Genesis of economic relevant fresh groundwater resources in Pleistocene & Neogene aquifers in Nam Dinh (Red River Delta, Vietnam).

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Regional Frame & Background of Study

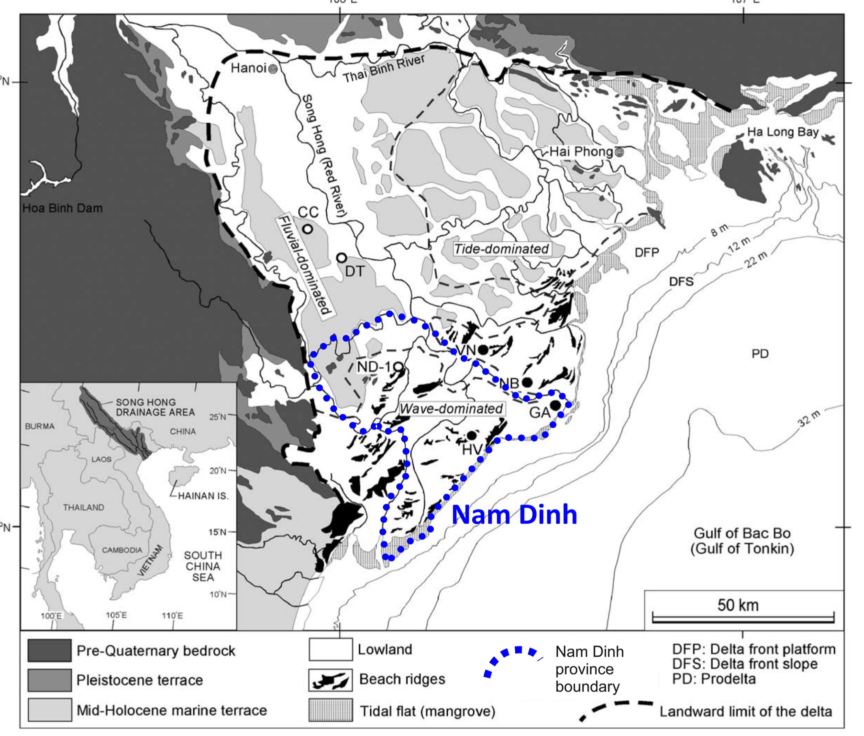

Fig. 1: Geological scetch map with geomorphology and topography of the Red River Delta (mod. after Tanabe et al. 2006), blue line indicates Nam

In Nam Dinh Province (Southern Red River Delta, Vietnam, Fig. 1), low saline pore water has been observed locally in unconsolidated confined Pleistocene (qp) and Neogene (n) aquifers. This high quality groundwater (GW) resource persists in close vicinity to brackish to saline pore water in the North and West Red River area (Fig. 2). Since the 1990ies, ongoing overexploitation of the fresh groundwater results in decreasing GW heads up to 0.6 m/a and development of a regional abstraction cone.

This study is a part of a comprehensive GW resources assessment. It focuses on 3D-distribution and genesis of fresh and saline pore water and provides recommendations for local GW management.

