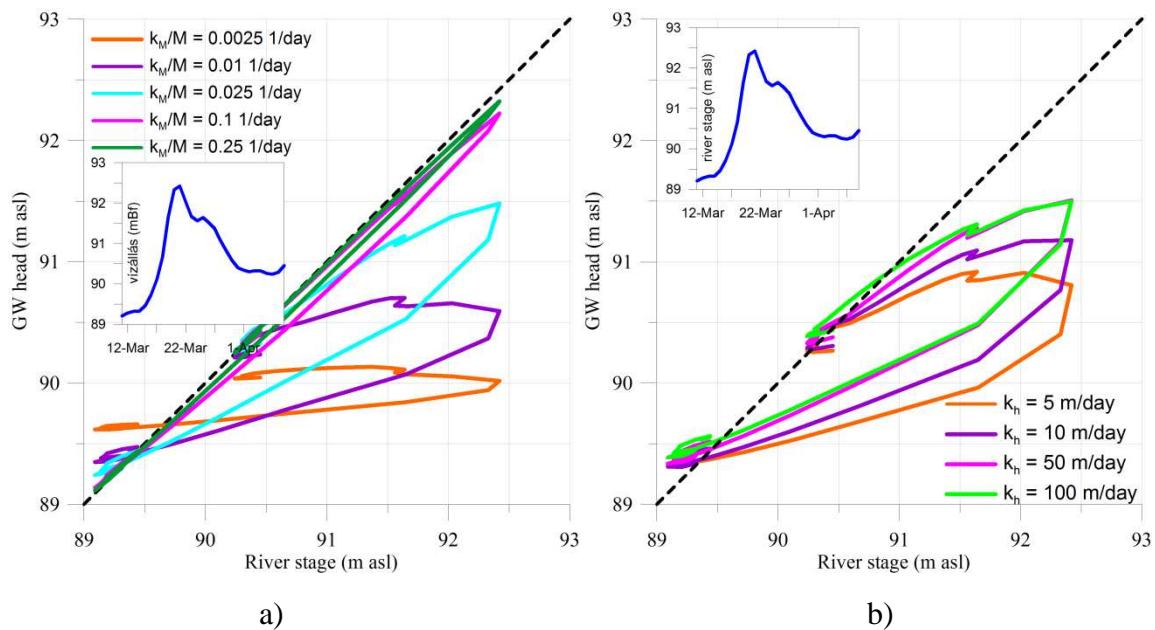


Figure 6. calculated flood looping curves a) in case of different riverbed conductance values
b) in case of different hydraulic conductivity values

