Artificial recharge of phreatic aquifers via surface infiltration within the framework of the WARBO Project

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Abstract

Artificial recharge is a tool for aquifer management where water is stored in a suitable aquifer during surplus times in order to recover it during times of need. Within the framework of the WARBO Project the application, management and environmental impacts of artificial recharge are studied on the basis of test sites in the Friuli-Venezia-Giulia and the Emilia-Romagna Region, Italy. Two recharge sites will be tested and prepared for continuous operation and two more sites are going to be idealized and evaluated concerning their artificial recharge suitability.

Keywords: Artificial recharge, WARBO Project, surface infiltration, managed aquifer recharge

1. Artificial Recharge Overview

While aquifer exploitation is common, the concept of artificial recharge stands for a significant new development in water management. Artificial recharge (AR) aims to store water in a suitable aquifer during times when a surplus is available and to recover it during times when it is needed. Furthermore, the underground storage has several advantages over surface storage (Bouwer, 2002; Maliva, Missimer, 2010). Artificial Recharge has particularly importance in Europe where 35% of its population lives under intense water stress conditions (EEA, 2005). The benefits can be manifold when applied correctly. AR not only enhances the groundwater resources by increasing the groundwater level or reducing the decline rate, but also can improve the groundwater quality, act as a barrier against seawater intrusion (Maliva, Missimer, 2010), increase the surface water flow in the dry season and increase the soil moisture, which subsequent improves flora and fauna and may reduce soil erosion (Gale et al., 2002) and land subsidence (Gelt, 1992). Nonetheless AR can also put the aquifer at risk. Contamination and salinization of the aquifer water, changes of the aquifer dynamics and reduction of the soils porosity are some of the possible outcomes of a negligent operation. To avoid these harms an extensive planning process and a carefully execution are essential.

The infiltration method is usually applied for unconfined aquifers, where large dedicated areas, permeable terrain and thick vadose zones exist. In regions characterized by shallow non-permeable soils or where the target is to recharge a confined aquifer, the direct injection method is preferred (Bouwer, 2002; Topper et al., 2004).

2. The WARBO – Water Re-born Project

The Project WARBO – Water re-born was accepted in 2011 as a Life+ project, partially supported by the European Union. It aims at facilitating the regulation of artificial recharge by testing its application to mitigate the groundwater level drop by utilizing the unused surplus surface water, which is usually lost during the high flow period. Various geophysical, hydrogeological and geochemical methodologies are going to be applied to improve the process understanding. The project intends to develop new approaches for further applications in similar climate, geological, environmental and socio-economic conditions.
The main challenges of the WARBO project are:

- estimation of the time and water volumes needed to stabilize/recover the piezometric level and to recreate a stable freshwater aquifer for water supply purposes;
- assessment of the environmental impacts of AR;
- knowledge improvement regarding the use of different subjects (hydrogeology, geophysics, geochemistry, modulation) in the study and management of AR;
- development of reliable models for managing AR activities.

Two summer schools will be held, one in Ferrara (2013) and another in Lisbon (2014).

3. Geology and hydrogeology in Friuli-Venezia-Giulia

The Friuli-Venezia-Giulia (FVG) Region can be divided in 3 main hydrogeological portions:

- the Alpin and pre-alpin mountain range,
- the high plains “Alta-Pianura” and
- the low plains “Bassa-Pianura”.

The FVG plains extend over a 2900 km² area and were formed over the Upper Pleistocene through the action of the alluvial deposition from the various rivers/stream from the Alpine mountain range, and powered by the natural subsidence. The different dynamics of the hydrographic network in the alluvial plain led to a subdivision of the area into two sectors: the Alta-Pianura, which is formed by coarse-grained detrital sediments, prevalently gravels, irregularly cemented in conglomerate horizons and intercalated with layers of sand and, less frequently, of clay; the Bassa-Pianura, characterized by sandy-pelitic deposits intercalated with gravel horizons, which become increasingly deep and rare southwards (Martelli, Granati, 2007).

