Seawater intrusion in the southern Po Plain, Italy: managing a geologic and historical heritage

Alexander Vandenbohede[1], Pauline N. Mollema[2], Nicolas Greggio[2], and Marco Antonellini[2]

[1] Department Geology and Soil Science, Ghent University, Gent, Belgium
[2] Integrated Geoscience Research Group, University of Bologna, Ravenna, Italy.

ABSTRACT

Irrigation in low-lying coastal plains may enhance the formation of fresh groundwater lenses and counteract salinization of groundwater and soil. This is discussed for the unconfined aquifer in the coastal plain near Ravenna, Italy. In this study area for example, a freshwater lens originates from an infiltration ditch used as a water reservoir for spray irrigation. Such incidental aquifer recharge practice from irrigation currently provides the only active freshening of an overall saline to brackish aquifer. The extend of the freshwater lens is controlled by the presence of drainage ditches, water level in ditches and rate of sea level rise. An integrated planning of irrigation within the water management of the coastal zone is necessary to have maximum benefits for freshening of the aquifer and making optimal use of the existing water and irrigation infrastructure.

INTRODUCTION

In low-lying coastal areas, groundwater is saline because of many interacting natural and human causes. The result is a complex distribution of freshwater and saltwater whereby the freshwater resources are often limited or under threat. This is not different for the coastal aquifer of the southern Po plain, Italy (Antonellini, 2008; Mollema et al., 2012). The study area (figure 1a) is located along the Adriatic coastline, south of Ravenna. From Roman times onward, human activity altered the layout of the Po plain and the coastline is currently characterized by river and canal mouths, wetlands, lagoons, developed areas with industrial facilities and reclaimed agricultural land.

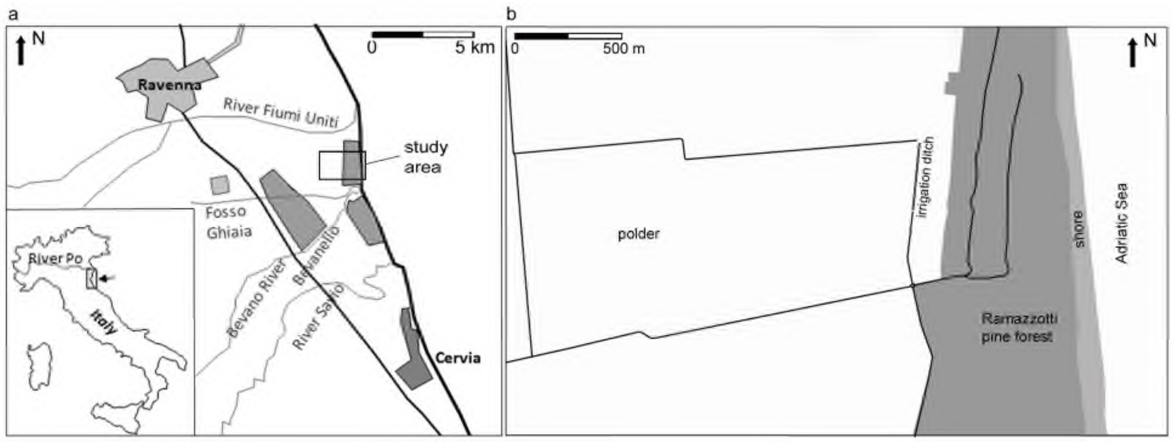

Figure 1. Location of the study area in the Po river plain (a) and detailed map of the field site (b) with indication of the major ditches (black lines).

FRESHWATER LENSES FROM IRRIGATION

Irrigation results in the formation of freshwater lenses via infiltration from irrigation water storage reservoirs into the aquifer. This, nowadays, is the only active freshening process of the aquifer (Greggio et al., 2012). A field example illustrates that a relatively large volume of freshwater can accumulate in the subsurface (Vandenbohede et al., 2014). The system is located in the polder bordering a coastal pine forest. It consists of a ditch used as a water reservoir (figure 1b). The water is used to irrigate the adjacent farmland with a sprinkler installation. Besides the ditch used for irrigation, a number of other ditches are used for drainage. Two such examples are present in the pine forest. A freshwater body accumulates in the aquifer between the irrigation ditch and the drainage ditches (figure 2). The freshwater body exhibits a clear seasonality. The level in the irrigation ditch is raised during the irrigation season (April to August) and water can freely infiltrate the aquifer. This results in an increase of the freshwater volume below the ditch up to a low permeable layer located at -8 m asl (above sea level). In between irrigation seasons, there is a flow reversal whereby there is an upward flow towards the ditch. Consequently, there is an up-coning of the fresh-saltwater interface towards the ditch and the amount of fresh water in the aquifer decreases. In terms of budget, however, there is an overall surplus of freshwater infiltration, which creates a permanent freshwater lens. Field observations (infiltration estimates, geophysical survey, water balance calculations) and numerical modelling, show that this freshwater lens is solely due to infiltration from the irrigation ditch whereby the contribution of the water sprinkled on the farmland is negligible.