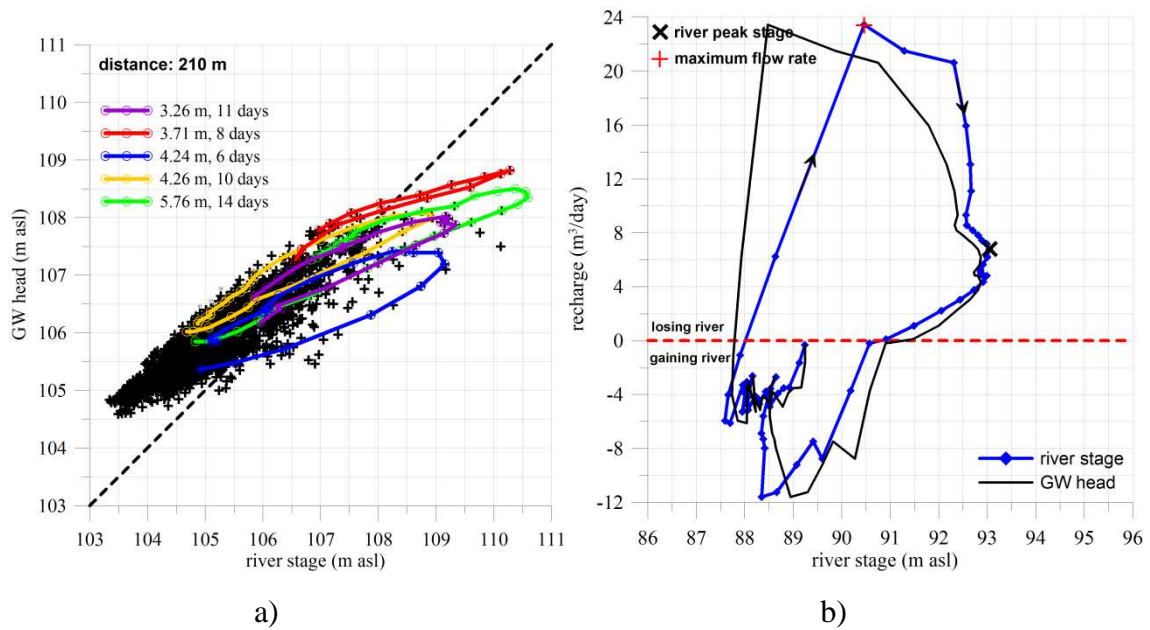


Figure 7. a) hysteresis curves for different floods in a monitoring well b) relationship between river stages/gw levels and flow rate during flood

4. thesis

I compared the permanent and transient numerical models of several river-influenced GW flow systems and found that **the flow path lengths and directions of water particles are different in permanent and transient flow conditions, and this difference increases approaching the river and with increasing simulation time. Consequently, the capture zones, the hydrodynamic dispersion and the direction, spatial extent and concentrations of dissolved contaminant plumes calculated with permanent and transient model are also different. Permanent GW flow and transport model in the distance of flow direction less able to accurately describe the system.**

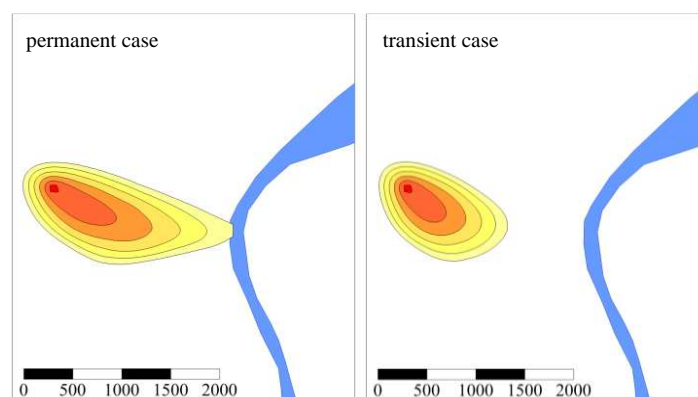


Figure 8. the spatial extent of contaminant plumes after 8 years simulation time in permanent and transient flow conditions

