# Effects of karst processes on surface water and groundwater hydrology at Skaistkalne vicinity, Latvia

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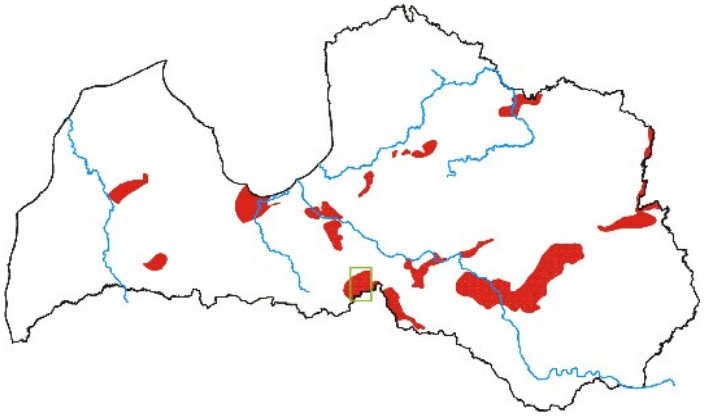
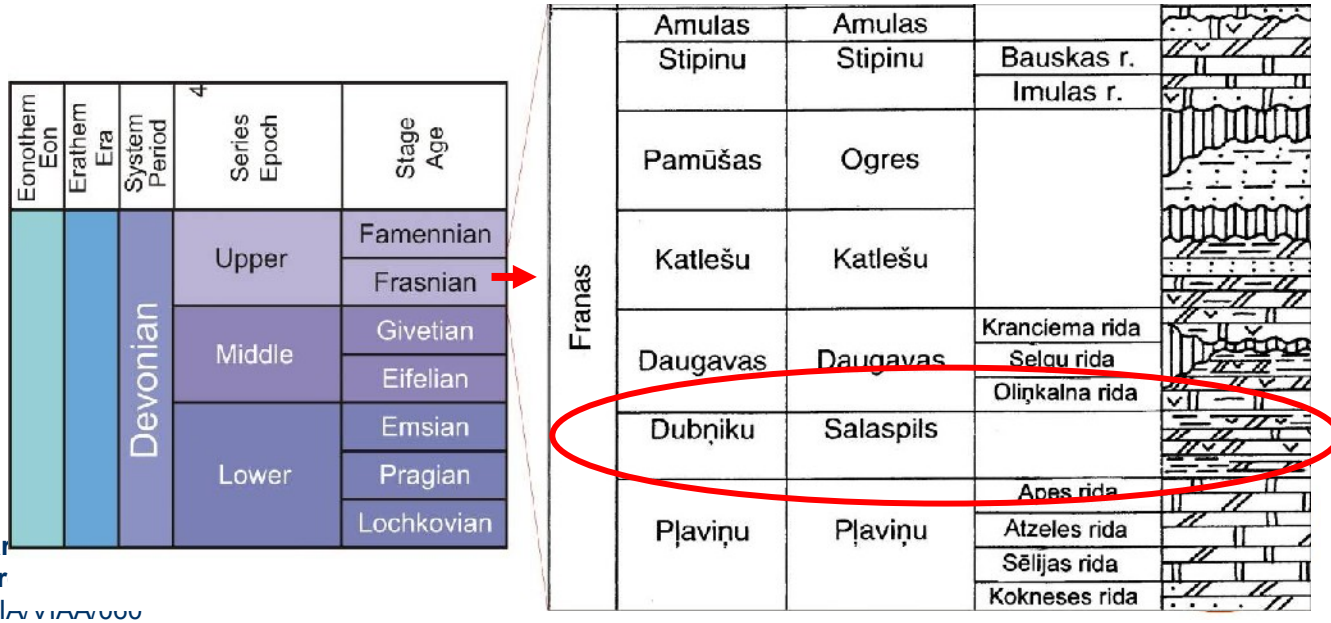
# Background information

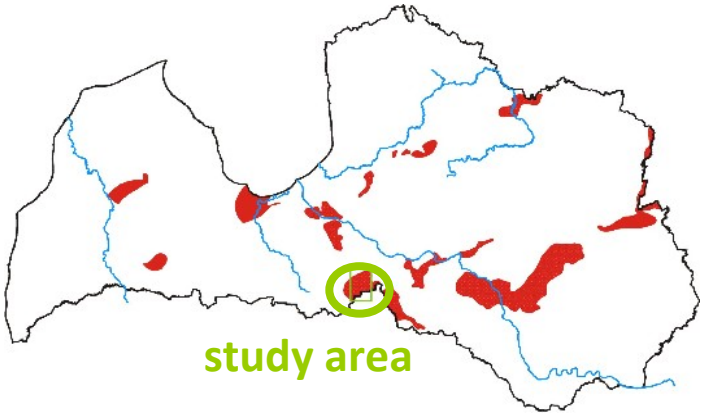
- Karst processes in Latvia occur in carbonate (dolomites, limestones) and gypsum formations
- More intense karst processes are bound to gypsum layers, distributed in central Latvia in Upper Devonian Salaspils Formation





# Background information

- Underground karst features include fractures, channels, and caves,
- Surface karst features are sinkholes, size from 1-2 m to 20-50 m in diameter, depth varies from 0.5-2 m to 15-20 m, sometimes filled with water

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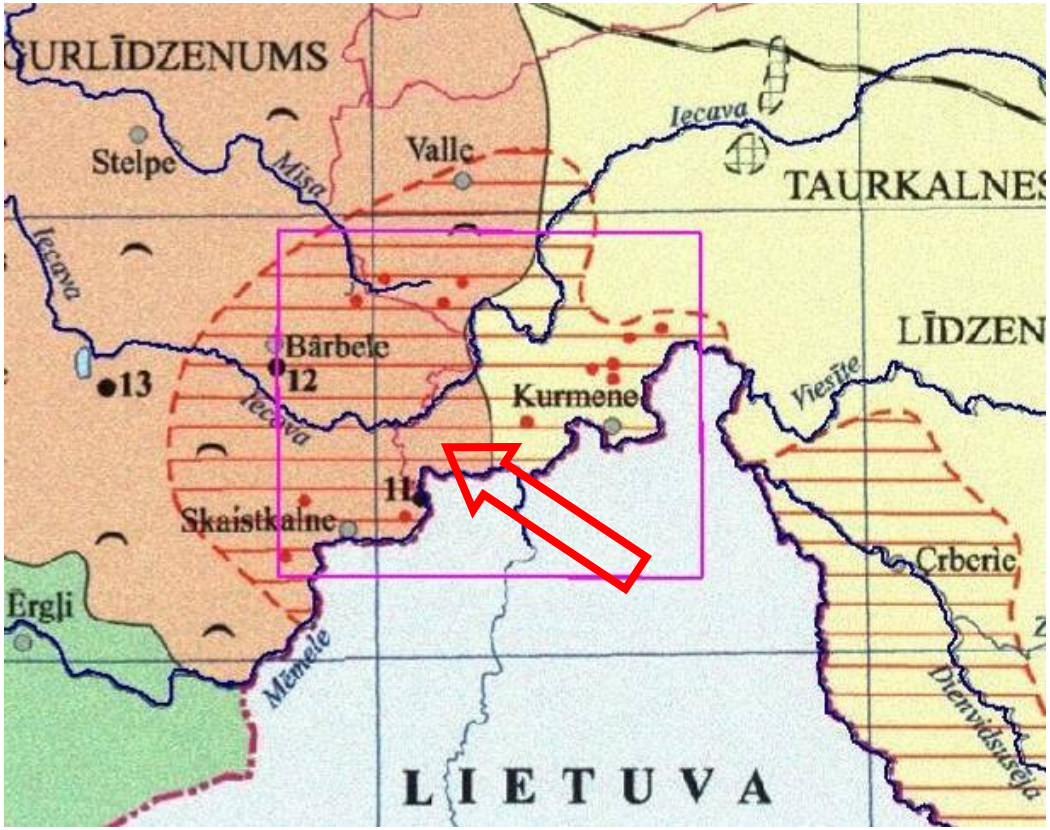
# Study area

- Skaitkalne karst area is located at the southern border of Latvia
- Northern border – Iecava River
- Southern border – Memele River
- Shortest distance between the rivers – 2-3 km
- Earlier studies of E. Klivs (Narbutas *et al*. 2003) showed that there is an underground hydraulic connection between Iecava and Memele Rivers

