WP3. ACTIONS TO INCREASE THE QUALITY OF NON CONVENTIONAL WATER USED IN AGRICULTURE

Output 3.4. No. of pre and post-treatment and MAR systems realized.

A 3.4.1 Implementation of MAR systems. Nitrate Vulnerable Zone of Arborea, Italy

Responsible partner: NRD-UNISS

30/12/2023

Menawara is a project funded by the EU unded the ENI CBC Med programme. Its total budget is €2.901.546,93 out of which €2.611.392,23 as EU funding (90% contribution).

This document has been produced with the financial assistance of the European Union under the ENI CBC Mediterranean Sea Basin Programme. The contents of this document are the sole responsibility of the LB, NRD-UNISS and can under no circumstances be regarded as reflecting the position of the European Union or the Programme management structures.

The 2014-2020 ENI CBC Mediterranean Sea Basin Programme is a multilateral Cross-Border Cooperation (CBC) initiative funded by the European Neighbourhood Instrument (ENI). The Programme objective is to foster fair, equitable and sustainable economic, social and territorial development, which may advance cross-border integration and valorise participating countries' territories and values. The following 13 countries participate in the Programme: Cyprus, Egypt, France, Greece, Israel, Italy, Jordan, Lebanon, Malta, Palestine, Portugal, Spain, Tunisia. The Managing Authority (JMA) is the Autonomous Region of Sardinia (Italy). Official Programme languages are Arabic, English and French. For more information, please visit:

www.enicbcmed.eu.

The European Union is made up of 28 Member States who have decided to gradually link together their know-how, resources and destinies. Together, during a period of enlargement of 50 years, they have built a zone of stability, democracy and sustainable development whilst maintaining cultural diversity, tolerance and individual freedoms. The European Union is committed to sharing its achievements and its values with countries and peoples beyond its borders

.

TABLE OF CONTENT

ABBREVIATIONS AND ACRONYMS

Acronym	Description
NRD-UNISS	Desertification Research Centre, University of Sassari
FIA	Forested Infiltration Area
MAR	Managed Aquifer Recharge
NBS	Nature-based Solution
PTS	Passive Treatment System
RL	Reactive Layer

1. Background

This technical report has been written in the context of the MENAWARA project on Non-conventional Water Re-use in Agriculture in Mediterranean countries.

The joint challenges of the MENAWARA project consist in providing additional resources by recycling drainage and wastewater, rationalizing water use practices and setting operational governance models in line with national and international plans. The project is designed to enhance access to water through the treatment of wastewater to be re-used as complementary irrigation and to strengthen the capacity of governmental institutions, non-state actors operating in the sector, technicians, and farmers.

The document reports the activities carried out in the third Work Package (WP3) of the MENAWARA project on *Non-conventional Water Re-use in Agriculture in Mediterranean countries* and, in particular, is related to **Output 3. 4 "Number of pre and post treatment and Managed Aquifer Recharge systems realized"** and **Activity 3.4.1 "Implementation of MAR systems"** as described in infographic below (Figure 1).

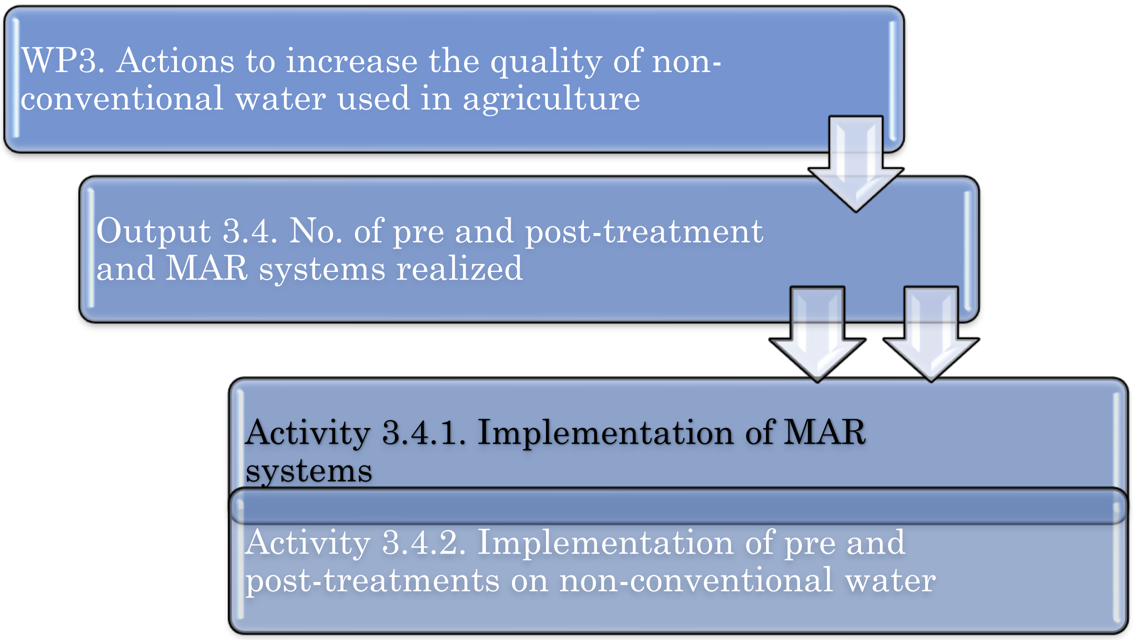


Figure 1. Infographic on the context of this technical report. MAR: Managed Aquifer Recharge.

This is the second technical report for the intervention in the Arborea site, within the Nitrate Vulnerable Zone (NVZ), central-western Sardinia, Italy, after the preliminary technical report related to the design of the MAR system (Forested Infiltration Area FIA) (Output 3.3, Activity 3.3.1) of August 2020, written by the Desertification Research Centre of the Sassari University (NRD-UNISS).

More specifically, the output 3.4 is described as follows: "Low-cost pre and post-treatments for each WWTP in the intervention areas realized and high-quality TWW supplied to irrigation distribution networks adopting more rational irrigation techniques compared to the pre-project situation. MAR systems (FIA) realized in Arborea by using improved non-conventional water to recharge the phreatic sandy aquifer exploited for agricultural purposes."

This document details the technical aspects of the MAR system through the FIA technique implemented in the Arborea site in Italy, under this output 3.4 over the period from September 2022 and May 2023 as part of Activity 3.4.1 "Implementation of MAR systems".

The document is structured considering as follows:

1. A general introduction of the area of intervention (Section 2);
2. Results achieved in the *ante-operam* monitoring phase (Section 3);
3. FIA system implementation: laboratory experiments and technical specifications (Section 4);
4. Description of the *post-operam* monitoring network (Section 5)
5. Concluding remarks (Section 6).

2. Area of intervention

The intervention site is located within the farming district of Arborea (about 60 km^2), in central-western Sardinia (Italy) (Figure 2), which represents one of the most productive agricultural sites in Italy, where more than 200 farms, associated in a strong farmers' cooperative, manage some 30,000 dairy cattle on a 6,000 ha.

The Arborea plain was a swamp that was reclaimed in the 1920–1930ies. A productive plain was generated which was organized in rectangular fields of 2 to 4 ha in size, with the long side oriented N-S, delimited and protected by eucalyptus edges and surrounded by a drainage network consisting of main channels and a dense network of smaller drainage channels with direction E-W and N-S. This drainage system also includes some dewatering pumping stations for the water flow regulation in the main channels.

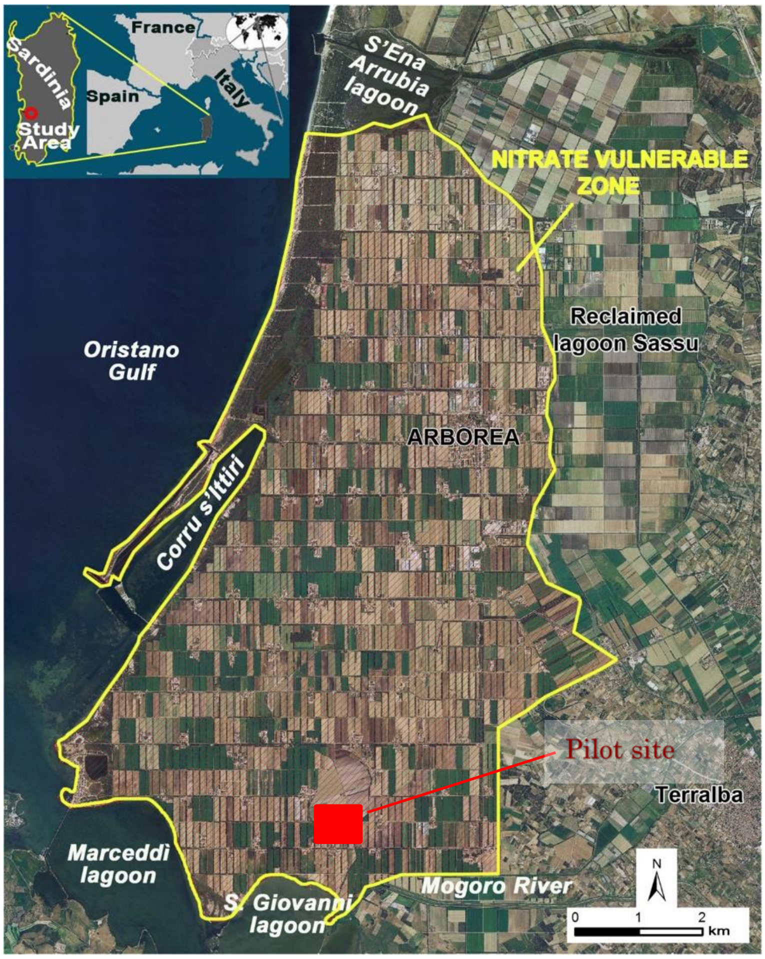


Figure 2. Nitrate Vulnerable Zone of Arborea and pilot site location

In application of the provisions of the Nitrates Directive 91/676/EEC, the Sardinia Region, with Regional Resolution No. 1/12 of January 18, 2005, identified a portion of the territory of the Municipality of Arborea as a Nitrate Vulnerable Zone of agricultural origin (NVZ). The implementation of the Directive, starting in 2006, imposed a series of constraints on the management of livestock effluents, resulting in a significant increase in production costs for farmers. On one hand, farmers are forced to limit the application of organic fertilizers (slurry and manure) to fields, within the limit of 170 kg N ha^{-1} (as defined by the Action Program). On the other hand, they are required to purchase external nitrogen fertilizers to cover the entire crop nitrogen requirement and rent fields outside the NVZ area to dispose of exceeding slurry. In 2018, following the letter C (2018) 7098 of formal notice under Article 258 of the Treaty on the Functioning of the European Union (TFEU) by the European Commission (EC) to Italy, the Sardinia Region has been subjected to an infringement procedure for failing to provide concrete and sufficient responses to solve the issue of nitrate pollution in the Arborea plain. Currently, it is not possible to know exactly what the economic and social repercussions of such an infringement procedure could be in the Arborea area, but certainly negative effects are predictable.