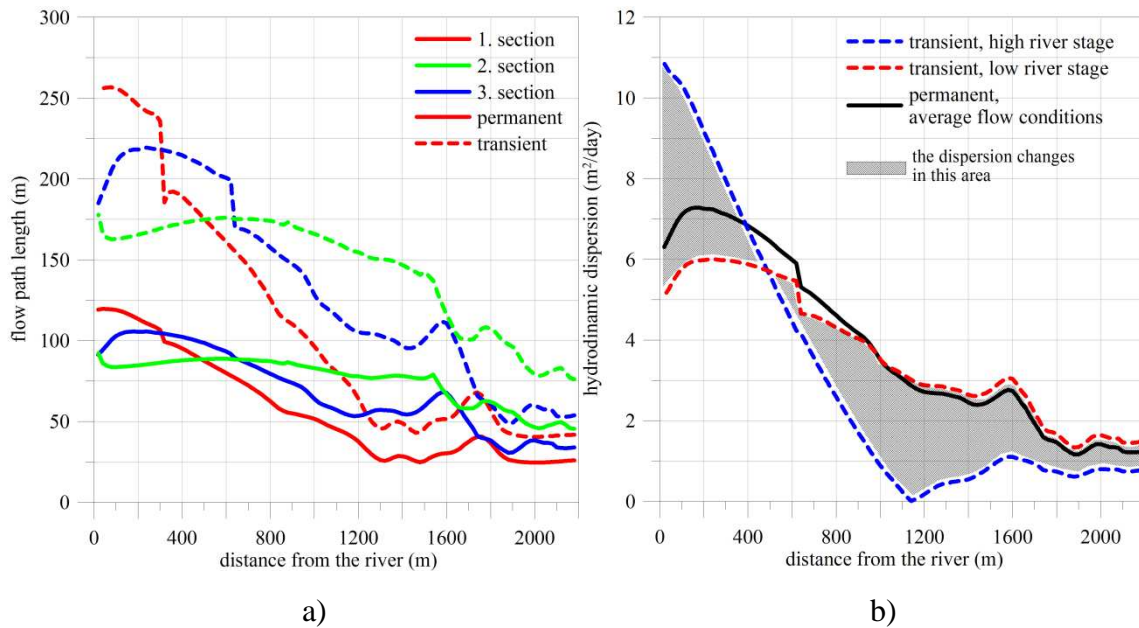


Figure 9. a) the flow path length and b) the dispersion in transient and permanent flow model

5. thesis

I studied the capture zones of theoretical bank-filtered water resources in permanent and transient flow conditions. My research showed that **the transient capture zones don't match the permanent capture zones, its extent and shape are different. I proved that this difference depends on the assumed GW flow conditions (assumed river stages) compared to the average permanent flow condition in the simulated 50 years. It also found that the difference between permanent and transient capture zones increases with increasing simulation time and riverbed conductance.**

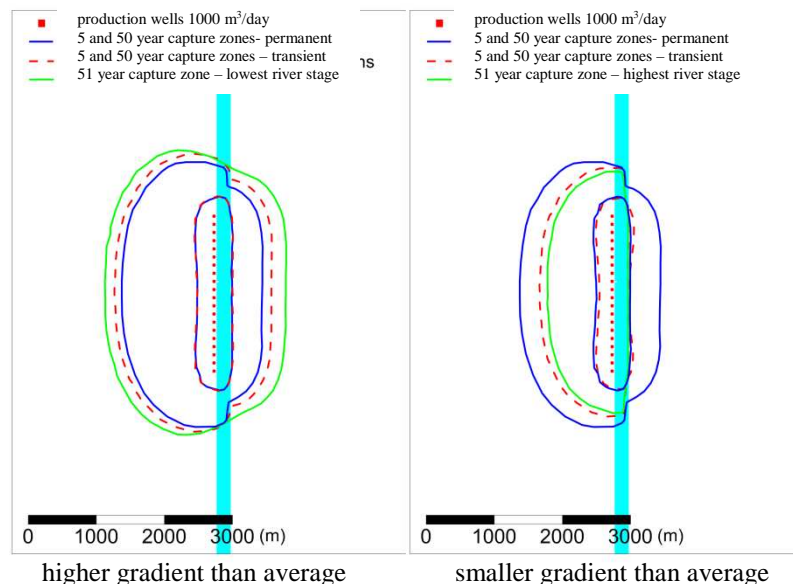


Figure 10. the capture zones for 5 and 50 years in permanent and transient model

With other words, the shape and extent of transient capture zones depend on how the river stages will change during the next 50 years. If gaining river is assumed and GW flow gradient is greater than the average gradient, then the extent of transient capture zone is larger than

permanent one. Whereas when losing river is assumed, or gaining river with the GW flow gradient is less than the average gradient, the extent of transient capture zone becomes smaller than in permanent case.

6. thesis

I examined the effect of the different temporal resolution with numerical calculations and it was concluded that **the temporal resolution, and applied river stages in the model's periods significantly affect the model's ability to simulate the GW dynamics accurately.** In rising river stages the reverse flow path lengths as well as the lasting of reverse flow situation are under- or overestimated.

The reason of under- and overestimation can be found in the difference of river stages between reality and the model's period. In case of smaller temporal resolution the few days periods of high river stages are neglected, which can result much longer periods of low river stages than in reality. At the same time assuming too high river stages for longer period causes the opposite effect.