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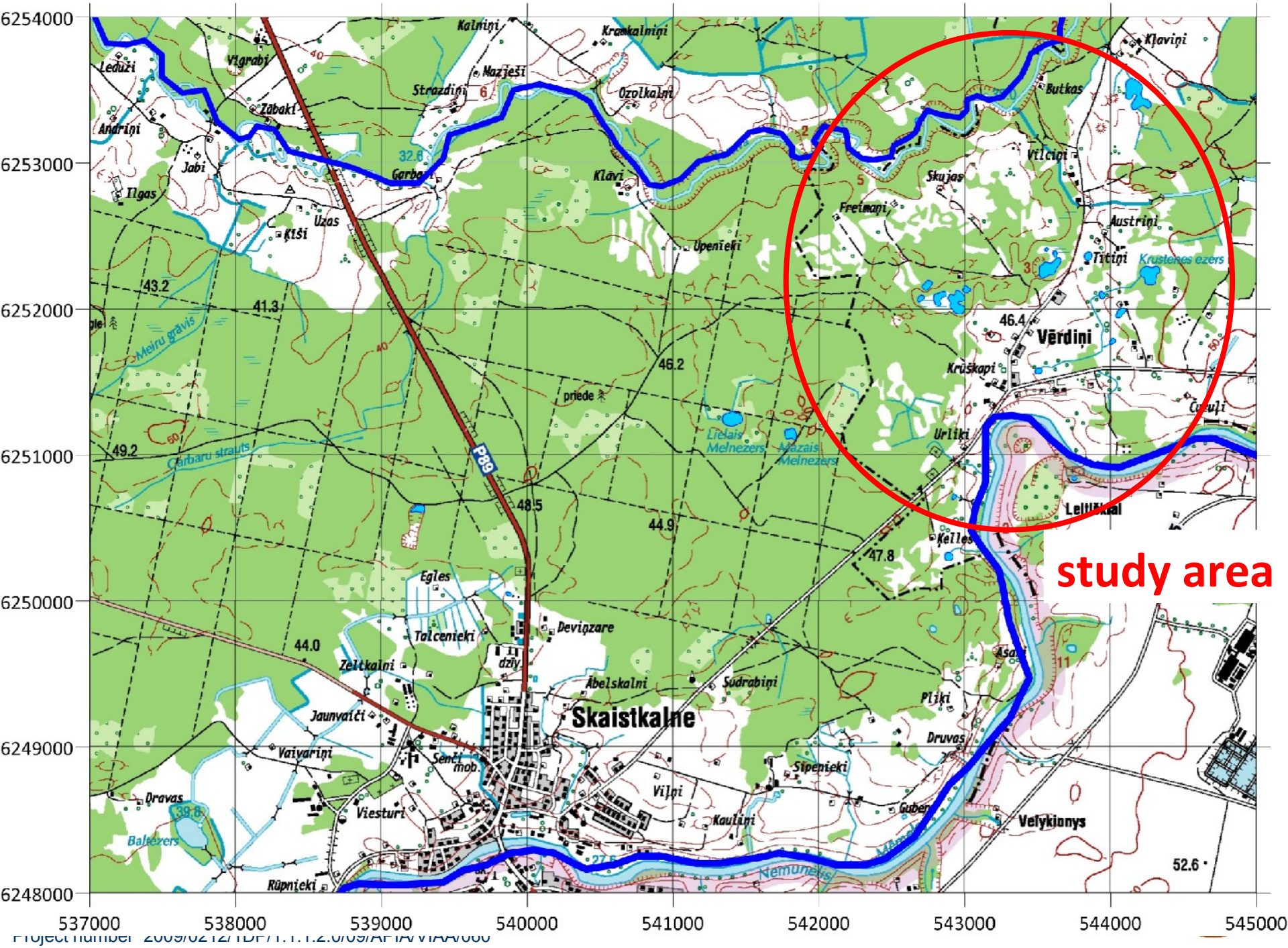
study area
Skaistkalne
Vērdiņi
Velykionys
Lelūzkal
Melnezers
Krustenes ezers
Nemunelis
BalteZers
Garbaru strauts
Melnu gravis
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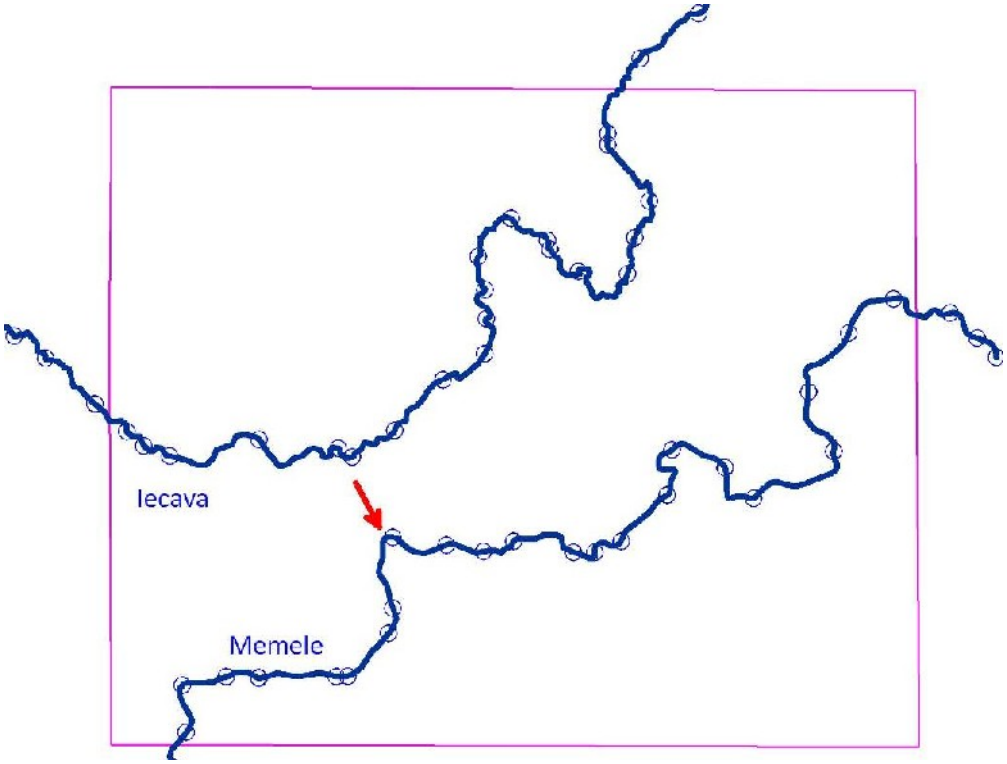
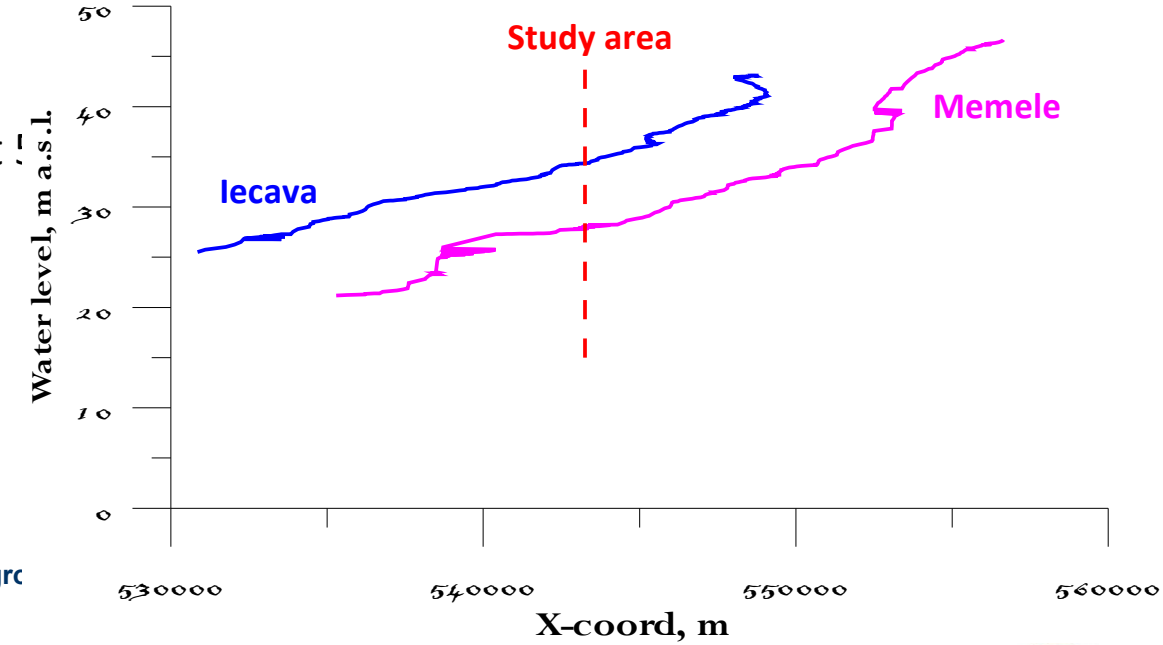
# Hydrology

- Iecava River:
  - water level 25,5-43,1 m a.s.l.
  - WL at study area 34,1 m a.s.l.
  - flow gradient 0,5 m/km
- Memele River:
  - water level 21,2-46,6 m a.s.l.
  - WL at study area 28,2 m a.s.l.
  - flow gradient 0,5 m/km
- constant difference in WL about 5-7 m

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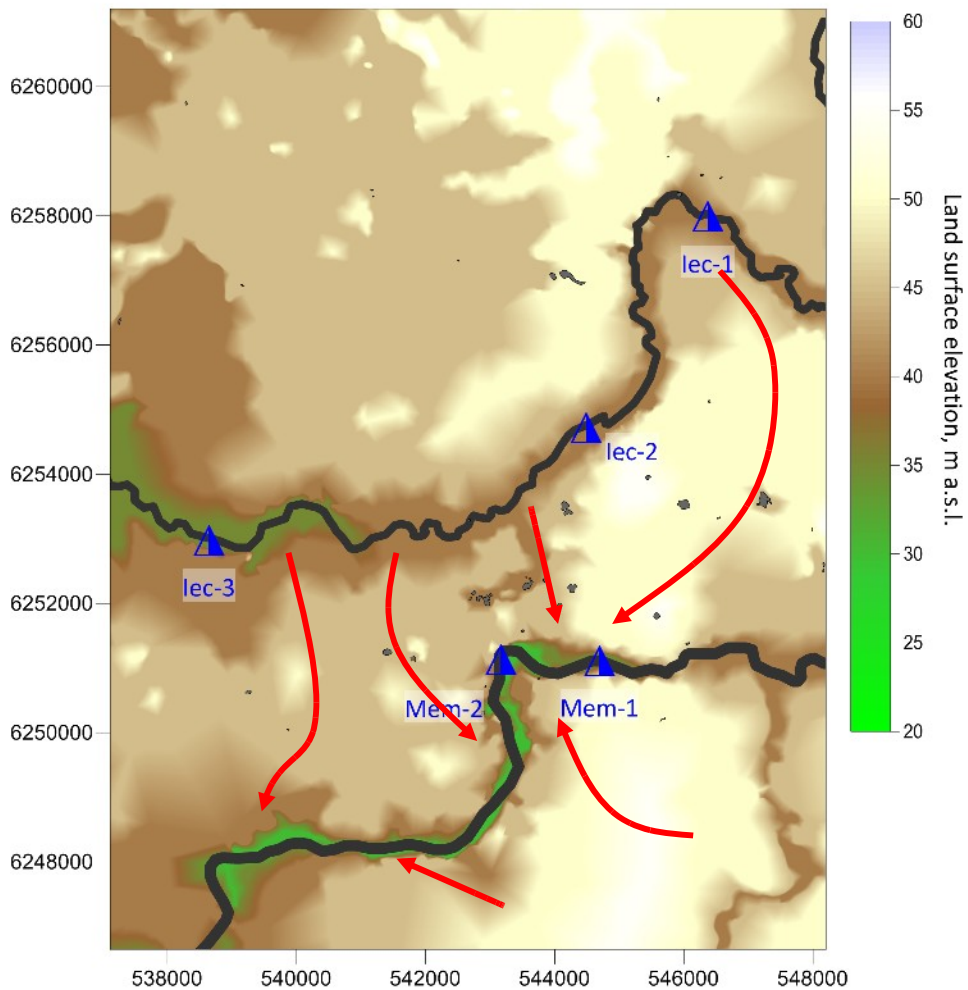
# Discharge

| Post | Q, $m^3/s$ | Q, $10^3$ $m^3/day$ | dQ, $10^3$ $m^3/day$ |
|---|---|---|---|
| Iec-1 | 1,68 | 145 | |
| Iec-2 | 1,54 | 133 | -12 |
| Iec-3 | 1,42 | 123 | -10 |
| Mem-1 | 5,93 | 512 | |
| Mem-2 | 22,48 | 1942 | +1430 |

- Iecava River loses 7-8 % of water between points 1-2 and 2-3
- Significant water discharge increase in Memele River in ~1 km stretch between points 1 and 2

