The MARSOL project has received funding from the European Union’s Seventh Framework Programme for Research, Technological Development and Demonstration under grant agreement no 619120.
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1 EXECUTIVE SUMMARY

Southern Europe and the Mediterranean region are facing the challenge of managing its water resources under conditions of increasing scarcity and concerns about water quality. Already, the availability of fresh water in sufficient quality and quantity is one of the major factors limiting socio-economic development. Innovative water management strategies such as the storage of reclaimed water or excess water from different sources in Managed Aquifer Recharge (MAR) schemes can greatly increase water availability and therefore improve water security. Main objective of the proposed project MARSOL is to demonstrate that MAR is a sound, safe and sustainable strategy that can be applied with great confidence and therefore offering a key approach for tackling water scarcity in Southern Europe.

For this, eight field sites were selected that will demonstrate the applicability of MAR using various water sources, ranging from treated wastewater to desalinated seawater, and a variety of technical solutions. Targets are the alleviation of the effect of climate change on water resources, the mitigation of droughts, to countermeasure temporal and spatial misfit of water availability, to sustain agricultural water supply and rural socio-economic development, to combat agricultural related pollutants, to sustain future urban and industrial water supply and to limit seawater intrusion in coastal aquifers.

The present report illustrates the activities and related objectives of the two Marsol pilot sites selected in Italy namely Demo Site 5 “River Brenta Catchment, Vicenza, Italy”. It is structured in the following sections:

- study area description;
- a detailed description of implemented activities;
- results obtained in two DEMO sites and objectives achieved using MAR solutions.
1.1 STUDY AREA

The two Marsol pilot sites selected in Italy, namely Demo Site 5 “River Brenta Catchment, Vicenza, Italy”, are located in the upper plain of the Veneto Region.

The following picture shows the two Marsol demo sites and the FIA (Forested Infiltration Area) area used during the LIFE+ funded TRUST project. One of the Marsol sites is located very close to the TRUST FIA, while the other site is suitable for serving two different functions: floods retention area and managed artificial recharge.

![Location of the two test areas in the Demonstration Site 5, River Brenta Catchment, Vicenza, Italy](image)

The two Marsol pilot sites selected are shown in detail in following picture:

- Schiavon Forested Infiltration Area (FIA) and
- Loria detention basin along the Lugana river
The Infiltration Area of Schiavon (FIA) is fed by the Brenta river through the existing network of irrigation channels. The FIA one is located in the Vicenza upper plain aquifer, which is an undifferentiated aquifer on the foothill area of the pre-Alps, and contains one of the most significant groundwater bodies of the Eastern Alps hydrographic district, in terms of both size and water supply provided. This land is therefore strategic for all the citizens who live in the area and who use this water resource.

The natural infiltration capacity of the soil is heavily compromised, while the decrease of flows towards the groundwater represents a problem for the ecosystem balances on one hand, and a direct threat for the citizens’ health on the other hand.

In particular, the slow impoverishment of the water resources, caused by the depletion of the undifferentiated groundwater table of the Vicenza upper plain, causes a series of problems such as: water shortage, water conflicts, outflow of the spring belt natural system, increase in the investment costs for the water supply, etc.

During the time from 2013 to 2015, the site was studied under the Aquor project, funded by the EC in the framework of the LIFE+ programme. From the operational point of view, the site is managed by the Brenta Consortium, which has entered into a lease agreement with the land owner for a period of 5 years.
The monitoring of surface and ground waters was carried out within the Aquor project from 2013 to 2015, and then by the MARSOL partners.

During this project, the Infiltration Area of Schiavon was provided with:

1. surface water monitoring of Roggia Comuna
2. groundwater monitoring well

The Schiavon forested infiltration area has been chosen to represent the typical MAR settings within the River Brenta Catchment. One of the reasons for selecting the Schiavon forested infiltration area was because this site already had a set of consolidated historical data, and because it provided the possibility to reach the following objectives:

1. Characterization of the heterogeneous River Brenta mega fan deposits at very shallow depth. Knowledge about sediment type composition and distribution will be required to evaluate infiltration capacity and its variability
2. Hydrostratigraphical characterization of the shallow subsurface within the EU water framework directive and
3. Evaluation and/or monitoring of the clogging effects.

The Loria detention basin is located next to the city of Treviso. In addition to the Lugana river, another water stream, the Trieste river, a flood-risk tributary to the Lugana, is intercepted. The Lugana’s maximum thirty-year flow is 10 m³/sec. The basin has a stock capacity up to 40.000 m³ and it fills up four times a year.

During this project, the monitoring of surface and ground water of Lugana river detention basin was carried out by the MARSOL partners through:

- surface water monitoring both of Lugana River and detention basin
- groundwater monitoring well
- Time-domain reflectometer (TDR probe).

The Loria retention basin has been chosen taking into account two possible uses for the infiltration test site, namely the infiltration capacity and the potential flood basin area.

1.2 Activities and Role of Partners

DEMO site activities included the implementation of monitoring and mathematical modelling in order to monitor and model infiltration rates and quality processes. The monitoring has provided insight about the enhancements that the FIA and flood retention basin offer for MAR both in quantity (improving infiltration rates) and quality terms (due to the effects of the biological systems linked to the plant roots). Mathematical modelling focused on assessing the impact of the MAR in the restoration of the resurgence system. The benefits of cultivation in the MAR area to prevent clogging have been asses as well as the potential of MAR to improve water quality aspects.
The implemented activities for Demo Site 5 “River Brenta Catchment, Vicenza, Italy” include following tasks:

- Task 7.1 - Site operation: MARSOL monitoring campaign (Task Leader: AAWA)
- Task 7.2 - Site analysis: analysis of the available data, preliminary to the modeling activity, hydrogeological model set-up and cost-benefit analysis of the MAR techniques (Task Leader: SGI)
- Task 7.3 - Site characterization: MOSAIC (Model Driven Site Assessment, Information and Control) research platform application (Task Leader: UFZ)
- Task 7.4 - Unsaturated zone monitoring: TDR sensor installation (Task Leader: ICCS)

1.3 PROJECT OBJECTIVES

The Application of MAR solutions to Demo Site 5 “River Brenta Catchment, Vicenza, Italy” has the objectives to:

- Demonstrate the possibility to use a Forested Infiltration Area (FIA) for MAR and its potential to combat groundwater over-exploitation;
- Demonstrate the potential of MAR to enhance the ecological status of groundwater in the North East (NE) Alpine District;
- Demonstrate innovative monitoring system based on the application of TDR sensors and monitoring technologies developed at ICCS and UFZ;
- Evaluation of quantitative and qualitative processes in the vadose zone and the groundwater in Schiavon demo site;
- Assess the benefits of the Forested Infiltration Area (FIA) for MAR but also for the environment and the economy of the area considering the potential of FIA in the provision of ecological services. This will entail the cost benefit analysis, but also other aspects considered in the MARSOL project, i.e. governance and legal issues, dissemination to stakeholders, training;
- Demonstrate the potential of MAR to improve environmental ecosystems by attracting animal species typical of humid environments, and in particular birds, by restoration of nature (establishment of stable plant communities) using FIA.
2 DESCRIPTION OF IMPLEMENTED ACTIVITIES

2.1 TASK 7.1 “SITE OPERATION”

In September 2014 AAWA the logistics support to UFZ was provided for the execution of the infiltration tests and geophysical survey.

In February/March 2015 the agreement with the Reclamation Consortium Brenta was finalized, through which the tasks of monitoring and management of the two test sites were made official.

Between February and March 2015 the activities for certification of utility clearance and UXO clearance in the two test sites were carried out.

In March 2015 logistical support was provided for Direct Push tests carried out by UFZ and setup of the boreholes for installation of TDR by ICCS.
In May 2015 a monitoring well 50 meters deep was installed for quail-quantitative monitoring of groundwater on the demo field of Loria and a monthly laboratory analysis program of physical and chemical parameters was initiated.

In May/June 2015 a monitoring network of surface water that feed the basin of Loria was designed and installed.
Figure 7 - Scheme of monitoring network of surface water in the test site of Loria

Schiavon DEMO site

Figure 8 - Scheme of Schiavon FIA
The site of Schiavon is a FIA (Forested Infiltration Area) of about 16200 m².

The monitoring scheme of Schiavon (Figure 9) is composed of:

- a remote continuous surface water quality-quantity monitoring system where main physical-chemical parameters and volume of infiltrated water are measured;

- monthly laboratory analysis of surface water for the following parameters: Specific Electric Conductivity, Turbidity, pH, Total Hardness, Chlorides, Nitrates, Sulfates, Ammonia, Nitrites, Arsenic, Cadmium, Tot. Chrome, Nickel, Lead, Copper, Escherichia Coli, Enterococcus, Total Coliforms;

- monthly laboratory analysis of groundwater of the same parameters of surface water, plus Trichloroethane, Trichlorethylene, Tetrachlorethylene;

- monthly measures of water table level;

Figure 9 - Scheme of the monitoring system in Schiavon
**Loria DEMO site**

The site of Loria site is a flood storage and infiltration basin of about 20350 m$^2$ and 30000 m$^3$ of volume. The monitoring scheme of Loria (Figure 10) is composed of:

- a remote continuous surface water quality monitoring system (on-line control) where main physical parameters are measured: Turbidity, pH, Temperature, Redox, Specific Electric Conductivity;
- Continuous measures (on-line control) of water level of Lugana river and water level in retention area (when it is activated);
- monthly Laboratory analysis of chemical and microbiological parameters of groundwater (groundwater monitoring well located downstream retention area);
- Continuous measures of water table level.

![Figure 10 - Scheme of the monitoring system in Loria](image-url)
Water quantity parameters measured during time period October 2015 – February 2016 will be available on-line in official MARSOL web site.

Figure below shows an example of measured data by sensor installed in Loria site – water level of Lugana river (October 2015 – February 2016).

Figure 11- Monitoring data in Loria site (Demo Site 5, River Brenta Catchment, Vicenza, Italy) - Water level in Lugana river.

