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Using the power-law behavior of density-driven solute breakthrough curves for contaminant plume development reconstitution and prognosis in a large alluvial aquifer

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Introduction

The upper Rhine valley alluvial aquifer is one of the largest groundwater reservoirs in France. **Formations below alluvium were exploited for potassium hydroxide (potash) during the period 1910-2002** on an area of 220 Km^2 and large amounts of extracted materials made of sodium chloride and mine waste have been stored at the land surface. Fifteen heaps have been created to store residuals of 568 million tons extracted. Due to rainfall and treatment activities, large quantities of chloride infiltrated to the aquifer from the waste heaps with concentration up to 200 g/L leading to a widespread contamination of the alluvial aquifer by high density plumes. **Observed chloride concentration time series in pumping and observation wells are similar to the shape of breakthrough curves (BTC) resulting from classical artificial tracer point injections with long tailing of more than 15 years following a power-law behavior.** Such tailing indicates important storage of the contaminant in the aquifer through one of the ways shown in figure 1.

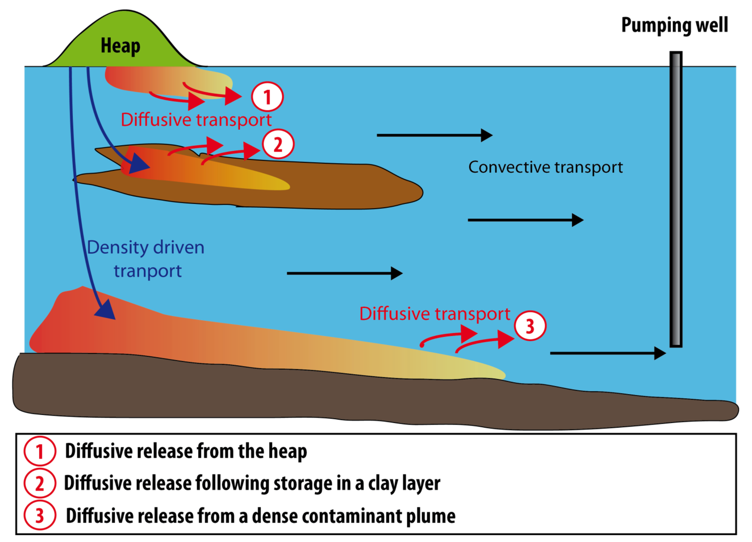

Figure 1 : Conceptual model of contaminant storage and release

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Field data interpretation

Based on chloride BTCs from **215 pumping/observation wells over the time period 1988-2015** and interpretation of the BTCs power law behavior, we were able to reconstitute the plumes historical development and behavior for the complete site. Examples of time series and data fitting are given figure 2.

