ANALYSIS OF MULTICOMPONENT GROUNDWATER FLOW IN KARST AQUIFER BY CFC, TRITIUM, TRACER TEST AND MODELLING, CASE STUDY AT SKAISTKALNES VICINITY, LATVIA

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INTRODUCTION

Groundwater in karst environments tends to have difficulties to distinguish multiple flows if several sources of water are present. Skaistkalne vicinity is such a case, where older groundwater, fresh groundwater and recharge from river Iecava occurs. Attempts were made to distinguish these different flows and groundwater residence time of multiple components applying CFC and tritium dating techniques supplied by tracer test and numerical model of study area.

STUDY AREA

Karst processes are are found at several locations in Latvia (Fig. 1), including southern part, where karst in gypsum layers takes place.

Study area covers territory between two rivers Iecava and Memele (Fig. 2) with water level difference of 7 meters and horizontal distance of 2.6 kilometres between both. Confined – unconfined groundwater is bound to the Salaspils aquifer lying at the depth of 10-15 m below ground surface.

There are Upper Devonian Salaspils Formation sediments consisting of gypsum and carbonaceous rocks covered by Quaternary low to high permeable deposits (glacigene till and sand, alluvium) found at the study area. Karst processes mainly have affected gypsum containing layers, and surface and underground karst features like sinkholes and karst lakes as well as highly permeable zones of fractures and channels are present in the area. Salaspils Formation has very complicated structure, where gypsum layers are interbedded with dolomite, clay and marl layers (Fig. 3).

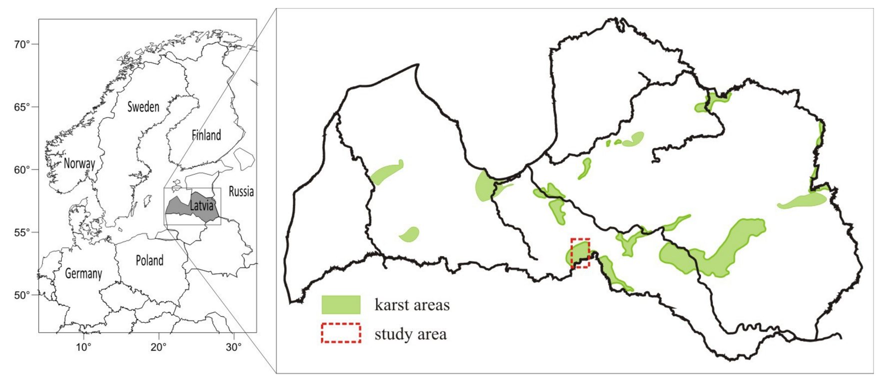

Fig. 1. Location of study site and karst areas in Latvia

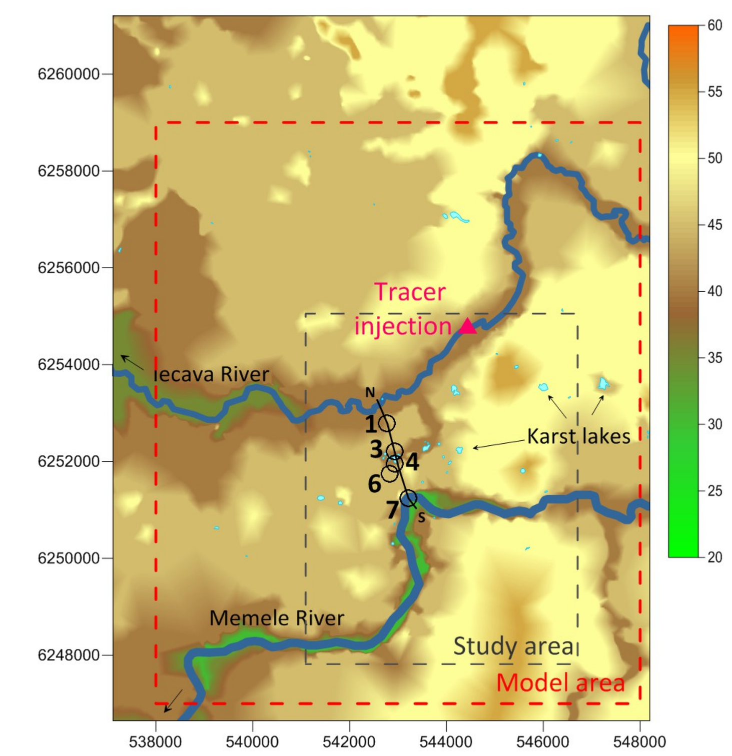

Fig. 2. Study area showing location of observation wells, tracer injection point, geological section line and numerical model area.