The identification and implementation of effective low-impact environmental solutions (Nature-based Solutions, NBS) for mitigating nitrate pollution of the aquifers could contribute to lightening the restrictive measures on nitrogen load management in the Arborea plain, or even defuse the ongoing infringement procedures.

The FIA technique was identified by NRD-UNISS' researchers as a NBS potentially useful for mitigating the nitrate groundwater pollution in the Arborea plain. Easy to implement even over large spatial scales, the FIA technique also offers a series of supplementary ecosystem services, such as the increase in biodiversity, carbon sequestration and environmental recovery, thus increasing the potentiality of replication of the technique also in contexts outside the Arborea area.

3. *ANTE-OPERAM* MONITORING

In order to implement the design of the FIA system and evaluate the effectiveness of the intervention, it was necessary to define the baseline of the quality of both drainage and groundwater, corresponding to an area of approximately 9 km² that surrounds the pilot site (Fig. 3). A monitoring phase was carried out to primarily understand the trend of nitrates over time, in particular, if there were movements and seasonal influences of the pollutant, due to the use of certain fertilizers in certain periods through 26 wells and the dewatering pumping station. Water samples were collected from the Luri dewatering pumping station and 12 wells from August 2020 until October 2021 on a monthly and bi-monthly basis, while the piezometric levels were monitored on all 26 wells.

Figure 3. *Ante-operam* monitoring network in the surroundings of the pilot site

Physicochemical analyses carried out on water samples at the Water and Soil Laboratory of the Department of Agricultural Sciences of Sassari University included the following parameters: pH, temperature, electrical conductivity, alkalinity, major anions (fluorides, chlorides, nitrites, bromides, nitrates, phosphates and sulphates), major cations (calcium, magnesium, sodium, and potassium), heavy metals (As, Cr, Cd, Hg, Ni, Pb, Cu, and Zn). Only for the drainage water samples, also BOD, COD, plant protection products and biocides (methyl and ethyl Chlorpyrifos, Linuron) were analyzed at an external laboratory.

3.1. *ANTE-OPERAM* MONITORING RESULTS

The drainage water showed a nitrate concentration above the threshold value of 50 mg L^{-1} many times during the monitoring period reaching a maximum value of 88.07 mg L^{-1} in February 2021. (Fig. 4).

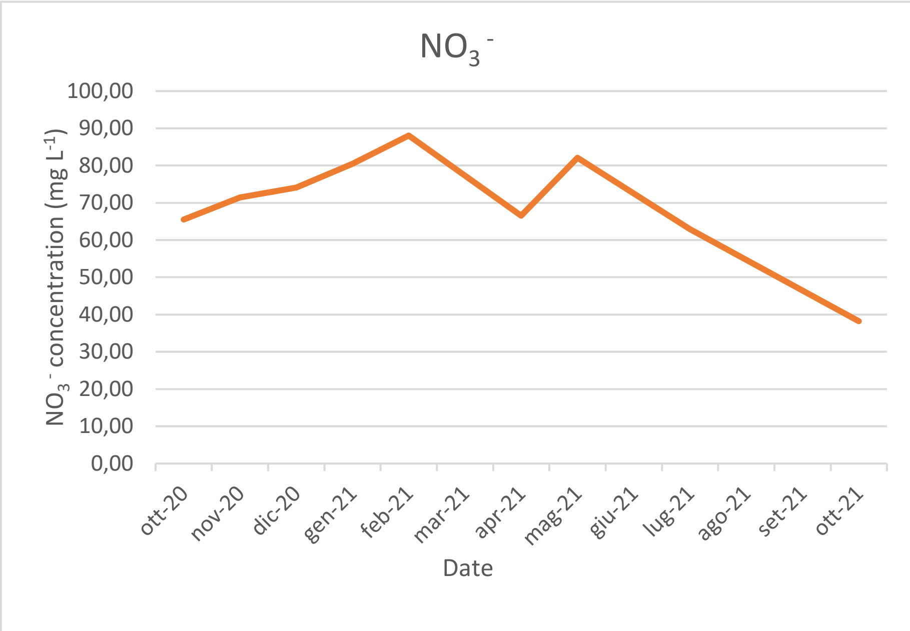


Figure 4. The trend of nitrate in the drainage water.

Regarding the phosphate concentration in the drainage water, it remained high concentration during the whole period with a peak of 5.40 mg L^{-1} in January 2021 (Fig. 5).

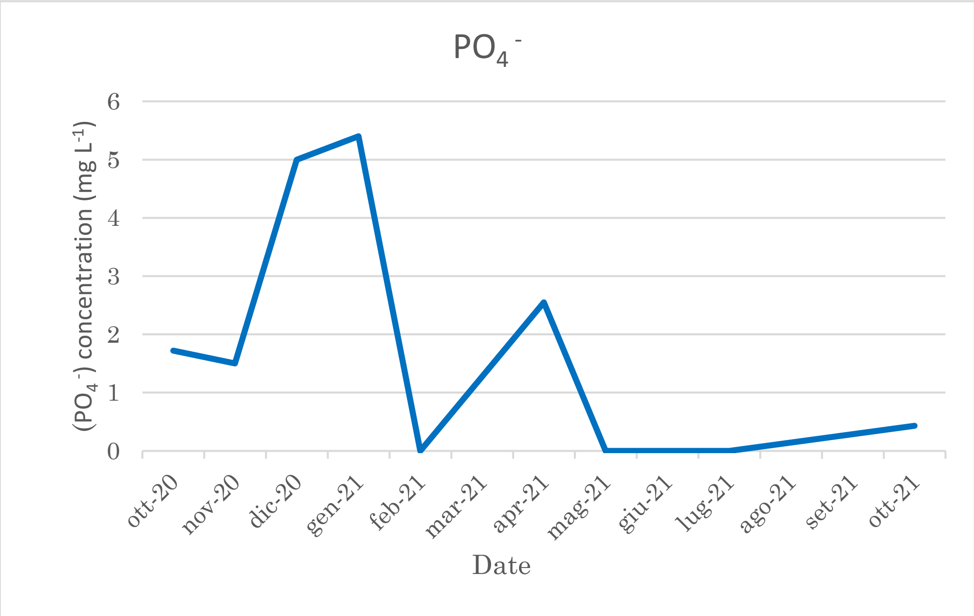


Figure 5. The trend of phosphate in the drainage water

Concerning nitrate concentration in groundwater, as shown in Table 1, 70% of the monitoring wells present average NO_3 concentration above the threshold value (50 mg L^{-1}).

Table 1. Average nitrate concentration for the monitoring wells

Sample No.	**NO_3 mg L^{-1}**	**SD**	**Sample No.**	**NO_3 mg L^{-1}**	**SD**
AD1	**69,93**	*14,55*	**P15**	**51,69**	*4,99*
P1	8,72	*1,95*	**P16**	3,03	*1,19*
P4	**166,79**	*25,91*	**P18**	**117,77**	*12,91*
P7	**157,79**	*17,58*	**P23**	19,52	*2,17*
P10	**89,09**	*9,24*	**P25**	**104,68**	*10,41*
P11	**53,40**	*4,13*	**P26**	**68,87**	*8,05*
P14	18,34	*2,41*			

It was possible to divide the nitrate concentration into three main categories, where it was found that only some wells, during the whole monitoring period, maintained concentration values below the limit threshold, such as the P1, P14, P16, and P23. In particular, the P16 showed the lowest values ever, hovering around 2 - 3 mg L^{-1}; immediately afterward, only P1 followed with values ranging from 6.5 to 12 mg L^{-1}, while the rest showed values around 20 mg L^{-1}. Wells P11 and P15 were the only ones that showed values that were around 50 mg L^{-1}. All the remaining wells, i.e., P4, P7, P10, P18, P25, and P26, showed values that exceeded the threshold value; for example, the well P4 reached 200.4 mg L^{-1}, which is the absolute highest value.

In Fig. 6, the graph compares the nitrate concentration in three wells that exemplify the three categories. Within the same well, it was possible to observe a seasonal alternation.

On the other hand, as regards the nitrite situation, for almost all the wells, apart from the P25, there were values, for the whole period, below the threshold value of 0.50 mg L^{-1}. P25 was the only one that showed an average value of around 2.20 mg L^{-1}, with a peak of 2.43 mg L^{-1}. Fig. 7 reveals the concentration trend of three exemplary wells.

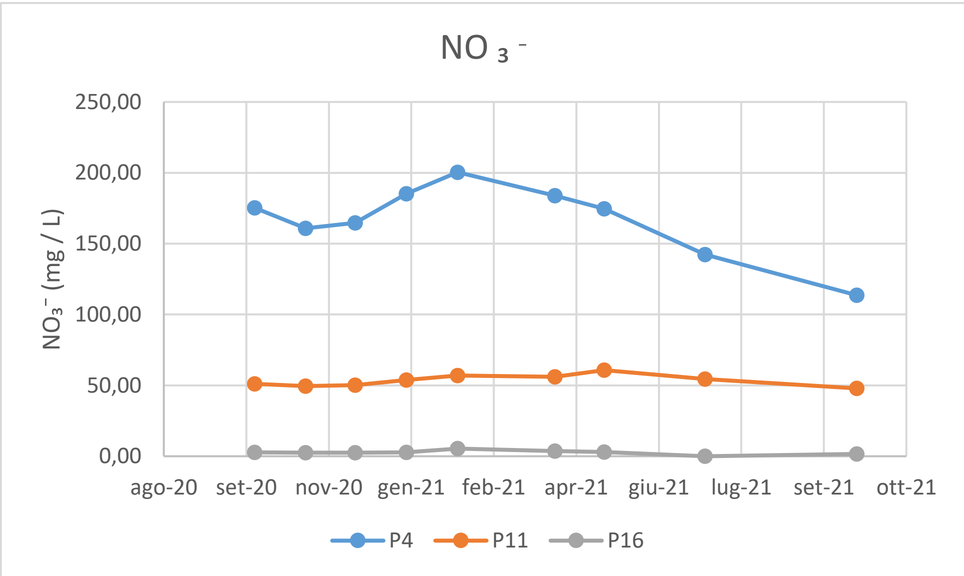


Figure 6. The trend of nitrates in 3 representative wells

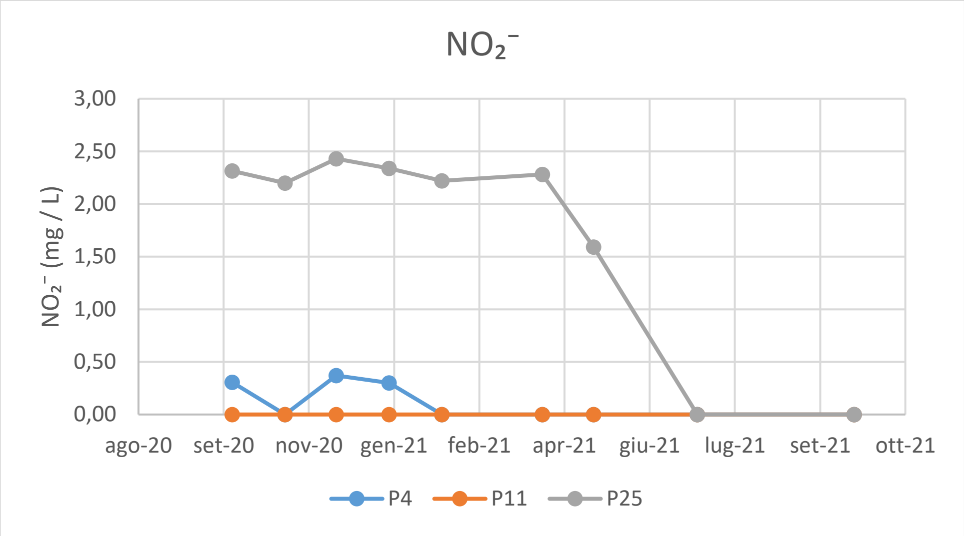


Figure 7. The trend of nitrites in 3 representative wells

Finally, as regards the phosphate concentration, all the wells showed an almost constant value of 0 mg L^{-1} for the whole period (Fig. 8)

