The effect of saline gravel pit lakes (Ravenna, Italy) on ground water chemistry.

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ABSTRACT
The hydrochemistry of gravel pit lakes excavated into Holocene beach gravel deposits near the Adriatic Coast of Emilia Romagna (Italy) was studied to determine the influence of these lakes on water and chemical budgets of the aquifer.

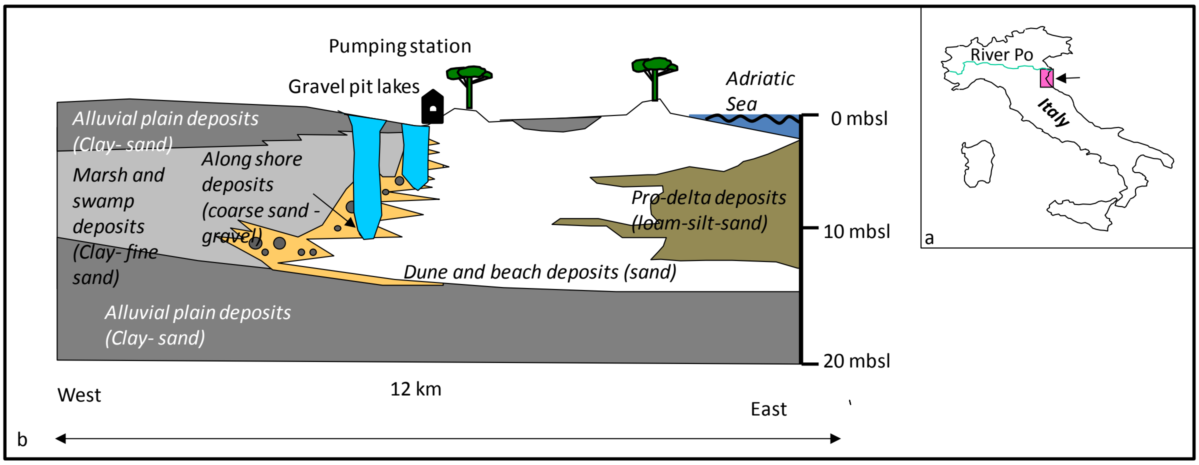

Fig 1. a: Location of study area in Italy and b: Geologic profile perpendicular to the coast with location of gravel pit lakes.

INTRODUCTION
Italy is the top gravel and sand producer after the United States with 14 $*10^6$ metric tons per year. Where gravel pits are dug below the water table in coastal zones, they may fill up with brackish/saline groundwater and become artificial lakes. Gravel pit lakes have a positive effect on water quality where they reduce the concentration of phosphates and nitrates, but they may also have a negative effect on water quality by allowing the mobilization of soil-bound elements like arsenic (this study; Muelleger et al. 2013). A large part of the study area, the coastal region near Ravenna on the Adriatic Sea (Italy), is below sea level and hydraulic gradients are typically directed inland. The unconfined aquifer is mostly brackish/saline, in part due to trapped Holocene transgression water (Mollema et al. 2013) and this affects soil quality and vegetation species diversity in the wetlands, pine forests and natural areas (Antonellini and Mollema, 2010). Small freshwater lenses form only near irrigation ditches (Vandenbohede et al. 2014; this volume). Surface water net evaporation rates are as high as 894 mm/year in the Mediterranean climate (Mollema et al. 2013). The water that leaves the lakes by evaporation and also by the intense land drainage is replaced by in-flowing ground water, making the lakes flow-through reservoirs. After excavation is

terminated, the gravel pit lakes near Ravenna are used for water sports including fishing, canoeing and swimming. At first sight the water may seem suitable for these activities. This study, however, shows that the water is not as clean as it seems.

METHODS

In total 40 ground and surface water samples were analyzed. All water samples were filtered in the field through a 0.45 µm filter and analyzed for major and trace elements by VU University Amsterdam and ACME Canada laboratories using conventional analytical methods (ICP-OES on acidified subsamples, IC for anions). Multi-Parameter Ground water Monitoring Dataloggers (Acquatroll™ and Divers) were used to log temperature and electrical conductivity changes with depth in the gravel pit lakes.