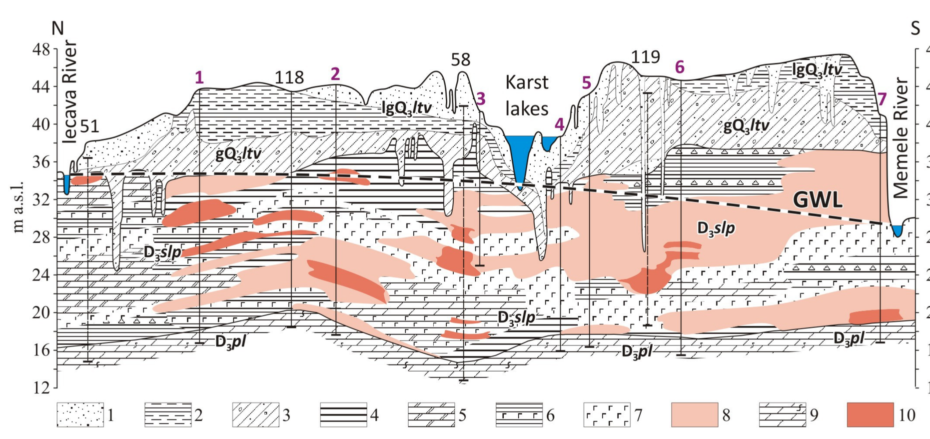

Fig. 3. Geological section of the study area along the line of sampled wells (Nos. 1; 3; 4; 7), the length of the section is 2.6 km (Tracevska et al. 1986)

Legend: 1 – sand, 2 – silt, clayey silt, 3 – till loam, 4 – carbonate clay, 5 – marl, dolomite marl, 6 – clayey gypsum, 7 – gypsum, 8 – dissolved gypsum strata with clay and dolomite flour, 9 – dolomite, fractured dolomite, 10 – karst cavities, partially filled with dolomite flour; GWL – groundwater level; lgQ_3ltv – glaciolacustrine sediments, gQ_3ltv – glacigene till deposits, D_3slp – Upper Devonian Frasnian stage Salaspils Formation sediments, D_3pl – Upper Devonian Frasnian stage Plavinas Formation.

MODEL SETUP

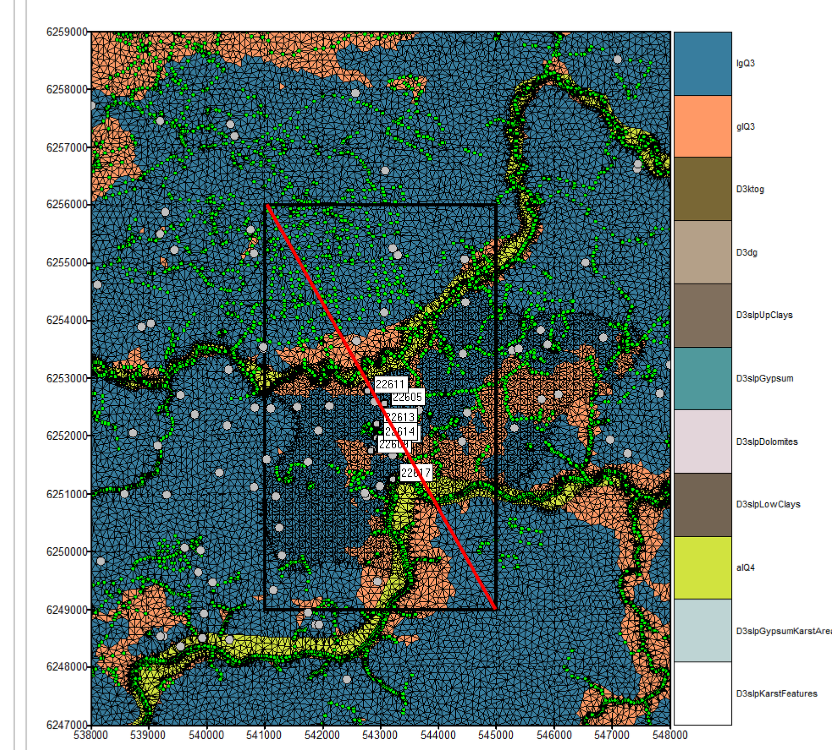

Fig. 7. Model setup: black frame – area of interest; green dots – assigned tophead; numbers – calibration wells; grey dots – wells for geometry building; red line- cross section (see Fig. 9.)