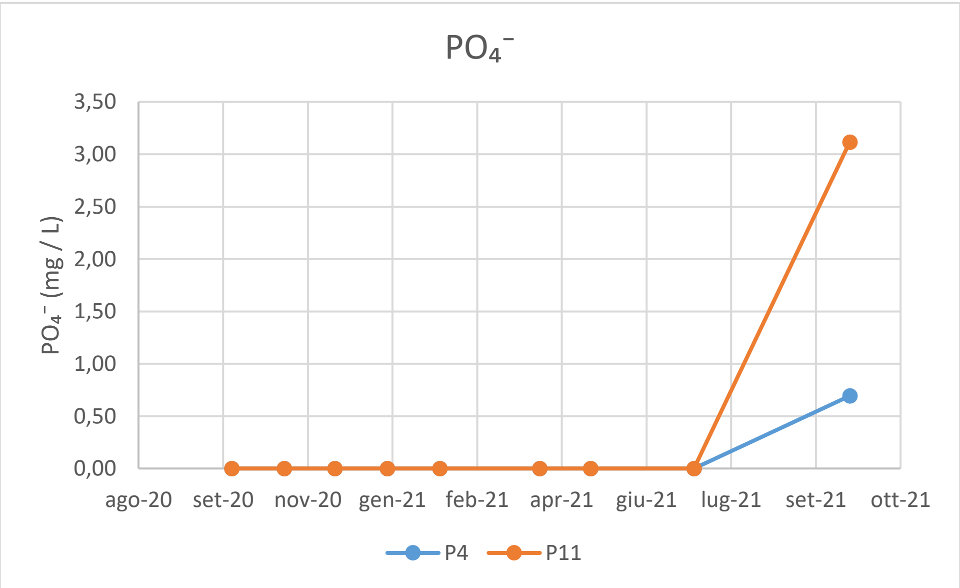


Figure 8. The trend of phosphates in 2 representative wells and in the drainage water

The spatial distribution of the nitrate concentration around the pilot site in January 2021, as representative of the winter season, is shown in Fig. 9. The figure illustrates that there are many areas with a high concentration level that reach a maximum value of 200 mg L^{-1} around P4 well.

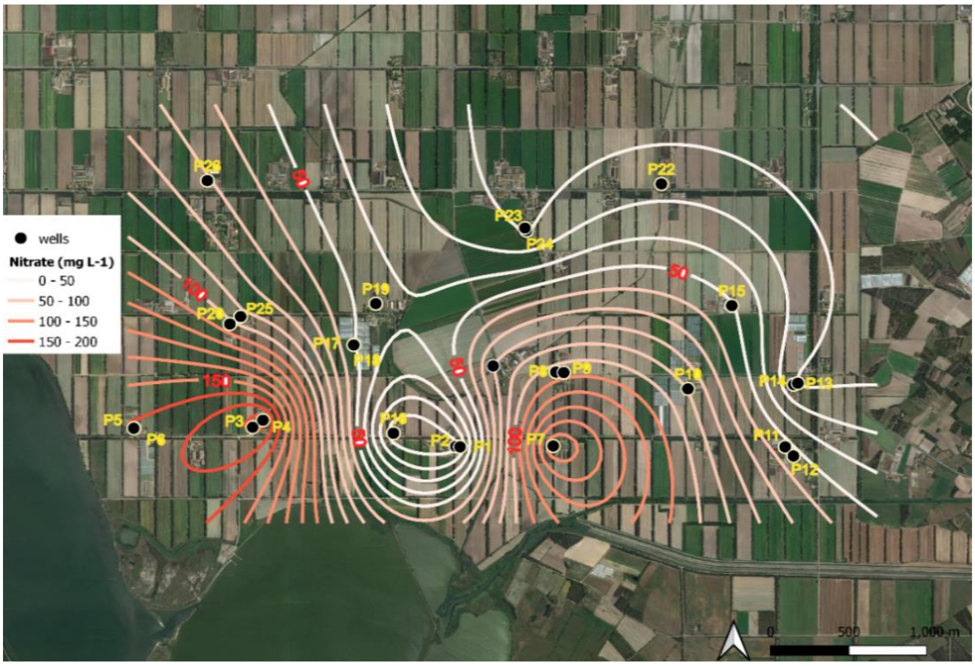


Figure 9. Distribution of nitrate concentration in January 2021

Fig. 10 shows the spatial distribution of nitrate concentration in the summer season (July 2021). This month shows a general nitrate distribution below the one observed in January, reaching a maximum value of 162 mg L^{-1} around P7.

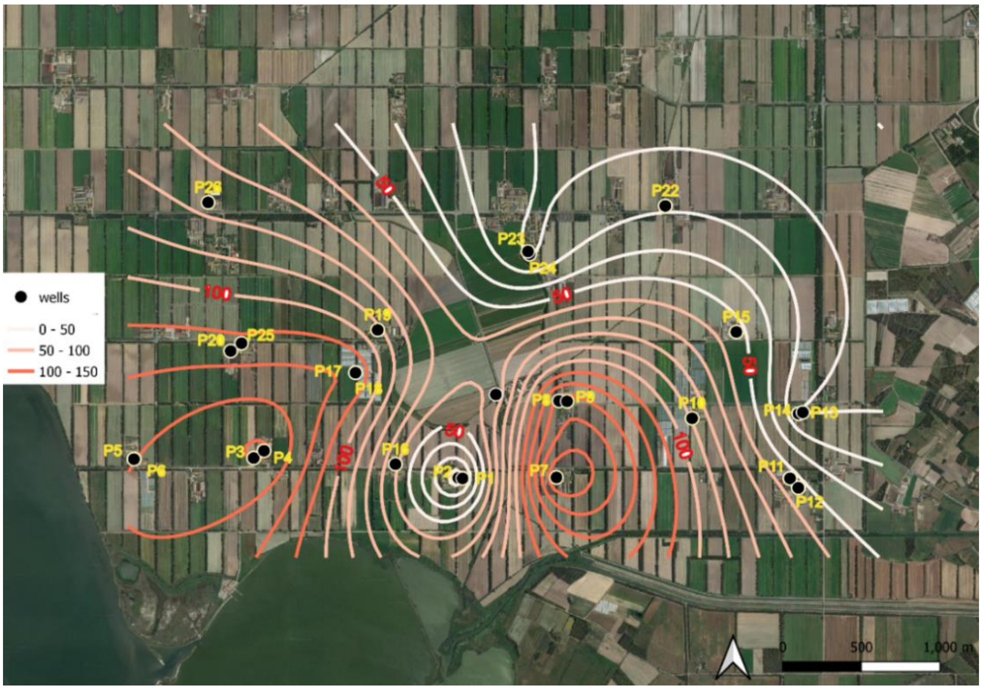


Figure 10. Distribution of nitrate concentration in July 2021

Regarding the piezometric levels measured during the *ante-operam* monitoring phase, Fig. 11 shows the piezometric contour lines related to January 2021 and the main groundwater flow paths in the area around the pilot site. The piezometric levels range between 0.50 m and 6.22 m.

Fig. 12 shows the main groundwater flow paths and the trend of the piezometric surface in the surroundings of the pilot site in summer 2021 (July 2021), where the piezometric levels range between 1.14 m and 8.30 m.