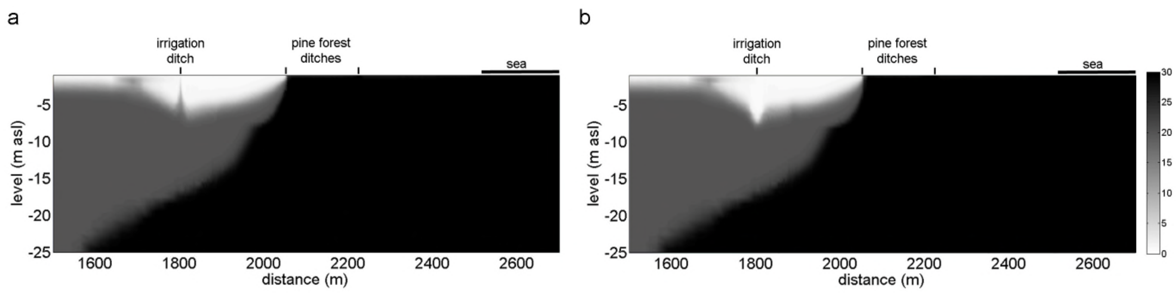

Figure 2. Simulated salinity (g/L) at the end of March (a) and at the end of August (b). The irrigated farmland is located between the irrigation ditch and the pine forest.

SCENARIO MODELING

A number of alternative scenarios were simulated. First, the water level in the irrigation ditch is kept high and freshwater can infiltrate into the aquifer during a whole year period (figure 3a). Evidently, the amount of freshwater increases with respect to the reference case of figure 2. After 30 years, there is twice more freshwater in the aquifer than by applying only a seasonal increase of the water level in the drainage ditch. The seaward extension of the freshwater lens remains defined by the pine forest drainage ditch. The aquifer between the drainage ditch in the pine forest and the irrigation ditch is now completely fresh down to the low permeable layer.

Case 2 differs from the baseline situation by a 30 cm lower level in the irrigation ditch during the irrigation season. The result is a similar seasonal change in freshwater volume but with the difference that the lens is smaller (figure 3b), because of the lower infiltration rate. Freshwater under the ditch nearly extends to the low permeable layer by the end of August and freshwater between the irrigation and drainage ditches is only present in the shallow part of the aquifer.

Case 3 aims to investigate the impact of multiple ditches where freshwater can infiltrate. The intention, here, is to increase the lateral extension of the freshwater lens by increasing also the water level in the landward ditch within the pine forest. In this case, the pine forest ditch works as an irrigation ditch during the irrigation season and as a drainage ditch otherwise (figure 3c). The seaward ditch in the pine forest remains a drain throughout the year. This results in a freshwater lens that extends seaward under the pine forest towards the seaward drainage ditch. Freshwater, in this simulation, is present between the two ditches in the pine forest. Aquifer recharge from the ditches, however, is limited and the freshwater lens develops in the shallow part of the aquifer and its lateral extension west of the irrigation ditch is small.