Model was built within MOSYS modelling system (Virbulis et al., 2012).

A 3D Darcy flow with free-surfaces and anisotropoc conductivity (Table 2) is assumed for the steady-state solution. As boundary conditions, waterlevel of largest rivers, known karst lakes and ditches were defined as tophead and slightly variable recharge of 1.4-1.5e-5 m/day in uppermost layer.

Karst affected area was treated like "honeycomb" structure (Fig. 8), where karst conduits were defined within comb frames.

Numerical model covers territory of 10×12 km, including buffer zone 2-3 km around the interest area (Fig. 7.).

Table 2. Hydraulic conductivity values in model

Layer	Kxy (m/day)	Kz (m/day)
alQ4	5	5
lgQ3	5	5
glQ3	0.003	0.003
D3ktog	0.0003	0.0003
D3dg	50	50
D3slpUpClays	0.0003	0.0003
D3slpGypsum	20	20
D3slpGypsumKarstFeatures	570	100
D3slpDolomites	30	30
D3slpLowClays	0.0003	0.0003

MATERIALS AND METHODS

Several approaches were used to determine groundwater component variability and content. CFC's and tritium were used to determine groundwater recharge time and to estimate water components of different age.

Hydraulic connection between the two rivers was proved by tracer test, where 600 grams of uranine were injected into the River 1 (Iecava) one kilometer upstream from potential linkage area (Fig. 2). Groundwater from monitoring wells located between these rivers were analyzed by GGUN-FL24 Fluorometer and adequate calibration was made before. Fluorometer was left in one well (No 7) while rest of monitoring wells were sampled in plastic bottles and analyzed by fluorometer afterward.

Hydrogeological numerical model of finite elements was made for territory of XX square kilometers including area with groundwater linkage between the two rivers.

RESULTS 1 – CFC AND TRITIUM

Analyzes of CFC's shows that apparent ages are different for each CFC meaning that water consists of mixture of water components with different recharge time or some of CFC's has been degraded (Table 1). It is very likely that CFC-11 has been degraded in anaerobic conditions and its degradation products can affect CFC-113 concentration because of signal overlapping. Therefore only CFC-12 can be used as age estimation parameter. CFC-12 concentration increases from Well 1 to Well 7 with increasing distance from river 1 but exception is in Well 3 where higher concentration was observed. It is very likely that groundwater in well 3 is recharging from near located sinkhole ponds.

Table 1. Tritium, CFC and field data

	tritium (TU)	CFC-12, pg/kg	CFC-11 apparent age	CFC-12 apparent age	CFC-113 apparent age	pH	EC, µS/cm	T, °C
Well No.1	8.1	75	57	44	28	7.05	739	8.6
Well No.2	6.5	83	57	43	49	7.20	2030	7.8
Well No.3	7.7	344	54	24	42	7.25	2250	7.9
Well No.4	-	-	-	-	-	6.96	2240	8.4
Well No.6	6.8	104	56	42	37	7.22	1933	8.1
Well No.7	4.5	155	55	38	36	7.00	2260	8.1

PHREEQC modeling showed that groundwater from Well 1 is the isn't in equilibrium with gypsum although other monitoring wells are in equilibrium. Well 1 characterizes by comparably low EC value and significant 'wrong' CFC's (Fig. 4).