2.2 TASK 7.2 “DEMO SITE ANALYSIS”

The activity consisted in gathering the available quantitative and qualitative historical data of the groundwater in the area of interest, prior to the start of the MARSOL monitoring campaign and the set-up of the hydrogeological model.

This task includes also the hydrogeological modelling activity and finally the cost benefit analysis of the MAR techniques at the demo site that compare aquifer storage recharge versus conventional development of water resources.
2.2.1 Data collection and analysis

The groundwater quality historical data have been analyzed taking into account two different levels of detail:

- regional historical data from ARPAV (Regional Authority for Environmental Protection of Veneto Region);
- local monitoring data in Schiavon site and in other six neighbouring demonstration areas collected during “AQUOR (LIFE 2010 ENV/IT/380)”, a project funded by the EU aimed at restoring the groundwater balance in the Vicenza Upper Plain and ensuring the sustainable use of this resource by current and future generations.

The historical groundwater quality data provided by ARPAV cover a time period between 2000 and 2015. The surface water and groundwater monitoring networks cover the entire Veneto region: there are 283 groundwater monitoring stations and 316 surface water stations. Figure below shows the distribution of available ARPAV monitoring stations.

![Figure 12 - ARPAV monitoring stations available for the data analysis of the Demonstration Site 5, River Brenta Catchment, Vicenza, Italy](image)

Taking into account the location of Demo Site 5, River Brenta Catchment, the most significant monitoring points to characterize the groundwater quality of the areas are the ones located inside the
GWB (Groundwater Bodies) named “Alta Pianura del Brenta” (APB), “Alta Pianura Trevigiana” (TVA) and in the surrounding GWB.

Figure below shows a zoom area of GWB where Demo Site 5, River Brenta Catchment, is located. Within the area the available monitoring points considered in the analysis are, respectively for surface water and groundwater quality, 25 and 105.

![Legend](image1)

**Figure 13 - Zoom area of Demonstration Site 5, River Brenta Catchment, Vicenza, Italy - Available ARPAV monitoring stations**

Chemical and physical monitoring of groundwater is carried out twice per year, in spring and in autumn. The parameters monitored within the piezometric stations are: temperature, conductivity, pH, dissolved oxygen, nitrates, pesticides, VOCs, metals (i.e. chromium, mercury, lead, nickel, cadmium, arsenic), chlorobenzenes, aromatic compounds (i.e. benzene, trichloroethylene, tetrachloroethylene).

Figure below shows an example of Nitrates concentration trend just U/S the Schiavon demo site: well 451 highlighted in red.
Figure 14 – Nitrates concentration upstream Demo Site 5, River Brenta Catchment, Vicenza, Italy

Chemical and physical monitoring of surface water is carried out every month or less frequently (bimonthly, quarterly, six-monthly) with respect to its intended use (i.e. potable water, environmental monitoring, aquatic life control). Table below summarizes main available parameters.
### Available chemical and physical parameters of surface water monitored from ARPAV

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Potable water</th>
<th>Environmental monitoring</th>
<th>Aquatic life control</th>
</tr>
</thead>
<tbody>
<tr>
<td>aromatic hydrocarbons</td>
<td>aromatic hydrocarbons</td>
<td>pH, BOD5, dissolved oxygen, Temperature, total hardness</td>
<td></td>
</tr>
<tr>
<td>metals (i.e Hg, Cr, Pb, Ni, As)</td>
<td>metals (i.e Zn, Pb, Hg, Ni, As)</td>
<td>metals (i.e Zn, Pb, Hg, Ni,)</td>
<td></td>
</tr>
<tr>
<td>herbicides</td>
<td>microbiological parameters</td>
<td>surfactants</td>
<td></td>
</tr>
<tr>
<td>VOCs</td>
<td>VOCs</td>
<td>nutrients (i.e. P, N-NO3, N-NO2, N-NH4)</td>
<td></td>
</tr>
<tr>
<td>halogenols</td>
<td>organic micropollutants</td>
<td>TSS</td>
<td></td>
</tr>
<tr>
<td>pesticides</td>
<td>pesticides</td>
<td>chlorides, NH3</td>
<td></td>
</tr>
</tbody>
</table>

Table 1 – Available chemical and physical parameters of surface water monitored from ARPAV

Chemical and physical monitoring of water quality, both surface water and groundwater, in AQUOR project began in September 2011 and it finished in May 2015. Errore. L’origine riferimento non è stata trovata. shows the area of interest of AQUOR project located in the upper Vicenza’s plain. It is bounded by Prealpi Vicentine on the North, by Monti Lessini on the West, by limit of springs belt area on the South. The area reaches the city of Bassano del Grappa and Tezze sul Brenta on the East.

![Figure 15 - Project area of AQUOR. Location of the seven monitoring stations considered in data analysis of the Demo Site 5, River Brenta Catchment, Vicenza, Italy](image-url)

Continuous data series of physical parameters were obtained with automated measurement stations. These measurement stations contain sensors for temperature, conductivity, pH, redox potential and dissolved oxygen.
Chemical parameters were monitored once per month. Parameters monitored in piezometric stations are: nitrates, sulphates, ammonia, chlorides, chrome, nickel, lead, copper, cadmium, nitrite, trichloroethylene and tetrachlorethylene, total coliform, Escherichia coli, enterococcal, VOCs. Also the chemical and physical parameters of surface water were measured once per month.

In order to evaluate Nitrates trend, recent groundwater quality data from “AQUOR” PROJECT have been analyzed: in particular the monitoring data in existing springs downstream SCHIAVON demo site. Table and map below show location, number and spring’s status investigated in AQUOR project.

<table>
<thead>
<tr>
<th>Location - Comune</th>
<th>Number</th>
<th>Status: Active (Perennial/Periodic)</th>
<th>Status: Extinct</th>
</tr>
</thead>
<tbody>
<tr>
<td>Altvilla Vicentina</td>
<td>6</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>Bolzano Vicentina</td>
<td>11</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Brendola</td>
<td>5</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Bressanvido</td>
<td>36</td>
<td>33</td>
<td>3</td>
</tr>
<tr>
<td>Caldogno</td>
<td>53</td>
<td>46</td>
<td>7</td>
</tr>
<tr>
<td>Costabissara</td>
<td>22</td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td>Creazzo</td>
<td>12</td>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td>Dueville</td>
<td>56</td>
<td>41</td>
<td>15</td>
</tr>
<tr>
<td>Isola Vicentina</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Pozzeleone</td>
<td>8</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>Quinto Vicentina</td>
<td>8</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Sandrigo</td>
<td>39</td>
<td>29</td>
<td>10</td>
</tr>
<tr>
<td>Schiavon</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Vicenza</td>
<td>2</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Villaverla</td>
<td>102</td>
<td>93</td>
<td>9</td>
</tr>
</tbody>
</table>

![Spring's location](image-url) - Spring’s location near the Demo Site 5, River Brenta Catchment, Vicenza, Italy and their status (active, extinct) – AQUOR Census 2005
Figure below shows a comparison of threshold concentration value (red line) with all available data of Nitrates trend (time period August 2013-April 2015) taking into account ARPAV upstream well (orange line), Spring n°12 values (blue triangles) and measured concentrations values in FIA site with recharge on (violet line) and with recharge off (green line).

The location of Spring 12 (on Sandrigo Municipality), used as reference to evaluate Nitrates concentrations downstream Schiavon Demo site, within the spring’s zone, is highlighted in red color in Figure 16.

Nitrates values measured in Schiavon FIA site always result below the threshold value (50mg/l, Groundwater Directive 2006/118/EC), however the concentration values appear to be lower during recharge -on period: the values during recharge -on period are about half of concentration’s values during recharge -off period.

![SCHIAVON site - NITRATES](image.png)

Figure 17 – SCHIAVON FIA Demo Site: Nitrates trend in different locations

During MARSOL project time period the monitoring activities in Schiavon Demo site continued and in Loria Demo site began and continued until September 2016.

Figure below shows concentration values of Nitrates measured at well located just downstream Loria flood retention area. The monitoring time coverage starts from May 2015 and finishes on August 2016 (monthly frequency). Nitrates values of groundwater measured in Loria retention area always result below the threshold value (50mg/l).
The data analysis performed has been used as part of the testing of the groundwater quality model of the demo site.

### 2.2.2 Hydrogeological Model Set-Up

The goal of the modelling activities was the development of a 3D physically based distributed hydrological model surface/subsurface water for the BRENTA basin to be used as helpful tool in order to simulate the whole hydrological cycle and perform spatial-temporal analysis for water management and planning, using open source and free codes. In addition such a model, once calibrated on the basis of recorded historical data, can also be employed for evaluating the effects on the aquifers of some MAR techniques, such as those ones that were established inside the BRENTA basin.

The first steps for the development of a similar model are the definition of the study area, the reconstruction of the geo-structural model and its characterization, the boundary conditions assessment and the evaluation of the water budget terms.

**The study area: the Venetian Central Basin**

The study area is located in north-eastern Italy and involves a large, deep multi-aquifer groundwater reservoir formed in the Quaternary deposits of the Po plain sedimentary basin. The area is the piedmont plain extending from the pre-Alps to the Adriatic Sea, encompassing the municipalities of Vicenza, Padua, and Venice (Rinaldo et al., 2009). The system is bounded by the Lessini mountain range and by the Berici hills (west), the Asiago plateau (north), and the Brenta River (east) (Figure 19).
Boundary conditions definition

The areal extent of the study area amounts approximately to 3,300 km$^2$ and was established as follows: the northern boundary was limited by the outcrop line of the basement; the southern boundary was placed at the limit of the Adriatic Sea (where hydrostatic boundary conditions were imposed for all aquifers); finally no-flow boundary conditions were assumed for both the eastern and western limits of the calculation domain, i.e. such limits were traced orthogonally to the available measured piezometric contour lines (Figure 19).