RESULTS

The results of the hydrochemical analysis are presented along a profile perpendicular to the coast (Fig. 1).The pH of the gravel pit lakes is on average 8.5 and this is higher than the pH of ground water near the gravel pit lakes (7.4), seawater (8.3) or river water (8.4). In general, the concentration of most cations, anions and chemical (trace) elements increases towards the coast (Fig. 2a). Water in gravel pit lake EMS is depleted in comparison with the average groundwater composition, regarding Al, Ca, Fe, Mn, Cr, Co, Cu, Ni and Zn and enriched in As, Ba, Cl, Mg, Mo, Sb, and pH (Fig. 2a, not all shown). The shallow groundwater below the paleo and coastal dunes is depleted in many elements with respect to the deeper groundwater. NO_3^- occurs in small amounts in the Apennine Rivers and in well EMS1, and only in P5S there is a high concentration of NO_3^- (56 mg/L).

DISCUSSION AND CONCLUSIONS

Creating gravel pit lakes, where there used to be a soil layer on top of an unconfined aquifer, brings about many changes, especially if there are many gravel pit lakes close to one another. For example, the lakes create an environment where many more algae, plant and animal species may thrive than in groundwater. This sets in motion a whole sequence of biochemical processes. These plus the typical chemical processes of coastal aquifers (cation exchange, calcite dissolution and redox reactions, (e.g. Stuyfzand 1989; Stuyfzand et al. 1999) and lake processes such as precipitation of calcite, metal (hydro)oxides and other minerals determine the hydrochemistry of the gravel pit lakes and aquifer downgradient (Fig. 2). Low-pH ground water rich in dissolved metals released by redox reactions flows into the gravel pit lakes where pH and oxygen content are higher. This chemical environment causes the precipitation of metal oxides and calcite to the bottom of the lake. Some elements such as As remain partly in solution. The lake water lost to net evaporation and to drainage is continuously replaced by new brackish saline groundwater. The salinity of the lake, therefore, may increase over time. The presence of the lakes implies the absence of soil and the unsaturated zone over a large surface (7% of the Quinto Bacino Watershed). The precipitation that falls on top of the lakes is mixed immediately with the brackish water of the lakes and thereby does not contribute to the formation of fresh groundwater lenses. The particular salinity range of the coastal gravel pit lakes and the lack of stratification make them less sensitive to eutrophication than freshwater gravel pit lakes (Bleich et al. 2011). As a consequence, there is less neoforming organic material available to fix (trace) metals to the lake bottom sediments. This may in part explain the relatively high concentration of for example As.

For gravel pit lakes in general and for the ones studied here in particular, the water quality needs to be monitored carefully for dissolved metals and trace elements to be able to use them safely after excavation.