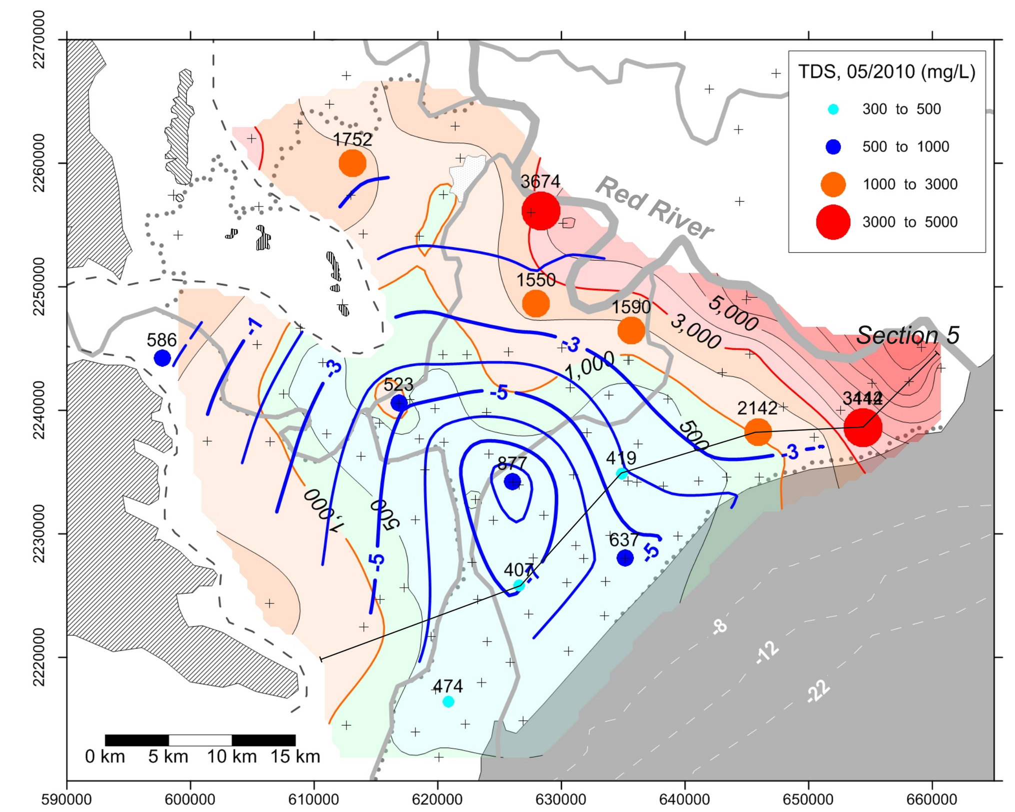

Fig. 2: Salinity (TDS) distribution in Lower Pleistocene (qp_1) confined aquifer, comparing own (scaled points, n=13, 05/2010) with archive data ("+", n=128, 1999-2000, interpolated using standard kriging). GW heads (blue, 05/2010) delineate a regional abstraction cone, resulting from qp_1 overexploitiation in the low saline area. Black line marks cross section 5 (Fig. 6, Fig. 9).

Approach of Study

- Installation of GW monitoring network in Nam Dinh, comprising total 15 stations and 30 wells, screened in Holocene (qh), Pleistocene (qp), Neogene (n) and Triassic (T) confined aquifers (Fig. 2)
- Studying origin, mixing and age of pore water of screened aquifers by applying hydrochemical & isotopic methods (δ^2H, $\delta^{18}O$, T, ^{14}C; Fig. 3, 4, 5)
- Establishing vertical salinity profiles based on induction well logging and pore water chemistry data (Fig. 6). Translating observed bulk formation conductivity data into pore water salinity.
- Evaluation of salinity diffusion in a quai-stagnant hydraulic environment using analytical modelling methods (FICK´s 2[nd] law, Fig. 8)
- Integrating results and conclusions into a conceptual system understanding (Fig. 9), quantification of relevant flow and transport processes.

Exploration of Fresh and Saline Pore Water in Unconsolidated and Confined Aquifers

Hydrochemical Fingerprinting

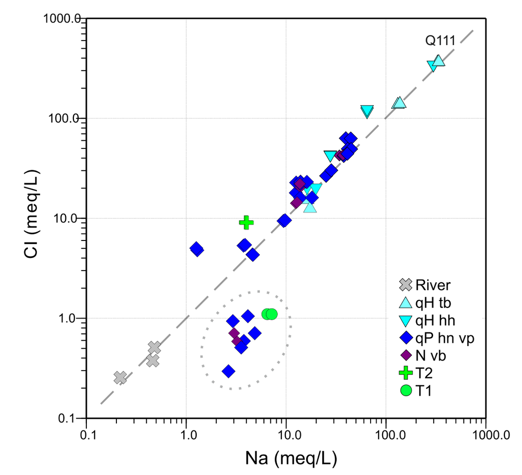

Fig. 3: Log. scatter plot of Na vs. Cl (meq/L), dashed line represents Na/Cl =1. Samples from qp, n in the center of low saline area form a distinct group with elevated Na/Cl, likely due to ion exchange processes in Ca-rich pore water.