The geo-structural model

The geo-structural system is formed by a single (undifferentiated) unconfined aquifer in the northern part of the domain and by seven (one unconfined and six confined) aquifers separated by six low-conductivity lenses of varying thickness in the southern part of the basin (Figure 20). Precisely such a complex system suggested the use of a 3D computational scheme for modelling purposes.
In detail the geo-structural system was constructed by using data taken from a number of geologic sections and stratigraphic records. Ten reconstructed sections, elaborated from geoelectrical and seismic surveys, were in fact available from literature (Dal Prà et al. 1977; Antonelli and Dal Prà, 1977). The accuracy of these reconstructed sections was somewhat limiting as they were mostly derived from seismic imaging and well stratigraphy records, dating from the 1970s and mainly focused on the deeper deposits of the basin. Nonetheless some recent geophysical logs and other stratigraphic records from newly operated deep wells allowed for a more accurate interpretation of the data for the 3D geo-structural model. In detail the depth of the bedrock was located accurately using the seismic surveys, well stratigraphic records, and geologic maps, whereas available information on filter locations for pumping wells was used to better localize the depth of the productive aquifers (Monego, 2009; Passadore, 2008). The total thickness of the system resulted ranging from a few meters at the northern boundary to more than 300 m at the south-eastern boundary, and the inception of the low-conductivity lenses appeared in the form of pinch-outs just north of the spring areas, localized in the central part of the study area (Figure 19).

**Hydrogeological parameters**

A number of geologic regions were identified for the phreatic aquifer on the basis of outcrop maps, so that different values of hydraulic conductivity could be assigned to each of them (Figure 3). For example zones containing actual or paleo-river beds and springs, i.e. surface zones of emergence of water table, were recognized and characterized by larger values of conductivity (Passadore, 2008). In this way the spatial variability of hydrogeological parameters resulted generally more pronounced in the northern part of the domain, while their distribution was practically uniform in the southern part because of the absence of modelled water courses. This spatial distribution was then applied to all the underlying layers of the model because of the lack of accurate information for the confined aquifers (Rinaldo et al., 2009).
Evaluation of the water budget: source/sink terms

In resolving the water budget the following components were considered: (1) net infiltration; (2) water discharge dispersed by rivers, irrigation channels and agricultural fields; (3) water discharge drained by rivers; (4) spring-water outflows; and (5) water flows pumped out by private and public wells. In particular they were estimated by: literature data; information obtained from new and more detailed acquisition campaigns (Passadore, 2008); stochastic treatment of available surveys (Monego, 2009).

In the case of public wells for domestic (100 units) and irrigation (50 units) use, the pumped flows were locally assigned to the 3D model cells taking into account the available information on filter locations. Instead, the private wells (industrial or domestic) couldn’t be modelled in the same way due to the big number of the wells active in the resurgence zone and the very poor data obtainable. Consequently they were simulated by assuming some withdrawal areas, and assigning them outflows on the basis of literature data.

Water flows assigned to the recharge zone of the unconfined aquifer (surface cells comprised between the resurgence zone and the northern mountains) were in addition: (1) net infiltration (rainfall from which estimated evapotranspiration and superficial fluxes were subtracted via standard hydrologic techniques); (2) water discharges dispersed by rivers and irrigation channels, (3) water discharges drained by rivers and (4) the water discharge outflowing from the springs, whose recorded history is notable in the area (Passadore, 2008; Monego, 2009). In brief, evapotranspiration fluxes were evaluated through the Hargreaves and Samani formulation, assuming then that the real evapotranspiration was a function of the water content in the soil and potential evapotranspiration. The processes, related to the separation of superficial and sub-superficial fluxes from deep infiltration, were modelled mathematically by applying the water balance to a control volume representative of the active soil. The water content \( S(t) \) in the soil was updated at each calculation step \( dt \) using the following balance equation:

\[
S(t + dt) = S(t) + P(t) - R_{sur}(t) - R_{sub}(t) - L(t) - ET(t)
\]

where \( P \) and \( ET \) are the components of precipitation and evapotranspiration, while \( R_{sur}, R_{sub} \) and \( L \) are the surface runoff, sub-surface runoff and deep percolation model states respectively. The surface runoff was expressed using the following equation, which is based on a threshold critical value beyond which a mechanism of dunnian flow (saturation excess mechanism) prevails:
where $C$ is a coefficient of soil saturation obtained by calibration, and $S_{\text{max}}$ is the content of water at saturation, depending on the nature of the soil and on its use (Ferri et al., 2010). In detail the following data were considered to calculate net rainfall infiltration rates: hourly rain intensities gauged at 25 pluviometric stations, maximum and minimum daily temperatures, soil use/cover maps and pedological maps (Figure 22).

As concerns the water fluxes dispersed by river beds and irrigation channels, they were estimated using empirical relations linking river (or channel) discharges to the dispersed flux per stream length unit. Such relations were derived from several field campaigns (see Sottani et al., 1982), integrated by data collected in more recent surveys. A similar procedure was also applied in order to evaluate the water fluxes drained by river beds.

Finally empirical relations between the spring discharges and the piezometric levels measured in suitable wells were assessed to obtain a continuous record of the spring discharge at various sites.

**3D Flow Model implementation**

Once completed the conceptualization of the study area domain and prepared the relevant geo-referenced input files, the next step was the implementation of the 3D computational scheme: in detail the model was developed using the public domain computational code MODFLOW, presently considered an international standard for simulating and predicting groundwater conditions and groundwater/surface-water interactions. The code has a modular structure, each module representing a specific sink/source of the hydrologic system being simulated, that allows it to be easily modified to adapt the code for a particular application. MODFLOW is developed by the U.S. Geological Survey, and solves the three-dimensional (3D) groundwater flow equation based on the discretization of a continuous aquifer system using the finite difference method (McDonald et al., 1988). The finite difference discretization consists on replacing the three-dimensional (3D) groundwater flow equation by a finite set of discrete points or cells in space and time where aquifer head values are calculated. It allows to simulate steady and transitory flow conditions in an irregularly shaped flow system in which
Aquifer layers can be confined, unconfined, or a combination of confined and unconfined. Flow from external stresses, such as flow to wells, areal recharge, evapotranspiration, flow to drains, and flow through river beds, can be simulated; hydraulic conductivities or transmissivities for any layer may differ spatially and be anisotropic and the storage coefficient may be heterogeneous; specified head and specified flux boundaries can also be modelled. First of all the model layers were implemented, potentially corresponding to the units defined in the conceptual geo-structural model. In particular the creation of top/bottom surfaces for each hydrostratigraphic unit, the distinction in active/inactive cells, the assignment of the hydrodynamic parameters were completed. Later the necessary boundary conditions and the various source/sink terms above described were also assigned.

**Steady state simulations**

Initially steady state simulations were performed: in this case the sum of all inflows (where outflow is a negative inflow) from adjacent cells and external stresses must be zero for each cell in the model because the storage term is null. In detail the calibration of the model, was carried out by comparing:

- the simulated and observed groundwater heads collected for the study area in 2007;
- the water budget terms, previously calculated and averaged for 2007, with those ones obtained by the model.

The selection of the 2007 data set was due to the fact that it represents the historical data series approaching the most the theoretical data series obtainable by averaging all the historical data recorded in the 2000-2016 period. The results obtained were satisfying both in terms of simulated groundwater heads and water budget volumes, as it is possible to observe from the following picture and table (Figure 23, Table 2).

<table>
<thead>
<tr>
<th>Water budget terms (m³/s)</th>
<th>Observed values</th>
<th>Simulated values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net infiltration</td>
<td>10.10</td>
<td>10.10</td>
</tr>
<tr>
<td>Dispersion of irrigation channels</td>
<td>19.48</td>
<td></td>
</tr>
<tr>
<td>Dispersion of agricultural fields</td>
<td>2.78</td>
<td>38.03</td>
</tr>
<tr>
<td>Dispersion of Leogra river</td>
<td>2.43</td>
<td></td>
</tr>
<tr>
<td>Dispersion of Astico river</td>
<td>2.59</td>
<td></td>
</tr>
<tr>
<td>Dispersion of Brenta river</td>
<td>10.89</td>
<td></td>
</tr>
<tr>
<td>Drainage of Brenta river</td>
<td>-12.31</td>
<td></td>
</tr>
<tr>
<td>Public withdrawals</td>
<td>-9.50</td>
<td>-27.72</td>
</tr>
<tr>
<td>Private withdrawals</td>
<td>-5.91</td>
<td></td>
</tr>
</tbody>
</table>

Table 2 - Comparison between calculated and simulated water budget terms.
Figure 23 - Comparison between the simulated isophratic contour lines and the observed ones (green line on the background).

In particular the simulated groundwater head was characterized by an average error of about 1 meter; in addition 90% of the study area showed an error less than 3.50 meters.

Transitory state simulations

The steady state solution obtained was then employed as a reliable initial condition for transitory state simulations, where the storage capacity of the groundwater has also to be taken into account. In detail the specific yield and storage were assumed constant inside the various aquifers ($S_y = 3 \times 10^{-5} \text{ 1/m}$, $S_s = 0.2$) and aquitards ($S_y = 3 \times 10^{-4} \text{ 1/m}$, $S_s = 0.45$).

Transitory state simulations were performed in order to evaluate the oscillations of the phreatic surfaces and the resurgence outflows on varying the other water budget terms. Therefore the average monthly values of net infiltration, water discharges dispersed by rivers, irrigation channels and agricultural fields, water discharges drained by rivers and water flows pumped out by private and public wells were firstly calculated and then assigned to model cells. Nevertheless the calculation was later performed on a daily basis in order to avoid any possible convergence issue.

The model was able to reproduce quite correctly the temporal trends of the various source/sink terms and observed groundwater heads, as shown in the following pictures reported Figure 24 and Figure 25).

In particular the maximum, minimum and average value of the absolute deviations, estimated comparing the temporal trends of simulated and observed groundwater heads, were calculated for each gage. Taking into account the studies previously carried out in this area, observation sites characterized by an average value less than 5 meters were assumed well simulated. Forty-two out of fifty sites satisfied this condition, and are reported in Figure 26.
Figure 24 - Comparison between the simulated and observed groundwater heads for the monitoring station in Crosara di Nove.