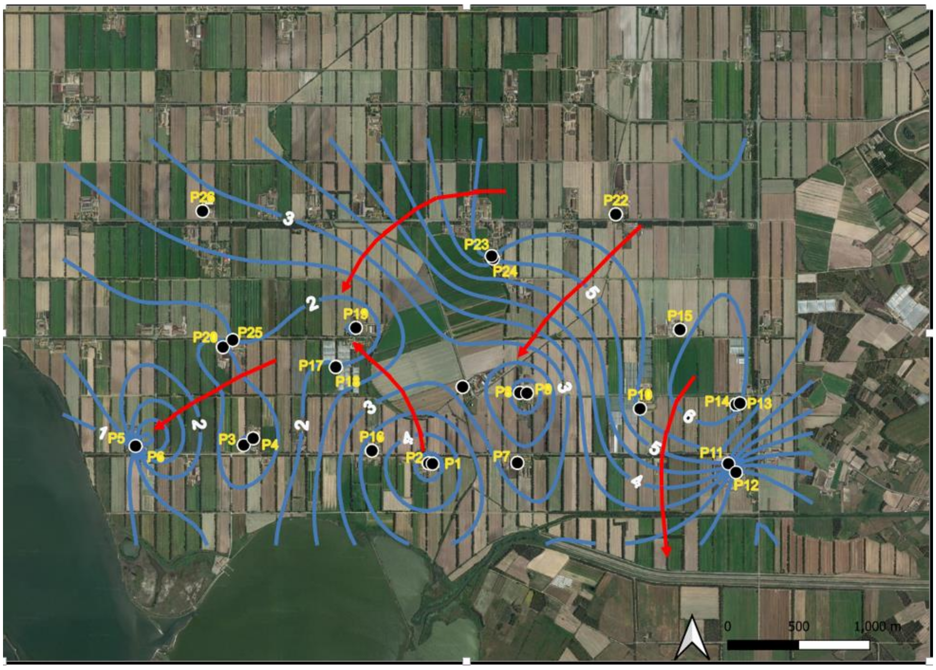


Figure 11. The piezometric levels and groundwater flow direction in July 2021

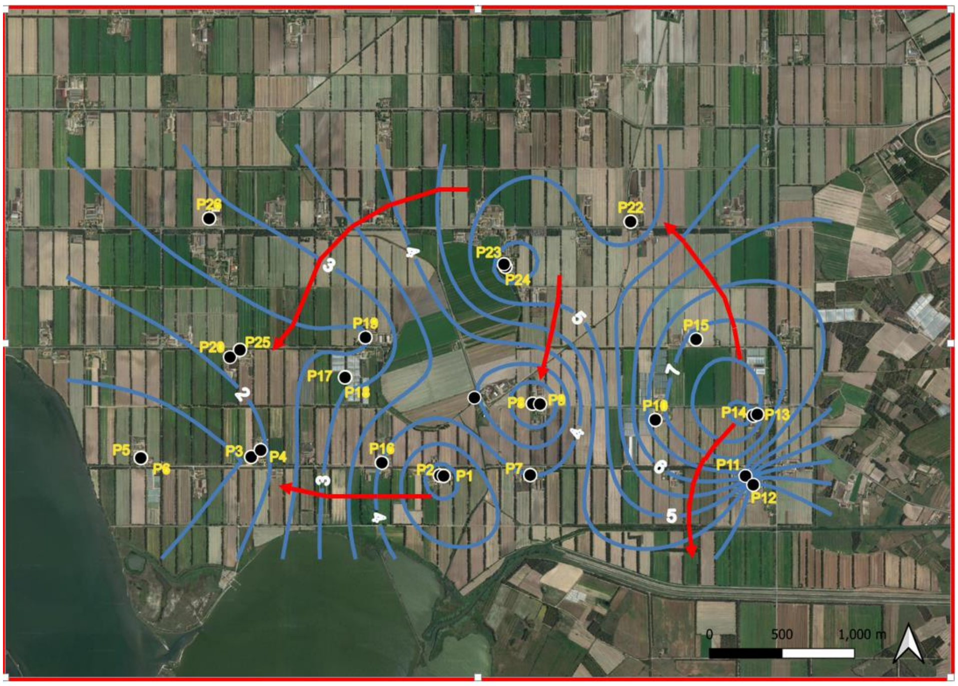


Figure 12. The piezometric levels and groundwater flow direction in July 2021

4. FIA SYSTEM TECHNICAL SPECIFICATIONS

The FIA is a MAR technique, where the surface water is distributed in specially equipped areas through a network of trenches and wooded patches featuring various tree and/or shrub species. In these forested areas, while the tree roots maximize the infiltration rate, the denitrifying bacteria living in symbiosis with the tree roots have a very effective action to promote nitrate attenuation (Fig. 13), but they also play a role in phosphorus control and other organic molecules derived, for instance, from agro-chemicals, which can be transported along with sediment, especially during heavy rainfall events. The FIA technique is based on various experiences carried out in Veneto Region in the North of Italy starting from the second half of the 1990s to monitor and control non-point pollution sources from agricultural practices through the use of forested areas. This purpose was subsequently joined by the need to cope with the increasing groundwater over-exploitation for more and more intensive drinking, agricultural and industrial purposes, the artificialization of river channels, the impermeabilization of soils and the modification of irrigation techniques, all factors that have led to a progressive depletion of the piezometric surface in the Venetian High Plain in recent decades.

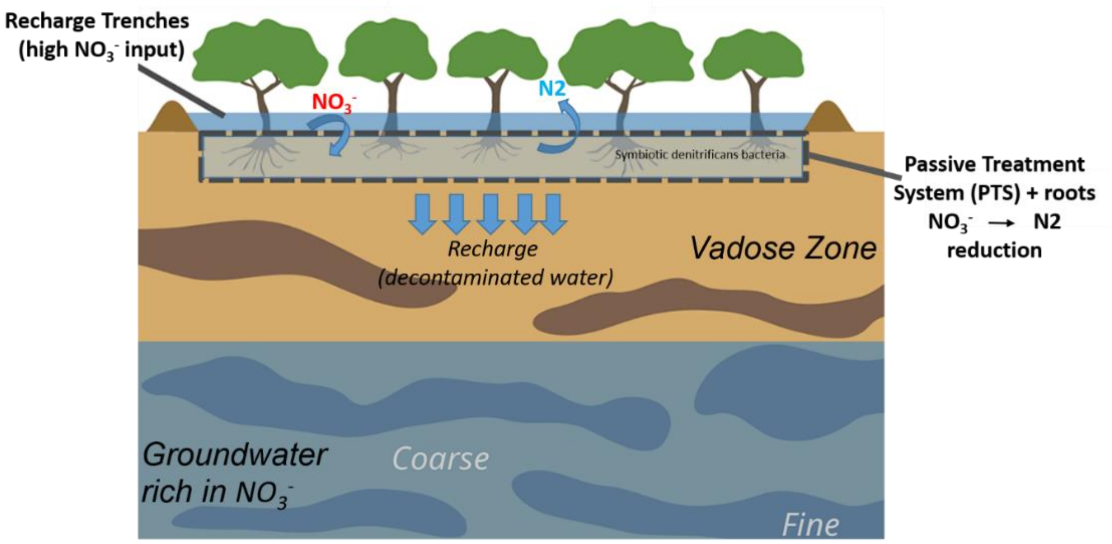


Figure 13. Scheme of the functioning of a FIA technique, with representation of the main involved processes.

Nowadays, the attention of the academic community is mainly directed to the benefits of the FIA system in improving groundwater recharge. Little investigations have been performed on the use of the technique related to its denitrification process as an effective denitrification action can be reached only when tree roots are fully developed, which generally requires several years after trees plantation. Considering the main Arborea challenge and the low quality (high nitrate concentration) of the recharge water, compared to the FIA systems implemented in Veneto, NRD UNISS' researchers, decided to test the technique, for the first time, for its denitrification process, and to install a Passive Treatment System (PTS) directly in the trenches in order to immediately activate the process.

The PTS consists of two main components: a Reactive Layer (RL) and a layer of inert materials (gravel and sand). The RL is a mixture including (a) inert materials (gravel and sand, 50% in volume) to provide structural integrity and maximize the hydraulic conductivity; (b) woodchip material (49% in volume) which provides a source of organic matter easily degradable, in order to trigger the denitrification process and to degrade organic micropollutants (e.g. pesticides); (c) minor clays (<= 1% in volume) and iron oxides (<= 0.1% in volume) for sorption of cationic and anionic organic contaminants. The RL is then covered by a layer of gravel and sand to ensure the mechanical filtering of suspended particulate matter and to prevent erosion.

The FIA pilot plant has been implemented on a surface of about 0.5 ha in Luri, in the southern part of the Arborea plain, close to the dewatering pumping station, which can ensure the supply of an adequate volume of drainage water characterized by high nitrate concentrations (Fig. 14). The drainage water is pumped from the station, treated in the FIA area by the PTS, and infiltrated in the underlying aquifer to contribute to mitigating nitrate contamination in groundwater, through dilution processes.

The implementation work of the FIA system started in October 2022 and was completed with the plantation of the forestry component and the installation of the *post-operam* monitoring network in May 2023.

Figure 14. Overview of the dewatering pumping station of Luri, in Arborea

4.1. Laboratory experiments to design the RL of the PTS

For agricultural nitrate pollution, a denitrification bioreactor is a highly effective passive treatment alternative. In a carbon-filled trench under anaerobic circumstances, this method utilizes heterotrophic denitrifying bacteria to transform NO_3 into atmospheric di-nitrogen gas (N_2).

Several laboratory experiments, in terms of batch and flow-through column experiments, were carried out at the Water and Soil Laboratory of the Department of Agricultural Sciences of Sassari University to evaluate the intrinsic potential and effectiveness of promoting nitrate attenuation of different organic materials characterized by different C/N ratio, also assessing the generation of undesirable compounds such as NH_3, NO_2, or PO_4. Two materials were selected and initially tested in the batch experiments: eucalyptus wood chips and barley straw. The former because it is widely present in the Arborea Plain, it was used to reclaim wetlands in the past and it is still present in large quantities as it is used as a windbreak along the borders of the fields; the second one because it is a plant easily cultivated in Sardinia, mainly for animal feed and therefore easy to find. Both materials have the prerequisites to be used as organic material in the RL of the PTS: they are easily accessible, inexpensive, easy to handle, low maintenance, and a source of labile carbon suitable for long-term denitrification.

4.1.1. Batch experiments

Batch experiments on eucalyptus wood chips and barley straw were carried out in August 2021 and October 2021, respectively. Each test was performed in triplicate and lasted 24 hours (Fig. 15). The water used for both experiments was drainage water collected from the pool of the Luri dewatering pumping station. To carry out the tests, sterilized laboratory glass bottles were used, with a volume of 500 mL and hermetic closure, with a cap featuring two autoclavable plastic taps, which allowed one argon to enter to remove the oxygen (create anoxic conditions), and the other to allow the water to escape for the sampling to be carried out during the experimentation. Inside the bottles, immersed in the water + eucalyptus wood chips or water + barley straw solution, two silicone tubes with porous septa at the end were connected to the bottle cap, which allowed one for the gasification of the solution and the other for the collection of the water sample, without rising material.

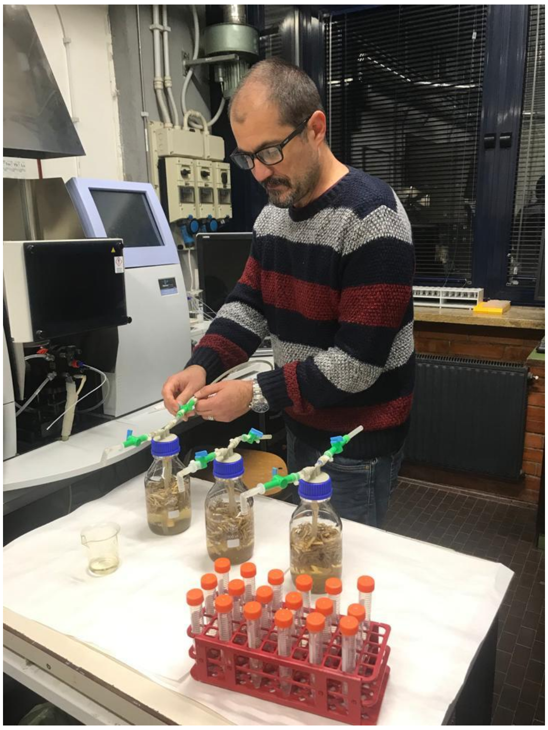


Figure 15. Batch experiment

At each interval (every 2 hours), a volume of 5-7 mL of water sample was collected from each bottle and analyzed to determine major anions (F, Cl, NO_2^-, Br, NO_3, PO_4 and SO_4). A certain volume of each sample was frozen and sent to the isotopic laboratory of the FUNDACIÓN BOSCH I GIMPERA (Barcelona) for the analysis of $\delta^{15}N$ and $\delta^{18}O$ of NO_3 and NO_2.

Fig. 16 shows the trend of the nitrate, nitrite and phosphate concentrations in the batch experiments for the eucalyptus wood chips and the barley straw, respectively. The eucalyptus wood chips proved to be a higher-performant material to promote denitrification than the barley straw. The former showed a nitrate concentration of around 70 mg L^{-1} until 10 hours from the start of the experiment, a quick decrease up to around 0 mg L^{-1} between the 10 and 14-hour, indicating the start of the denitrification process, and a slight increase up to around 10 mg L^{-1} from the 20-hour. Contrarily, the second one showed a reduction of 30% of the initial nitrate concentration at maximum.

