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Innovative technologies for the sustainable management of water resources: the WARBO (WAter Re-BOrn) project

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ABSTRACT The WARBO project will facilitate the regulation of water artificial recharge (AR) and determine how to respond to the need to safeguard, protect and enhance water and land ecosystems. The project will focus on sites with AR problems hosting ecosystems of community interest where urgent measures are needed to fight against water scarcity and to develop protocols able to specify how to manage recharge activities. The protocols concerning direct (hydrogeological, geochemical and isotopic) and indirect (geophysical and remote sensing) surveys will be finalized and applied to two main macro-areas. The first is the Friuli plain (NE Italy), with the aim of identifying the short- and long-term effects of the recharge of highly permeable aquifers in order to mitigate the lowering of piezometric levels and the degradation of the forested areas impacted by a gradual shift of the springs towards lower altitudes and to estimate the water savings that could be achieved through the reclamation and use of grey water in the ZIPR test site (San Vito al Tagliamento, Pordenone). The second is the southern Po Plain in the Copparo area (Ferrara, northern Italy) in order to assess the effectiveness and the issues connected with recharge activities in salinised aquifer inland characterized by medium-low permeability and to estimate the effectiveness of phyto-purification systems and the improvement of biodiversity. The aims of the WARBO project are: the integration and updating of the CAMI-LIFE database to improve existing knowledge and to better evaluate the hydrogeological and geochemical evolution of aquifers; the updating of the conceptual model and identification of test areas; the application of innovative hydrological 3D models implementing state-of-the-art numerical procedures to solve partial differential equations (as finite elements, mixed finite elements, finite volumes).

Key words: Artificial Recharge, multidisciplinar approach, phyto-purification, water resources.

1. Introduction

Dramatic reduction in the availability of water and limited access to water resources is foreseen in Europe in the incoming years and the artificial recharge (AR) appears to be a suitable way to protect both surface water and aquifers. The need for AR is underlined in the documents of the Stakeholder Forum on Water Scarcity and Droughts, in national and international literature

and in the European and technological projects funded by the EU. AR techniques have already been applied in the coastal brackish aquifers to decrease salt intrusion, but AR is not yet subject to regulations. Directives take into account methodologies for the determination of water resources; chemical and physical characteristics and chemical interactions, structure of the aquifer; recharge methods; environmental impact and monitoring methodologies. An uncontrolled use of AR may jeopardise the aquifer's quality for contamination, for mixing of freshwater from different water bodies with problems of salinisation, reduction of porosity, variation of the dynamic of the aquifer and other uncontrolled factors.

The Italian CAMI project (Water-bearing characterization with integrated methodologies) has been co-financed by the EU in the frame of the LIFE programme. It contributed to identify, develop and test an integrated method aimed at characterizing of the hydro-geological districts, the analysis of the environmental impact of human activities on the water resource and to the evaluation of sustainability (Nieto and Santarato, 2009). The Italian project TRUST (Tools for Regional-scale based assessment of groUndwater Storage improvement in adaptation to climaTe change) co-financed by the Italian Ministry for Environment and Land and Sea identified adaptation measures based on artificial aquifer recharge to mitigate the impacts of drought and water scarcity and to adapt the groUndwater of the Veneto and Friuli Plain to the adverse impacts of climate change.

WARBO will take advantages of the results obtained during previous LIFE Projects (CAMI and TRUST) for developing strategies and actions to contrast the drying up of aquifers and decay of wetlands which is affecting many European territories.

The OGS - Istituto Nazionale di Oceanografia e di Geofisica Sperimentale will be the WARBO project coordinating beneficiary. The associated project beneficiaries are: the University of Ferrara, the University of Udine, the University of Padua, the Regional Agency for the Environment Protection of the Friuli Venezia Giulia Region (ARPA-FVG), the Copparo Municipality, the Botti Elio s.a.s., TARH – Terra, Ambiente e Recursos Hídricos Lda, and EUREKOS s.r.l.

Expected results of the project are:

- definition of the recharge method, development of a model to evaluate the response of aquifers, and assess the experimental WARBO methods in the test areas;
- estimates of the time and water volumes needed to stabilise the quality and quantity of an unconfined aquifer, and to recover the initial piezometric level; for salty aquifers, estimates of the time and volumes needed to recreate a stable freshwater aquifer for water supply purposes;
- modelling of the dynamics of the spring line, whose levels should increase after AR;
- assessment of the impact of AR on: 1) degradation of organic substances due to the input of high quality water; 2) increase in the piezometric level of the aquifer; 3) protection of the environmental characteristics of rivers and streams as a result of the recovery of the feeding functions of artificially recharged aquifers;
- reduction in subsidence caused by excessive withdrawal of underground water;
- use of aquifers as water storage and transport systems as an alternative for building dams and costly water-supply systems;
- transfer of knowledge with a view towards the acquisition of data and the management of

AR for geothermal purposes; and
- development of reliable models for managing AR activities.