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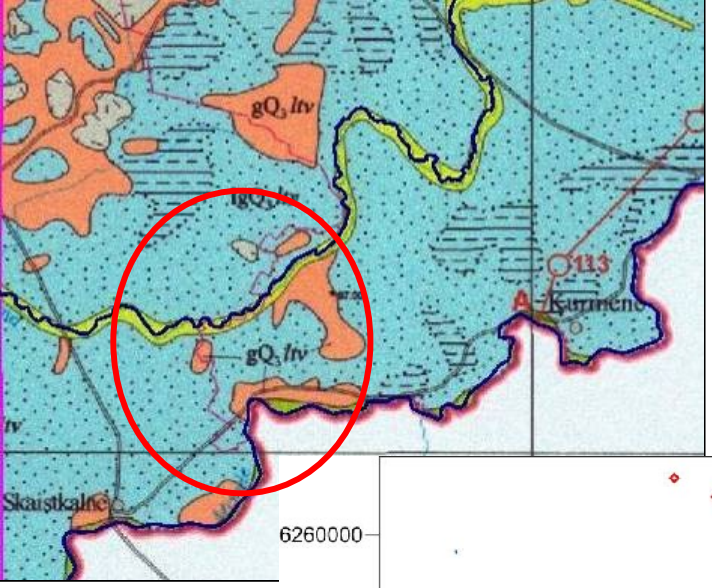
# Geology


gQ3 ltv
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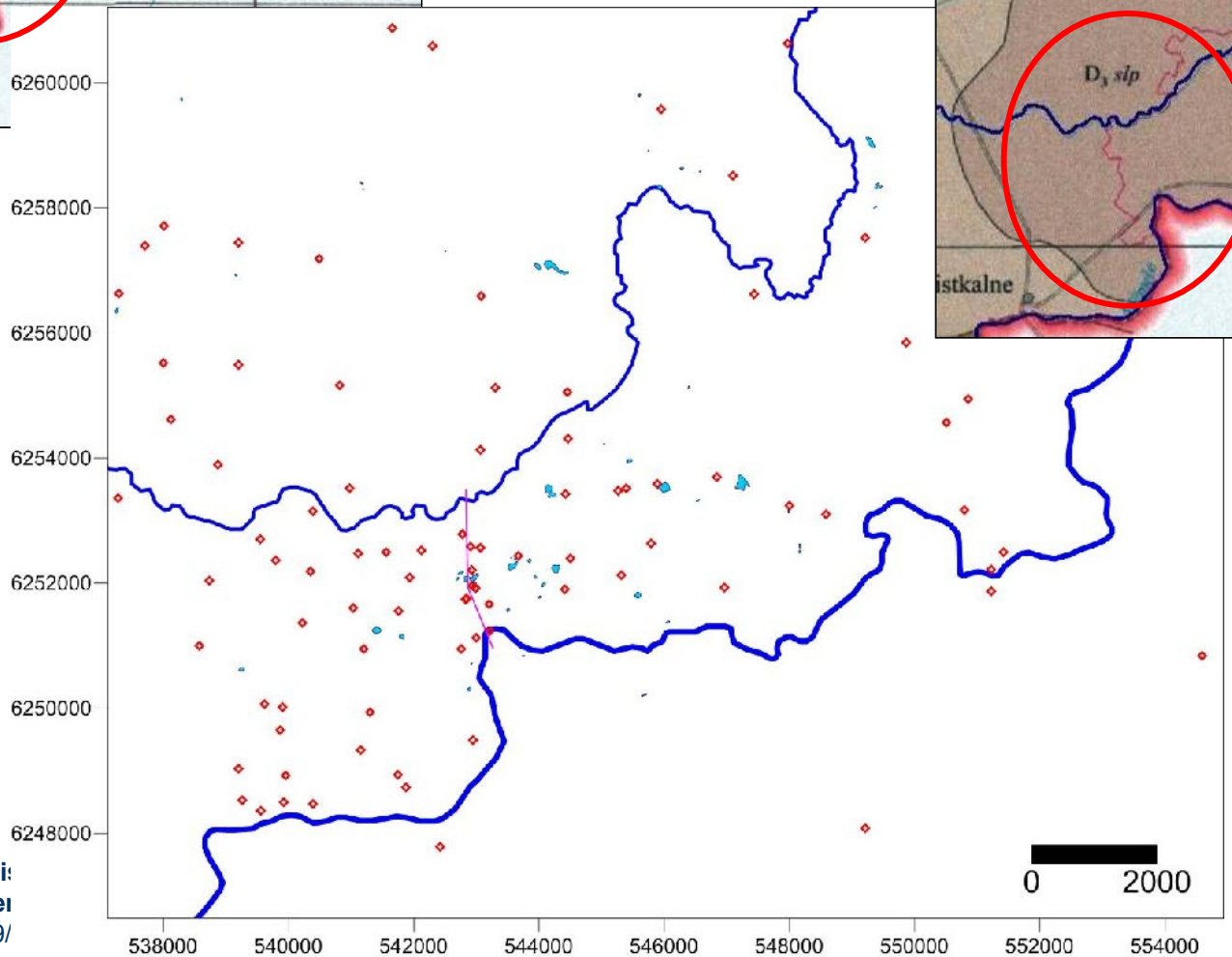
Kurmene
Skaistkalne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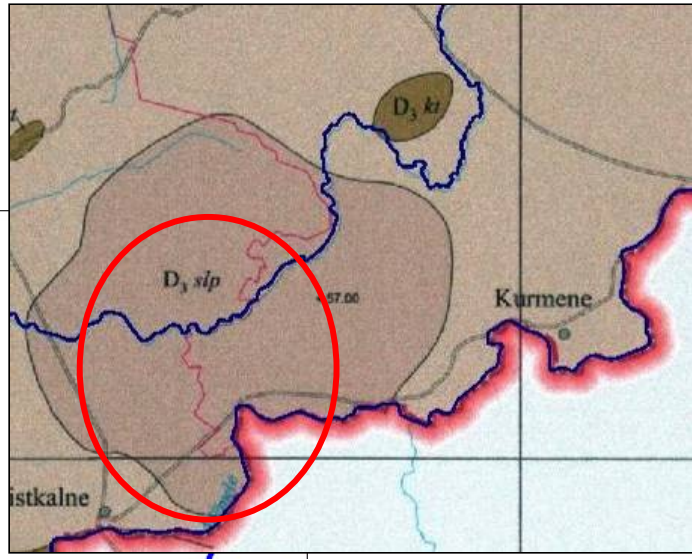
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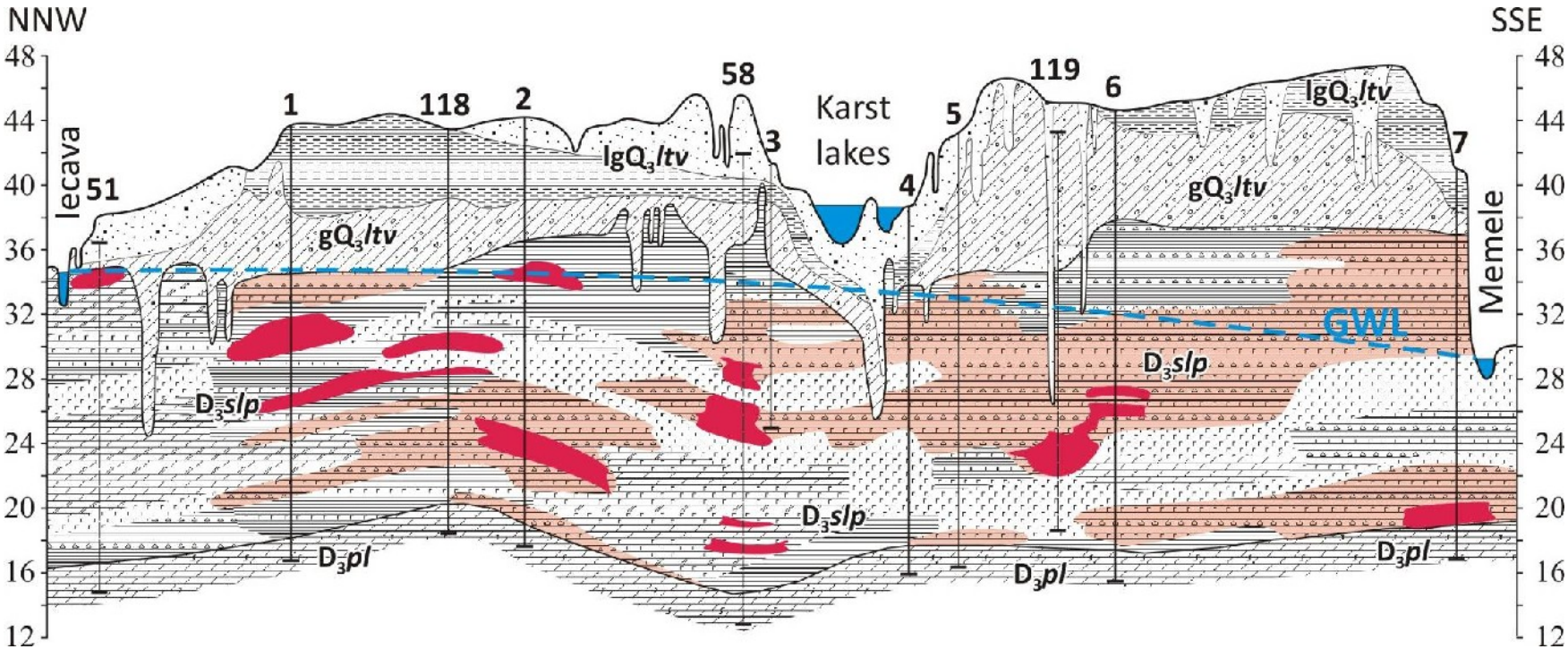
Kurmene
istkalne

# Geological structure




- ($lgQ_3ltv$) glaciolacustrine deposits - sand, fine, silty (0-5 m) and clay, silty clay, sandy clay (0-5 m)
- ($gQ_3ltv$) Weichselian (Latvia) Formation glacigene deposits – till loam with gravel and pebbles (1-10 m)
- ($D_3slp$) Upper Devonian Salaspils Formation – carbonatic clay, gypsum, dolomite, dolomite marle (15-20 m)
- ($D_3pl$) Upper Devonian Plavinas Formation – dolomite, with fractures, clayey dolomite (20-25 m)