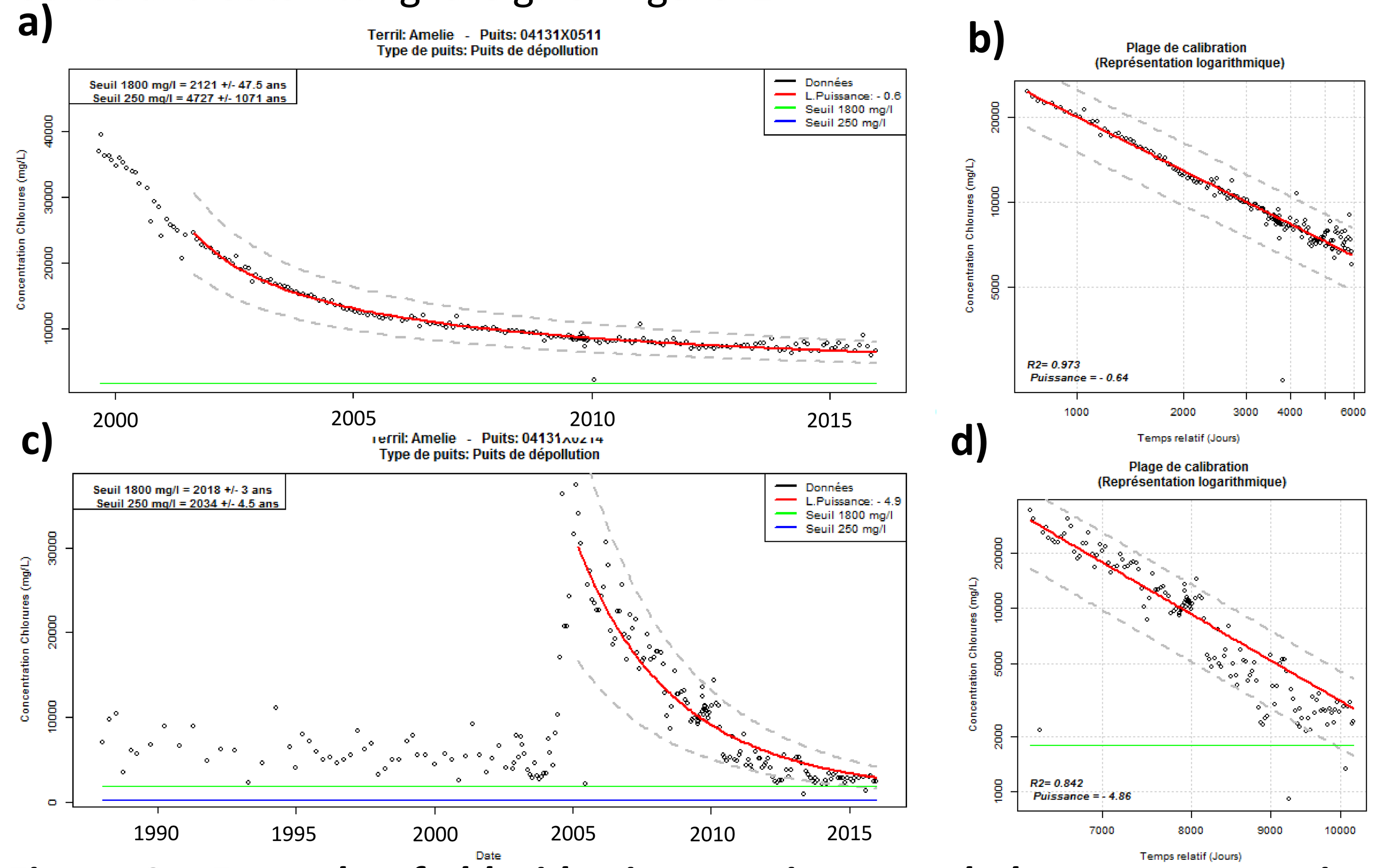
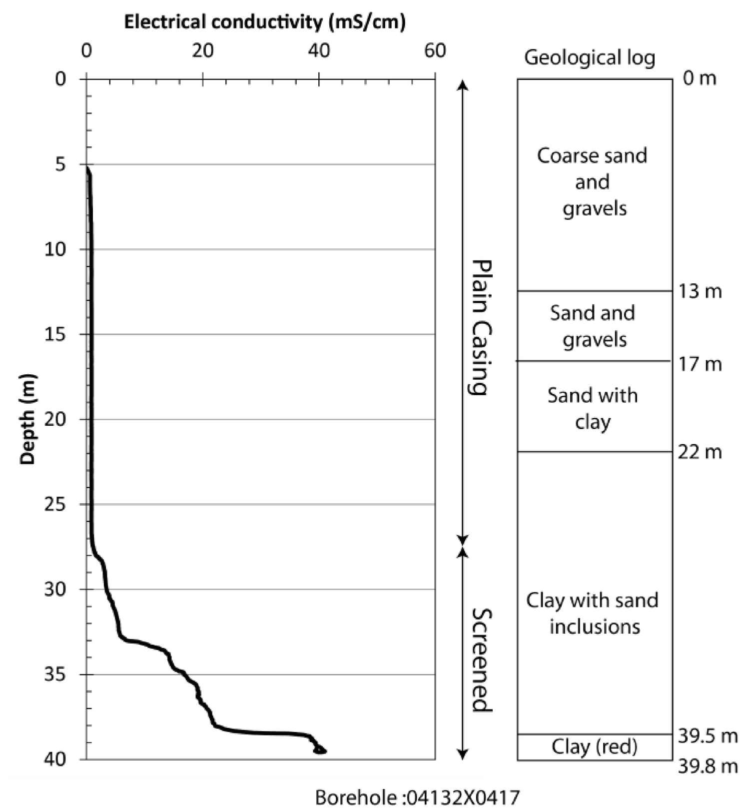


Figure 2 : Example of chloride times series recorded at some pumping wells (black) with power law fitting (red) for different heaps. b) and d) graphs represent the fitting period on a log-log scale



Geophysical investigations (ERT) and borehole water electrical conductivity logging confirm the stratification of the chloride contamination in low permeability horizons (figure 5) mostly in the deepest part of the aquifer.

Figure 3: Electrical conductivity log and geological log showing stratification of the contamination

Numerical modelling

Several aquifer and contaminant sources configurations were tested by numerical modeling to evaluate the capacity of a layered aquifer system to produce BTCs following a power-law behavior. Numerical simulations were performed on 2D cross sections using the flow and transport code MARTHE (Thiery, 1991-2014) taking into account density effects. One example of simulated configuration is presented figure 4.