The staff of the three beneficiaries has expertise in the coordination and implementation of European and international projects. All project beneficiaries have established working relationships with other groundwater stakeholders of the region supporting the set up of the stakeholders group and the project implementation and dissemination.

2. WARBO test sites

The WARBO tests will be implemented on sites hosting endangered ecosystems and where urgent measures are needed to combat water scarcity. The involvement of public and private stakeholders ensure a future application of the developed methods of AR.

The WARBO project for the reconstruction of the subsurface structure will be a correct application of the AR methods in an area that is especially vulnerable and complex. The AR system will be designed based on the detailed reconstruction of the spatial extension of the aquifer and by adopting methodologies that will help designing interventions to mitigate the severe degradation of quality and quantity of groundwater supplies.

The selected test sites for WARBO (Fig. 1) are located in the Friuli plain (NE Italy) and in the Copparo area (Ferrara, northern Italy). In all test sites the effectiveness of phyto-purification systems and improvement of biodiversity will be estimated.

2.1. The Friuli test site

Direct and indirect investigations in the Friuli plain can define short- and long-term effects of recharge in highly permeable unconfined aquifers through a monitoring of the degradation of the forested areas, measures of piezometric level and the flow increase of springs. In the same area, a water savings for the treatment and the use of grey water will be produced in the ZIPR test site (San Vito al Tagliamento, Pordenone). The test areas in the Friuli plain are located in the upper and middle plain of the Tagliamento River where there are an AR of the undifferentiated aquifer in the northern Friuli plain in infiltration recharge basins (gravel pits) featuring the typical problems of glacial gravel sediments. With a view to safeguarding one of the most valuable freshwater resources in the regions of Friuli and Veneto, precise knowledge of the dynamics and vulnerability of these highly permeable aquifers will be acquired through the application of innovative remote sensing, geochemical, hydro-geological and geophysical techniques and by means of geochemical and isotopic tracers. The results, processed within an innovative multidisciplinary conceptual model, will permit to evaluate the short- and medium-term effects of the recharge on the water table, on the spring line and on the biodiversity rate of the habitats involved.

In the Friuli region, an analysis of the potential uses of purified grey waters will be provided through the introduction of innovative solutions to reclaim the water purified by the SARC s.r.l. laboratory, which is currently discharged in the surface-water hydraulic system, in order to achieve savings and to implement an ecological compensation policy. A few of the metals contained in the purified water, especially zinc, moderately exceed the levels set by the Legislative Decree 152/06. Treatment with Thlaspi Caerulescens, i.e., a bioaccumulator of

metals, is therefore planned.

2.2. The Copparo test site

In the demonstration activity in the southern Copparo plain (Ferrara) it is to prove the effectiveness of AR in low- to medium-permeability sediments through monitoring of the purified freshwater injected into the unconfined aquifer and in the first confined aquifer containing brackish water. The project also aims at providing an estimate of the potential impact of the recharge on the increase of water availability and of the time needed to significantly improve the quality of underground water. Furthermore, the project tries to understand whether AR can help stop desertification and to provide freshwater resources in large areas of the southern Po Plain where the salinisation of some aquifers appears to be an irreversible phenomenon. By intervening on a highly compromised aquifer, it is possible to quickly estimate the response and modelling of the system to the AR for the storage of freshwater in areas at high risk of desertification.

In the Copparo area the following aims will be pursued.

- Defining the abstraction and purification procedures with respect to the water of Po di Volano and to phyto-purification. The final aim is the injection of good quality freshwater, purified also with respect to water-rock interactions, to be strategically stored in the underground for later use as drinking water in cases of water scarcity. After identifying suitable areas where to abstract excess water to recharge the aquifer, analytical procedures will be applied to check their suitability. The storage capacity will also be improved, as will the infrastructures for decantation and phyto-purification.
- Developing a specific procedure to combat the impoverishment of inland water through artificial storage of high-quality freshwater.
- Applying, testing, monitoring and disseminating this innovative method.
- Compensating the lowering of piezometric levels, guaranteeing a positive water balance in areas affected by serious water stress and mitigating salinisation and salt-wedge ingression.
- Defining the renewal rate of water in the two above-mentioned macro-areas via isotopic tests (oxygen, deuterium and tritium) and quantifying the effectiveness of aquifer recharge.
- Hydrodynamic and hydrochemical models.
- Performing a cost-benefit analysis of AR to evaluate its economic sustainability and identifying economically viable measures and actions to safeguard the quality and quantity of receptor aquifers.