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# Study tasks and methods

- **Tracer test**
  - fluorescine dye 1 kg
  - inserted in Iecava River, occurence of tracer observed in possible discharge sites
- **Water pH, EC, t° measurements**
  - WTW pH315 and LF330 handheld microprocessors, SenTix41, TetraCon325 electrodes
  - measurements made in late autumn 2008 and summer 2010
  - measurement points located in Iecava and Memele Rivers and karst lakes
- **Surface water sampling**
  - samples taken late autumn 2008 and summer 2010
  - sampling sites – Iecava River, Memele River, karst lakes, Skaistkalne spring
- **Groundwater sampling (summer 2010)**
  - groundwater monitoring wells in a profile were used (3 in Q and 3 in D3slp)
  - wells were purged, samples taken from fresh water, flowing to the wells
  - water level measurements with electric water level meter KLL30
  - water pH, EC, t° measurements in the pumped water
- **Chemical analysis of water samples**
  - late autumn 2008: sulphates, calcium, magnesium
  - summer 2010: major ions ($SO_4^{2-}$, $HCO_3^-$, $Cl^-$, $Ca^{2+}$, $Mg^{2+}$, $Na^+$, $K^+$)
- **Numerical modeling**
  - to analyse groundwater flow, hydraulic connection of Iecava and Memele rivers
  - to simulate effect of low flow and high flow in rivers on groundwater levels

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# Tracer test

- 06/12/2008 at 14:30 tracer fluorescin $C_{20}H_{12}O_5$ applied in Iecava River

- 07/12/2008 at 12:40 observed in karst lakes (from side and from bottom in the middle of the lake, weak colour)

- 09/12/2008 at 8 am observed in Memele River bank as “springs” (intensive colour)

- 11/12/2008 at ~9 am at Skaistkalne spring, colour disappeared before 11 am

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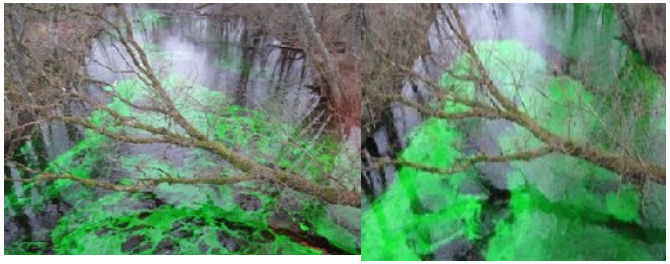

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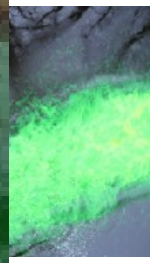

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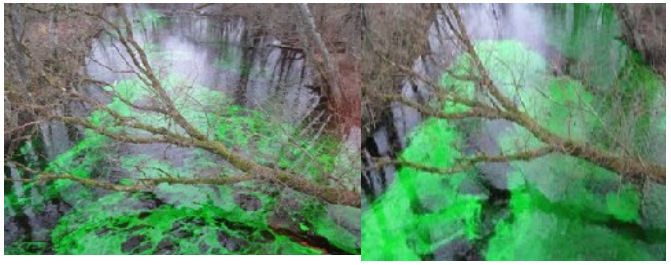

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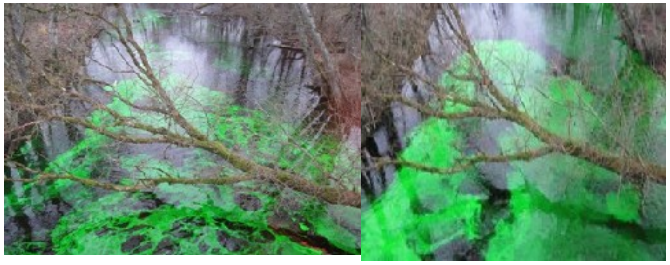

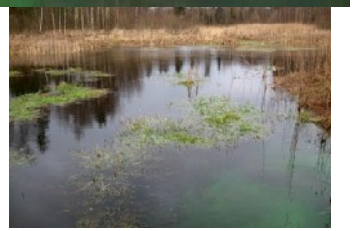

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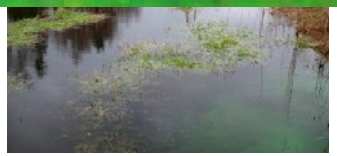

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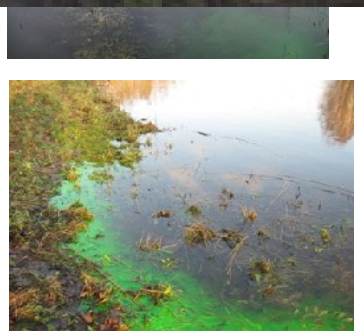

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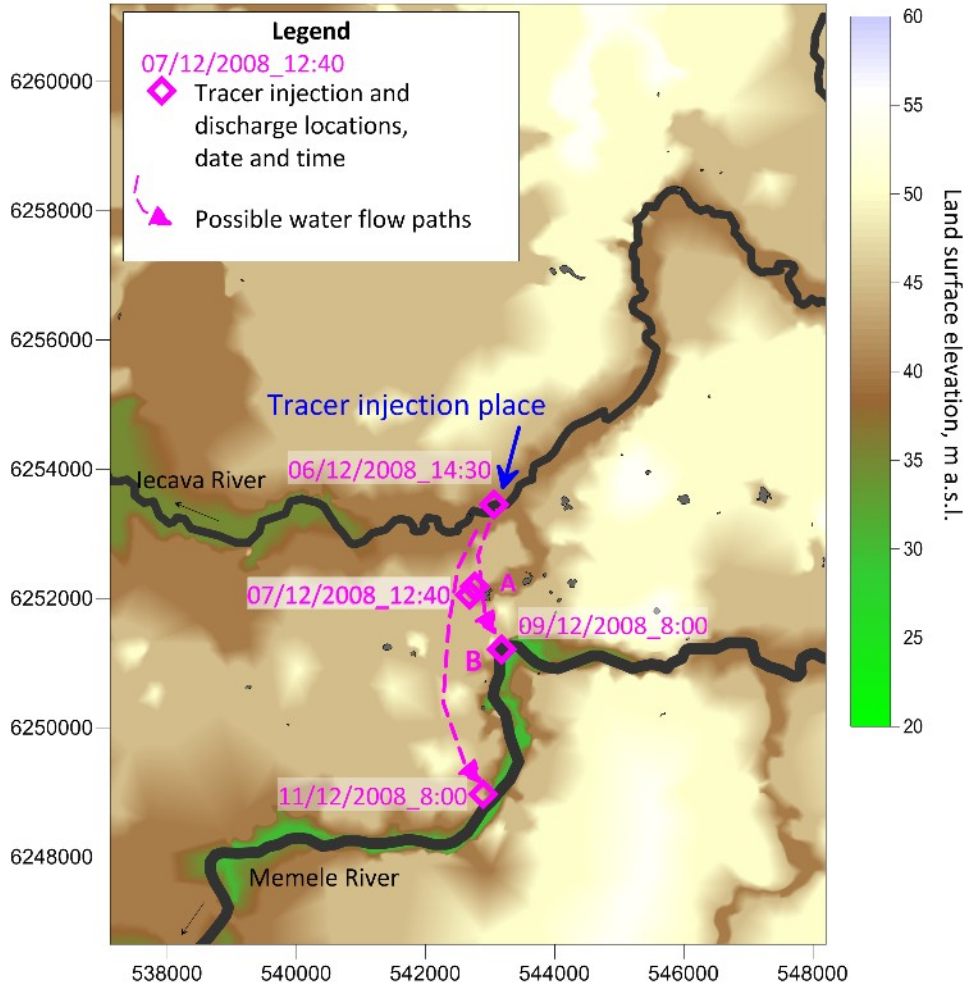
# Tracer test

- Tracer travel time and velocity calculated

$$v = \frac{s}{t}$$

| | Distance, m | Travel time, days | Tracer velocity, m/d |
|---|---|---|---|
| | *s* | *t* | *v* |
| Iecava | 0 | 0 | 0 |
| Karst lakes | 1200 | 0,93 | 1290 |
| Memele | 2200 | 2,75 | 800 |