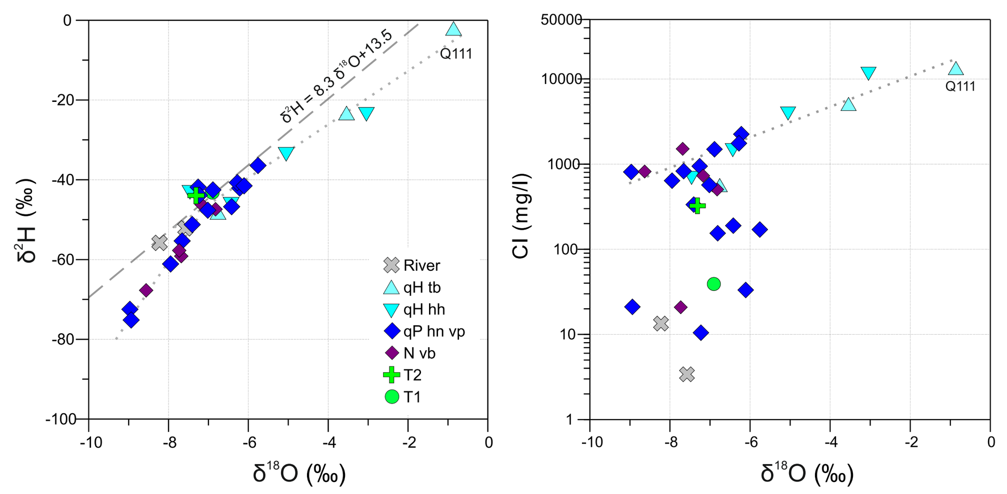

Fig. 4: δ^2H and Cl vs. $\delta^{18}O$ in Mai 2010 versus LMWL (dashed line, Larsen et al. 2008). Dotted line represents mixing line of fresh GW with (paleo-) sea water (Q111).