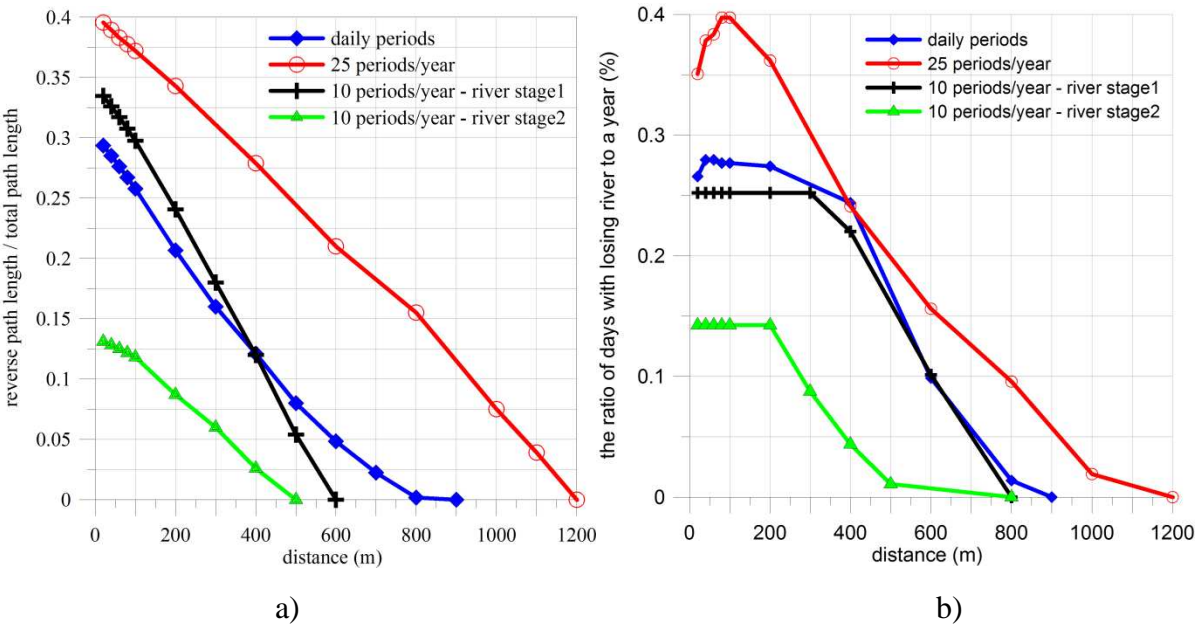


Figure 11. the effect of temporal resolution for the flow paths a) the ratio of reverse flow path length to the total length b) the simulation time of reverse flow conditions

7. thesis

I examined the effectiveness of commonly used tools in calibration process of permanent and transient numerical models. I found that **minimizing the fitting error of measured and calculated GW head is not acceptable calibration tool if - within the simulated time period - fitting is performed for only one time or more, but with similar flow conditions.** The gained parameters don't ensure the smallest error for the entire simulation period.

I proved that the transient models must be calibrated adjusted to the river stages, the time period used in calibration have to contain at least a period when the river changes from gaining to losing situation.

In losing river condition two new calibration tools are introduced, which can effectively be used to find the appropriate model parameters: (1) fitting of measured and calculated maximum head difference during floods along a section perpendicular to the river (2) fitting of measured and calculated hysteresis curves.