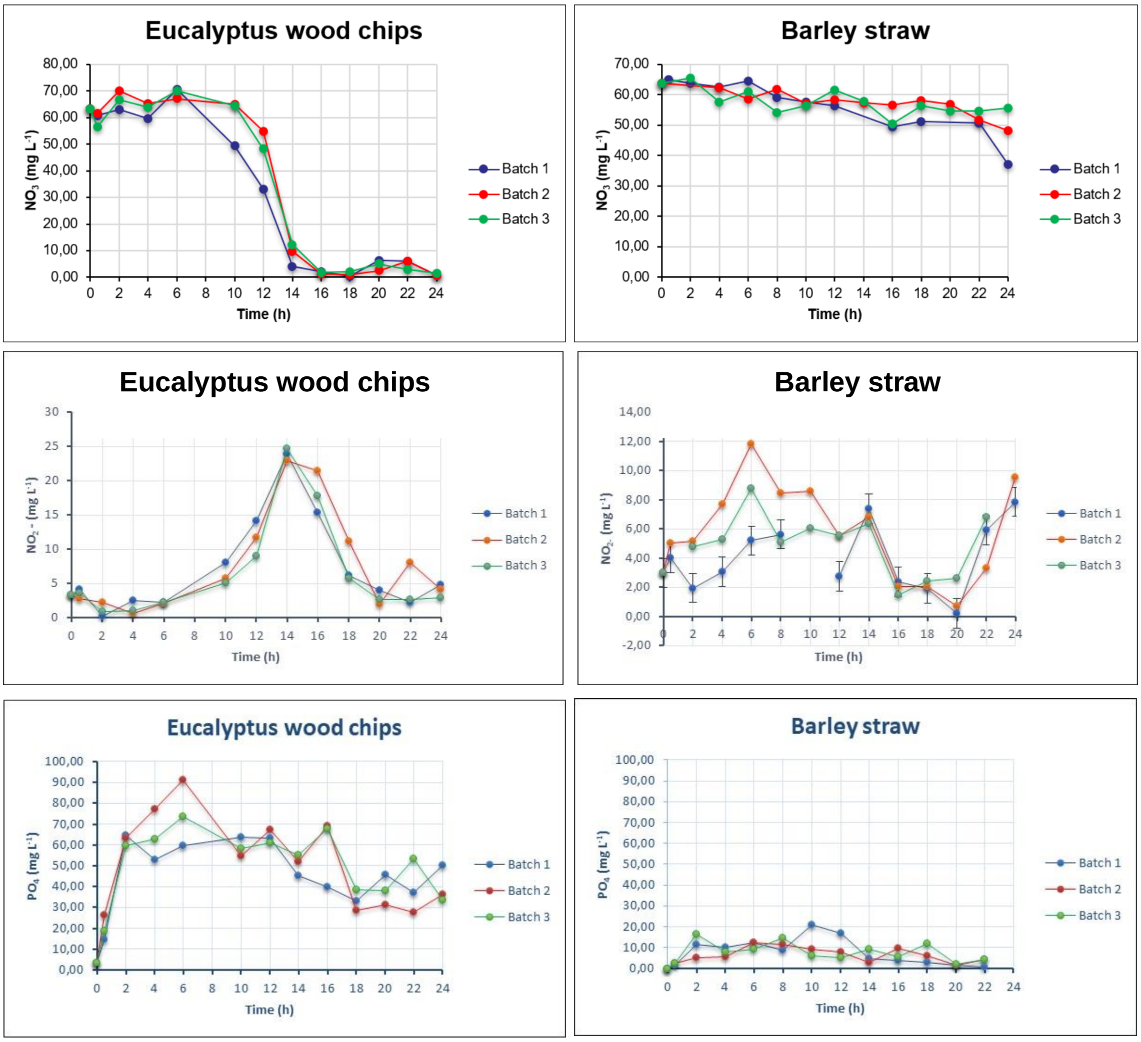


Figure 16. Results of the batch experiments for eucalyptus wood chips and barley straw

In the case of the eucalyptus wood chips, the trend of nitrite concentration showed a peak up to 25 mg L^{-1} after 14 hours, corresponding to the maximum rate of the denitrification process. For the barley straw, there was not a clear trend (Fig. 16). Both materials showed high concentrations of phosphate throughout the experiment due to their leaching in the solution in anaerobic conditions. Eucalyptus wood chips showed a rapid increase at the beginning of the experiment from 0 up to 90 mg L^{-1} after 6 hours and a continuous decrease up to around 40 mg L^{-1} (ever very high concentration) at the end. For the barley straw, the leaching was lower reaching a concentration of 20 mg L^{-1} at the maximum which decreased to 0 mg L^{-1} after 20 hours (Fig. 16).

4.1.2. Flow-through column experiments

According to the results coming from the batch experiments, two flow-through tests were conducted, in March 2022 and July 2022, by using a constant water flow rate (1 and 4 mL min^{-1}) respectively, only on the eucalyptus wood chips which showed the highest performance in promoting denitrification of nitrate-contaminated water.

Flow-through experiments were performed by using the eucalyptus wood chips mixed with inert materials (sand and gravel) to produce a homogenized mixture as shown in Fig. 17. The reason for adding the sand and gravel was to provide structural integrity and ensure hydraulic conductivity to the mixture.

Figure 17. A mixture of sand, gravel, and eucalyptus wood chips

Also in this case, the experiments were carried out by using the drainage water collected from the dewatering pumping station of Luri. A Master Student, Ahmad Alkharoubi participated in the experiment in the framework of his Master Thesis titled "*Mitigation of nitrate groundwater contamination through a Forested Infiltration Area (FIA): the case study of a Nitrate Vulnerable Zone in Arborea (Sardinia, Italy)*". The drainage water was previously filtered and then stored in sterile PVC containers with a capacity of 20 L. The mixture was placed inside the column while the tank was connected to the column to allow the water supply (drainage water) by using a peristaltic pump to maintain the desired flow, after filtration with a 1 µm pore filter, as shown in Fig. 18. A tube was connected to the column to allow the temporary storage of a sufficient of outflow water to monitor continuously the Eh redox potential through an electrode placed inside the tube and connected to a portable pH-Eh meter.

Figure 18. Setting up the flow-through column experiment

The first flow-through experiment with a flow rate of 1 mL min^{-1} lasted around 198 hours, while the second one, with a flow rate of 4 mL min^{-1}, lasted around 222 hours. Water samples were collected at regular intervals (every 2 hours during the 1st day and every 4 hours during the rest of the experiment) during the day, and there was a collection during the night.

At the beginning and at the end of each sampling (around 20 min to collect each sample), the values of Eh redox potential were recorded. For each sample pH, electrical conductivity, ammonia and major anions (F, Cl, NO_2^-, Br, NO_3, PO_4 and SO_4) concentrations were measured. In addition, 15 mL of each water sample was frozen and sent to the isotopic laboratory of the FUNDACIÓN BOSCH I GIMPERA (Barcelona) for the analysis of $\delta^{15}N$ and $\delta^{18}O$ of NO_3 and NO_2.

In the following, some graphs show the trend observed for nitrates NO_3, nitrites NO_2, ammonia NH_3 and phosphates PO_4 concentrations related to both experiments. As Fig.19 illustrates for the first experiment, the initial nitrate concentration was a little bit above the threshold limit (50 mg L^{-1}) and decreased noticeably up to around 0 mg L^{-1} after 9 hours, indicating that the denitrification process started. No substantial change was highlighted until 105 hours when the trend began to increase up to a maximum value of 28 mg L^{-1} after 152 hours. Finally, it decreased slowly to get a final value of 17 mg L^{-1}.

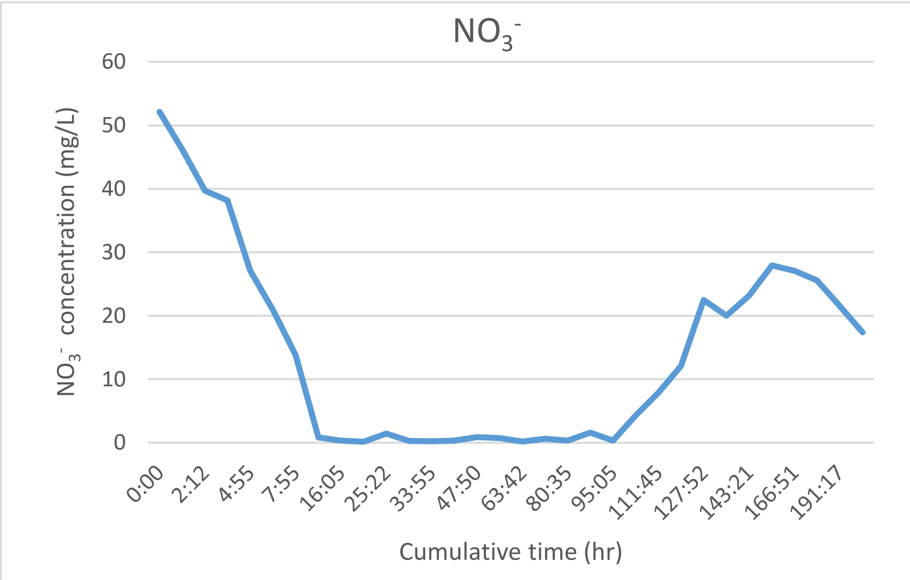


Figure 19. The trend of nitrate concentration in the first experiment

As shown in Fig. 20, it's clear that the denitrification started during the filling of the column during the night before the starting of the 2nd experiment, with a noticeable rate, since the initial nitrate concentration in the drainage water was 49 mg L^{-1} and it decreased to 4.6 mg L^{-1} at the time the first sample was taken. The nitrate concentration kept decreasing, reaching the lowest value of the concentration of 0 mg L^{-1} after 9 hours. The concentration started showing an increase after 118 hours up to around 8 mg L^{-1}. The samples kept showing an increase in the nitrate concentration compared to the initial samples, with an average value of 6.7 mg L^{-1}.

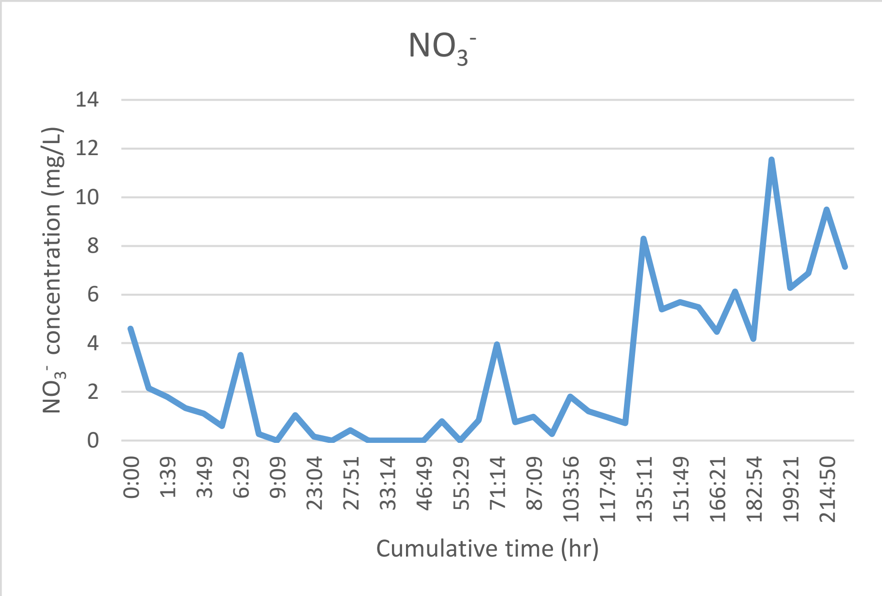


Figure 20. The trend of nitrate in the second experiment

Concerning the first experiment, a trend that underlines the nitrate decrease was followed by an almost proportional increase in nitrites up to 40 mg L^{-1} after 9 hours. After, there was a rapid decrease to less than 10 mg L^{-1} between the 8th and the 9th sampling. From this point, the concentration decreased slowly until it reached the lowest value of 0 mg L^{-1} after 90 hours and then it fluctuated until the experiment finished, as shown in Fig. 21.