- average water flow velocity is 1050 m/day

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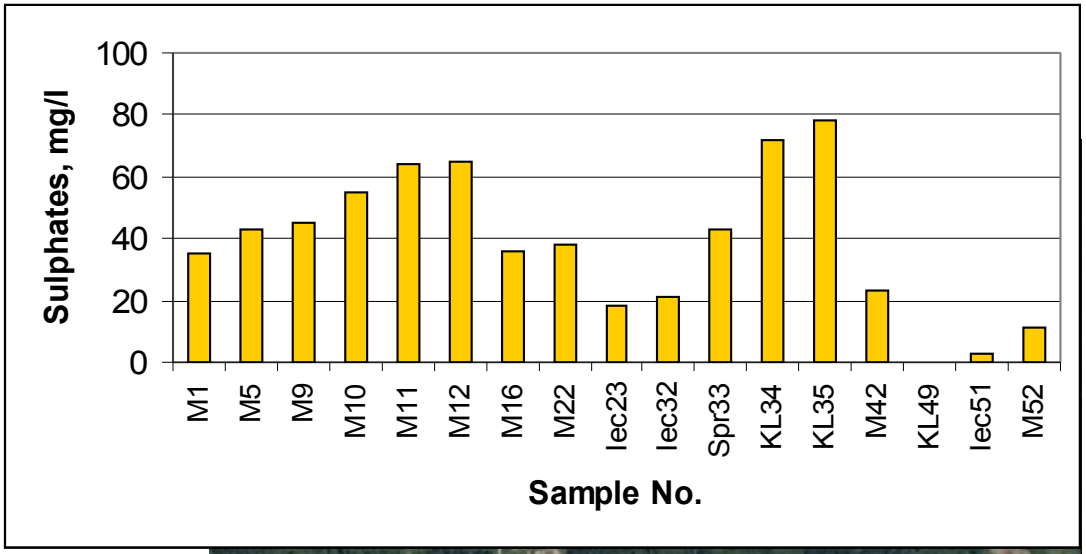
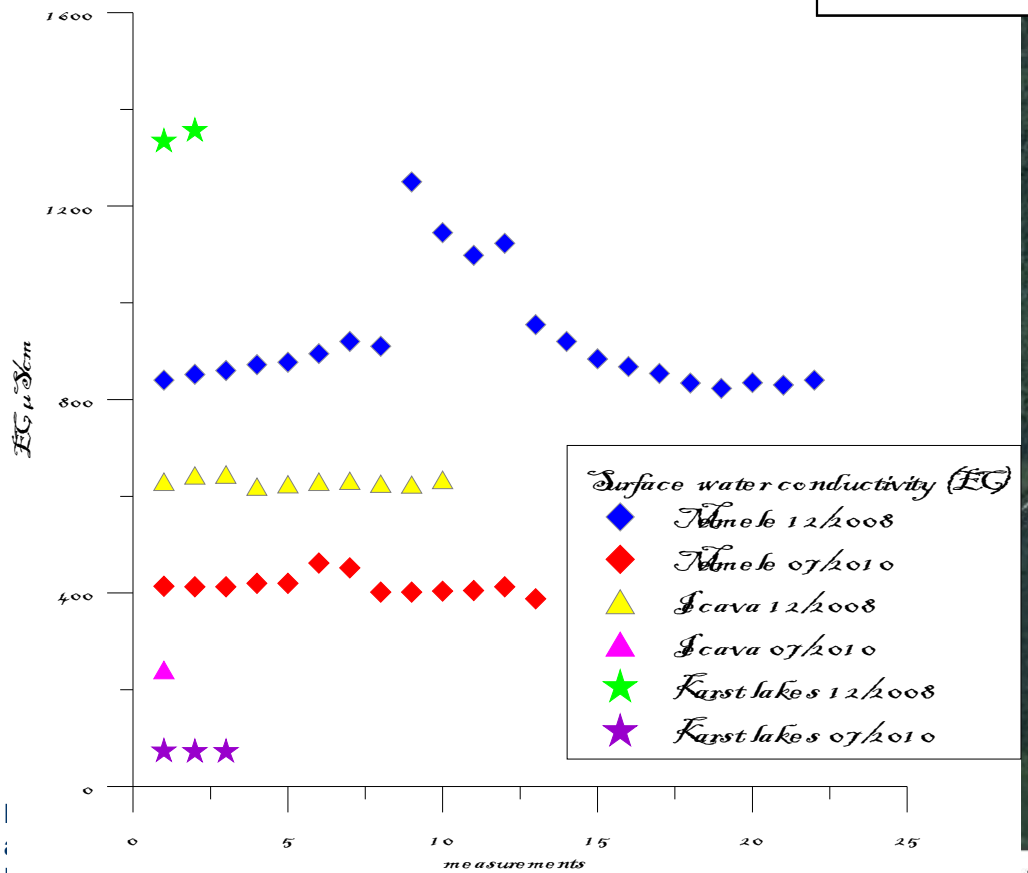
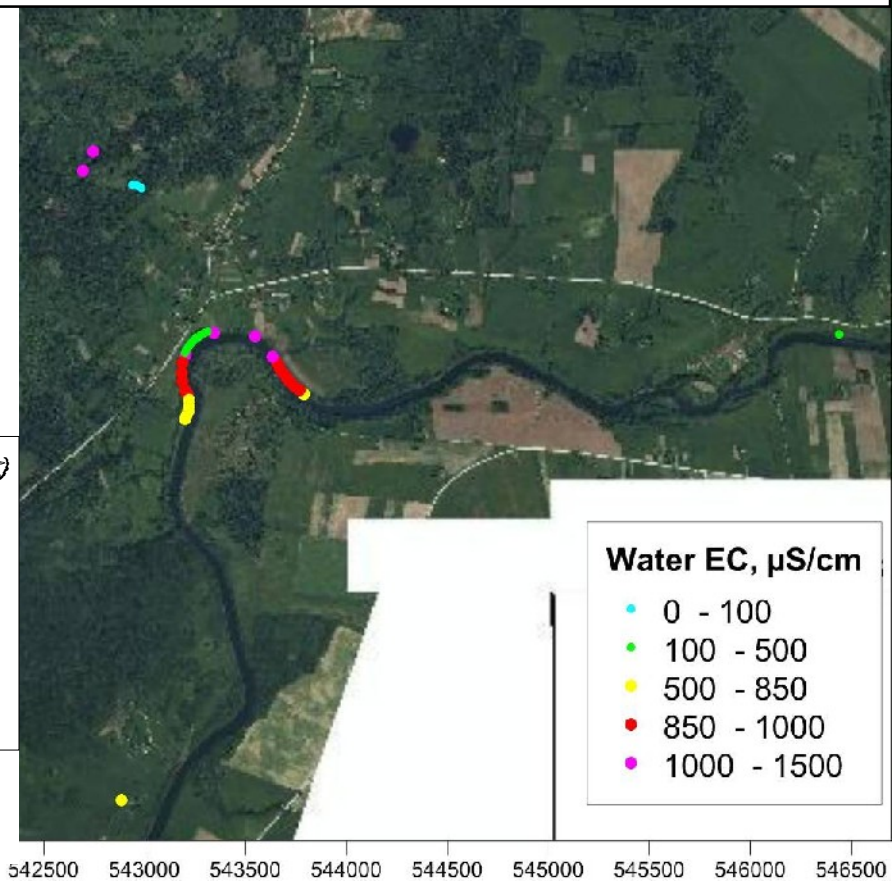
# Surface water chemistry