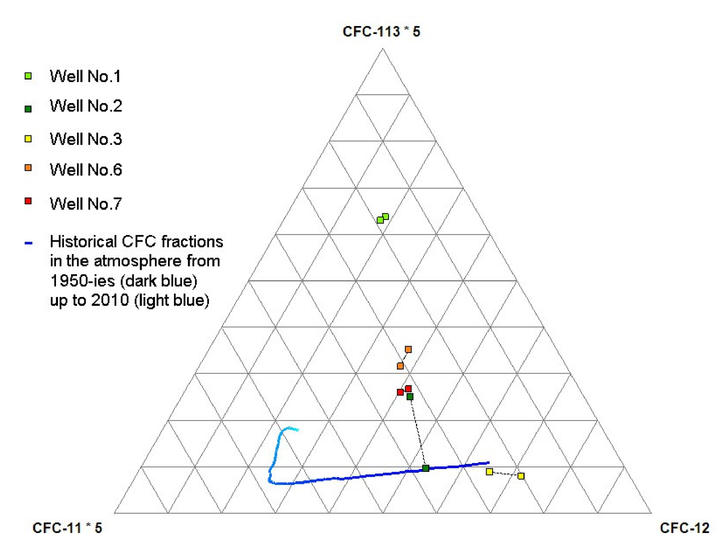

Fig. 4. Ternary diagram for CFC's

RESULTS 2 – TRACER TEST

Tracer test proved underground connection between both rivers and two monitoring wells (Well No.4 and No.7), but tracer wasn't found in well No.1 and No.3. Presence of uranine in well No.7 was detected by immersing fluorometer into well therefore very detailed concentration changes can be analyzed (Fig. 5).

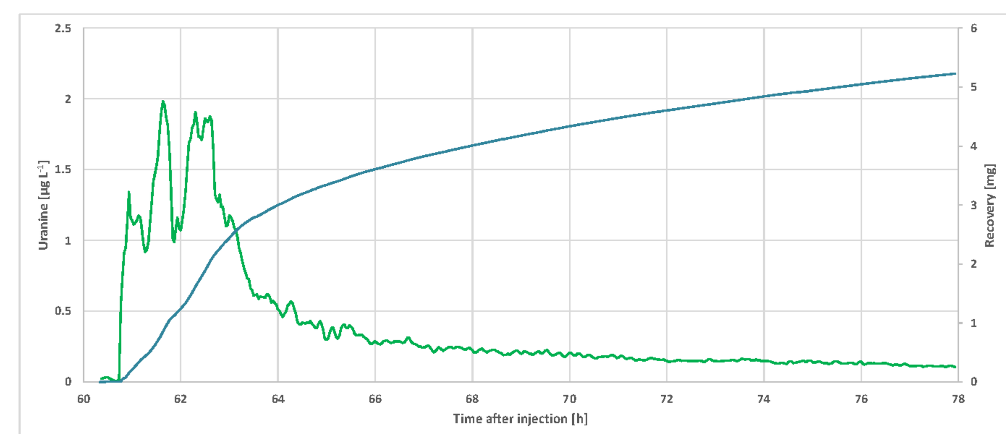

Fig. 5. Uranine concentration and recovery in well No.7

Tracer concentration grew very rapidly after first appearance at 60.76 hours after injection. Three tracer concentration peaks can be observed in well No.7 with 30 minutes in between each peak. Modeling results showed that at well No7. Groundwater convergences therefore it's possible that main flow divides and connects together afterward leading to several close-standing tracer peaks. Total mass of 5.23 grams of uranine flowed through the well No.7.