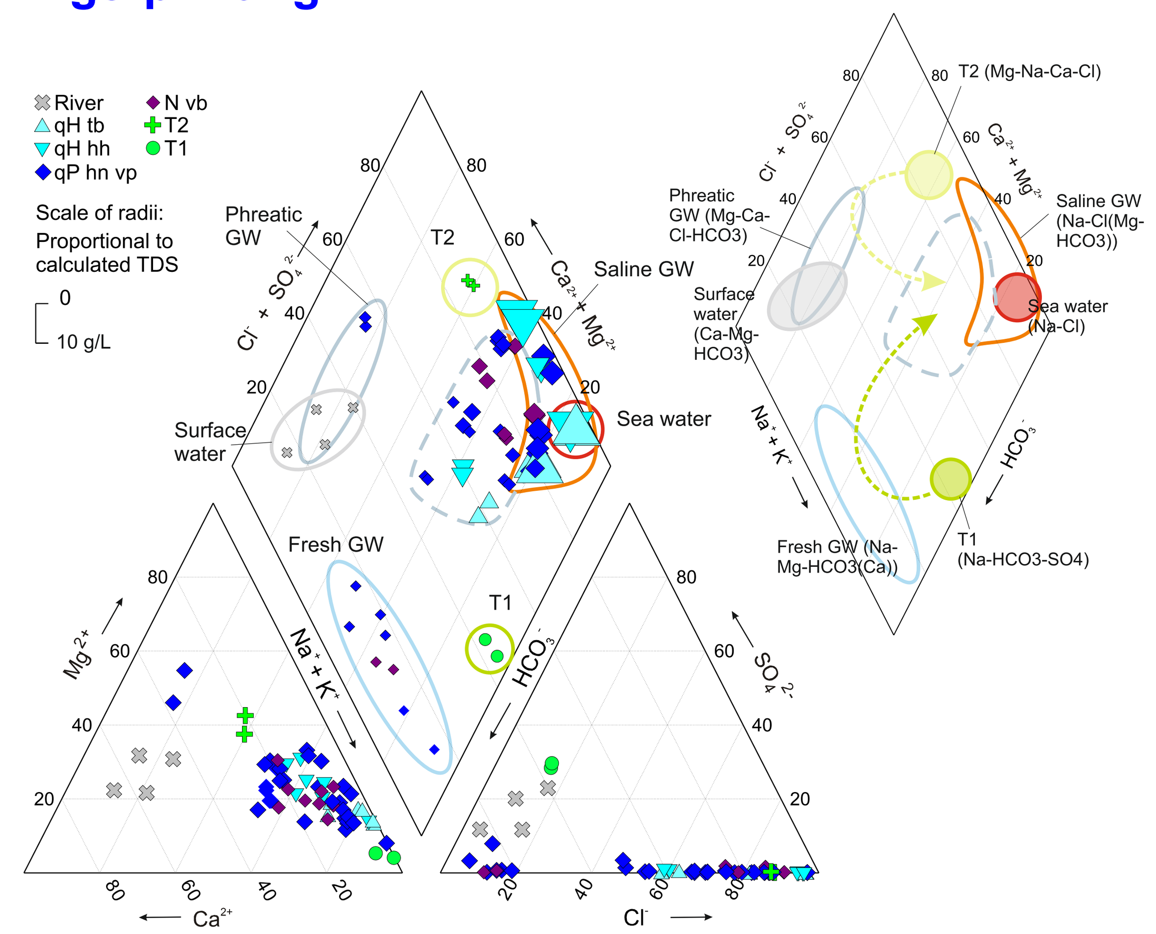

*Fig. 5, left: Major water composition in Nam Dinh area (05/2010, n=43, left), symbol size up to TDS 10 g/L (note: max. TDS 23 g/L, Q111). **Right:** Suggested GW mixing lines between end members T1, T2, sea water and surface water.*