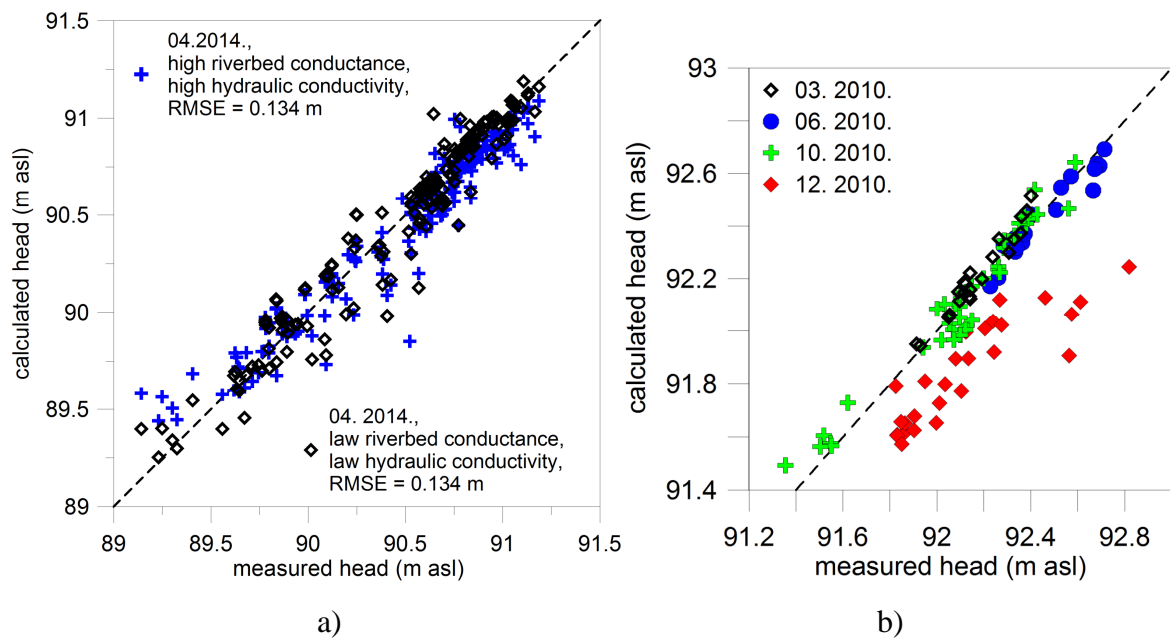


Figure 12. a) same fitting error with two parameter settings b) three acceptable fitting, but wrong fitting for the fourth time

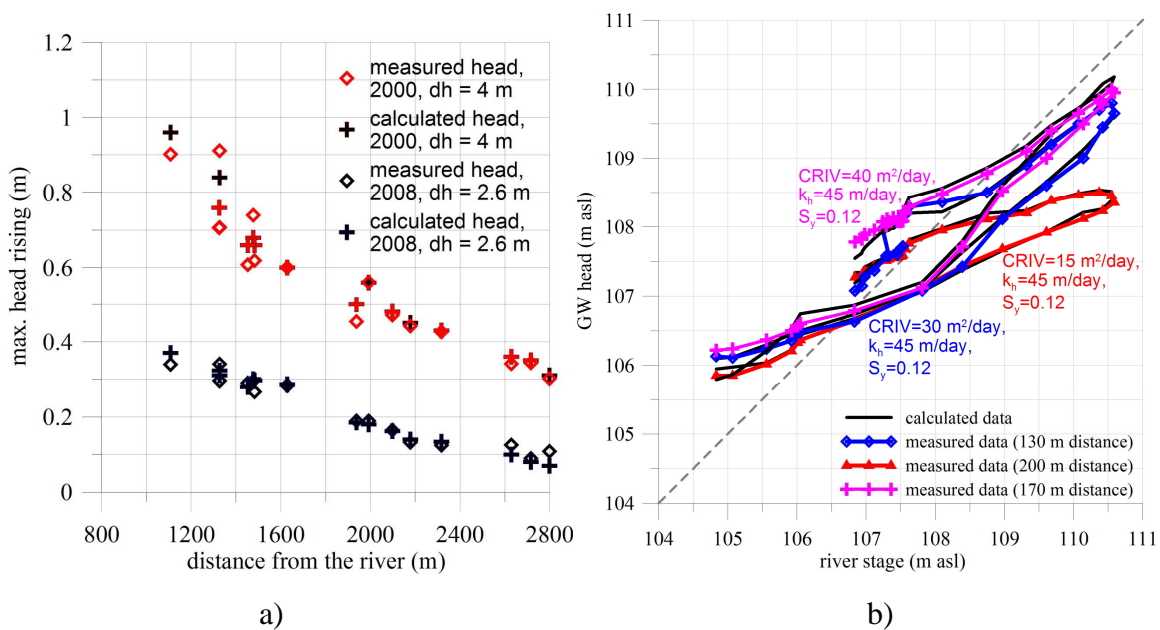


Figure 13. a) fitted measured and calculated maximal GW raise during two floods, b) the final fitting of hysteresis curves for three wells during the spring flood of 2006

OPPORTUNITIES FOR APPLICATION

Within the PhD topic I tried to look for answers to practice-oriented questions. In addition, many issues are generated from the practice. Direct practical applications of the results particularly come from numerical modeling part of the research topic.