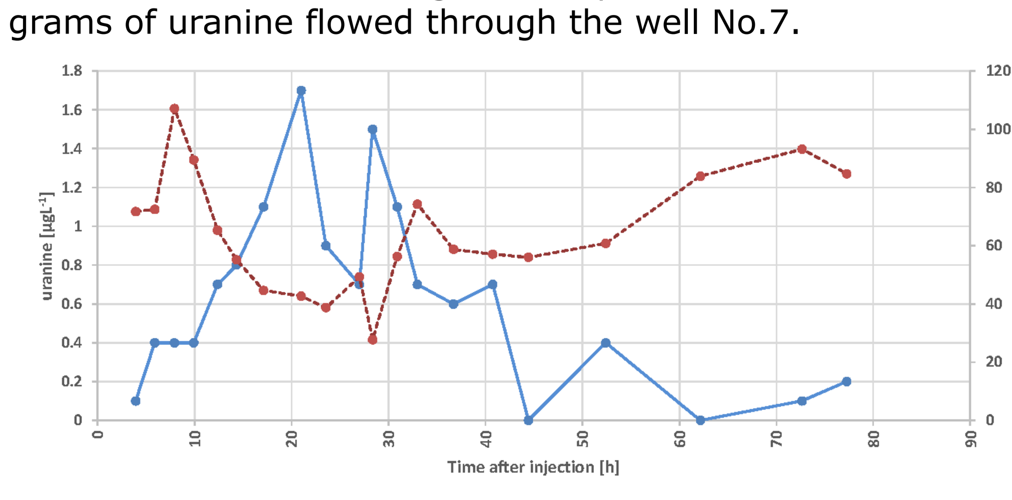

Fig. 6. Uranine concentration and turbidity in well No.4

Uranine was detected in well No.4. as well by analyzing collected samples at different time. Two peaks can be observed although it's possible that some fluctuations has been between sampling times (Fig. 6). Sampled water had different turbidity values because of iron sedimentation during storage and it may affect uranine measurements.

RESULTS 3 – GROUNDWATER FLOW MODEL

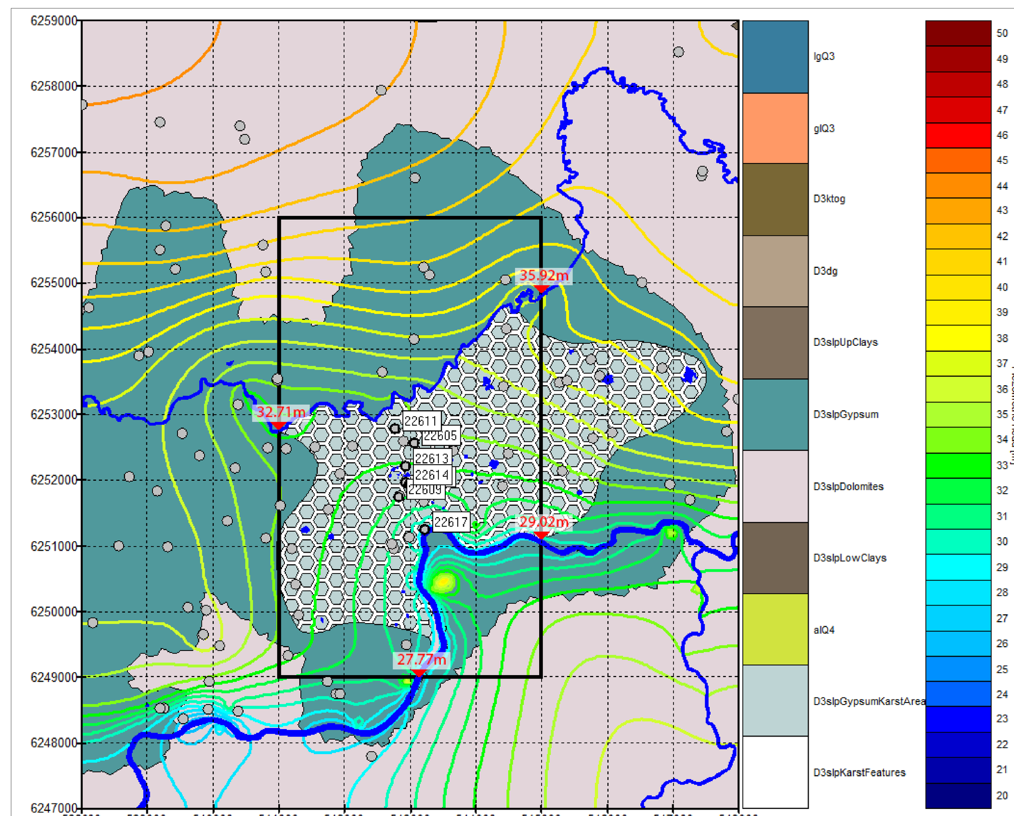

Fig. 8. Calculated pjezometric head in Salaspils aquifer in area of two rivers (blue lines); observed water level in both rivers are in red color.

Introduction of honeycomb structure in the module significantly improved results (Fig. 10), comparing to the previous model (Delina et al, 2010), where higly permeable continuous layer was used to represent karst features in the Salaspils aquifer.

Modelled piezometric heads in Salaspils aquifer allows to delineate potential pathways of the tracer (Fig. 8), and this corresponds to the fact that tracer was not observed in wells closer to Iecava river.