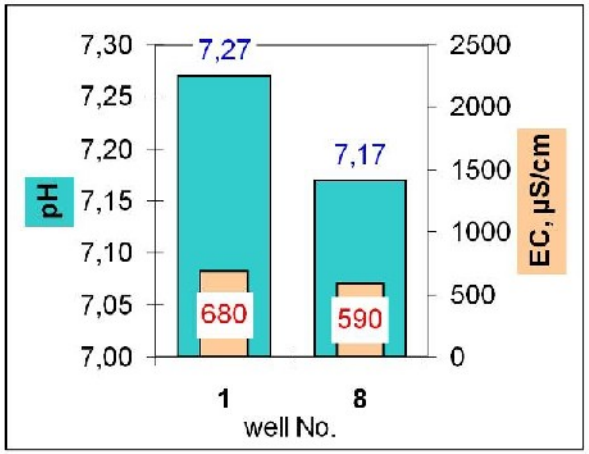
- 52 measurements
- 17 samples

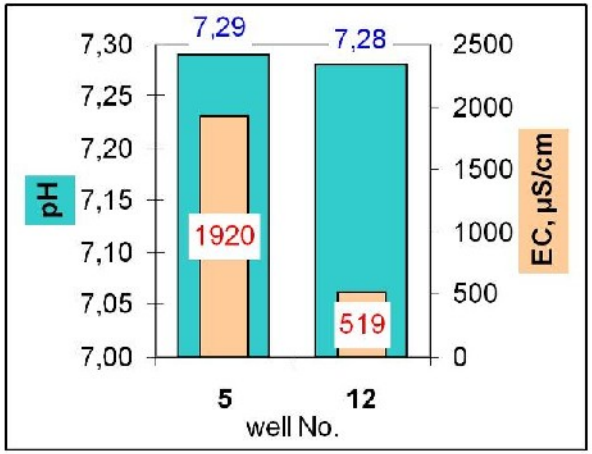


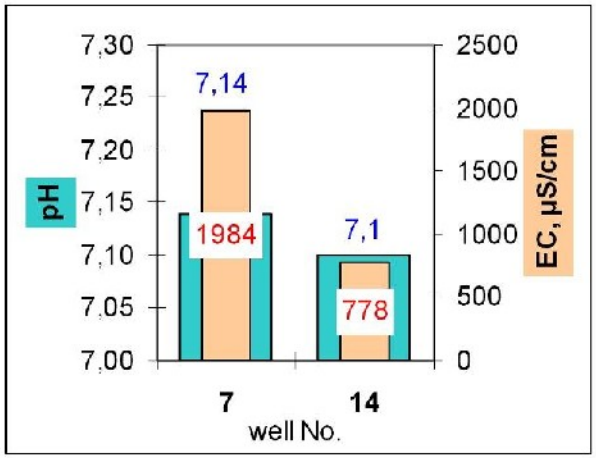



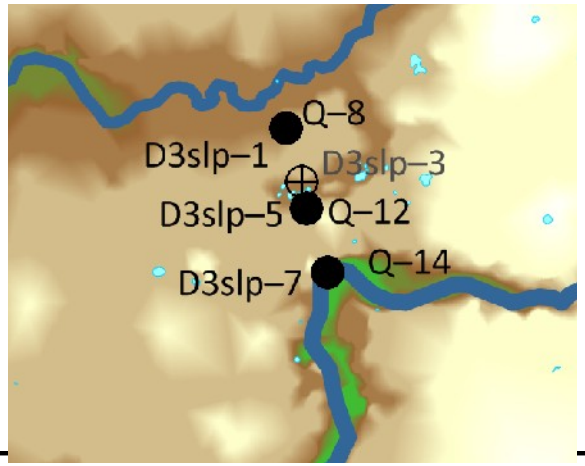
# Ground-water pH, EC

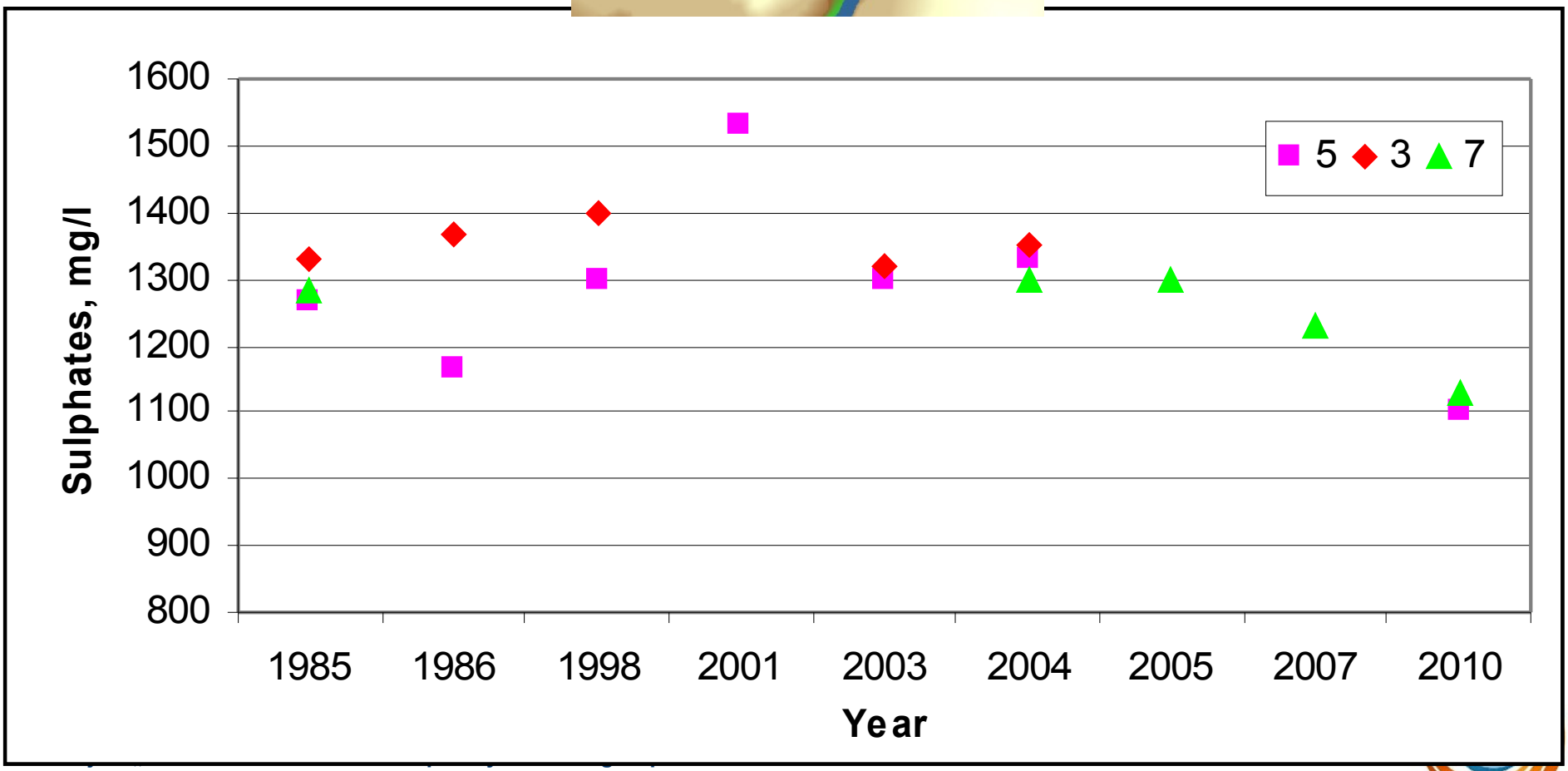



# Groundwater chemistry

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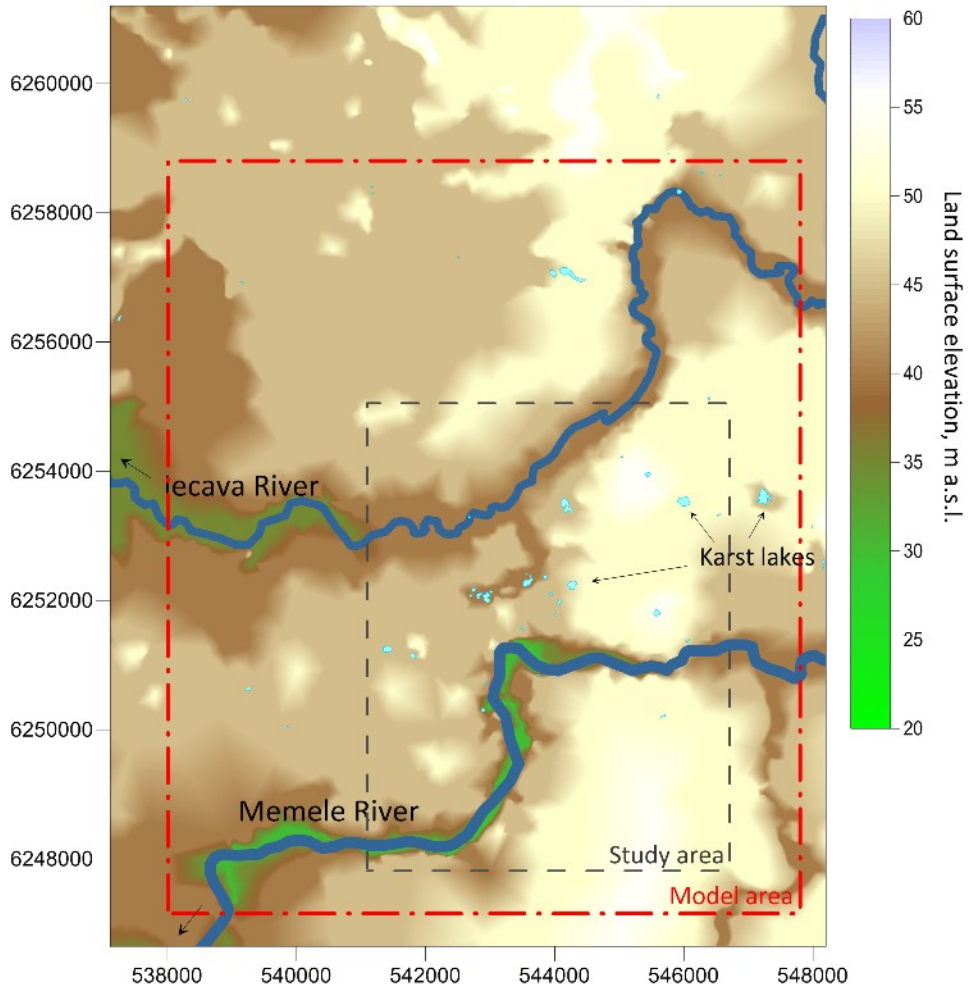
# Numerical modelling of groundwater flow

- Tasks:
  - to analyse groundwater flow, hydraulic connection of Iecava and Memele rivers
  - to simulate effect of low flow and high flow in rivers on groundwater levels,
  - to check the validity of Darcy's law to describe the groundwater flow in the karst environment

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# Model structure and lithology

- Modela area 120 $km^2$
- Latitude is 10 km and longitude is 12 km.
- Regular mesh step 75×75 meters based on cartographic map data
- Further refined with irregular point cloud at areas of river valleys
- Vertical resolution based on the log resolution of about 0.5 meter
- 5 stratigraphic units are used
- 8 layers, including 2 confining layers are used

# Model data and methods

- Land surface elevation data - cartographic map scale 1:50,000 and 1:10,000.
- Geological data (72 boreholes) - Latvian Environment, Geology and Meteorology Centre (LVGMC) borehole database.
- Model layers generated in *MeshEditor* (Bethers *et al* 1998a) from borehole data with kriging algorithm and smoothed for reduction of interpolation uncertainty.
- Model layers combined into one structure using *HiFiGeo* software (Bethers *et al* 1998b, PAIC 2002).
- Geologic structure corrected by comparing three cross sections from generated model and ones made based on geophysical methods earlier (Tracevska *et al* 1986).

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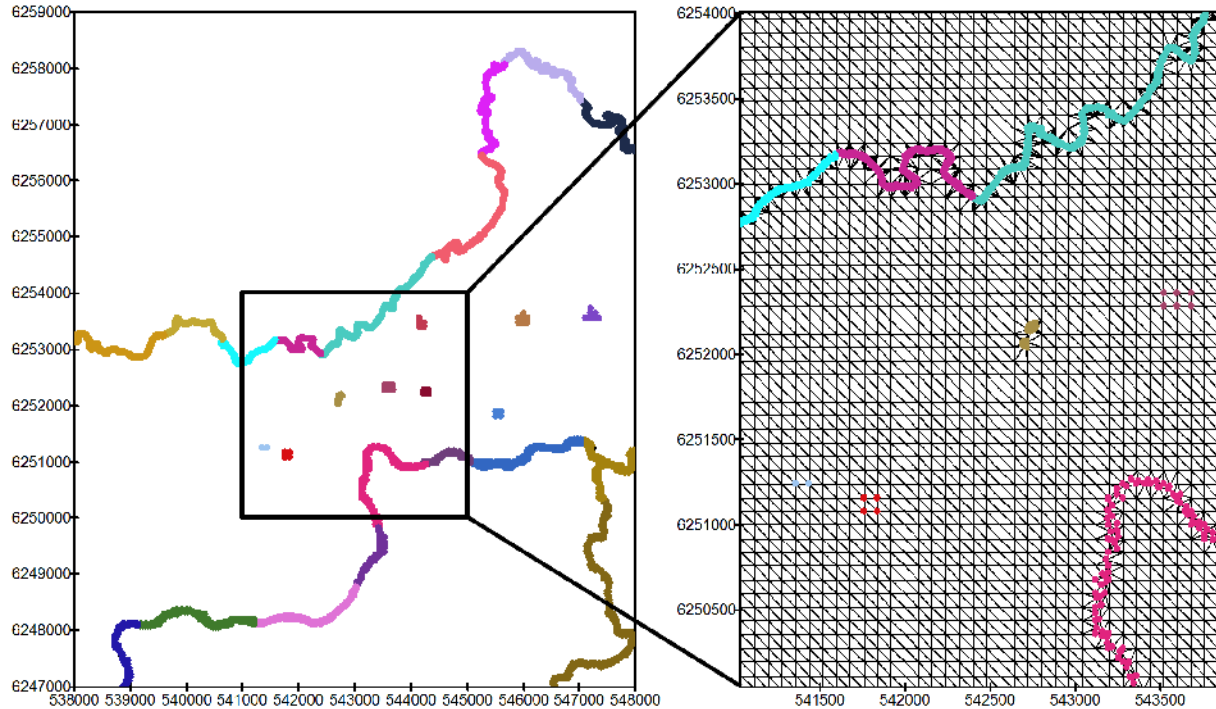
# Boundary conditions




- Boundary conditions set for Iecava and Memele rivers and larger karst lakes, model margins and model surface:
  - Cauchy boundary conditions were set on every aquifer margins, with regional impact coefficient $\alpha = 0.6$
  - Constant head boundary condition was set to rivers and larger karst lakes
  - Recharge was set as 0.000005 mm/s on materials exposed to the ground surface
  - The low and high water conditions in rivers were simulated changing boundary conditions of the rivers:
    - –1 m from mean water level was applied for low water
    - +1 m – for high water, based on long-term data that average water level changes is 1,5-2 m (Pastors,1987).