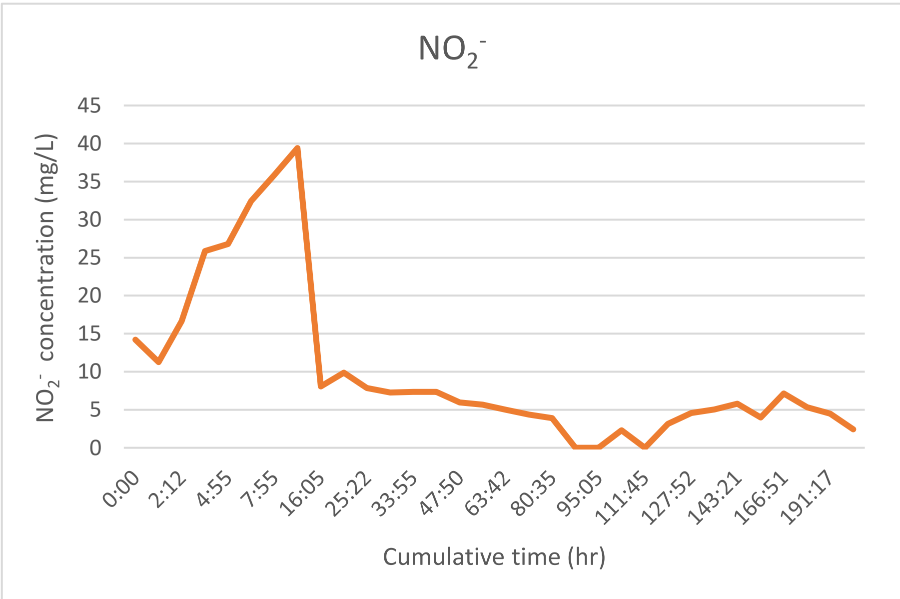


Figure 21. The trend of nitrite concentration in the first experiment

In the second experiment, the decrease in NO_3 concentration was coupled with a slight increase in NO_2, which reached values of up to 6.2 mg L^{-1} on the first day, as shown in Fig. 22; after that, the samples were shown an average value of 0.05 mg L^{-1}. Then there was a slight difference at the end of the experiment with a value of 3.45 mg L^{-1}.

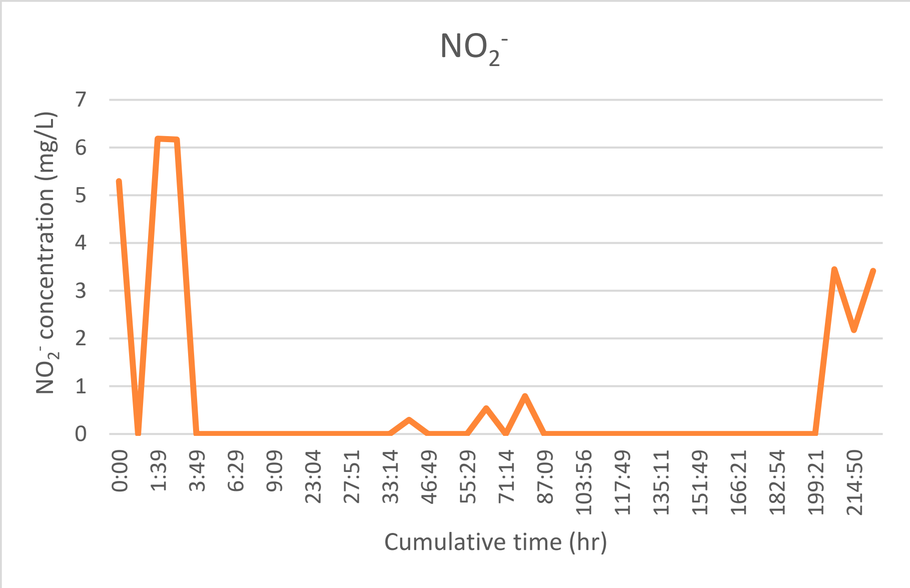


Figure 22. The trend of nitrite in the second experiment

In the first experiment, an increase in the ammonia concentration occurred at the beginning up to 35 mg L^{-1}; after that, it kept decreasing during the denitrification process and reached 0 mg L^{-1} at the end of the experiment, as shown in Fig. 23.

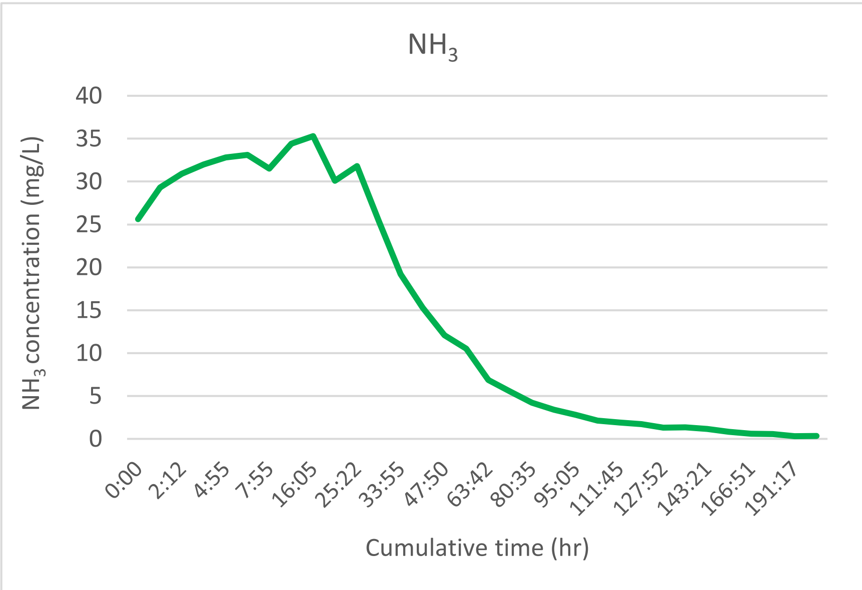


Figure 23. The trend of ammonium concentration in the first experiment

Just as in the first experiment, an initial increase in the ammonia concentration occurred at the beginning of the second one. It kept decreasing until it reached 0 mg L^{-1} at the end of the experiment, as shown in Fig. 24.

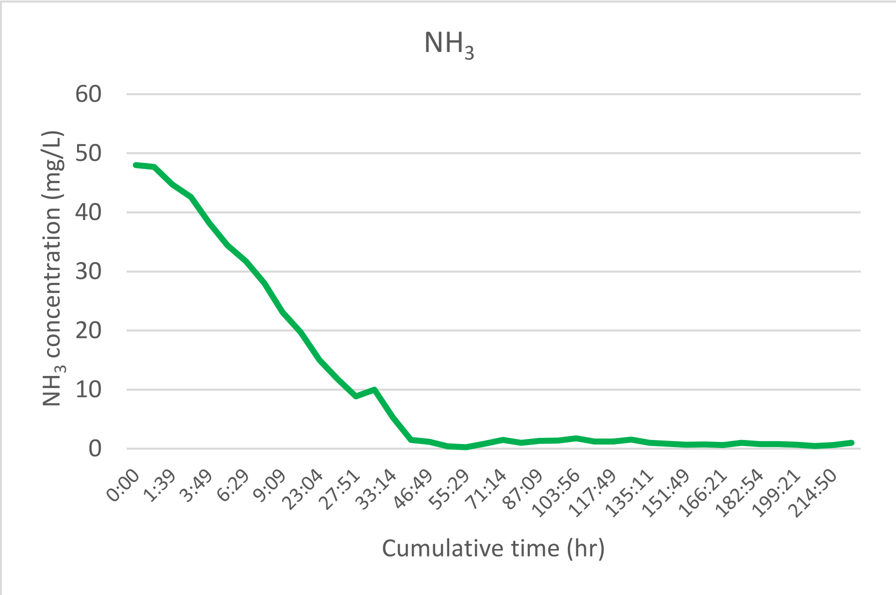


Figure 24. The trend of ammonium concentration in the second experiment

Regarding the trend of phosphate concentration during the first experiment, a very high concentration of phosphate (70 mg L^{-1}) was measured at the beginning, due to the leaching from the eucalyptus wood chips. During the experiment, the concentration decreased quite rapidly up to a value of 1.5 mg L^{-1} at the end of the experiment which is equal to the phosphate concentration in the drainage water (Fig. 25).

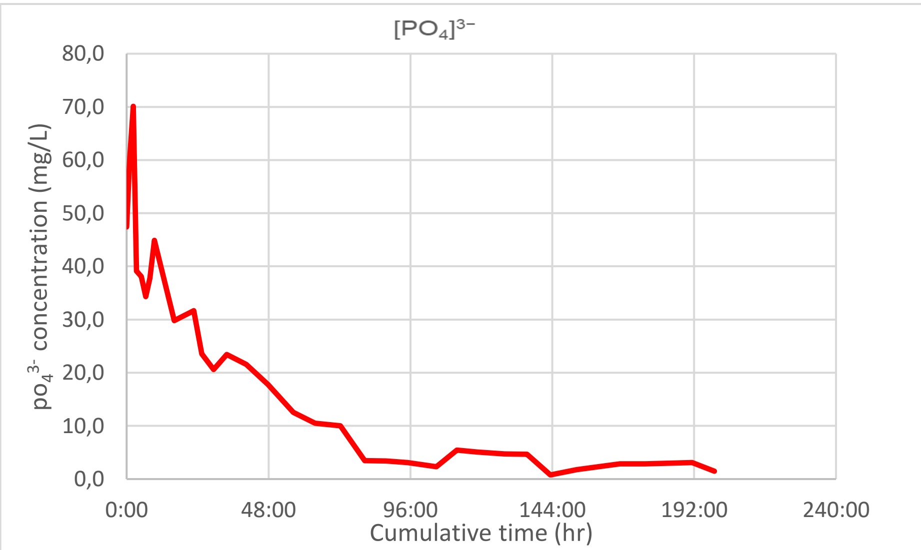


Figure 25. Trend of phosphate concentration in the first experiment

As in the first experiment, the phosphate trend showed a rapid decrease during the second one, starting from 90 mg L^{-1} and ending up with 6.70 mg L^{-1} at the end of the experiment (Fig. 26).