Figure 25 - Comparison between the simulated and calculated outflows for some resurgence areas.

Figure 26 - Water table measurement stations considered in the calibration process.
Stream-aquifer interactions modelling (steady state simulations)

As already stated, the water fluxes dispersed/drained by river beds were estimated using empirical relations linking river (or channel) discharges to the dispersed/drained flux per stream length unit. In detail such relations were derived from several field campaigns (see Sottani et al., 1982), integrated by data collected in more recent surveys. Dispersive/draining river trunks were then introduced into the model by polylines, characterized by specified inflows/outflows previously calculated and then distributed along their development: no stream-aquifer interaction was therefore modelled. However it is evident how a similar approach has some faults because changes in the environmental system could make invalid these correlations. Consequently stream-aquifer interactions were later simulated using the MODFLOW-2005 Streamflow Routing package (Niswonger and Prudic, 2010). This package defines the characteristics of streams used in the groundwater model. Each stream is discretized into segments, which are a portion of the stream with constant or linearly varying properties. These segments are overlaid on the model grid, and the intersection of a segment with these cells is referred to as a reach. Segment boundaries are defined when there is a tributary, diversion, streamflow gage, or a non-linear change in a stream property, and their physical properties are defined at the upstream and downstream end of the segment itself.

Therefore point streambed geometry cross-section data, streambed thickness, roughness coefficients for the channel and overbank, vertical hydraulic conductivity, streambed elevation were defined into the model. In addition flow hydrographs were introduced as boundary conditions for the upstream sections of the rivers to be modelled. In detail they were calculated by a geomorphoclimatic hydrological model, previously developed and calibrated for the study area, enabling to simulate hydrologic processes in the mountain zones, delimiting the northern boundaries of the present calculation domain where there are no aquifers. The geomorphoclimatic approach relates the transfer function of rainfall-runoff characteristics of the basin to the topology of its river network, and therefore to its geomorphology and climate characteristics. Moreover it reproduces the processes of snow accumulation and melting and the processes of rainfall-runoff separation, solving the water balance in a volume of hydrological active soil (vadose zone), through a realistic description of the temporal dynamics of water content and adopting a physically based parameterization of processes that takes into account the vegetation cover, the soil texture and its slope.

Also in this phase, initially, steady state simulations were performed and the calibration of the model, was carried out by comparing:

- the simulated and observed groundwater heads collected for the study area in 2007;
- the water budget terms, previously calculated and averaged for 2007, with those ones obtained by the model.

The results obtained were satisfying both in terms of simulated groundwater heads (Figure 27) and water budget volumes (Table 3), as it is possible to observe from the following pictures and tables. The average error in the simulated groundwater head was again about of 1 meter, and 90% of the study area was characterized by an error less than 3.50 meters.
<table>
<thead>
<tr>
<th>Water budget terms (m²/s)</th>
<th>Calculated values</th>
<th>Simulated values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net infiltration</td>
<td>10.10</td>
<td>10.10</td>
</tr>
<tr>
<td>Dispersion of irrigation channels</td>
<td>19.48</td>
<td>22.26</td>
</tr>
<tr>
<td>Dispersion of agricultural fields</td>
<td>2.78</td>
<td>2.43</td>
</tr>
<tr>
<td>Dispersion of Leogra river</td>
<td>2.78</td>
<td>2.43</td>
</tr>
<tr>
<td>Dispersion of Astico river</td>
<td>2.59</td>
<td>2.59</td>
</tr>
<tr>
<td>Dispersion of Brenta river</td>
<td>10.89</td>
<td>10.89</td>
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</table>

<table>
<thead>
<tr>
<th></th>
<th>Calculated values</th>
<th>Simulated values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drainage of Brenta river</td>
<td>-12.31</td>
<td>-12.31</td>
</tr>
<tr>
<td>Public withdrawals</td>
<td>-9.50</td>
<td>-15.41</td>
</tr>
<tr>
<td>Private withdrawals</td>
<td>-5.91</td>
<td></td>
</tr>
</tbody>
</table>

Table 3 – Comparison between calculated and simulated water budget terms.

Figure 27 – Comparison between the simulated isophreatic contour lines and the observed ones (green line on the background).

In addition the draining and dispersive river trunks were adequately simulated by the model (Figure 28).
Figure 28 – Comparison between the dispersive/draining trunks of the rivers, well known in literature, and those ones obtained by the simulations carried out.

Consequently differences between the isophreatic contour lines obtained by modelling rivers with SFR package or as dispersive/draining trunks were negligible (Figure 29).

Figure 29 – Isophreatic contour lines obtained by modelling rivers with SFR package (blue line) or as dispersive/draining trunks (red line).

Stream-aquifer interactions modelling (transitory state simulations)

The steady state solution obtained was then employed as a reliable initial condition for transitory state simulations. Transitory state simulations were conducted by maintaining unchanged the water budget
terms previously calculated, expect the stream leakage because rivers were modelled with SFR package rather than as dispersive/draining trunks. The goal was to evaluate if there were differences in the new simulated temporal trend of stream leakage, and if this output had affected the phreatic surfaces and the resurgence outflows.

Although a few information were available about the water withdrawal/restitution from/to rivers, the model was able to reproduce quite correctly the temporal trends of the various source/sink terms and observed groundwater heads, as shown in the following pictures reported (Figure 30 and Figure 31). In particular, also in this case, the maximum, minimum and average value of the absolute deviations, estimated comparing the temporal trends of simulated and observed groundwater heads, were calculated for each gage. Again observation sites characterized by an average value less than 5 meters were assumed well simulated. Forty-two out of fifty sites satisfied this condition.

Therefore, on the basis of the results obtained, it is possible to state that the hydrogeological model developed can be effectively used as a reliable tool for simulating the whole hydrological cycle for the study area under observation, and also to evaluate the effects on the aquifers of MAR technologies, such as the Forested Infiltration Area (F.I.A.) in Schiavon, that were established inside the BRENTA basin.
2.2.3 Cost-Benefit analysis of the MAR techniques at the Demo Site

A Cost-benefit analysis of MAR techniques at the Brenta Demo site versus conventional solutions for water supply was made in collaboration with the development of WP15.

As mentioned in WP15 Deliverable D15.1, the approach to the Financial Analysis is derived from the European Commission Guidelines to Cost-Benefit Analysis of Investment Projects\(^1\) and adjusted to the specific case of Managed Aquifer Recharge.

Deliverable D15.1 describes in detail the Financial analysis implemented, the parameters used to evaluate the costs and results obtained in terms of suitability of MAR techniques applied in Brenta Demo site. Basic data used to carried out the financial analysis are:

- Users figures (number of inhabitants, agricultural area and production, etc.)
- Users unitary demand/production of water and possibly its seasonal distribution if significant
- Current and projected source of water or way of treatment and predicted deficit
- Physical features regarding the facility (area occupied by the plant, infiltration rates, etc.)
- Physical features regarding the aquifer (volume, depth, water balance, etc.)
- Investment and current costs regarding the facility
- Current supply/treatment costs for water
- Average local Evaporative losses (m\(^3\)/m\(^2\)/y)

In Brenta Demo site, in which the investigation concerns the quantity of water rather than the quality, a time horizon of 30 years is considered for the hydraulic infrastructures, according to well established international standards\(^2\).

The target of the financial analysis is to assess the increase in tariffs that would allow the hypothetical large scale project to be financially sustainable, seen from the point of view of the MAR facility’s manager.

Deliverable D15.2 actually on going will describe economic analysis developed at the Demo site therefore taking into account environmental externalities (e.g. the increase of water availability) and indirect benefits (e.g. environmental benefits due to establishment of stable plant communities in FIA pilot area, environmental restoration and landscaping) derived from technologies in Brenta Demo site.

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\(^1\) European Commission, 2014, Guide to cost-benefit analysis of investment project.

\(^2\) Generally speaking, “infrastructure projects are generally appraised over a period of 20-30 years [...]. Although the physical assets may last significantly longer than this [...] it is not generally worthwhile trying to forecast over longer periods” (ISPA Guidelines). For Water and Environment projects the average time horizon is close to 30 years [Source: European Commission, 2014, Guide to cost-benefit analysis of investment project].
2.3 **Task 7.3 “Site Characterization”**

In March 2014 a site visit was organized with UFZ geologists in order to verify the suitability of the selected Demo sites and make plans for the application of the MOSAIC (Model driven site assessment information and control) technology. For the occasion, a workshop was held in the premises of Brenta Consortium with the involvement of the MARSOL partners – AAWA, SGI and UFZ - and of Aquor project partners, i.e. the Province of Vicenza, Veneto Agricoltura and the Water Resources Center of Novoledo. Presentations were made to illustrate the equipment/monitoring systems, logistic and administrative requirements as well as geographical and hydrogeological framework of the proposed demo sites. The Aquor and Redafi projects were also presented.

![UFZ’s visit to demo sites on 14 March 2014](image)

Based on this site visit, the Loria infiltration basin and the Schiavon forested infiltration site were chosen to represent two typical MAR settings within the River Brenta Catchment. The following research questions were defined for the two investigation sites:

- **Loria basin infiltration test site (seasonal infiltration); special relevance of this test site as EU flood directive and EU water framework directive apply.**
  - How to efficiently characterize the shallow subsurface of large scale MAR infrastructures
  - How to quantify sediment input and mobilization of fines within the upper 1-2 m depth following infiltration/recharge events
  - How to characterize and monitor infiltration capacity (against the background of potential basin base area colmation)

- **Schiavon forested infiltration site:**
  - How to characterize the heterogeneous River Brenta mega fan deposits at very shallow depth. Knowledge about sediment type composition and distribution will be needed to evaluate infiltration capacity and its variability
  - How to conduct a hydrostratigraphical characterization of the shallow subsurface in the above mentioned framework
How to evaluate and/or monitor clogging effects due to colmation in the infiltration trenches

The pilot site analysis during the first site visit was supported by providing already existing data. Based on this information the project groundwater team composed of SGI, AAWA and UFZ defined the most appropriate investigation campaign. To address the aforementioned research questions, two field campaigns (September 2014 and March 2015) were performed at both sites. In the following, a brief description of the site investigation concept, employed site investigation techniques, and results are presented.