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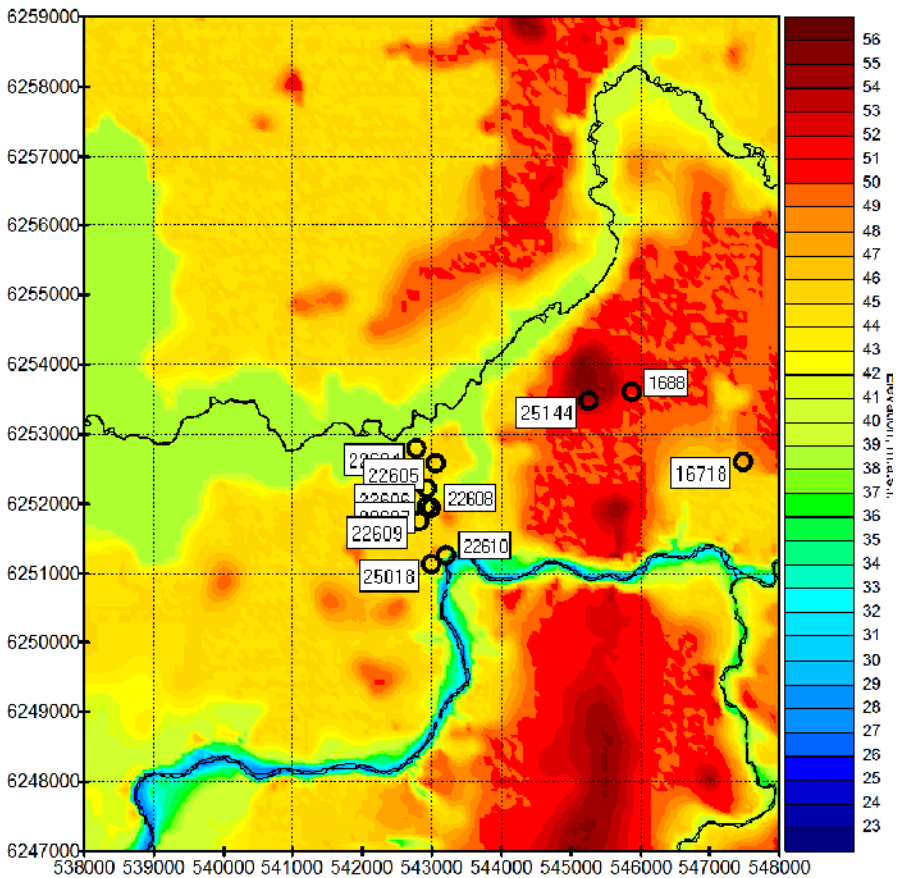
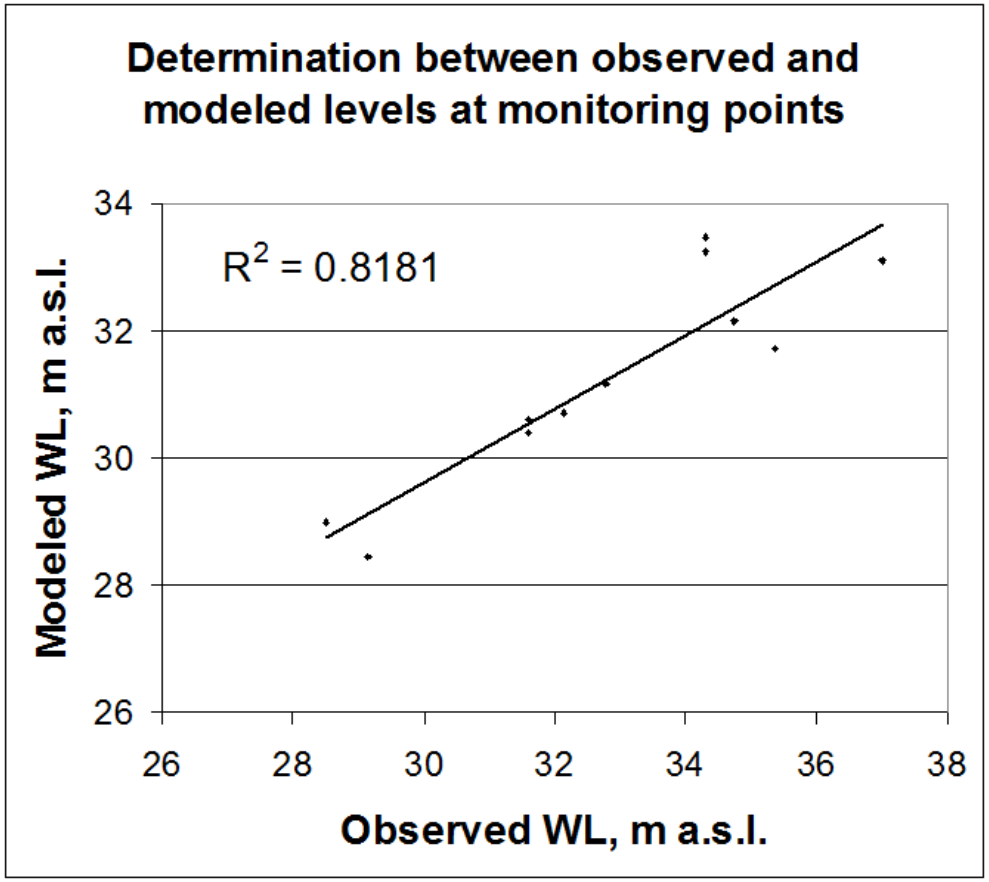
# Model calibration

- Calibrated for steady state conditions
- Calibration target - water level (WL) in monitoring wells



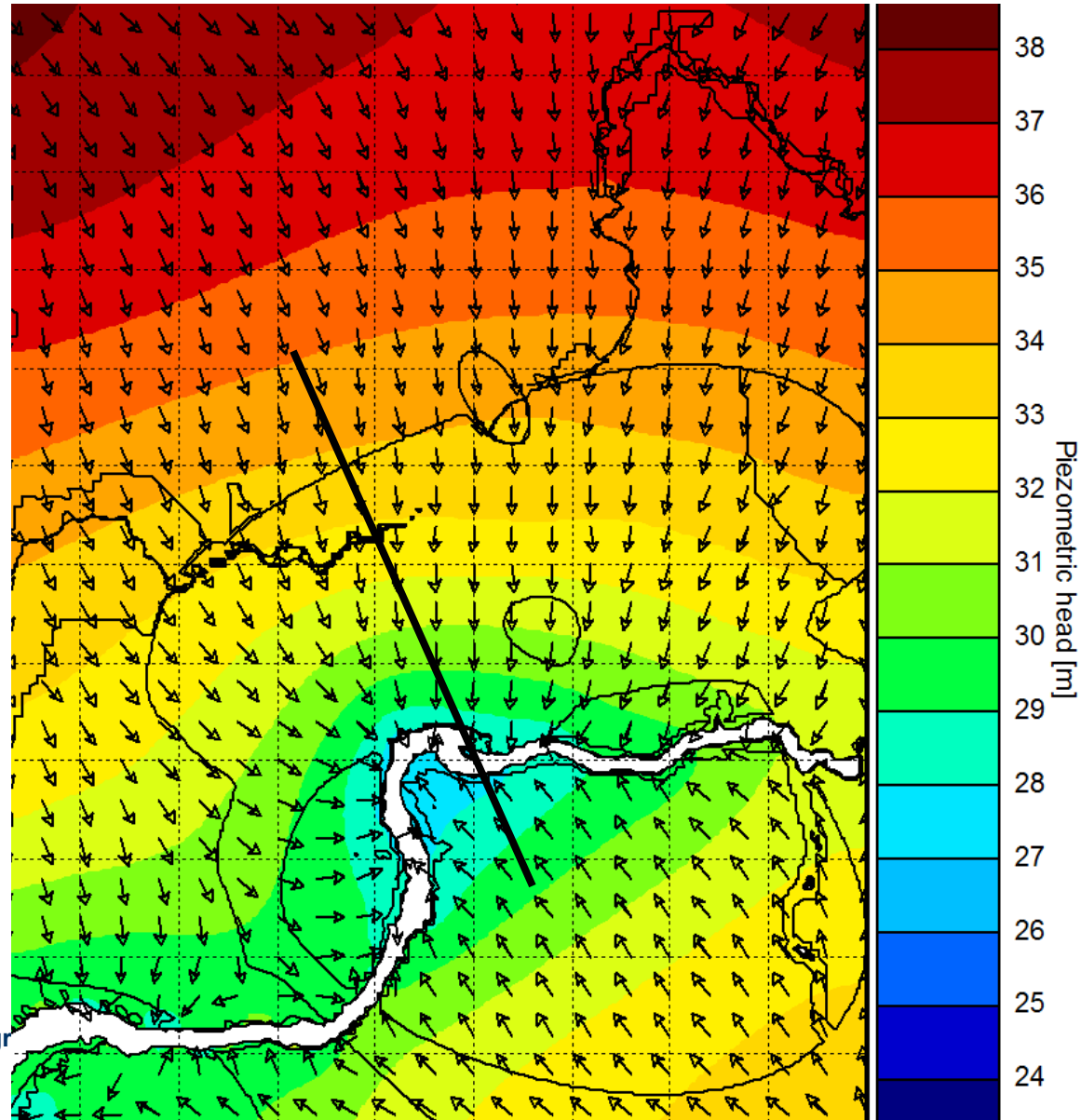
# Model sensitivity assessment

- Reduction of recharge – the greatest impact on water level

# Modelling results

section Z=35 m a.s.l.

- GW flow in $D_3$slp aquifer in the study area is directed to Memele River valley, the sub–regional sink of the upper aquifers