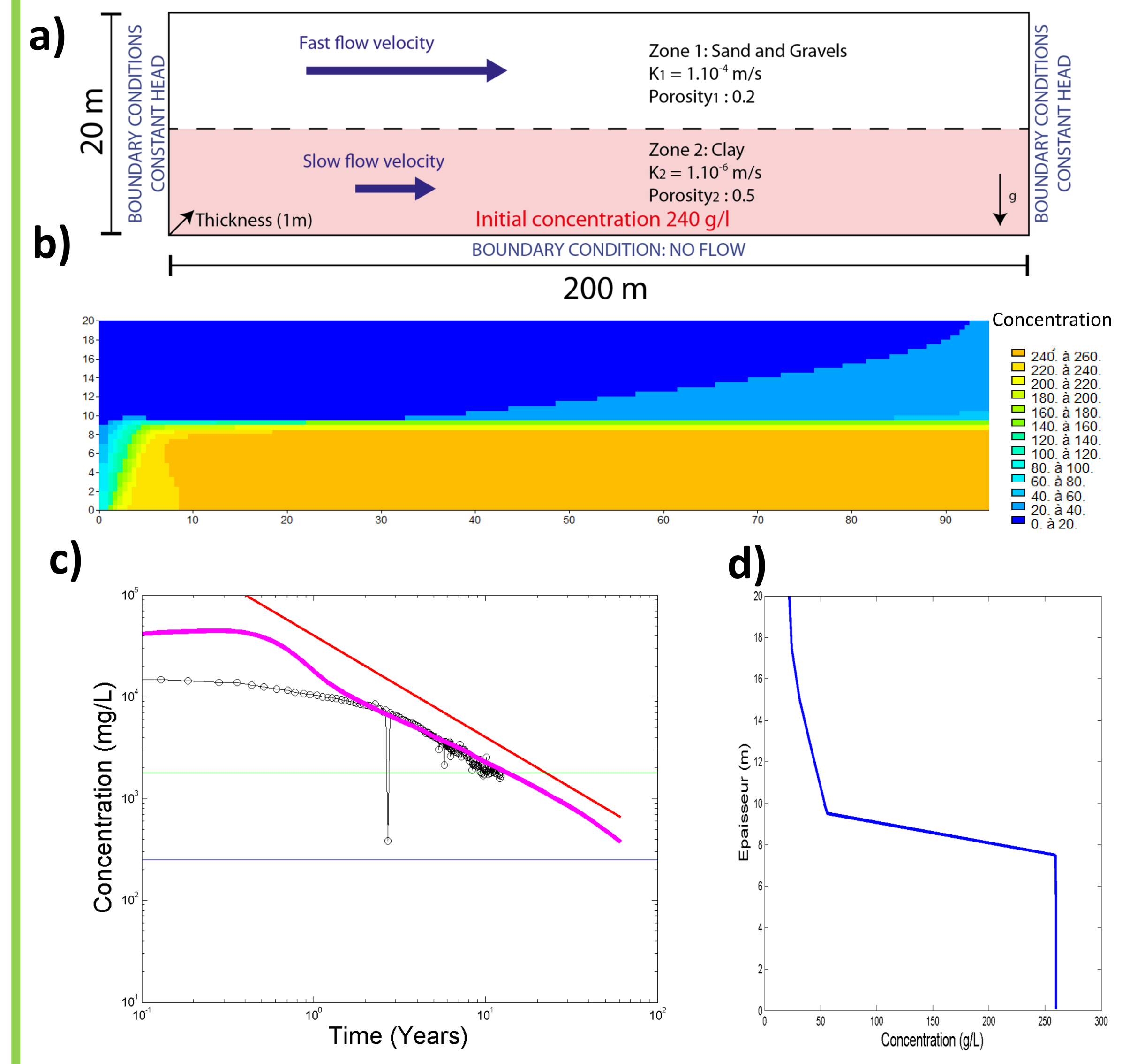


Figure 4 : Release of dense contaminant from a low permeability layer to a high transmissivity layer with: a) the simulated configuration, b) the concentration distribution , c) the resulting BTC curve (Purple), the power law (red) and the data (black), d) the vertical concentration profile

Simulated BTCs present power law behaviors with exponents that will slightly differ according to the different scenarios (injection mode, shape of the storage media/low permeability layer).