A detailed knowledge of subsurface structures and processes is an important prerequisite for the understanding and the solution of hydrogeological tasks. Against this background, exploration and monitoring technologies must be addressed to the challenges which arise from the difference between process scale and exploration scale, the temporal variability of process, heterogeneity of natural systems and its dimensions. The MOSAIC site investigation approach was employed for a problem-oriented, rapid site characterization. The MOSAIC platform comprises mobile modular data acquisition units for adaptive field investigations and contains vehicles equipped with direct push probing devices in combination with geophysical measuring techniques as well as hydrogeological and geotechnical equipment. Thereby, surface geophysics allow rapid mapping of subsurface structures while Direct Push can be used for high resolution in situ parametrization of detected layers/units. Thereby, Direct Push describes a technology that uses hollow steel rods that are hammered and/or pushed into the subsurface. Sensor probes can be attached to the end of the rod string to collect continuous vertical high resolution profiles of hydrogeological, geotechnical, geophysical or geochemical properties under in situ conditions. Alternatively, Direct Push can be used to rapidly install permanent or temporary ground water wells or to retrieve soil samples. As the Direct Push technology allows on-site decision making it is often advantageous over conventional solely sample based site characterization approaches concerning data reliability, adaptability, and efficiency.

**Loria Infiltration Basin**

Loria infiltration basin: Prior to the first field campaign in September 2014 the infiltration basin was flooded after a strong precipitation event. As a result, most of the basin area was covered with a fine-grained sediment layer of approximately 10 cm thickness. This limited site accessibility with the mobile MOSAIC equipment (track mounted Direct Push rigs of 4.5 t weight and mobile geophysical equipment pulled by a car) as well as applicability of geophysical measurement methods. However, it enabled us to investigate the site under unbiased site conditions after flooding. The following work was performed:

- Extensive electromagnetic profile measurements (profiles of EM38DD, EM31) and gamma-ray spectrometric measurements to characterize the heterogeneity of sediments, e.g. identification of areal zonation in composition within basin
- Hood infiltrometer tests to determine infiltration rates and to determine potential differences in infiltration capacity caused by soil cover and structure (comparison between ploughed soil, grass cover, etc.)
- Soil sampling for grain size analyses and to conduct laboratory soil column experiments on the change of infiltration capacity in response to potential colmation
The clay cover and sedimentary composition with a broad spectrum in grain size distribution (clay to rocks) was challenging for the application of investigation techniques. However, surface geophysics as well as Direct Push probing at shallow depths was successfully applied for site characterization. Results of the surface geophysics surveys did not indicate different aerial zonation within the basin (Figure 33). Solely the presence of an area with strong wetness in the northern part of the basin that impeded performance of measurements indicated a zonation. Before the second field campaign the clay cover within the basin was ploughed and mixed with the existing sediments during regular basin maintenance. This enabled site accessibility with Direct Push equipment. Following the MOSAIC site investigation approach, high resolution vertical Direct Push profiling was employed for the subsurface characterization, as ground truth for the geophysics data, and to provide in-situ measured data for enhanced site parametrization. Direct Push investigation points were distributed in a way to retrieve representative subsurface information over the entire site. In addition, special focus was placed on the wetting zone in the northern part of the infiltration basin. Subsurface investigations conducted in March 2015 included the following activities:

- Cone Penetration Testing (CPT) at all marked locations 1-10 (see Figure 33)). Obtained CPT measurements revealed information about soil behaviour type that was used to infer subsurface lithology. The CPT system was deployed in combination with a frequency domain based add-on module to determine vertical profiles of volumetric water content in the subsurface. This tool allows determination of variations in soil water content on decimetre scale based on in-situ measurements and was especially useful to determine thickness of the clay rich surface cover in the northern part of the basin. Vertical profiles of the distribution of electrical conductivity were measured in addition to identify potential presence and thickness of clay containing layers that may inhibit infiltration over depth (see Figure 33).

- Installation of 2 waveguides to a depth of 4m below ground surface to be used for continuous soil water content monitoring at location 3 (see (Figure 33 for location and Figure 37 for installation process) by ICCS.

- Vertical high resolution (10 cm sampling intervals) soil sampling at waveguide installation locations. Volumetric water content was determined for samples using gravimetric analyses to support in-situ measured CPT and soil water content data.

- Additional soil sampling at location 10 to a depth of 4 m below ground surface for soil description and determination of volumetric water content.

- Extensive soil column experiments to assess the impact of grain size distribution and amount of suspended sedimentary load and its mobilization during flooding events on the clogging behaviour.
Figure 33 – Loria basin field campaign

Figure 34 - Direct Push investigation locations (numbered 1-10) and selected Direct Push electrical conductivity logging results.

★ EC/SMP profiling
★ TDR installation
Schiavon Forested Infiltration Site

Similarly, the MOSAIC approach was performed at the Schiavon forested infiltration site. Work included:

- Extensive electromagnetic measurements (profiles of EM38DD and EM31 between infiltration trenches) to characterize the unsaturated zone in terms of sedimentary areal zonation. Thereby, different zones of interest in different depths were identified.
- Geoelectric measurements (two profiles of 140 and 172 m length) for vertical characterization of sedimentary structures/layers supported the findings of the electromagnetic surveys.
- Outcrops photography and mapping for validation of the electromagnetic measurements.

Based on the geophysics results, 6 zones of interests (see Figure 36) were identified for detailed subsurface investigations during the March 2015 field campaign. Specific activities that were conducted are the following:

- Use of Direct Push vertical electrical conductivity profiling at locations 1-6 as a tool to identify potential small scale clay rich (high electrical conductivity) layers in the shallow subsurface (here up to 7m below ground surface) that may constrain water infiltration; see Figure 36 for results and Figure 35 for employed field equipment.
- Direct Push based installation of 2 waveguides to a depth of 3m below ground surface to be used for continuous soil water content monitoring by ICCS.
- Vertical high resolution (10cm sampling intervals) soil sampling at waveguide installation locations. Volumetric water content was determined for samples using gravimetric analyses; results can be used to calibrate initial waveguide TDR measurements performed by ICCS.
- Installation of a 2” diameter ground water monitoring well in close proximity of the waveguide installations for ground water level monitoring.
- Additional soil sampling at locations 1, 2, 5 (see Figure 36 left) for stratigraphic analysis and analysis of bulk density up to a depth of 8m below ground surface.
Figure 35 - Field equipment used for Direct Push electrical conductivity logging

Figure 36 - Results of the site characterization. Results of the electromagnetic survey, EM32 with 6m penetration depth (left) and location of Direct Push investigation points; Electrical Resistivity Tomography (Top); selected results of vertical Direct Push electrical conductivity logging (bottom)
2.4 **Task 7.4 “Unsaturated Zone Monitoring”**

The research activities involved the conceptualization and installation of prototype TDR sensors in the demo sites of WP7. The site in Schiavon, regards the application of AR through recharge trenches, while the site in Loria involves the application of MAR through recharge basin. The optimal location of the TDR sensors was decided based on the above type of MAR facilities, and in combination with the information from the surface geophysics surveys conducted by MET-UFZ. The installation for the test of the TDR took place between 18 and 22 March 2015, as shown in the following figures.

The above TDR sensors have the following characteristics:

- **Schiavon Site:**
  - TDR1: Sensor length 2.80m
  - TDR2: Sensor length 3.00m

- **Loria Site:**
  - TDR3: Sensor length 3.00m
  - TDR4: Sensor length 3.00m
The TDR installations were followed by on-site TDR readings at all four points. The following figures show the sample TDR readings from all the aforementioned points.

Figure 38 - Installation of developed TDR sensors in (a) Schiavon and (b) Loria, MAR sites.

Figure 39 - TDR readings from sensors TDR1 & TDR2, in Loria site
During the 1\textsuperscript{st} and 2\textsuperscript{nd} of September 2016 the installation of the TDR monitoring and data logging system has been implemented. The monitoring system has been connected to the TDR waveguides that have already been installed at specific locations in the Loria and Schiavon sites (March 2015).

At both sites the infrastructure for the protection of the waveguides (concrete rectangular openings with concrete cover), heavy duty tubing buried underground for the protection of the signal transfer coaxial cable and a concrete sump with concrete cover for the protection of the TDR instrumentation box and the battery have already been constructed in-place.

The work consisted of the:

- Installation of low loss coaxial cables for the TDR signal;
- Connection of TDR and sealing of TDR waveguides;
- Connection and test of TDR monitoring and data logging system.

The installations were followed by various test and TDR readings.
Figure 41 - Overview of two TDR waveguides protected holes at Loria site

Figure 42 - 1st TDR waveguide hole at Loria site.
Figure 43 - TDR instrumentation box and concrete sump at Loria site.

Figure 44 - TDR instrumentation box at Loria site.
Figure 45 - Overview of TDR waveguide and TDR instrumentation box at Schiavon site.

Figure 46 - Overview of TDR waveguide and TDR instrumentation box at Schiavon site.
Figure 47 - Sample TDR reading at Loria site

Figure 48 - Sample TDR reading at Schiavon site
3 RESULTS OBTAINED AND OBJECTIVES ACHIEVED

Following paragraphs illustrate results obtained from DEMO site implementation and analysis carried out through monitoring and modelling activities.

3.1 POSSIBILITY TO USE A FORESTED INFILTRATION AREA (FIA) FOR MAR AND ITS POTENTIAL TO COMBAT GROUNDWATER OVER-EXPLOITATION

The experimental site of Schiavon (VI) covers an area of 1.0 ha and is situated in the Venetian High Plain, which hosts a widespread unconfined aquifer whose phreatic surface lays tens of metres below ground surface: therefore, in such a scheme, the movement of the infiltration water in the unsaturated zone is expected to be mainly vertical. In detail local stratigraphic profiles confirmed the presence of an upper horizon stressed by tillage and roots growth, below which there is a 50 m deep layer, composed of gravels, sands and pebbles in different particle sizes, locally interrupted by some modest clay layers. The interpretation of the performed geological surveys allowed to evaluate a hydraulic conductivity for the pebbly deposits ranging between $10^{-3}$ m/s and $10^{-4}$ m/s, in addition seismic and electrical resistivity tomography tests validated the lateral continuity of these units.