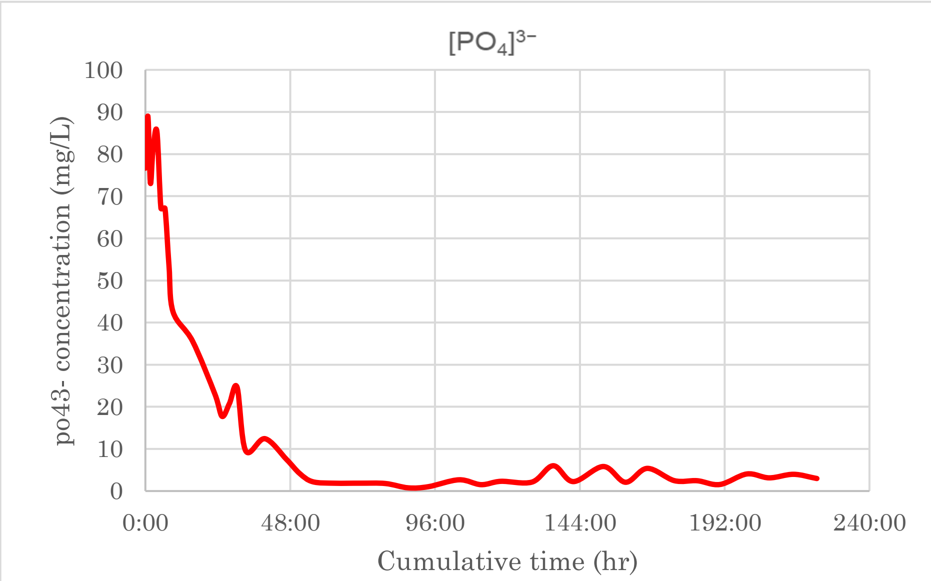


Figure 26. The trend of phosphate concentration in the second experiment

4.2. Description of the technical solutions adopted

The FIA system includes several units, which will be described in detail in the next sections. Annex 1 shows the spatial layout of the facilities, and some graphic details of the components:

1. Power and water supply (connection with existing infrastructure)
2. Pumping system
3. Filtration system
4. Pipelines
5. Filtration trenches
6. Fences
7. Forestation

4.2.1. Power supply

The FIA system is supplied with the water drained by the Luri dewatering pumping station, which has a nitrate concentration usually ranging from 40 to 80 mg L^{-1}. The system involves the installation of two horizontally operating submerged pumps in the upstream pool of the dewatering station of Luri (Fig. 14). Power supply and protection are ensured by an inverter control panel located on a dedicated anchoring structure positioned in the intervention area. The power supply is provided by a new main line, partially underground and partially in an existing tunnel (inside the building), connected to a newly constructed independent control panel, with power withdrawal from the general panel of the pumping station (Fig. 27).

The electrical system includes the following plant works: electrical panels, conduits and main lines, grounding system and equipotentiality, protection against direct and indirect contacts - overload and short circuit. The electrical system was designed, realized and finally certified by a professional electrician following the rules imposed by the Italian law. The electrical schemes, reporting the full details of the electrical structures, power supply characteristics and connections to the existing infrastructure, are included in this document as Annex 2.

Figure 27. Panel for the FIA supply power installed in the facility of the Luri dewatering pumping station (left) and auxiliary power panel for controlling the pumps from the FIA field.

4.2.2. Pumping system

The pumping system consists of 2 submersible electric pumps (model 6HR34/4, Fig. 28) needing a power supply of 5.5 kW each. The details of the technical characteristics of the pumps are reported in this document and Annex 3. The pumps are installed in the step between the upstream and downstream pools of the pumping station, at a depth of about 4 meters below ground level, considering the reference level of the upstream pool which is lower than the pilot site one (about 1.50 m). The head of the pumps is 25 m at least, including distributed and localized head losses along the supply pipeline, those at the filtration system, geometric level differences, and the pressure set at the beginning of the FIA parcel, while the outlets of the lines in the individual trenches will occur at atmospheric pressure. The operation of the pumps is controlled by speed regulators (inverters, Fig. 28) that adapt the pump operation to the actual demand of the field and ensure protection against adverse events (e.g., dry running). In Annex 4, the full characteristics of the inverter (refer to model INVERTER PLUS 2 400 10) are reported. The pumps were selected to ensure a flow rate of approximately 80 m^3 h^{-1} and a head of 25 m at the point of maximum work efficiency. The technical choice to install two pumps is related to the necessity of flexibility in the system management, as water supply needs are expected to vary during the lifespan of the FIA. Furthermore, in case of a pump failure, it is still possible to ensure a certain flow, albeit reduced to the recharge trenches.

Figure 28. Pumps (upper panels) and Inverter (bottom panels)

4.2.3 Filtration system

The filtration system (120 mesh) aims at reducing the total suspended solids content in the drainage water pumped from the pumping station pool before being conveyed into the FIA system. This phase is very important in order to optimize the operation and efficiency of the FIA system and preserve the Passive Treatment System installed in the recharge trenches from clogging processes. The filtration system (Fig. 29) is equipped with a cleaning system that automatically activates when the filter is dirty to restore filtration efficiency. The filtration system, along with the control panel of the electric pumps, is located on a gravel bed within a fenced area measuring 9 m^2 (3x3 m) in the space adjacent to the boundary with the Luri dewatering pumping station property. Please see Annex 5 for the details of the technical characteristics of the filter.

Figure 29. Filtration system installed in the field

4.2.4. Pipelines

Two 25 m PE PN6 pipelines (one for each pump) with 90 mm in diameter connect the dewatering pumping station's pool to the filtration system. They run for a length of 10 m at the bottom and on the edge (north side) of the upstream pool of the dewatering pumping station. The remaining part of the pipelines, within the pumping station perimeter, for a length of 15 m, is buried in a narrow trench with a width of 0.30 m and a depth of 0.50 m, excavated using mechanical means. From the outlet of the filtration system, a 230 m long PVC PN 6 pipeline with a diameter of 160 mm (Fig. 30) leads the water to the recharge trenches in the FIA plot. The pipeline is buried in a narrow trench with a width of 0.30 m and a depth of 0.50 m, excavated using mechanical means.

Within the FIA plot, branches extend from the main supply pipeline to each head of the recharge trenches through T connection and PVC PN6 pipelines with a diameter of 90 mm. At the head of each recharge trench, a prefabricated concrete calm pit (80x80x80 cm) is positioned and partially buried. On the west side of the pit (pipeline side), an opening is made at a height of 0.60 m from the base of the pit to allow the entry of the pipeline. This is equipped, at the end, with a closing valve and a floating valve (Fig.

30) to maintain a constant hydraulic load in the pit. On the east side of the pit (trench side), a fissured pipeline of PVC PN6 with a diameter of 160 mm and 1.5 m long supplies the water to the trenches.

At the end, the different trenches are connected through pipelines in PVC PN 6 with a diameter of 160 mm, with a total length of 38 m. The connection with each trench is made by installing a prefabricated concrete calm pit (80x80x80 cm), partially buried, at the end of each trench. The installation of the pipeline was carried out by excavating a narrow and forced trench using mechanical means, with a width of 0.30 m and a depth of 0.50 m.

Figure 30. Buried pipelines and connection with the pits (upper panels) and details of the floating valves in the pit (lower panel).

4.2.5. Trenches and PTS

Six recharge trenches, arranged in parallel in an E-W direction, with a total length of 290 m, have been excavated using specially created mechanical means (Fig. 31) with a depth of 1.00 m and an inverted trapezoidal section, with the smaller base measuring 0.50 m and the larger base 1.50 m. The spacing between two consecutive trenches is 8.00 m to allow the maintenance of the FIA system. In particular, the recharge trenches are 13, 29, 45, 59, 69, and 75 meters long, respectively. The organic soil resulting from the excavations was spread out in the spaces between the trenches, and the remaining inert deep soil was accumulated at the border of the plot.

The trenches are filled up to 0.20 m from ground level with a Passive Treatment System (PTS) installed above a bed of medium-coarse gravel (particle size between 4 and 16 mm), with a thickness of 0.10 m.

Figure 31. Phases of construction of the PTS in the excavated trenches

The PTS consists of two main parts (from the bottom to the top): a Reactive layer and a gravel layer with different but complementary functions each. The Reactive Layer, with a thickness of 0.60 m, is composed of a homogeneous mixture of the following components:

- inert materials, such as gravel (particle size between 4 and 16 mm) and sand, constituting 50% of the volume of the mixture. Its function is to provide structural integrity and ensure adequate hydraulic conductivity to the mixture.

- eucalyptus wood chips (Fig. 31), produced by chipping naturally seasoned trunks with a moisture content not less than 35%, constituting 49% of the volume of the mixture.

- minor clays (<= 1% by volume), mainly consisting of non-expansive illite, providing sites for adsorption of cationic organic contaminants.

- iron oxides (<= 0.1% by volume), providing sites for adsorption of anionic organic contaminants.

A layer of medium-coarse gravel (particle size between 4 and 16 mm) with a thickness of 0.10 m is placed above the Reactive Layer (Fig. 31). Its function is to prevent flotation of the underlying material constituting the mixture and prevent erosion.

The installation of the PTS has followed the following stages. At first, all the components of the PTS, namely the sand and the gravel, the eucalyptus wood chips, and the clay were mixed outside the trenches, using mechanical means, to obtain a relatively homogeneous mixture. Then, the obtained mixture was installed, using mechanical means, on the gravel bed previously laid in the trenches. After the installation of the mixture, the iron oxides were distributed manually on its surface. Finally, the mixture was covered, using mechanical means, with medium-coarse gravel until a 0.1 m thick layer was obtained.

4.2.6. Fences

Two fences have been installed, one around the area occupied by the filter and the pump control panel, and the second around the area occupied by the recharge trenches (Fig. 32). The fencing was constructed with galvanized wire mesh, with a height of 1.50 m, anchored to support posts made of T-section galvanized metal, measuring 35*35 mm and with a thickness of 3 mm, braced with galvanized iron stakes of the same section. The area has been equipped with appropriate signage to highlight the presence of open excavations and to indicate the prohibition of access to unauthorized personnel.

Figure 32. Fences in the FIA plot

4.2.7. Forestation

After the realization of the trenches, eucalyptus (*Rostrata*) and poplar trees (*Populus Alba, Populus nigra Luisa Avanza*), were planted at 1.50 m from the edge of each trench (Fig. 33). In overall, about 200 trees as phytocells were planted at 3.00 m from each other along the rows, after digging a hole with mechanical drill at least the double of the size of the root volume of the phytocells filled at the bottom with compost.

Figure 33. Forestation of the FIA plot and activation of the trenches

The planting was carried out with the involvement of students from the Agricultural Technical Institute of Bosa who were trained in the field on the general functioning of the FIA system and planting techniques (Fig. 34).

Figure 34. Students from the Agricultural Technical Institute of Bosa involved in the planting operations of the FIA plot

Since the planting was carried out in May 2023, it was necessary to equip the FIA with an emergency irrigation system by drip irrigation, connected to the irrigation distribution network of the Land Reclamation Consortium (Fig. 35). This allowed us to minimize the failure rate of the trees. The system was equipped with a filter, a flow meter and a control unit for the automatic supply of irrigation events. The system was set to irrigate each plant 4 times a day providing 8 L for each irrigation event. Emergency irrigation was maintained until the end of September 2023.