Formation cond. vs. pore water conductivity

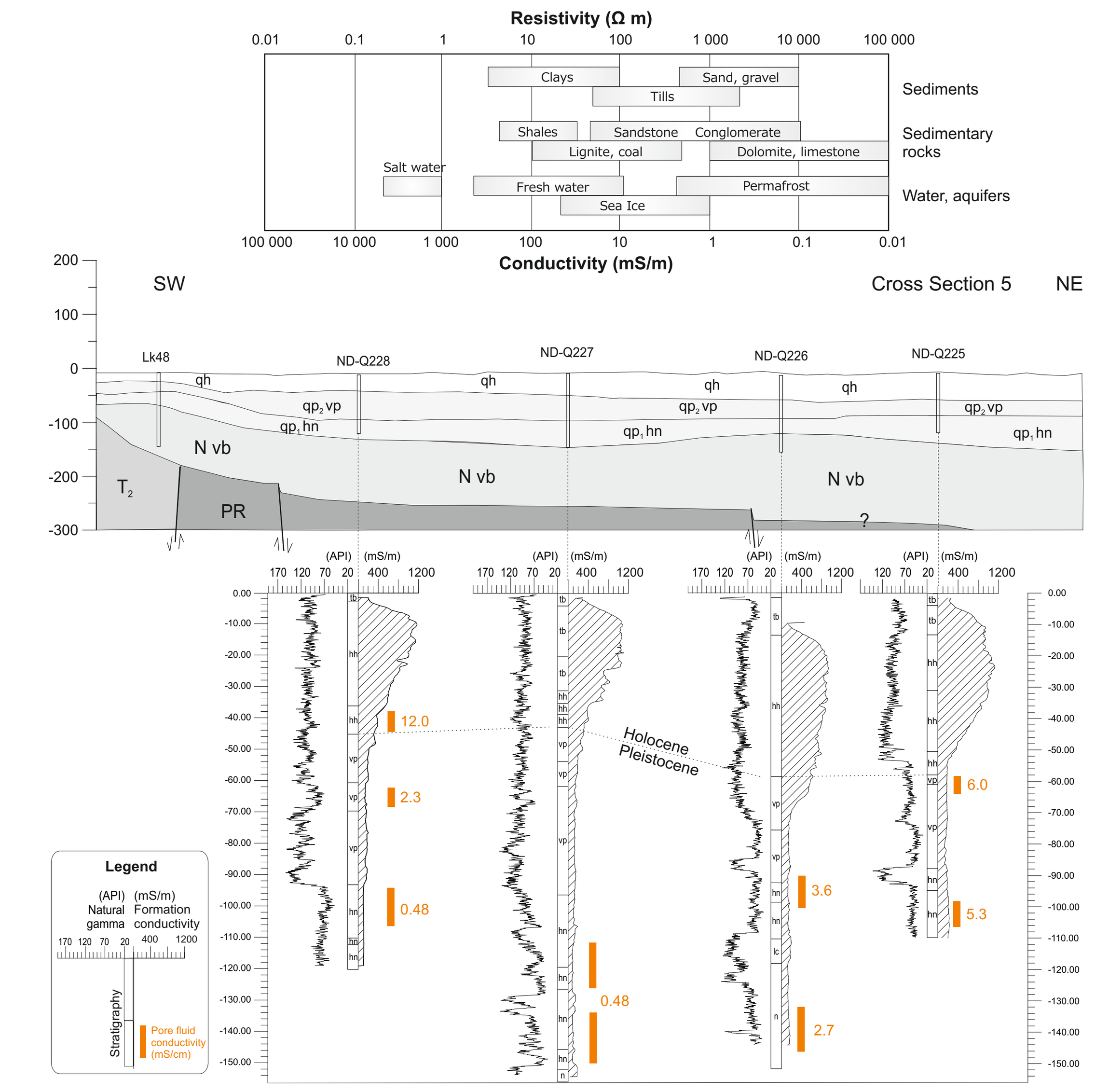

Fig. 6: Depth profiles of gamma (API) and induction log (mS/m) along cross section 5, suggests that formation conductivity is dominated by pore water salinity in both, coarse (low API) and fine grained (high API) sediments. Orange colour indicates observed pore water conductivity (mS/cm) and screen depths. ***Fig. 6, top:*** *Electric conductivity/resistivity of various waters and rock types (after PALACKY 1987).*

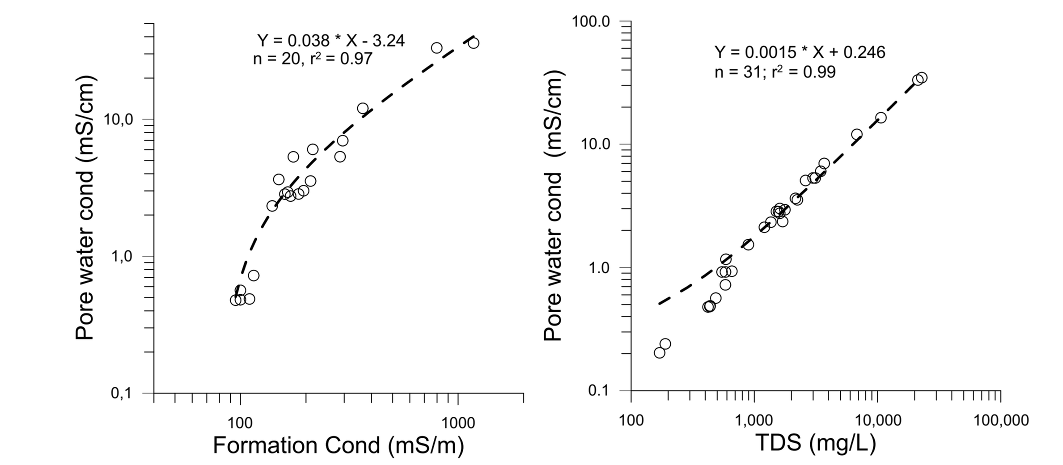

Fig. 7: Scatter plot of bulk formation conductivity (left) and TDS (right) versus pore water conductivity. Linear fittings have been used to estimate vertical salinity profiles in sandy formations.

Reference: WAGNER F., DANG TRAN T., HOÁNG DAI P., LINDENMAIER F. (2011): Assessment of groundwater resources in Nam Dinh Province, Vietnam: Final technical report part A: 149 S., Hanoi. (*www.bgr.bund.de/igpvn*)

Genesis of Fresh and Saline Groundwater

Vertical Salinity Diffusion

For given boundary conditions

$c(x,t) = c_i$,	for x>0,	t=0
and $c(x,t) = c_0$,	for x = 0,	t>0;
$c(x,t) = c_0$,	for x = 0,	t >0

the solution of FICK´s 2[nd] law is (APPELLO 2009):

$$c(x,t)=c_i+(c_0-c_i)\,erfc\left(\frac{x}{\sqrt{4D_e t}}\right)$$

Thus, vertical diffusion of Cl^- from saline qh to qp pore water is modeled for t=3000 years (Fig. 9), c_0=400 mmol/L, c_i=0.4 mmoL/L. Effect. diffusion coeff. D_e ($D_e=D_i * n_e$) has been adopted by varying effect. porosities n_e (n=0.2- 0.4; $D_i=1.1x10^{-9}\ m^2/s$).