In this site infiltration is promoted by a system of nine ditches 7.5 m spaced that let most of the ground surface available for farming and accessible from agricultural machinery. Each ditch is 163 m long: therefore overall channels 1400-1600 m long are usually excavated for a similar plant. Each ditch is 0.7 - 0.8 m deep to reach the permeable sediments below the tillage layer, and has a trapezoidal shape (0.7 - 0.8 m wide at the top and 0.3 - 0.4 m wide at the bottom).

The ditches are fed by a channel connected with the local network of irrigation canals, diverted from the Brenta River. Specifically the inflow is adequately managed by a gate, in order to avoid possible overflows: the maximum permitted water volume is 100 l/s. Overflows are further prevented thanks to the limited natural slope of the field, that is around 4–5‰.

Later this inflow is equi-distributed among the various ditches in order to guarantee that their bottom is permanently submerged, so that it is possible to maximize the draining surface and thus the infiltration rate. The system is also equipped with a sedimentation tank, installed at the upstream end, in order to capture sediments transported by the river, that could reduce the recharge capacity once settled on the bottom of the ditches.

**Monitoring activity in Schiavon**

To address the feasibility of applying MAR strategies in a large scale, pilot tests have firstly to be studied in order to properly design and construct a comprehensive MAR scheme (Mastrociccio et al., 2015). Therefore a monitoring activity on the Schiavon site was conducted to assess the working conditions of such techniques: in detail a series of discharge measurements were performed at the inflow of the different ditches to evaluate the consequent infiltration rates. All the inflow in fact contributed to the aquifer recharge because the Schiavon F.I.A. was over-dimensioned, i.e. the system was designed in order to avoid overflows and outflows.
In the picture below the results of the monitoring activity, performed from October 2014 to February 2015, are reported as example (Figure 49).

On the basis of the data collected during the entire experimental phase, it was possible to ascertain that the average infiltrated flow was of about 18.50 l/s, therefore less than 100 l/s assumed as reference in the design of the plant. Anyway such flow is in line with the results obtained in other previous studies, where it was comprised between 17-44 l/s for hectare (Mezzalira et al., 2014).

In order to have an idea about the potential recharge volume per year, it has to be taken into account that farming practices and local irrigation needs strongly influence the seasonality of the F.I.A.s. During the irrigation season, in fact, all available water resources are primarily used to irrigate crops. In addition it must be remembered that:

- irrigation systems are normally subjected to periodic maintenance in winter;
- F.I.A.s need to be suspended in case of flood events to prevent clogging.

Thus, by assuming F.I.A.s operative about 200-250 days a year (from September-October to April-May), the consequent potential annual recharge for a plant of one hectare would be:

\[ V = 0.018 \frac{m^3}{s} \times 200 \frac{days}{year} \times 86400 \frac{s}{day} = 311'040 \ m^3 \]

If these technologies were further extended in order to reach a total area of 100 ha, the consequent potential annual recharge would be in turn:
\[
V = 1.8 \frac{m^3}{s} \cdot 200 \frac{days}{year} \cdot 86400 \frac{s}{day} = 31'104'000 \ m^3
\]

This is a very significant value, near to the total capacity of the Corlo reservoir that represents presently one of the main water resources inside the Brenta megafan.

**Modelling activity in Schiavon**

All the collected experimental data were later used to perform reliable simulations by the hydrogeological model, previously calibrated for the entire Venetian High Plain, in order to evaluate the effects on the aquifers of such recharge works. In detail the availability of such a tool permits:

- to forecast the effects of the recharge in terms of potential infiltrated water volumes;
- to quantify the portion of the territory affected by these processes;
- to manage the recharge process itself, by taking into account also parameters as the seasonality of operation of MAR strategies, etc.

In detail transitory state simulations were performed by assuming as *ante operam* scenario the results obtained by the model considering the water budget terms relative to 2007. As already reported earlier, this choice was performed since such water budget terms represent the historical data set nearest to the average conditions for the study area.

The *ante operam* scenario was then compared with two *post operam* scenarios:

- the first one considered operative only the Schaivon F.I.A., thus the average infiltrated flow, resulted from the experimental activities (18.50 l/s for hectare), was added to the other already implemented water budget terms. The F.I.A. was assumed working from October to April (212 days for year), in order to take also into account its seasonality (Figure 50), and during this period a constant recharge flow was set since the plant is able to guarantee a steady inflow.

![Figure 50– F.I.A. recharge flows assumed in the first post operam scenario.](image)

- the second one considered operative the Schaivon site and other four existing F.I.A.s located inside the Brenta megafan: Tezze sul Brenta, Schiavon 2, Carmignano, Pozzoleone (Figure 51).
The average infiltrated flows for the new F.I.A.s were estimated on the basis of the average infiltrated flow, evaluated experimentally in Schiavon and equal to 18.50 l/s for a plant of one hectare, and the surface of the other plants (Table 4).

<table>
<thead>
<tr>
<th>F.I.A. name</th>
<th>Surface area (ha)</th>
<th>Recharge (m³/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schiavon_Marsol</td>
<td>1.33</td>
<td>0.019</td>
</tr>
<tr>
<td>Schiavon_area_2</td>
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<td>0.016</td>
</tr>
<tr>
<td>Tezze_Brenta</td>
<td>1.81</td>
<td>0.025</td>
</tr>
<tr>
<td>Carmignano</td>
<td>2.94</td>
<td>0.041</td>
</tr>
<tr>
<td>Pozzoleone</td>
<td>0.60</td>
<td>0.008</td>
</tr>
</tbody>
</table>

Table 4 – Main features of the F.I.A.s considered in the second post operam scenario.

Again the recharge flow was retained constant inside the period comprised between October and April (212 days for a year), so that the seasonal working of the F.I.A.s was also simulated (Figure 52)
The model was not calibrated by comparing the simulated and observed groundwater heads since this area is characterized by marked natural fluctuations of the water table (Figure 53), thus the mounding effect of the recharge, induced by the F.I.A. system operation, couldn’t be adequately evaluable.

However a fictitious monitoring station was considered, placed inside the area that could be potentially affected by the F.I.A.s’ operation (Figure 51), in order to compare the temporal trends of groundwater levels, resulted from the various simulated scenarios.

In particular, from the elaborations carried out, some meaningful results were obtained and are reported in the following:

1. the potential infiltrated water volumes were about 348’019 m³ for a year in the first post operam scenario, and 1’996’531 m³ in the second post operam scenario (Figure 54). Thus the approximate estimations previously performed were confirmed.
2. The F.I.A. recharge determined an average water table mound comprised between 0 and 0.013 m for the first post operam scenario, and between 0 and 0.10 m for the second post operam scenario, as it is possible to state from the following picture, showing also the portion of the domain area affected by these processes (Figure 55).

Therefore the assumption of ignoring the existing monitoring stations for calibration purposes was justified, since the mounding effect of the recharge induced by the F.I.A. system operation would certainly have been masked by the natural water table fluctuation of the local unconfined aquifer. The long-term record shows in fact a mean seasonal fluctuation approximately of 2 m with peaks of 5 m (Figure 53), which is by far higher than the mounding effect of the F.I.A. system operation.

In addition, by observing the temporal trend of the water table rise simulated in the fictitious monitoring station, it was evident how the F.I.A.s’ seasonality influences strongly the mounding effect (Figure 56). In fact during the irrigation season the ground water levels tend to reach again the original values characterizing the ante operam scenario.
3. The increase of ground water levels determined effects on different water budget terms:
- Smaller stream dispersion volumes (Figure 57), i.e. the water volumes supplied by rivers to the aquifers in the mountain trunks, because the difference between the river stage and the groundwater head was reduced;

![Stream dispersion flow](image)

Figure 57 – Stream dispersion volumes obtained in the two simulated post operam scenarios.

- Greater stream drainage volumes (Figure 58), i.e. the water volumes supplied by aquifers to rivers in the valley trunks, because the difference between the groundwater head and the river stage was augmented;

![Stream drainage flow](image)

Figure 58 – Stream drainage volumes obtained in the two simulated post operam scenarios.
greater resurgence outflows (Figure 59), because the difference between the groundwater head and the ground level was augmented.

Figure 59 – Recharge outflows obtained in the two simulated post operam scenarios.

Therefore, on the basis of the results achieved by the experimental and modeling activities carried out, it is possible to ascertain that similar MAR strategies could be considered valuable options to replenish the unconfined aquifer of the Brenta megafan, recently affected by a significant and generalized drop in groundwater heads due to heavy exploitation, massive land-use change and climate change. In fact it was demonstrated how if these technologies were extended in order to reach a total area of 100 ha, the consequent potential annual recharge would be about 30 millions m$^3$ for a year, i.e. near to the total capacity of the Corlo reservoir that represents presently one of the main water resources inside this area. In addition such a recharge determines effects on different water budget terms: smaller stream dispersion volumes, greater stream drainage volumes and above all greater resurgence outflows.

### 3.2 The potential of MAR to enhance the ecological status of groundwater in the North East (NE) Alpine District

#### 3.2.1 Schiavon DEMO site

In order to evaluate the potential of MAR to enhance the ecological status of groundwater both monitoring and modelling activities were considered. Figure below shows the groundwater level and the Nitrates concentrations measured just downstream Schiavon demo site during recharge-on time period (October 2015-February 2016) and recharge-off time period (April/March 2016 - September 2016).
Taking into account the amount of recharge flow in pilot FIA, namely 0.019 m³/s, obviously it does not seem to produce relevant increases in groundwater level measured.