Prognosis maps

Using the power law behavior, for each borehole the dates for decontamination (threshold 1800 mg/L) and drinking limit (250 mg/L) were computed in order to forecast the duration of aquifer treatment required. Results in a form of predictive maps are shown for one heap as an example figure 5

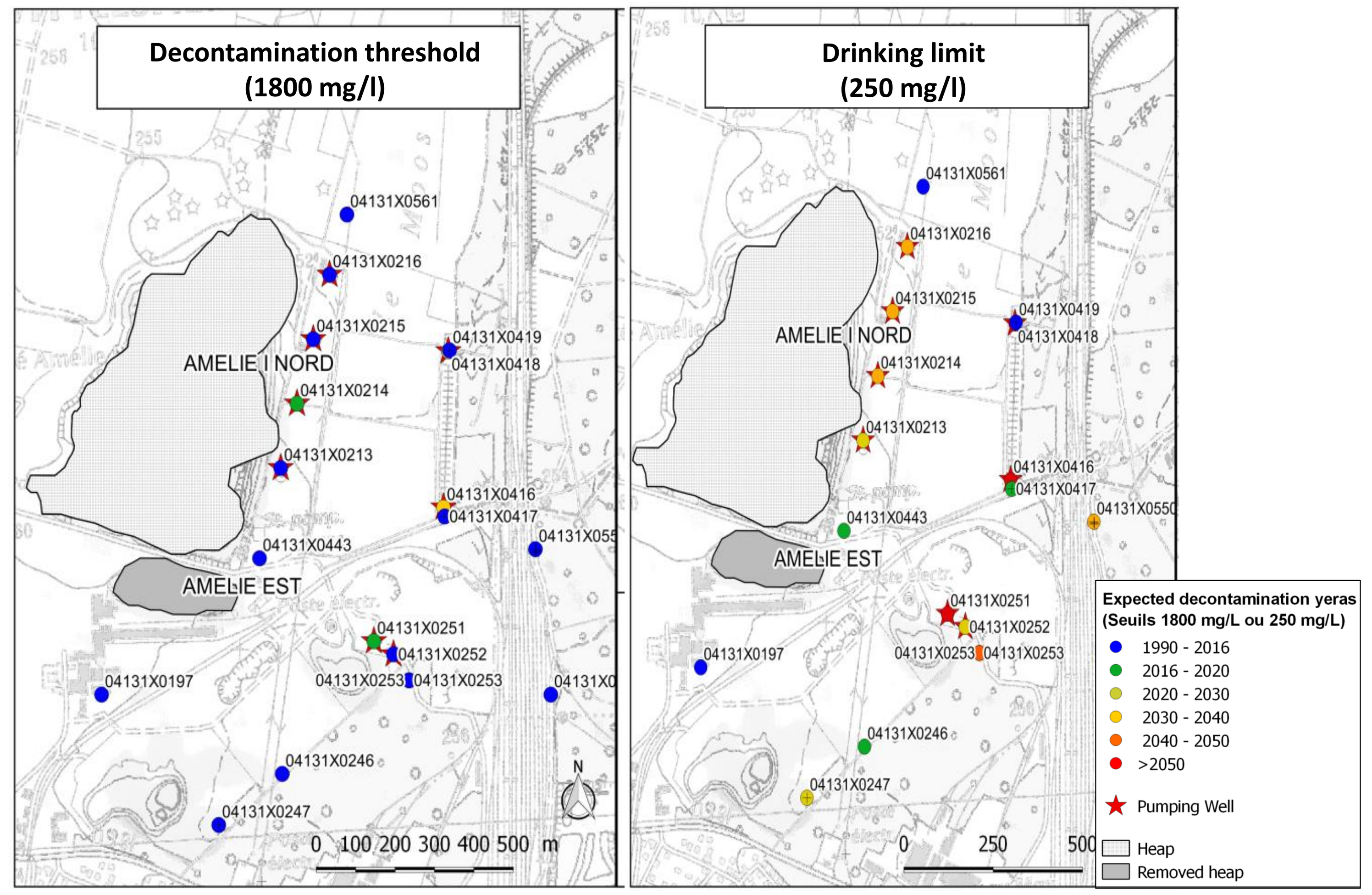


Figure 5 : Predictive maps of decontamination for the thresholds of 1800 mg/l and 250 mg/l

Conclusions

This study makes a substantial enhancement on the understanding of plume evolution and storage processes occurring in the potash basin of Alsace, France using a cost and time effective methodology based on BTC produced from the waste heaps fitted by power law models.

Data interpretation hypotheses have been tested by numerical modelling and independent field data. Forecasting the evolution of contaminant concentrations gives clear picture on the present pollution and the decontamination capacity of the remediation system in operation.

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