The hydrogeology of the Alta-Pianura is characterized by a single, almost continuous and non-stratified aquifer with a thickness up to 600 m (ARPA FVG, 2011) and even 800 m. The hydraulic conductivity is generally high, ranging from $10^{-2}$ to $10^{-6}$ m/s. A steady drop in the piezometric levels has been reported since the 70’s. The aquifer recharge is mainly provided by the streams (largely the Tagliamento River), while the precipitation plays a relatively small role (around 30%) (Regione FVG, 2007).

The Bassa-Pianura is characterized by the presence of finer materials, such as silt and clay from with er alluvial (low speed sedimentation) or marine transgression. These finer sediments form confining layers (aquitards) with the regional aquifers that are characterized by a high degree of stratification. Eight to eleven different alluvial aquifers were identified (Martelli, Granati, 2007; Regione FVG, 2007). The aquifer permeability in Bassa-Pianura is also high, ranging from $10^{-2}$ to $10^{-4}$ m/s, depending on the aquifer (Martelli, Granati, 2007). With depths down to 300 m b.s.l. the confined aquifers in Bassa-Pianura are recharged by the groundwater flowing from the Alta-Pianura unconfined aquifer (Martelli, Granati, 2007, 2010).

A progressive increase of fine deposits characterizes the transition from Alta to Bassa-Pianura, creating a barrier to the subsurface water flow, which is constrained to flow up and spring in several sites, which connected forms the spring line. The spring line crosses the territory from east to west and represents the limit between Alta and Bassa-Pianura. It is one of the main features of the FVG hydrogeological system and its status is one of the main indicators of the hydrologic and hydrogeologic state of the region (Regione FVG, 2007). Data provide evidence of a significant lowering of the summer flows (or even no flow) from the spring line, and a southward migration, indicating a clear drop of the groundwater levels (ARPA FVG, 2011)

3.1 The Mereto di Tomba test site (in Friuli-Venezia-Giulia)

The challenge: surface water infiltration tests, where water from an irrigation channel is intended to infiltrate into a high permeable phreatic aquifer, in order to mitigate the long term level drop in the piezometer level.

In the test site Mereto di Tomba in Alta Pianura, a large pond, of about 6 m depth and 45×7 m width will be used for surface water infiltration. The recharge water will be supplied by a nearby irrigation channel which is fed from the Tagliamento and the Ledra River. As described above, the typical geology of the Alta-Pianura Friulana consists of a thick non-differentiated layer of coarse alluvial sediments. However, a log statigraphy analysis in wells within a range of 6 km showed a certain heterogeneity degree with the presence of some intercalating layers of gravel, conglomerate and clay. The results in the geophysical profile (ERT) also display some heterogeneity, at least in the upper meters.
No information on the local hydraulic conductivities is available wherefore a surface infiltration test was carried out in the pond and the calculated vertical hydraulic conductivity (in the non-saturated mean) was $10^{-4}$ m/s. **Subsequently the infiltration rates (61 cm/h) and flows (120 l/s) were calculated with the Green-Ampt formula.** The gradients are rather low (0,002) and so, considering the recharge water supply constraints, the recharge influence area is likely to be small, possibly making the monitoring network unsuitable, although relatively dense. New piezometers may have to be drilled to accurately measure variations in level and water quality.

A number of tests still need to be carried out to close knowledge gaps, to finish the conceptual and numerical model and to start the infiltration tests. Planned tests and actions are geophysical profiles, pumping tests, Lefranc tests, drilling of new piezometers south of the infiltration pond, a vadose zone permeability test, a hydrogram analysis and a chemical analysis.

### 3.2 The Industrial Zone of Ponte Rosso (ZIPR) test site (in Friuli-Venezia-Giulia)

**The challenge:** define a methodology for the use of the treated industrial waste water with the objective of infiltration in the groundwater.

The industrial zone of Ponte Rosso is located in the Bassa-Pianura, just below the spring line. It is a densely industrial area with active synergies promoted by the consortium where, between other things, waste waters are managed by a common treatment plant. The effluent has general good quality for surface water disposal with the exception of the zinc content. Three phytodepuration lagoons were installed downstream of the waste water treatment plant, trying to create an effluent with desirable quality, suitable for the infiltration.