Nitrates concentration results quite low during all monitoring time period (3-11 mg/l) due to physical filtration process of surface water from Roggia Comuna and also to a purification process through the micro-organisms that live in symbiosis with the roots of FIA area. Furthermore, you may notice a lower pollutant concentration i.e. 3-6 mg/l mainly during recharge-on time period (October 2015-February 2016): indeed Nitrates concentration measured in Roggia Comuna, which feeds the pilot FIA, are equal about 4 mg/l. Therefore, monitoring data allows to check an improved water quality even if it is only a local condition considering the small extension of pilot demo site.

As described in previous paragraph, on the basis of the hydrodynamic results achieved by the modeling activities carried out, it is possible to ascertain that similar MAR strategies could be considered valuable options to replenish the unconfined aquifer of the Brenta megafan. The second one scenario analysis was also used to evaluate the effects of recharge in term of improved groundwater quality: Nitrates concentration was considered. Nitrates indeed, are the parameter/pollutant examined, since they are the most widespread groundwater contaminants in study area due to the diffuse impact from extensive agriculture.

**Water quality model set-up**

Transport model selected is MT3DMS (USGS): a modular 3-D Multi-Species Transport Model for Simulation of Advection, Dispersion, and Chemical Reactions of Contaminants in Groundwater Systems. MT3DMS was set-up to simulate changes in concentrations of miscible contaminant in groundwater considering advection, dispersion and external sources or sinks packages.

The partial differential equation describing the fate and transport of contaminants of species \( k \) in three-dimensional, transient groundwater flow systems can be written as follow:

\[
\frac{\partial (\theta C_k)}{\partial t} = \frac{\partial}{\partial x_i} \left( \theta D_{ij} \frac{\partial C_k}{\partial x_j} \right) - \frac{\partial}{\partial x_i} (\theta v_i C_k) + q_k C_k + \sum R_k
\]

where:
\( C^k \) is the dissolved concentration of species \( k \), ML\(^{-3}\);

\( \Theta \) is the porosity of the subsurface medium, dimensionless

\( t \) is time, T;

\( x_i \) is the distance along the respective Cartesian coordinate axis, L;

\( D_{ij} \) is the hydrodynamic dispersion coefficient tensor, L\(^2\)T\(^{-1}\);

\( v_i \) is the seepage or linear pore water velocity, LT\(^{-1}\);

\( q_s \) is the volumetric flow rate per unit volume of aquifer representing fluid sources (positive) and sinks (negative), T\(^{-1}\);

\( C_s^k \) is the concentration of the source or sink flux for species \( k \), ML\(^{-3}\);

\( \Sigma Rn \) is the chemical reaction term, ML\(^3\)T\(^{-1}\).

The advection term of the transport equation describes the transport of miscible contaminants at the same velocity as the groundwater. For many field-scale contaminant transport problems, the advection term dominates over the other terms.

Dispersion in porous media refers to the spreading of contaminants over a greater region than would be predicted solely from the average groundwater velocity vectors (Anderson, 1979 and 1984). Dispersion is caused both by mechanical dispersion, a result of deviations of actual velocity on a microscale from the average groundwater velocity, and by molecular diffusion driven by concentration gradients. Molecular diffusion is generally secondary and negligible compared to the effects of mechanical dispersion, and only becomes important when groundwater velocity is very low. The sum of mechanical dispersion and molecular diffusion is termed hydrodynamic dispersion, or simply dispersion.

The fluid sink/source term of the governing equation, \( q_s C_s \), represents solute mass entering the model domain through sources, or solute mass leaving the model domain through sinks.

The MT3DMS code is capable of handling equilibrium-controlled linear or non-linear sorption, nonequilibrium (rate-limited) sorption, and first-order reaction that can represent radioactive decay or provide an approximate representation of biodegradation.

The simulation implemented considered only a conservative pollutant namely Nitrates concentrations.

The scenario considered operative the Schiavon demo site and other four existing F.I.A.s located inside the Brenta megafan: Tezze sul Brenta, Schiavon 2, Carmignano, Pozzoleone (second scenario post operam, see paragraph 3.1).

The Nitrates concentration of average infiltrated flows for the new F.I.A.s were estimated on the basis of the average concentration of Nitrates measured on Roggia Comuna which feeds the FIA Schiavon Demo site: 4 mg/l.
The Nitrates concentration from dispersion of river and irrigation channel are assumed equal to 5-15 mg/l. The average Nitrates concentration of groundwater was assumed conservatively 20-25 mg/l with reference to historical groundwater quality data provided by ARPAV in study area (see Figure below).

![Figure 60 - Average Nitrates concentration in study area - ARPAV 2015](image)

Figure below shows results of hydrogeological model in term of average Nitrates concentration simulated during the year 2007: orange-yellow color represents average concentration in aquifer model equal to about 20-25 mg/l, blu color shows concentration from dispersion of river equal to about 4-10 mg/l and green color the average concentration values from dispersion of irrigation channel namely ~10 mg/l.
In Veneto Region the suitable area to realize enlarged MAR are already identified by the land reclamation Consortium within the LIFE Trust Project (EU). Figure below shows the red area in different GWB suitable to realize MAR, for instance in the GWB of Alta Pianura del Brenta the Consorzio di Bonifica of Brenta identified 100 ha of suitable area (blue circle in the below figure).

The purpose of modelling activity is therefore to support the realization of these MAR and in particular the F.I.A.s trying to identify the areas with “high priority” namely the suitable area where Nitrates concentrations seems more critical (see figure below).
The evaluation of the effect in the aquifer due to the Nitrate infiltration was analyzed through a regional hydrogeological model take into account that the spring zone, with high value of ecological services, is located downstream the pilot MAR.

Therefore the model simulates the MAR areas considering a regional aproach in order to preliminary estimate the effect on the rehabilitation of the spring belt zone. The effect of the MAR on the spring zone is tangible in the results shown in the Figure 63.

3.2.2 Loria DEMO site

During monitoring period of MARSOL project Loria flood retention area has been activated only for short time period (few days) and with very low water level (about 10-20 cm). Unfortunately this condition, mainly due to rainfall seasonal patterns not particularly intense, did not allow to fully evaluate the recharge effects through flood retention area both in term of water quantity and in term of improved water quality. Figure below shows an example of measured parameter’s trend at Loria demo site in time period from August 2015 to November 2015 during which time the flood retention area has been activated:

- trend of groundwater Nitrates concentration measured just downstream flood retention area (red line);
- water level measured in flood retention area (blue line);
- rainfall trend (green line);
The graph shows a clear correlation between the rainfall trend and the operation of retention area e.g. in mid-September 2015 when the water level reached 40 cm in relation to a daily rainfall of 22 mm. On the other hand, since the retention area has been inactive for the most part of the monitoring time also the dilution of pollutant (e.g. Nitrates concentrations) due to infiltration process results very uncertain to estimate: measured Nitrates concentration results very low during all monitoring time period i.e. 4-10 mg/l.

### 3.3 INNOVATIVE MONITORING SYSTEM BASED ON THE APPLICATION OF TDR SENSORS AND MONITORING TECHNOLOGIES DEVELOPED

#### 3.3.1 Schiavon DEMO site

Results at the Schiavon Site showed the relevance for spatial high resolution characterization of the sedimentary architecture over depth. The combined use of different surface geophysics techniques with different penetration depths (ranging from 1 m to about 10-15 m) in combination with Direct Push vertical profiling proved to be highly beneficial. Thereby, structures detected in the geophysical surveys were parameterized with the Direct Push. In addition, ground truths obtained by mapping and sampling proved the reliability of the employed tools. The Schiavon Forested Infiltration Site is a typical example that characterization of heterogeneous deposits solely based on information collected from drilling cores and laboratory analysis requires a large numbers of samples and laboratory analyses to provide sufficient spatial information about the distribution of relevant characteristics (porosity, hydraulic conductivity). However, this effort is in many cases not financially feasible and may impact economic and environmental sustainable MAR operation. Against this background, the application of the MOSAIC site investigation concepts proved to be reliable and efficient for the characterization of large scale MAR infrastructures as well as of MAR site with complex sedimentary architecture.

Unfortunately, TDR sensor monitoring data will be fully available only in next time period of MARSOL Project.
3.3.2 Loria DEMO site

Application of the MSOAIC approach was used to describe subsurface properties at the Loria infiltration basin. In particular, the MOSAIC approach was used to determine presence and thickness of clay containing layers that may impede water infiltration. Thereby, two cases must be differentiated:

a) Clay bearing layers within the natural subsurface that need to be identified during site characterization before MAR infrastructure installation and

b) fine grained sediments that are being brought into the basin during flooding events and are dispersed within the shallow subsurface by percolation or by ploughing during site maintenance. The natural clay bearing layers were reliably detected at the Loria site using Direct Push Profiling. Direct Push electrical conductivity allowed exact determination of layer depth and thickness. Results of initial laboratory scale column experiments with glass beads showed that the general clogging behaviour, e.g. mobilization of fines during percolation processes, was dependent of the grain size distribution and amount of sediment load of the infiltrated water during the experiments. Further column experiments with natural sands indicated a more complex dispersion behaviour. As site maintenance can be associated with high costs, this has to be considered during MAR infrastructure planning and operation. While the application of the Direct Push Water Content Profiler that measures in situ electrical permittivity was a good indicator for areas of higher fine content over depths, exact determination of clay and silt content within the heterogeneous soil matrix was easily achieved based on soil sampling and grain size analysis. Effects of increasing clay content upon water infiltration capacity can be quantified by performing permeameter laboratory test on samples. Hence, the MOSAC approach was useful to determine relevant sampling locations.

The installation of prototype TDR sensors in both demo site was planned in order to study and to characterize the processes in unsaturated zone (see paragraph 2.4).

As already mentioned, the site in Schiavon, regards the application of MAR technologies through recharge trenches so the monitoring of unsaturated zone allows to evaluate:

- water which infiltrates into the deep layers of the soil is effectively filtered by the roots of the trees;
- potential reduction of drainage capacity in the long term (clogging effect) due for instance to solid material that is transported by water in the ditches (e.g. in case of flood event) or produced by the cutting of trees of FIA area (e.g. foliage and shrubs);
- the effects of purification process through the micro-organisms that live in symbiosis with the roots.