In the Copparo test site, the aquifers with salt contamination due to seawater intrusion will be transformed into fresh water aquifers through the AR. The first 200 m of the Po Plain aquifer in the Ferrara territories consist of five hydro-stratigraphic units (Fig. 3): a) the A0 free unconfined, b) the A1 aquifer which is generally under pressure, c) three more deep artesian aquifers (A2, A3 and A4) (Dugoni *et al.*, 2007; Rapti-Caputo and Martinelli, 2007, 2009). The A0 unit is well characterised, thanks to a network of large diameter wells, even as the deep aquifers are not completely well characterised. In the A1 aquifer only local relationships between aquifer and current bed of the Po River at the same time will be investigated as the aquifer away from the river is not known (Dugoni *et al.*, 2007; Rapti-Caputo and Martinelli 2007). For instance, the monitoring network of the A1 aquifer is based on 9 wells of which six are developed along the

Fig. 1 - Test sites of the WARBO project: Friuli plain and Copparo area.

present bed of the Po River, two wells are located near the Po di Volano river, near the coast area and one is located NW of Ferrara territory where structural highs can favour the ascent of high salinity water and consequent contamination of A1 aquifer. On the contrary, geochemical and hydro-geologic characterisation of the deep aquifers (A2, A3 and A4) is less accurate and does not cover the entire territory of Ferrara (Dugoni *et al.*, 2007).

The test site of WARBO project is located in an area where no monitoring network is available and the hydro-geological interpretations are based on a constant sedimentation model that identifies the litho-stratigraphic features of aquifers in the regressive sands of glacial period and the aquitards in the clay deposits of the marine transgressions of inter-glacial phases. This interpretation does not take into account the influence of structural elements which have been reconstructed from the interpretation of gravimetric and seismic geophysical studies.

Unfortunately, the underground structures in the test site area of Copparo are not fully known and there is no detailed mapping of the compressional deformations due to the northward propagation of the Apennines fold-and-thrust belt. These structures have surely

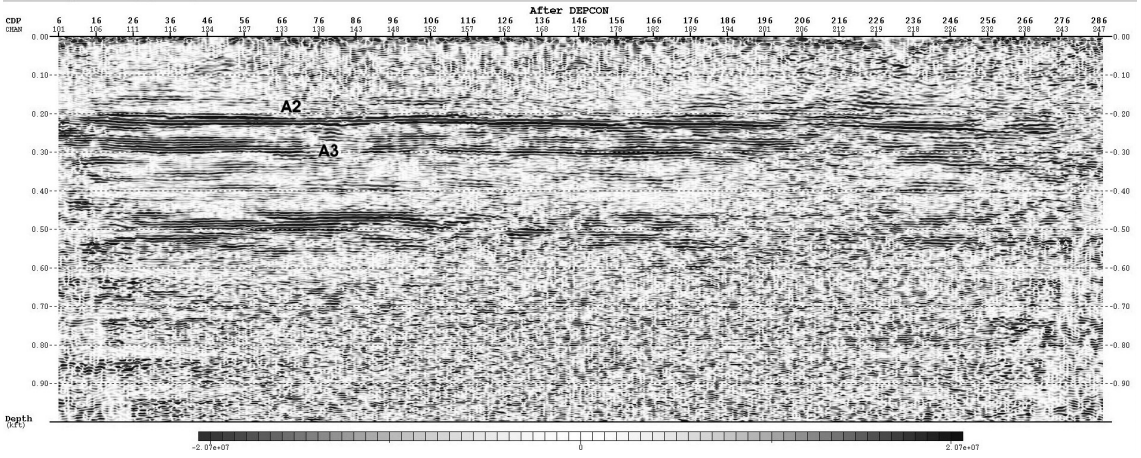

Fig. 2 - Example of the results (acquifer A2, A3) in seismic section (stack line) near the test site in the Friuli plain.

influenced sedimentation and aquifer geometries.

3. Employed methodologies

In the Friuli plain the conceptual model and identification of test areas will be developed with the integration and updating of the CAMI-LIFE database. The application of innovative 3D models with state-of-the-art numerical procedures to solve partial differential equations can allow more characterisation of the aquifers (Fig. 2) and of the volumes of water required for the AR. The AR by infiltration basins in the undifferentiated aquifer will be monitored using innovative remote sensing, geochemical, hydrogeological and geophysical techniques, geochemical and isotopic tracers. Results will permit to evaluate the short- and medium-term effects of the recharge on the water table, on the spring system and on the biodiversity.

For the grey waters of the SARC s.r.l., WARBO proposes, in a system of forest infiltration areas, a further treatment with Thlaspi Caerulescens, a vegetal bio-accumulator of metals, to permit a decrease the level of some metals and an innovative thermometric surveying integrated with geophysical measurements will be monitored the quantify the dispersion and diffusion of recharge and the optimization of the infiltration.