The research has shown that a permanent flow and transport model is suitable only with limitations to describe certain phenomena, because a constant GW flow direction and gradient is assumed. In the dissertation I suggested several limitations for the application of permanent models.

I showed that the transient capture zones of riverbank-filtered water resources are different from the permanent capture zones in its shapes and spatial extent. The largest spatial extent was delineated in case of the highest GW flow gradient towards the river. Therefore I suggested for the protection zones of bank-filtered water resources to be delineated in flow condition belongs to the lowest river stage.

I examined the calibration process and tools of transient GW flow models. I suggested that the time period of measurements used in the calibration process would contain at least one period with losing river conditions. In losing river condition the application of two new tools in calibration is suggested. The fitting of measured and calculated flood hysteresis curves can be applied for estimating the riverbed hydraulic conductance.

The correlation calculations between the river and GW levels and between GW-GW levels can be used in the optimization process of GW monitoring systems.

SUMMARY

In my PhD thesis work river and groundwater interaction and the hydraulic effects of river flow on the connected aquifer were thoroughly examined. Monitoring data analysis and numerical calculations were performed in pilot sites along the Danube and Tisza rivers.

Based on the results of river and groundwater data analysis, and groundwater flow velocity calculations I separated the river's hydraulic effects and its distances. I studied the temporal and spatial variation of the flow velocities and its dependence on the aquifer's hydraulic conductivity and the riverbed's conductivity. Because of periodically changing river stages, groundwater flow velocity continuously (dynamically) changes in time within a certain distance from the river, and it depends on both parameters logarithmically. The daily groundwater level is delayed compared to river stages, which has constantly rising and falling stages. It causes hysteresis (looping curves) in daily correlation between the two levels with shapes dependent on the physical properties of the aquifer and river.

The results modify the earlier idea that the groundwater flow can be simulated with a constant flow gradient and flow direction in most of the year at riverside areas, because even though in gaining stages of the river the groundwater flow direction and gradient constantly changing in a certain distance. Based on the numerical calculations it is proved that the accuracy of permanent numerical simulations deteriorate in that distance from the river where the groundwater flow direction is constantly changing. Particle pathlines, capture zones of wells, contaminant plume's movement (direction and velocity) is different from reality in permanent simula-

tion. I have shown that the shape and areal extent of capture zones for bank-filtered water resources depend on the river water level changes we assume in the simulation time. The largest spatial extent of capture zones is obtained for the lowest river stage.

The difficulties of transient numerical modeling are not only the needed large datasets, but also its temporal resolution and calibration. The time periods of the model must be fitted to the river stages in a way that the hydraulic effects of the river is simulated more precisely in time and space. During the model calibration, in addition to the hydraulic conductivity and specific yield of aquifer, the generally unknown hydraulic conductance of riverbed must also be changed. Meanwhile, the density of the measured data in space and time - which we used for calibration - is not enough. This leads to a high degree of uncertainty in calibration, which can be reduced only with multi-step process. This means the simultaneous execution of multiple, non-traditional fitting procedures, using different stage periods and floods of the river.

The thesis work highlights the importance of continuous monitoring activity, since the research results presented as evidence that for investigations with all purposes is essential to track the system's changes in time. My research work were carried out based on pilot sites, but there are several general outcomes between the results, which can be applied in any similar river-groundwater interaction.

Potential applications of the results are audit of bank-filtered water resources, optimizing groundwater monitoring systems, exploration, remediation and monitoring activities of existing or potential pollution of groundwater at industrial sites. The results provide a basis for a later detailed development of new method by which flood hysteresis between the river and groundwater levels can be used for the calculation of riverbed hydraulic conductance without pumping tests. Continuation of the research is the involvement of other riverside areas, expanding the database, comparing the new results to the previous ones, as well as expansion of the quantitative impact assessment with qualitative analysis.