In the Loria demo site the scope was the evaluation of the potential infiltration after several events of flooding that fill the retention area, but as before mentioned the weather condition in the project period have not allowed the activation of the existing storage. Consequently, the evaluation of the infiltration effect was not possible to evaluate.

During the 1st and 2nd of September 2016 the installation of the TDR monitoring and data logging system has been implemented so, unfortunately, the parameters measured will be available after the refining of the data collected. The next months could produce enough data from TDR monitoring to check modelling activity already implemented.
3.4 ECOLOGICAL SERVICES AND COST BENEFIT ANALYSIS

This paragraph summarizes results obtained from financial analysis implemented in Brenta Demo site with reference to WP15 Deliverable D15.1.

It is known that 20 MCM/y are required from municipalities and industries willing to shift their water supply source from the polluted downstream rivers to the high-quality upstream aquifers and resurgences. A financial analysis has been carried out (see WP15 to detailed analysis implemented) to calculate the increase in tariffs that makes the hypothetical large scale project able to infiltrate 20 MCM/y financially sustainable in 30 years (from the point of view of the MAR facility’s manager).

Limiting factors for the large scale project are:

- Minimum Environmental Flow of river Brenta is 5 m$^3$/s and additional 20 m$^3$/s shall always be left in the river to satisfy the authorized withdrawals of downstream users,
- the MAR system can be operated for only 194 days/year due to occurrence of low flows, high turbidity (i.e. risk of clogging) and diversion of water to agricultural fields for irrigation,
- the applicable infiltration rate without risk of clogging the system is 20-50 l/s/ha.

It is concluded that to infiltrate 20 MCM/y in 194 d/y at an average rate of 20 l/s/ha and considering a recovery rate of 80%, the large scale project shall cover an area of 75 ha; the costs (financial outflows) and revenues (financial inflows) of the Forested Infiltration Area pilot project of Schiavon have been considered, and scaled up accordingly.

Costs include implementation costs (supply and installation of monitoring system, instruments, trees plantation, furrowing, testing and model development), operation and maintenance costs (ordinary and extraordinary).

Revenues are expected to be mainly generated by the increase in water tariffs of the users, that currently amount to 1.15 €/m$^3$ for the municipal water supply and 0.01 €/m$^3$ for the agricultural supply.

A by-product revenue will also come from the harvest of plants every 5 years, since the biomass that is collected and chipped can be sold to energy production plants at a rate of 6,000 €/ha (1,200 €/y/ha).

The analysis has proven the 75ha-scheme to be financially sustainable if the increase in water tariffs is equal or higher than 1.5%, considering the following assumptions:

- a loan for covering project implementation costs of 1,800,000 €
- time for debt extinguishment due to the loan equal to 15 years
- interest rate 2%
- discount rate 4%.

The Financial Net Present Value of investment and the Financial Internal Rate of Return of investment are shown in the following Table.
Table 5 – Brenta Demo Site 5 – Summary of financial indicators

<table>
<thead>
<tr>
<th>Description</th>
<th>Increase in tariffs</th>
<th>FNPV/C</th>
<th>FRR/C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recharge aquifer with required 20 MCM/y via 75 ha FIA</td>
<td>1.5%</td>
<td>1,788,500</td>
<td>13.5%</td>
</tr>
</tbody>
</table>

To conclude the outcome of the financial analysis carried out is that the large scale MAR project shall cover an area of 75 ha and the average increase in tariffs of 1.5% applied to the municipal users will ensure the financial sustainability of the project. The size of the MAR facility in this case will comply with the minimum target of 20 MCM/y.

Results of economic analysis (see Deliverable D15.2) therefore will only confirm and improve the results so far obtained since they will take into account also potential indirect benefits arising from MAR technologies.

Indeed, the cultivation of fast-growing trees in FIA area generate an economic benefit for land owners whilst providing an environmental service: environmental restoration and landscaping through the establishment of stable plant communities and attraction of animal species typical of humid environments, in particular birds.

Figures below shows the potential ecosystem services (e.g. potential indirect benefits) associated to the AFI area and resurgencies ecosystems.

<table>
<thead>
<tr>
<th>Ecosystem services categories</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ecosystem Type</strong></td>
</tr>
<tr>
<td>Nutrient cycling</td>
</tr>
<tr>
<td>Rivers, Lakes, Lagoons, wetlands (including resurgence ecosystems)</td>
</tr>
</tbody>
</table>
4 CONCLUSION

The MOSAIC approach, i.e. the combination of surface geophysics and minimum invasive Direct Push technology was successfully applied for the efficient characterization of the Schiavon FIS with complex sedimentary architecture as the Loria infiltration basin as an example for large scale MAR infrastructure. The applied techniques are already available on the market today and often advantageous over traditional site investigation approaches in terms of resolution and efficiency. However, their uptake is yet beyond their capabilities. The site characterization results clearly show that the locations of infiltration infrastructure need to be carefully chosen based on (hydro-)geological as well as hydrological aspects (e.g. sediment loads) to allow environmental and economically sound system operation. The basis therefore, is a reliable and financially feasible site characterization approach.

On the basis of the results achieved by the experimental and modeling activities carried out, it is possible to ascertain that similar MAR strategies could be considered valuable options to replenish the unconfined aquifer of the Brenta megafan, recently affected by a significant and generalized drop in groundwater heads due to heavy exploitation, massive land-use change and climate change.

Modelling activity implemented can be used as decision support to realize large scale F.I.A.s in Veneto upper Region.

The outcome of the financial analysis so far carried out is that the large scale MAR project shall cover an area of 75 ha and the average increase in tariffs of 1.5% applied to the municipal users will ensure the financial sustainability of the project. The size of the MAR facility in this case will comply with the minimum target of 20 MCM/y.

Finally, in addition to economic benefits for owners, FIA area and consequently MAR technologies could play many positive roles for the community (see economic analysis results on going):

- recharging of groundwater and regeneration of springs (as demonstrated by monitoring and modelling activities);
- production of renewable energy (e.g. wood to biomass);
- reduction of greenhouse gas emissions;
- enhancement of the landscape;
- increase in biodiversity.
5 PUBLICATIONS

SGI issued the following publication during the reporting period. The scientific article mainly concerns a previous EU Life+ Project (TRUST), but, given the scientific and technical links with the ongoing MARSOL project concerning the Demo Site 5 (WP7), a specific mention to the MARSOL is made in the Acknowledgements.


6 OTHER DISSEMINATION ACTIVITIES

1. A workshop was held on 28 May 2014 at Brenta Consortium’s premises in Bassano del Grappa during the visit of Dr. Giorgio Pineschi from the Italian Ministry of the Environment and the representatives of IRSA (Italian Water Research Institute) and Aquor partners. During the workshop the MARSOL partners presented the MAR techniques that will be applied in the Schiavon and Loria pilot sites as well as the TRUST and AQUOR projects experience.

![Figure 66 – Workshop held on 28th May 2014 with the Italian Ministry of Environment and IRSA](image)

2. On October 3rd 2014 SGI and AAWA will present the MARSOL project at the conference “Managed Aquifer Recharge – MAR” that will take place in Piacenza (Italy).

4. SGI, AAWA. Participation to a European event: MAR to Market 2014 – Barcelona, Spain, with the presentation “The MARSOL and LIFE+ TRUST projects: enabling Tools in Italy for the implementation of the EU Water Framework Directive 2000/60/CE”, 4th November 2014;


Short description of the Event n.5: the Water Framework Directive (2000/60/EC) also aims to “promotes sustainable water use based on a long-term protection of available water resources”. The River basin management Plan (RBMP) is the implementation tool of the directive.

The river basin authority, in the activities of the development of the RBMP of the Eastern Alps, has planned an intensive public consultation in order to promote the active participation and sharing choices plan of stakeholders, from the earliest stages.

In this context, the present event concerned the theme of the relationship between water and agriculture.

It was therefore decided to take this opportunity to show the structure and potential of the "MARSOL project" to participants, who could be interested in the topics covered by the project. They were attended by representatives of the agricultural world, the land reclamation, municipalities, provinces, environmental agencies and environmental groups.

6. Participation to European and international event MARSOL Lavrion Workshop in Athens (16-18 March 2016) was made and an illustrative poster was prepared.
7. Participation to MARSOL Workshop (6 June 2016) was made in Venice (Italy).
9. An illustrative panel of the two Demo site has been prepared and placed in two demo site:
Il monitoraggio

L'obiettivo del monitoraggio è quello di raccogliere i dati sullo stato degli acque del Dotta, utilizzando un sistema di rilevamento installato nel bacino del fiume. Il monitoraggio avviene attraverso un sistema di sensore che misura vari parametri, come la temperatura, la turbidità, la salinità, la pH, l'ossigeno dissolto, la radiazione solare e altre variabili ambientali. Il monitoraggio è stato realizzato in collaborazione con l'Area di monitoraggio MARSOL, che ha fornito i dati e la documentazione necessaria per l'analisi degli effetti delle attività umane sul bacino del Dotta.

Il progetto

Il progetto MARSOL (Managing Agri-Food Reservoirs as a Solution to Water Scarcity and drought) è una iniziativa finanziata dall'Unione Europea nel contesto del programma di sviluppo regionale EASME (European Social Fund for Employment and Social Cohesion). Il progetto ha come obiettivo principale la gestione sostenibile delle risorse idriche attraverso la creazione di riserve idriche e lo sviluppo di strategie di gestione idrica.

Il monitoraggio idrogeologico

Per le caratteristiche di queste riunioni interattive si sono verificati diversi fenomeni, che hanno influenzato il comportamento del sistema idrogeologico. L'analisi dei dati rilevati ha permesso di identificare le principali cause delle variazioni di comportamento e di elaborare modelli che permettono di prevedere le evoluzioni future del sistema.

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References