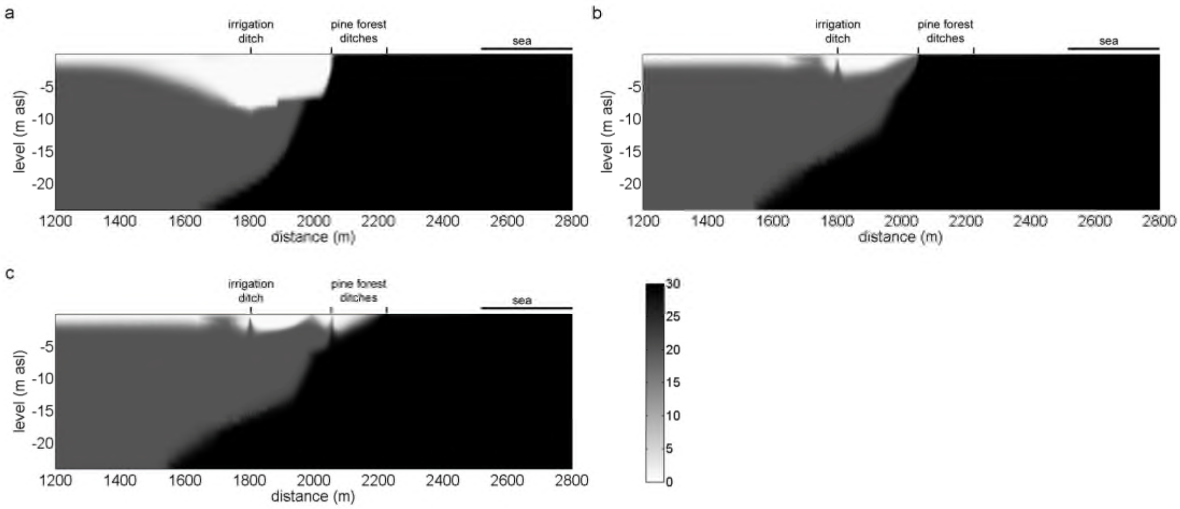

Figure 3. Salinity (g/L) after 30 years for case 1 (a), case 2 (b) and case 3(c) using alternative irrigation scenarios and water level management in the ditches.

In general, sea level rise decreases the volume of freshwater in coastal areas and this is not different here. The influence of a sea level rise of 60 cm and of 100 cm per century was simulated. Initially, the extension of the freshwater lens increases, because the lens is not yet in equilibrium. The volume decreases, however, after 20 and 50 years of sea level rise, respectively for a rate of 60 and 100 cm per century. Sea level rise causes a larger inland-directed hydraulic gradient compared to the current situation. Consequently, there is an increase in the landward groundwater flux and an increased saline seepage to the artificially drained agricultural fields.

DISCUSSION AND CONCLUSIONS

Irrigation could have important implications in terms of mitigation of the saline seepage to shallow groundwater and surface water as well as to soil quality preservation of low-lying coastal zones with a (semi) -arid or subhumid climate. The monitoring and modeling results from the Ravenna field site illustrate that a relatively large volume of freshwater can be accumulated provided that this type of irrigation with recharge from a storage pond is maintained over several years. By making use of the existing hydraulic infrastructure of irrigation and drainage ditches, the freshwater lenses can be maintained and even forced to increase. Different engineering measures (e.g. managed aquifer recharge using injection wells or infiltration ponds, deep drainage instead of surficial drainage) are applied to enhance freshwater recharge but these are often costly options. Freshening of the aquifer as side-effect from irrigation could be a low-cost alternative to these other techniques.

Careful planning and managing of the water levels is necessary as is shown by the simulation of the different scenarios. Such managed irrigation and aquifer recharge practices should be included in long-term coastal zone development integrating groundwater extraction, drainage, irrigation, geomorphologic changes (e.g. to the coastline), and relevant socio-economic and environmental factors. The management of these irrigation water lenses should be considered within the principles of integrated water resources management aimed to address typical water quality and quantity concerns by optimizing water management and sustainability under the provisions of the Water Framework Directive implementation.

In the specific case of the Ravenna coastal plain, this means, for instance, taking into account the relative sea level rise. The necessary low water levels in the agricultural fields form a pre-conditioned constrained situation that will cause further stresses from saltwater seepage due to a rising sea level and a subsiding land surface over the next decades. This means that the currently present freshwater lenses will become smaller. A good planning, taking into account sea level rise, is necessary if surplus irrigation water is used for freshening the aquifer at new locations.

REFERENCES

Antonellini, M., P. Mollema, B. Giambastiani, K. Bishop, L. Caruso, A. Minchio, L. Pellegrini, M. Sabia, E. Ulazzi, and G. Gabbianelli. 2008. Salt water intrusion in the coastal aquifer of the southern Po Plain, Italy. Hydrogeology Journal 16:1541-1556.

Greggio, N., P. Mollema, M. Antonellini, G. Gabbianelli. 2012. Irrigation management in coastal zones to prevent soil and groundwater salinization. In: Abrol V, Peeyush S (edt.) Resource management for sustainable agriculture, Intech.

Mollema, P., M. Antonellini, G. Gabbianelli, M. Laghi, V. Marconi, and A. Minchio A. 2012. Climate and water budget change of a Mediterranean coastal watershed, Ravenna, Italy. Environmental Earth Sciences 65, 1:257-276.

Vandenbohede, A., P. Mollema, N. Greggio, M. Antonellini. 2014. Seasonal dynamic of a shallow freshwater lens due to irrigation in the coastal plain of Ravenna, Italy. Hydrogeology Journal, doi: 10.1007/s10040-014-1099-z.

Contact Information: Alexander Vandenbohede, Ghent University, Department Geology and Soil Sciences, Krijgslaan 281 (S8), Gent, Belgium, Phone: 32-9-2644652, Fax: 32-9-2644653, Email: avdenboh@yahoo.co.uk