REFERENCES

- Bezdán M., 2011, A szabályozott Tisza vízjárása tulajdonságai a Tiszafüred alatti folyószakaszokon. Doktori értekezés, Szeged, p. 117.
- Csoma R., Gálos M., 2009, A Duna vízjárásának hatása a talajvíz-viszonyokra az Infopark-Budapest térségében. Hidrológiai Közlöny 89 évf. 4. szám, pp. 1-8.
- Csoma R., Emszt Gy., Gálos M., 2012, A Duna árhullámainak hatása a talajvízszint-változásra egy folyóra merőleges szelvényben. Mérnökgeológia - Kőzetmechanika Kiskönyvtár 7. Műegyetemi Kiadó
- Deák J., Hertelendi E., Süveges M., Barkóczy Zs., 1992, Partiszűrésű kutak vizének eredete trícium koncentrációjuk és oxigén izotóparányaik felhasználásával. Hidrológiai Közlöny 72 évf. 4.szám, pp. 204–210.
- Fejes I., 2014, A talaj-, és talajvízrendszer komplex környezeti szempontú értékelése városi területen, Szeged példáján, Doktori értekezés, Szeged, p. 123.
- Kármán K., Deák J., 2012, A Szigetköz rétegvíz-áramlási rendszerének vizsgálata trícium modellezés alapján. XIX. Konferencia a felszín alatti vizekről, Absztrakt kötet. 20.

Kármán K., Maloszewski P., Deák J., Fórizs I., Szabó Cs., 2013, Transit Time Determination in Riverbank Filtrated System by Oxygen Isotopic Data Using the Lumped Parameter Model. *Hydrological Sciences Journal*.

Kontur Á., 1988, Szabadalmi leírás — Eljárás és berendezés folyó- vagy állóvízmedre alatti porózus anyagban uralkodó folyadéknnyomás meghatározására (Országos Találmányi Hivatal, lajstromszám: 187530)

K. Tóth A., Kovács B., Fekete Zs., Tóth M., Madarász T., 2015, Az almásfüzitői vörösiszap-tározók komplex geotechnikai, vízföldtani vizsgálata, Kutatási zárójelentés, TÁMOP-4.2.2/A-11/1-KONV-2012-0049 jelű „KÚTFŐ” projekt, Miskolci Egyetem

K. Tóth A., Madarász T., 2014, Felszín alatti vizekkel kapcsolatos kutatások a Miskolci Egyetemen: A Kútfő projekt, *Méző Újság XXI:(2)* pp. 17-19.

Léczfalvy S., 2004, Felszín alatti vizeink 1-2. Elte Eötvös Kiadó, p. 819.

Molnár B., Hajdú K., 2003, A földtani felépítés, a csapadék, a tiszai vízállás és a talajvízállás közötti összefüggések Szeged-Gyálarét környékén. *Hidrológiai Közöny 2003. évf., 5-6. szám*

Rózsa A., 2000, Beszivárgási vizsgálatok a Szentendrei-Duna medrében. *Hidrológiai Közöny 2000. évf., 2. szám.*

Völgyesi I., 1992, Folyók mederellenállásának meghatározása próbaszivattyúzással. MHT vándorgyűlés, Szeged, pp. 227-237.

PUBLICATIONS IN TOPIC OF THE PHD DISSERTATION

K. Tóth A., Kovács B., 2015, Calibration process for groundwater flow model of a river influenced shallow aquifer, *Central European Geology*, Vol. 58/1–2, pp. 186–198.

K. Tóth A., 2015, Folyó és talajvíz kapcsolata - változó talajvízszint hatásának vizsgálata esettanulmányok tükrében, *Geotechnika 2015 Konferencia, Konferenciakötet, Absztrakt.* p.49-50.

K. Tóth A., Kovács B., Fekete Zs., Tóth M., Madarász T., 2015, Az almásfüzitői vörösiszap-tározók komplex geotechnikai, vízföldtani vizsgálata, Kutatási zárójelentés, TÁMOP-4.2.2/A-11/1-KONV-2012-0049 jelű „KÚTFŐ” projekt, Miskolci Egyetem.

Madarász T., Szűcs P., Kovács B., Lénárt L., Fejes Z., Kolencsik-Tóth A., Székely I., Kompár L., Gombkötő I., 2015, Recent trends and activities in hydrogeologic reserach at the University of Miskolc, Hungary. *Central European Geology*, Vol. 58/1-2., pp. 171-185.