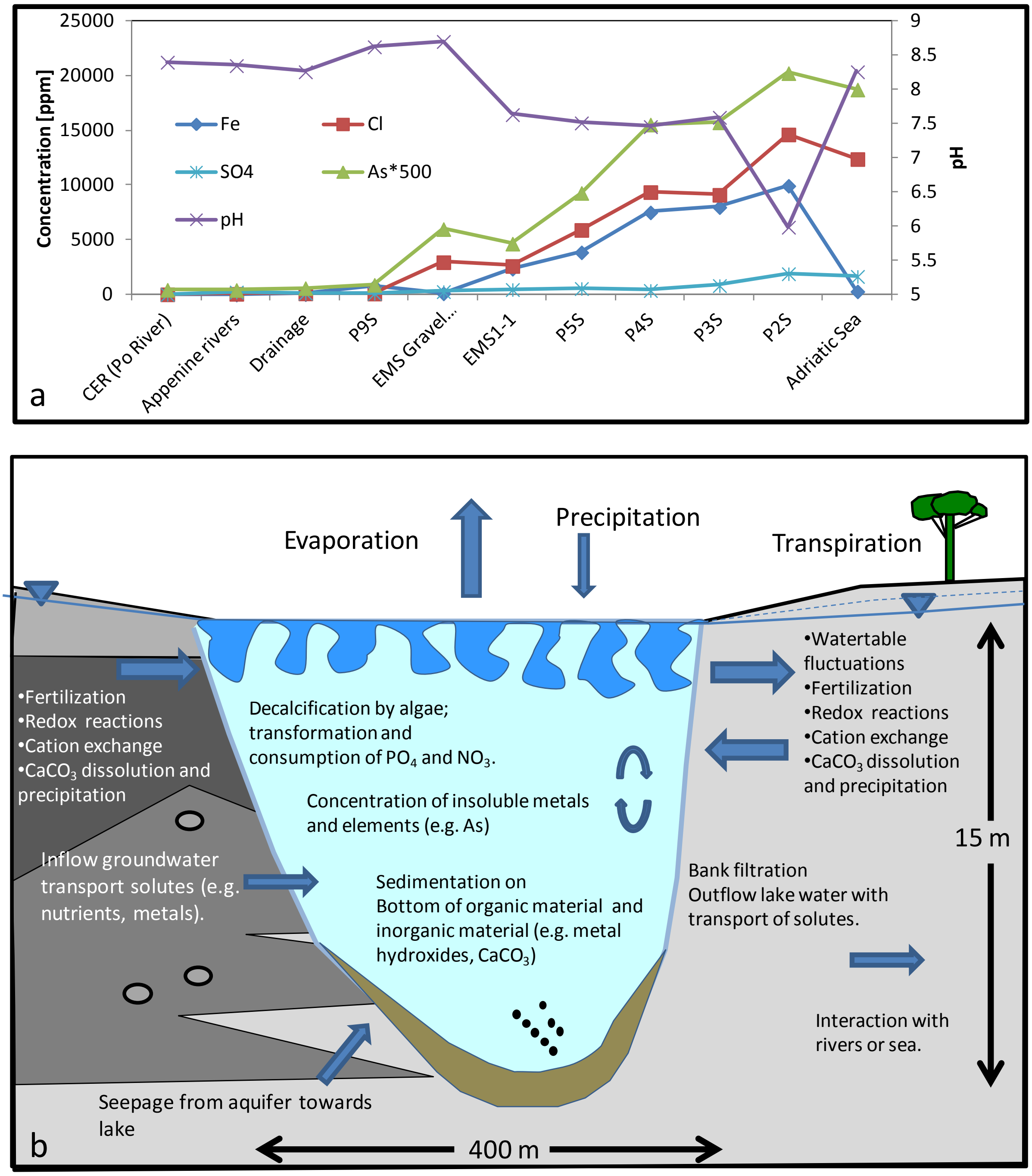

Fig 2. a. Concentrations averaged for observation wells and a gravel pit lake in a profile perpendicular to the Adriatic coast. P2S, P3S, P4S, P5S, EMS1 and P9S are the names of groundwater monitoring wells, CER is the name of the channel that brings water from the Po River to Ravenna. Surface water composition is shown for comparison. b. Hydrochemical processes occurring in and around coastal gravel pit lakes.

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REFERENCES

Antonellini M. and Mollema P. 2010. Impact of groundwater salinity on vegetation species richness in the coastal Pine forests and wetlands of Ravenna, Italy. Ecological Engineering 36: 1201-1211.

Bleich S., Powilleit M., Seifert T., Graf G., 2011. β-diversity as a measure of species turnover along the salinity gradient in the Baltic Sea, and its consistency with the Venice System Marine Ecology Progress Series 436: 101–118.

Mollema P.N., Antonellini M.,.Dinelli E., Gabbianelli G., Greggio N, Stuyfzand P.J. 2013. Hydrochemical and physical processes influencing salinization and freshening in Mediterranean low-lying coastal environments. Applied Geochemistry 34:207-221.

Muellegger C., Weilhartner A., Battin T.J., Hofmann T. 2013. Positive and negative impacts of five Austrian gravel pit lakes on groundwater quality. Science of the Total Environment 443: 14–23.

Stuyfzand P. J. 1999. Patterns in groundwater chemistry resulting from groundwater flow. Hydrogeology Journal 7:15–27 .

Stuyfzand, P.J. 1989.Factors controlling trace element levels in ground water in The Netherlands. Proc. Sixth Int. Symp. Water Rock Interaction, Malvern (UK), August 3-8 1989, D.L. Miles (ed), Balkema Rotterdam, 655-659.

Vandenbohede A, Mollema PN, Antonellini M, Greggio N. 2014. Seasonal dynamics of a shallow freshwater lens due to irrigation in the coastal plain of Ravenna, Italy. On-line by Hydrogeology Journal .

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