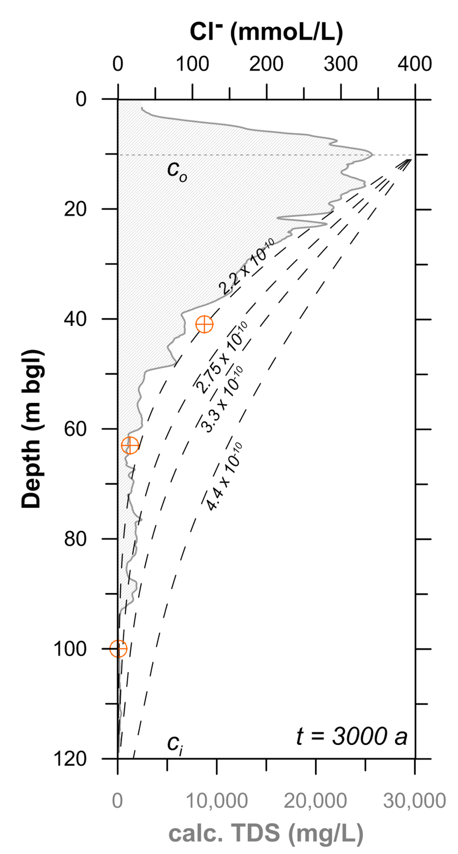

Fig. 8: Molar Cl measured in pore water (orange, Q228 station) plotted against simulated diffusion profiles (dashed lines, italic various D_e indicated italic) and vertical salinity profile (TDS, grey), derieved from formation conductivity data.

Major Conclusions

1. Formation conductivity in brackish, saline clastic sediments is dominated by pore water salinity (Fig. 6).
2. Linear correlation of pore water conductivity with bulk formation conductivity and TDS suggests estimation vertical pore water salinity in sandy strata (Fig. 6, 7)
3. Shallow qh marine sediments represent a major salinity source for underlying confined aquifers. Vertical diffusion as major transport process explains high salinity in qp, n aquifers (Fig. 8).
4. A „tongue-shaped" fresh GW resource in qp and n is fed by adjacent triassic karst T_2 and sandstone T_1, locally flushing saline pore water (Fig. 9).

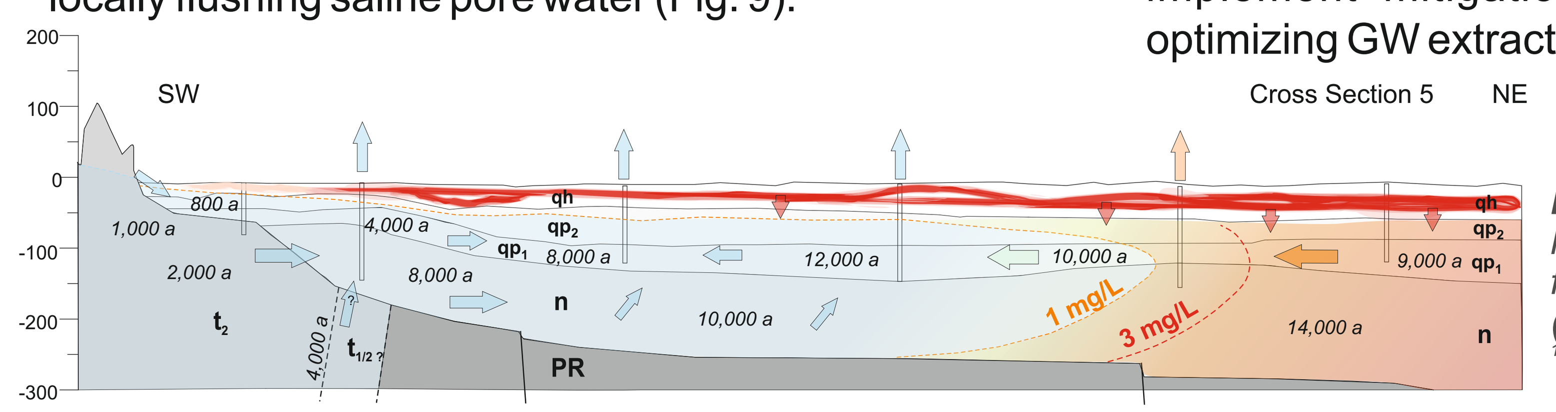

Figure 9: Pore water salinity & flux in hydrogeological units. Colours represent fresh (blue), brackish (orange) and saline (red) pore water, italic figures proposed ^{14}C-age in years (a).

Summary & Outlook

- Since the applied approach is only valid for sandy strata, further laboratory studies with clay/silt need to improve estimated pore water salinity in fine grained sediments.
- Amount of renewable fresh water from triassic karst (T_2) and sandstone (T_1) is quantified using 3D numerical flow modeling methods.
- Current GW extraction exceeds renewable amount of fresh water, resulting in salinisation of fresh GW resource. 3D density flow modeling recommended to quantify saline intrusion process.
- Local authorities urgently need to monitor the migrating GW salinity boundary in qp, n aquifers as well as to implement mitigation strategies for controlling and optimizing GW extraction & use.

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