In the Copparo test site, WARBO will prove the effectiveness of AR in low- to medium-permeability aquifers by monitoring of the path of freshwater injected into the unconfined aquifer and in the brackish confined aquifer. The project also aims at evaluating whether AR could be used to contrast desertification and to increase freshwater resources in large areas of the southern Po Plain where salinisation appears irreversible at the moment. Intervention on a highly compromised aquifer could permit to estimate the response and to model AR for the storage of freshwater in areas at high risk of desertification. Sources of water for AR will be the extraction and purification procedures of water in the Po di Volano river and after phyto-purification their injection in the aquifer. The WARBO action will also comprise the application, testing, monitoring and disseminating of this innovative method.

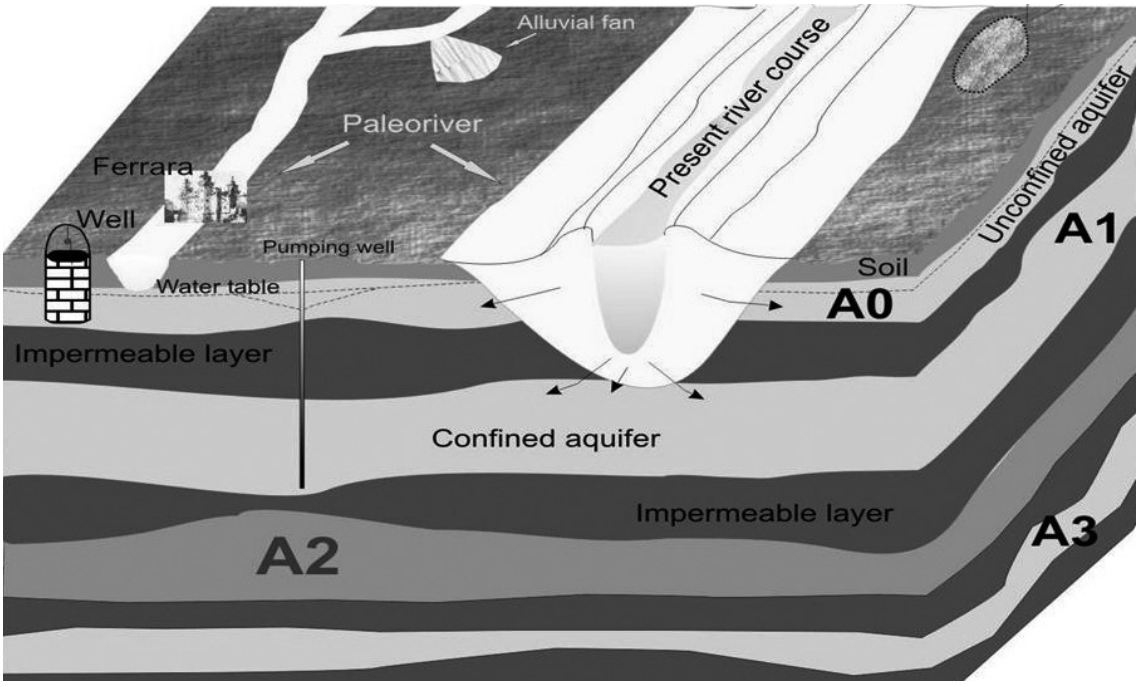

Fig. 3 - Simplified hydrogeological model in Copparo plain (Ferrara).

4. Expected results

Effects of recharge will be monitored in a radius of 1 km from the test areas. The main indicator will be the progressive recovering of natural level of spring barriers-depth and surface of the shallower aquifer. The required water volumes will be identified with the support of ARPA, Interregional Aqueduct Consortium for land reclamation of Ferrara and local institutions. Volumes will be calculated to reach in 3 years the following objectives:

- in the Friuli area an increase of about 0.5 m in the spring area with effects in the shallower confined aquifer (increment of 0.25 m^3/s about 1/100 of the natural recharge flow). A recover of dispersion from surface grid able to guarantee a supply of 10 l/s to infiltration systems giving an infiltration value of about 0.040 l/s.;
- in the low Ferrara plain, a decrease of salinity of the free aquifer and for the confined aquifer.

The main impact of the AR will be found on:

1) degradation of organic substances by the supply input of high quality water, to accelerate self-purification processes;
2) increase of the piezometric level of the aquifer, resuming its feeding functions;
3) protection of the environmental characteristics of rivers and streams by the recovery of the feeding functions of artificially recharged aquifers;
4) reduction of subsidence;
5) treatment of purified grey water to meet production demands and assessment of potential

uses;

6) awareness raising by campaigns and dissemination of information on the method for a large-scale application of AR.

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