Cross-section view (Fig. 9) assures that Iecava river drains only Quaternary sediments, and recharges Salaspils aquifer in the study area, but Memele river is major drain in the raea collecting unconfined and confined groundwater there.

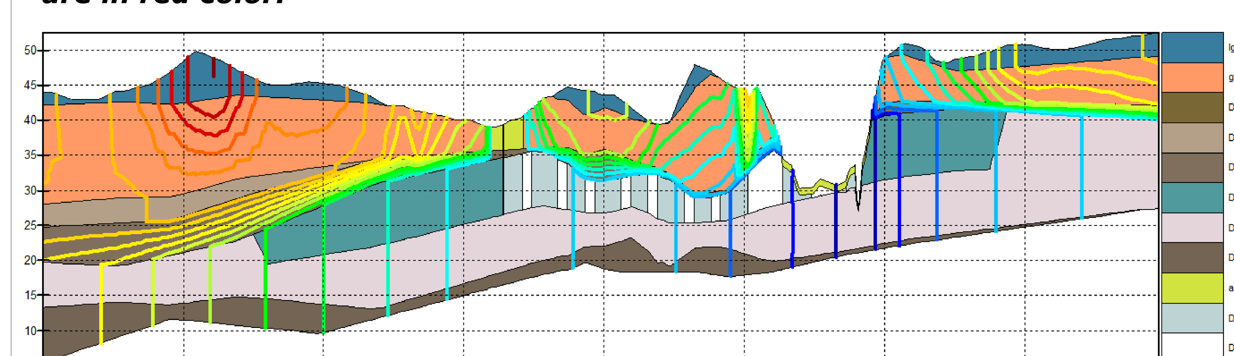

Fig. 9. Cross section of modeled area (see Fig. 7.) with pjezometric heads

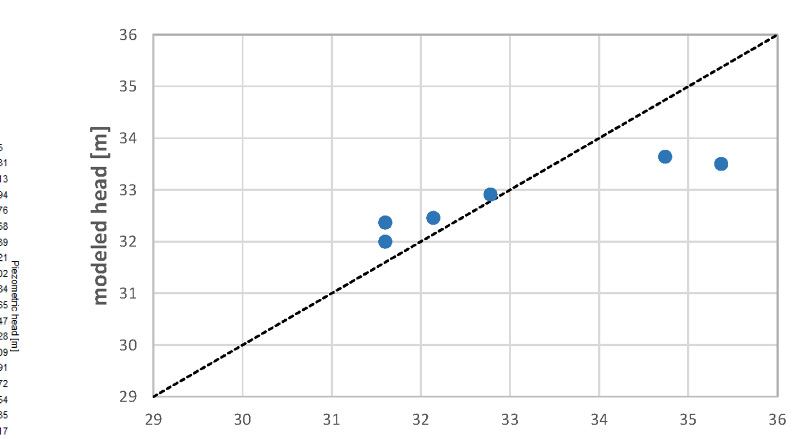

Fig. 10. Modeled water head versus observed head

SUMMARY

Groundwater flow in karst area between two rivers at Skaistkalne vicinity consists of multiple components characterized by different recharge time and flow velocity. Several approaches were used in order to distinguish different water components. CFC's showed that groundwater recharge time increases from Iecava river to Memele river and some direct recharge of Salaspils aquifer occurs along the way, although straightforward conclusions can't be made because of conduit presence. Conduits were investigated in tracer test where water flow velocity of 500-1000 m/day was observed. Tracer test showed that only two of monitoring wells are in fast flow zone. During tracer sampling several concentration peaks were observed. Conclusion was made that several inter-connected conduit channels are present in area.

Numerical model with honeycomb conduit pattern yielded good results and explained groundwater movement between both rivers observed by tracer test. The best results were obtained when horizontal hydraulic conductivity for gypsum conduits was set to 570 m/day.

Complicated flow pattern, where groundwater in Salaspils aquifer includes aquifer baseflow as well as recharge of unsaturated precipitation and river water favors karst process activity until today.

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EIROPAS REĢIONĀLĀS ATTĪSTĪBAS FONDS

IEGULDĪJUMS TAVĀ NĀKOTNĒ

EIROPAS SAVIENĪBA