K. Tóth A., Szűcs P., 2014, Analysing the flood effect on relationship between the river Danube and a shallow aquifer, *microCAD 2014*, University of Miskolc, Paper 11., ISBN:978-963-358-051-6.

K. Tóth A., Madarász T., 2014, Felszín alatti vizekkel kapcsolatos kutatások a Miskolci Egyetemen: A Kútfő projekt, *Méző Újság XXI:(2)* pp. 17-19.

Turai E., Kolencsikné Tóth A., Kovács B., Madarász T., Szűcs P., 2014, A talajszennyezési csóvák kimutatásának új módszere az IP adatok TAU-transzformációjának alkalmazásával: New method for detection of soil contamination tails using TAU-transformation of IP data. X.

Kárpát-medencei Környezettudományi Konferencia, Kolozsvár, Románia, Ábel Kiadó, pp. 101-105.

K. Tóth A., Kovács B., Fekete Zs., 2013, The effect of riverbed colmatation (conductivity) for the transient flow pattern characteristics in a shallow aquifer. IX. Kárpát-medencei környezettudományi konferencia: Konferencia kiadvány. Miskolci Egyetem Műszaki Földtudományi Kar, pp. 414-419. ISBN: 978-963-358-032-5.

Kovács B., K.Tóth A., 2013, Evaluation of groundwater-surface water interaction along the Tisa river. Proceedings of the IAHR Central European Groundwater Conference, Szeged: Szegei Egyetemi Kiadó, pp. 118-121. ISBN: 978-963-306-217-3.

Kovács B., K.Tóth A., Szanyi J., 2012, Transient modeling of surface and subsurface water interaction at a riverbank aquifer. 39th International Association of Hydrogeologists Congress, Kanada, Congress Program and Abstract, p. 308.

Szűcs P., Tóth A., Virág M., 2006, A leggyakoribb érték (MFV) módszerének alkalmazása a hidrogeológiai modellezésben. Hidrológiai Közlöny 86:(4) pp. 29-36.

Szűcs P., Tóth A., Zákányi B., Madarász T., 2006, Inverziós módszerek a hidrogeológiában. Magyar Geofizika 47:(4) pp. 169-172.

Toth A., Szucs P., 2006, Parametric vs nonparametric statistics in case of environmental data analysis. microCAD 2006, C szekció: International Scientific Conference. Miskolc: pp. 135-140.

Tóth A., 2005, Spatial characterization of contaminant plumes. 5th International Conference of PhD Students. Miskolc: University of Miskolc, pp. 211-216. ISBN: 963 661 678 7.

Tóth A., 2005, Using statistical tools for environmental decision making at contaminated sites. microCAD 2005 International Scientific Conference. Miskolc: Miskolci Egyetem Innovációs és Technológia Transzfer Centrum, pp. 77-82. ISBN:963-661-646-9

Szűcs P., Tóth A., 2005, A new geostatistical concept in hydrogeological calibration. microCAD 2005 International Scientific Conference. Miskolc: Miskolci Egyetem Innovációs és Technológia Transzfer Centrum, pp. 65-70., ISBN: 963-661-646-9.

Szűcs P., Civan F., Tóth A., 2005, Application of Geostatistics in Calibration of Groundwater Modeling. Managing Matured Fields and Wells. 306 p. Budapest: Akadémiai Kiadó, pp. 195-209. (Progress in Oilfield Chemistry; 6.) ISBN:963 05 8301 1

Tóth A., 2005, Tényfeltárás, a kármentesítés első lépése - tervezéstől a döntéshozatalig. Doktoranduszok Fóruma: Műszaki Földtudományi Kar szekciókiadványa. Miskolc-Egyetemváros: Miskolci Egyetem Innovációs és Technológia Transzfer Centrum, pp. 108-114.

Szucs P., Toth A., Virag M., Fesus A., 2004, A new geostatistical tool ingroundwater modeling applications. Intellectual Service for Oil and Gas Industry: Analysis, Solutions, Perspectives. Proceedings. Ufa: Ufa State Aviation Technical University, pp. 225-232. Vol. 3. ISBN:5 98755 001 7.