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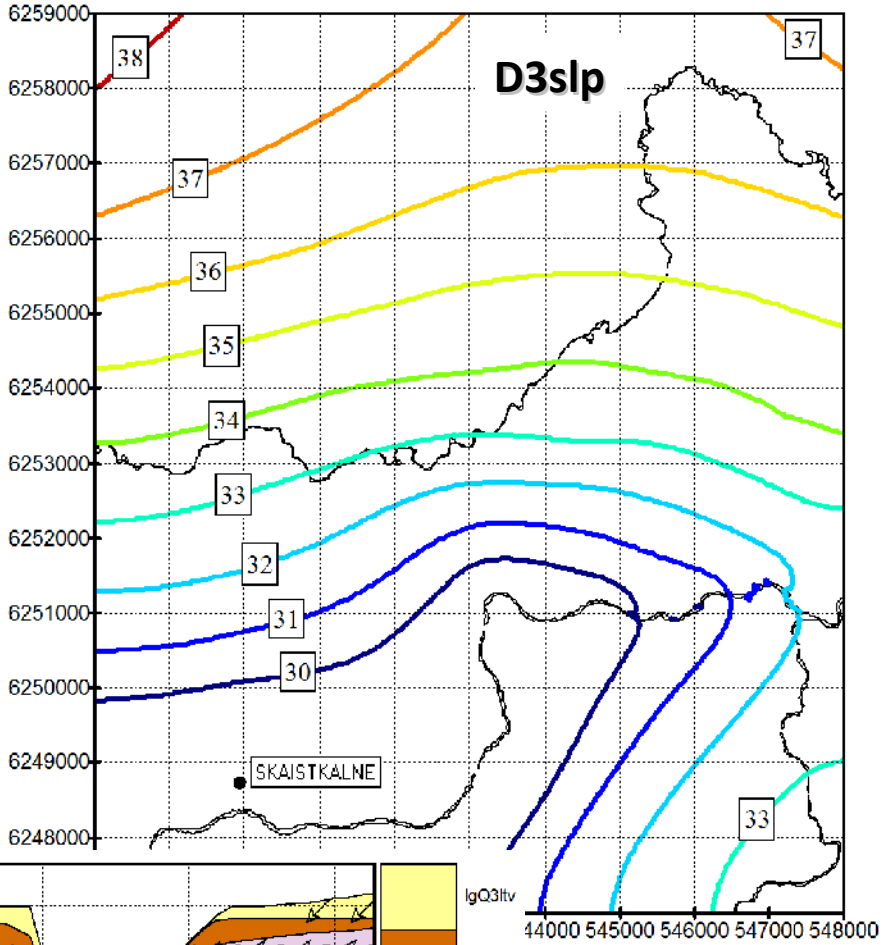
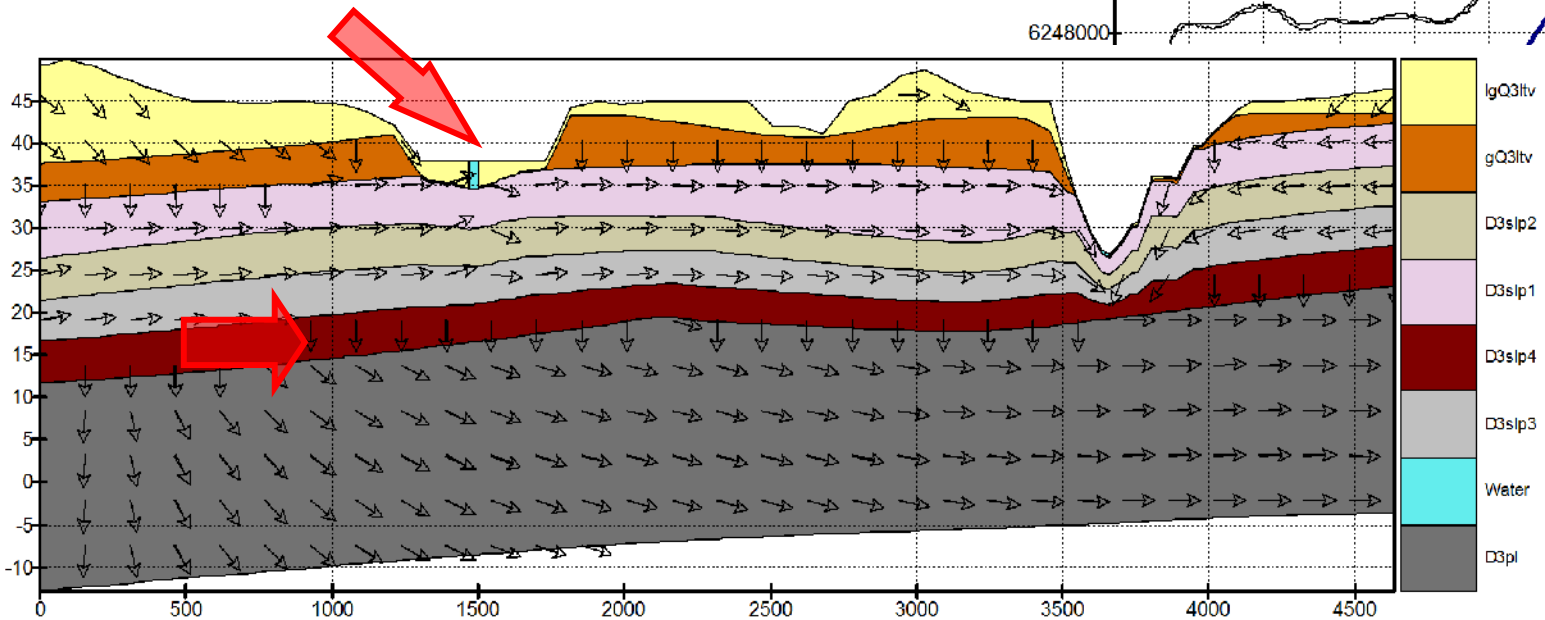
# Modelling results

- The Iecava River recharges the upper part of the Salaspils aquifer (cross-section), but it has insignificant effect on regional piezometric head distribution

- The aquitard between Salaspils and Plavinas aquifer is semi-confined and hydraulic connection between these two aquifers exists

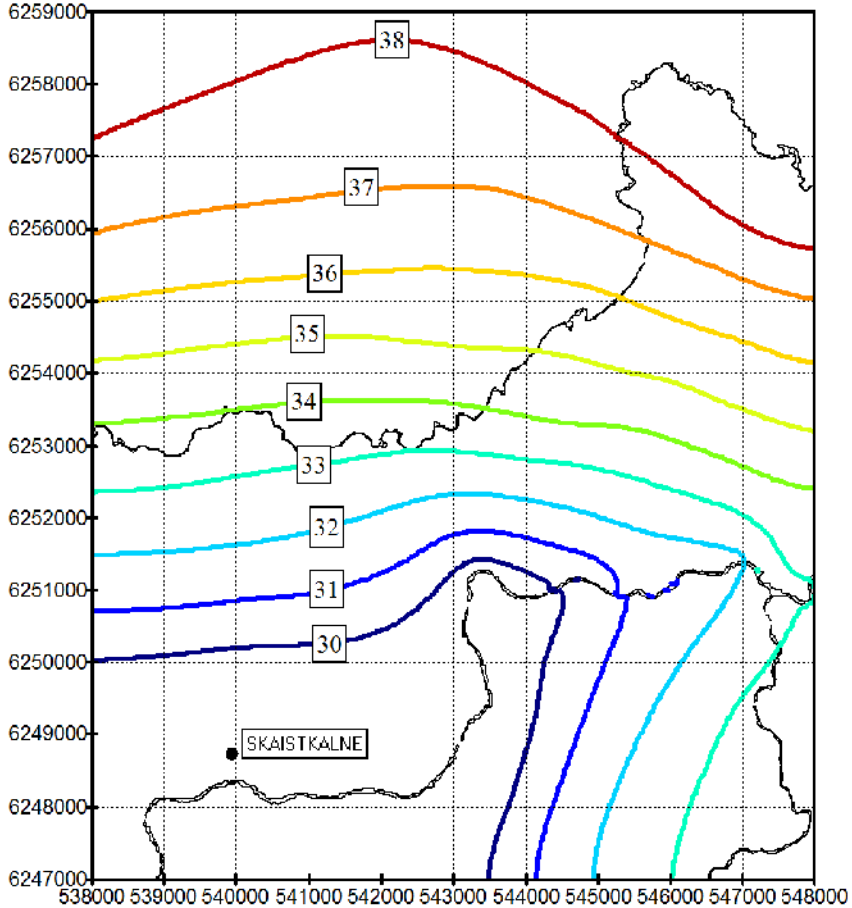


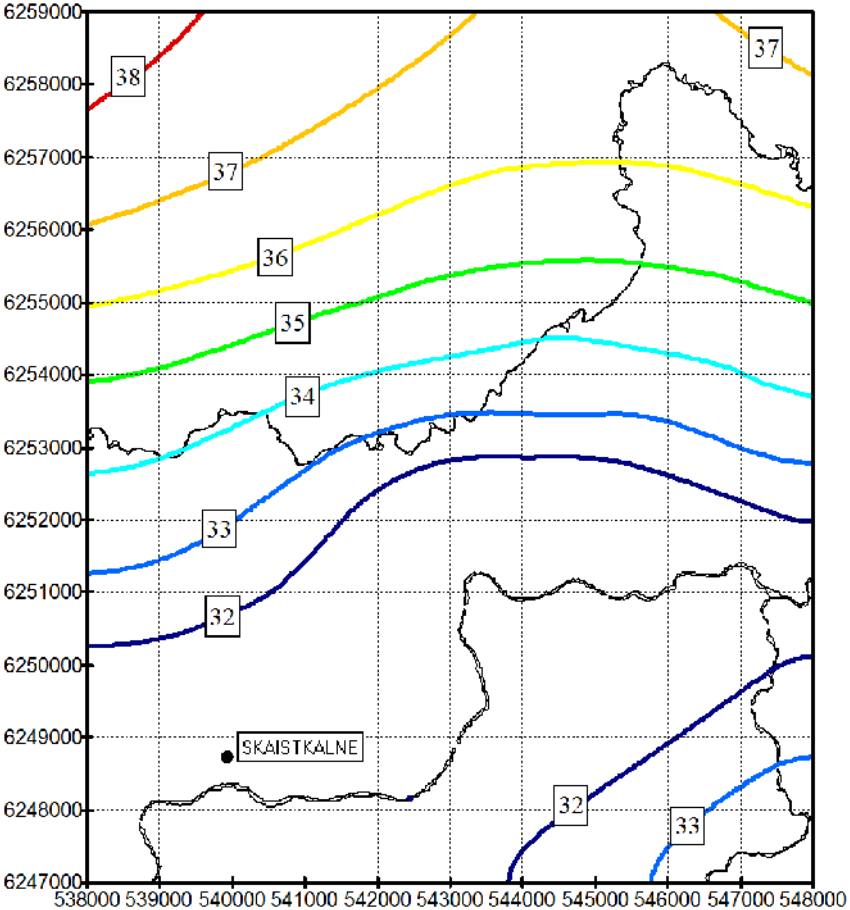
# Impact of seasonal river level changes

- During the high season the hydraulic gradient is larger and the groundwater flow is faster,
- At the low season the hydraulic gradient is smaller and the flow is slower

**High season, +1 m from mean WL**




**Low season, -1 m from mean WL**



# Groundwater hydraulics

- Hydraulic gradient between the rivers

$$i = \frac{H_1 - H_2}{s}$$

| | WL (H), m a.s.l. | Distance (s), m | ΔH | i |
|---|---|---|---|---|
| Iecava | 34,1 | 0 | 5,9 | 0,0027 |
| Memele | 28,2 | 2200 | | |

- Darcy velocity of groundwater flow

$$v_r = ki$$

| | Hydraulic conductivity, m/d | Darcy velocity, m/day |
|---|---|---|
| | $k$ | $v_r$ |
| min | 30,6 | 0,09 |
| max | 100 | 0,28 |
| aver. | 60 | 0,17 |

- Groundwater flow velocity (active/effective porosity of dolomites and gypsum ~0,3)

$$v = \frac{v_r}{n_a}$$

| | Darcy velocity, m/d | GW flow velocity, m/d |
|---|---|---|
| | $v_r$ | $v$ |
| min | 0,09 | 0,29 |
| max | 0,28 | 0,93 |
| aver. | 0,17 | 0,56 |

- The calculated groundwater flow velocity based on tracer test results is great 800–1290 m/day, in average 1050 m/day.

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Project number 2009/0212/1DP/1.1.1.2.0/09/APIA/VIAA/060

# Conclusions

- Tracer test proved that there is underground hydraulic connection between Iecava and Memele rivers.
- Iecava River discharge loses 10–25% from the river discharge upstream karts area. But Memele River discharge increases for 200% compared to the upstream discharge due to the flow from Iecava River and massive groundwater inflow, characterised by the increased sulphate values in river's water.
- Huge difference between calculated (0,3-1 m/d) and observed (800–1300 m/d) water flow velocity shows that large karst conduits should be developed in Iecava – Memele water divide area. Therefore another numerical model should be developed for proper representation of karst environment including turbulent flow in the large conduits and dual porosity effects of the geological strata.
- Numerical model shows that groundwater discharge to Memele River should vary by seasons. Little discharge is characteristic for high season and intensive discharge for low season.

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# Thanks!

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