### 3.3 The Torrate test site (in Friuli-Venezia-Giulia)

**The challenge:** define the methodology and protocols for the possible use of surface channel water for AR in the Bassa-Pianura Fruiliana.

In the previous Life + CAMI Project, the spring park of Torrate was extensively surveyed with different kinds of geophysical surveys, geochemical analysis, hydrogeological methodologies and a 480 m deep well, with samples analysis. A conceptualization of a recharge model will be idealized using the available information from these various surveys, and an evaluation of the importance and suitability of these methodologies will be evaluated.

### 4. Geology and hydrogeology in Emilia-Romagna

The Po plain in the Emilia Romana Region is mostly composed of alluvial deposits provided by the numerous streams with origin in the Apennine Mountain range. A relatively straight strip of land along the mountains is characterized by coarser sediments and is the most water producing zone of the region. The stratification of the aquifer begins moving seawards, where more fine sediments were deposited due to the lower flow velocity (Regione Emilia-Romagna, 2009). In the coastal area (mainly in the Po river delta) the sea also played a role in the sedimentation process: here successive marine regression and transgression shaped the underground structures with clay and silt intercalations, rich in organic matter. In the Ferrara area, the upper 200 m of the Po Plain sedimentary sequence is subdivided in five hydro-stratigraphic units:

- the A0 unconfined aquifer;
- the A1 aquifer, which is generally under pressure;
- three more deep artesian aquifers (A2, A3 and A4).

Only the A0 unit is well characterized by a network of large diameter wells. A certain hydraulic connection exists between the A1 aquifer and the present bed of the Po River (Dugoni et al., 2007; Rapti-Caputo and Martinelli 2007, 2009).

A complex network of old river beds (paleo channels) has been identified, consisting of alluvial coarser sediments. Due to the higher permeability, these geomorphological structures can play an important hydrogeological role (Regione Emilia-Romagna, 2009).

### 4.1 The Copparo test site (in Emilia-Romagna)

**The challenge:** surface water infiltration tests, where water from irrigation channels is intended to infiltrate into the semi-permeable, semi-confined aquifer to improve the groundwater quality.
Initially, the recharge was planned in the confined aquifer, but legal constrains forced all the efforts to be directed to a phreatic/semi confined aquifer recharge using a pond originated from clay and sand excavation. The pond is quasi-triangular shaped, with a perimeter of 1.5 km and an area of 5.7 ha. It has a maximum depth of 4 m and is partially filled with water. The pond is likely hydraulically connected with the semi confined aquifer (believed to be a 4 m thick sand layer), as the basin water level exhibits a slow reaction to precipitation but also varies in relation with the regional groundwater table. The electrical conductivity of the pond water (3000 \( \mu \text{S/cm} \)) is higher than the electrical conductivity of the semi-confined aquifer (1000 \( \mu \text{S/cm} \)), probably due to evaporation. Therefore the water of the pond must be replaced before infiltration may begin. The semi-confined aquifer is relatively salty in the test site, thus infiltration of surface water with approximately half of the electrical conductivity will make water quality changes visible.

According to the geomorphological map of Unione dei Comuni Terre e Fiumi (2011), there is a strong possibility of a hydraulic connection with a paleo channel from the Po Delta, with mainly high permeable materials which cause a preferential infiltration way. An estimation of the infiltration rate is not possible at the date due to the lack of information regarding permeability and geological structure. Therefore geophysical profiles, Lefranc tests, drilling of new piezometers as well as sieve, hydrogram and chemical analysis will be carried out. The aquitard efficiency is also still uncertain and so a leakage value should be estimated.

5. Conclusion

The WARBO project is aimed at developing and testing simple methodologies for the effective management of artificial aquifer recharge that will provide medium term positive effects on the groundwater level and quality. Information improvement by geophysical investigation are expected to increase the reliability of groundwater recharge modeling creating more accurate predictions and therefore simplifying the recharge management.

The results from the infiltration test sites will be evaluated and used to develop guidelines to support the decision makers.

6. References

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