Figure 35. Emergency irrigation system by drip irrigation

5 *POST-OPERAM* MONITORING NETWORK

The *post-operam* monitoring network aims at assessing the effectiveness of the Forested Infiltration Area (FIA) technique in reducing nitrate concentrations in contaminated groundwater. It includes several components (Fig. 36):

- Weather station
- Flow meter
- 3 vertical FDR probes (from 0 to 120 cm of depth) connected to a CR1000x datalogger
- Watermark sensor connected to a CR1000x datalogger
- 3 disk lysimeters placed below the PTS
- 6 piezometers equipped with automatic pressure transducers (DIVER)
- 9 sampling chambers in the trenches for GHG (N_2O, CO_2, CH_4)

The monitoring started in June 2023 and finished in November 2023. Water quality samples (including the pumped drainage water, ponding water in the trenches, deep drainage, and groundwater) were collected once a week, while greenhouse gas emission monitoring started on September 15th 2023. However, based on the data results, the monitoring scheme was continuously adjusted to better observe the involved processes and dynamics.

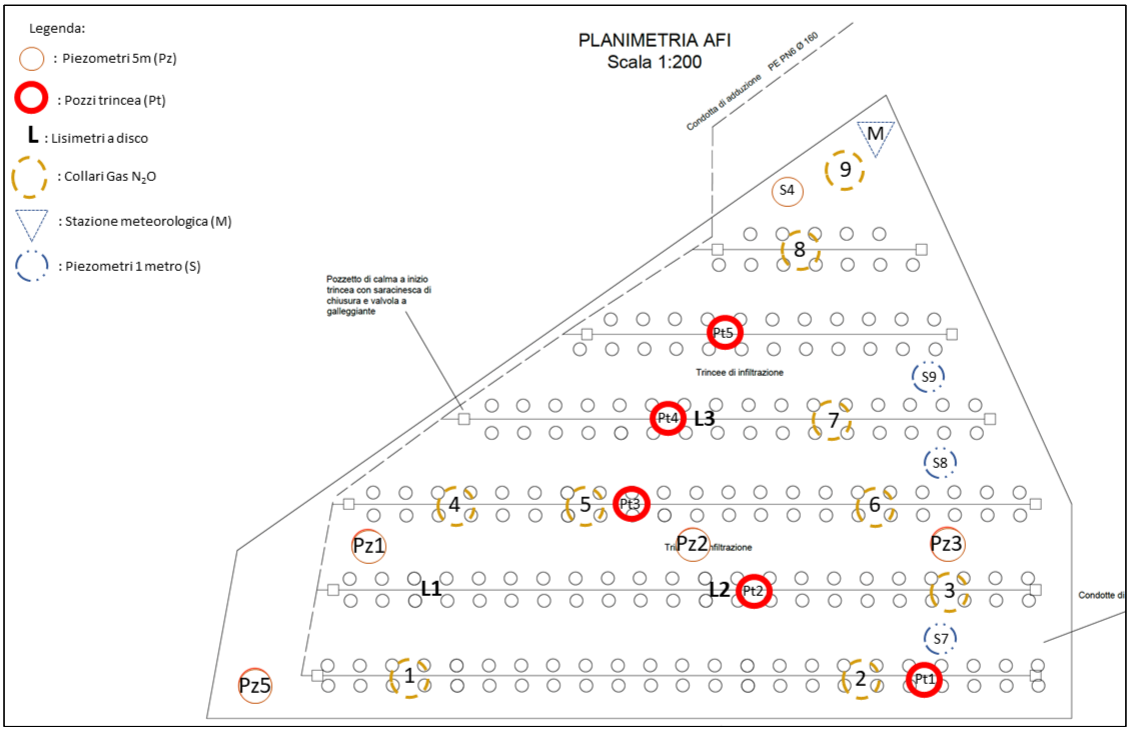


Figure 36. *Post-operam* monitoring scheme

For the groundwater sampling, six piezometers (Fig. 37) were drilled at a depth of 5 meters within the FIA plot, and one at a depth of 9 meters outside the area. These piezometers are screened by fenestrated pipes with a diameter of 110 mm and covered by caps for security reasons. Automatic pressure transducers measure water table fluctuations in these wells.

Figure 37. Drilling and final setup of the piezometers

All automated instruments, such as a weather station, pressure transducers, and soil moisture probes, measure data every 10 minutes. Data from these instruments are downloaded every two weeks during field visits using a notebook.

The inflow rate, which is equivalent to the infiltration rate as the system, does not have surface water output, is measured by a flow meter (Fig. 38). This counter is then connected to a GSM transmitter, which records pulses (with a minimum resolution of 1 m^3) occurring every hour. The data are stored in a cloud and can be accessed and downloaded in real-time through a desktop application. In addition to the flow rate, the pressure head of the hydraulic system can be observed using a metallic manometer and a pressure transducer located in the filtering system. The measurement of the latter can be read on the inverter panel, controlling the pump's operation.

Figure 38. Analogic flow-meter and GPRS device for remote transmission of the flow rate data

5.1. Geophysical and geognostic surveys to identify the best location for the piezometers of the *post-operam* monitoring network

Geophysical and geognostic investigations were carried out in the pilot area in February 2023 and May 2023, respectively, to know the hydraulic potential of the constituent materials, acquire further useful elements for the correct evaluation of their hydrogeological mechanical characteristics and identify the possible presence of materials that could have limited the capacity of infiltration of the recharge water towards the aquifer. This information was of fundamental importance for identifying the best location for the piezometers of the *post-operam* monitoring network.

5.1.1. Geophysical survey

The investigation was conducted by carrying out 2 sections of seismic tomography for the geomechanical characterization of the materials, and 6 sections of electrical tomography for the determination of the possible presence of materials with low water infiltration capacity in the ground.

Concerning the seismic tomography survey, the data acquisition in the field was performed using a system composed of the following parts:

- seismograph: model Echo 12/24 2010, AMBROGEO;
- energizing source: impact generated by the fall of a mallet weighing 6 kg on a special aluminous hitting plate;
- triggers: electric circuit closed by a reed starter system in the instant the bat hits the strike base; this allows a capacitor to discharge the previously stored charge and produce a pulse that begins the recording of seismic data;
- receiving equipment: to receive P waves, 24 vertical Sensor geophones with a natural frequency of 14 Hz were used, connected to the seismograph via a pair of seismic cables (each with 12 appropriately spaced takeouts) and a pair of extensions.

The data processing was developed through the following phases:

- formation of a database containing the geometry of the seismic line (altimetric and planimetric position of the geophones and bursts) and the first arrival times for each burst. Conversion of data into ASCII format.
- Delta t-V inversion for the reconstruction of one-dimensional (1D) depth/velocity profiles.
- optimization of the profile, for subsequent iterations, through WET (Wavepath Eikonal Traveltime) tomographic inversion, which allows the calculation of the wave trajectories (wavepath) through the finite difference solutions of the equation that expresses the propagation modes of a wave in an isotropic medium.
- control of the "fitting" between measured times and calculated times and possible reiteration of the inversion process and graphic output of the tomographic section (Surfer 10 software).

As mentioned, the seismic data were acquired along 2 tomographic sections arranged according to the plan in Fig. 39.

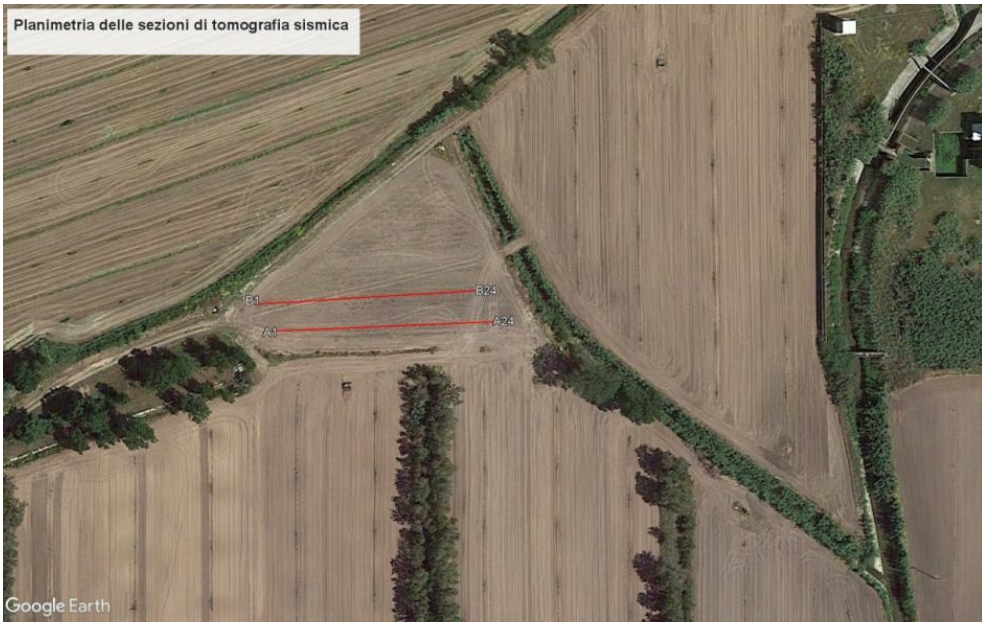


Figure 39. Location of the seismic sections in the pilot site

Each section was created by preparing an alignment of 24 P-wave geophones, with a natural frequency of 14 Hz and a geophone interval of 3.00 m and a total length of 72 m (including external shots). In order to acquire the quantity of data necessary for the correct use of tomographic interpretation techniques, for each seismic section, 9 energization points were considered, arranged along the array according to the following scheme (Fig. 40):

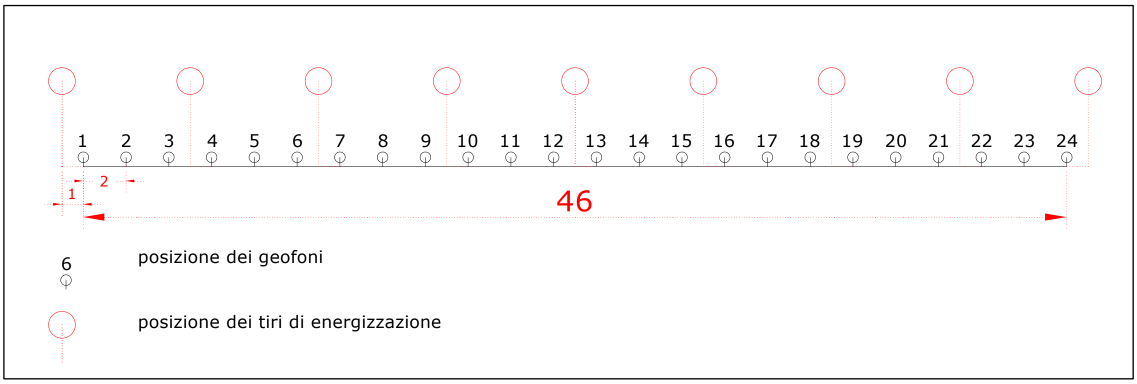


Figure 40. General scheme of the geophones and energization points

The result of the tomographic seismic survey is represented by the tomographic sections processed with the RAYFRACT software where, using an appropriate color scale, the variations in the Vp within the section concerned are represented.

As an example, Fig. 41 shows the result of the analysis of the seismic data acquired for section A, where it is possible to observe the distinction between the speed of the seismic wave on the surface and deeper. This allowed us to distinguish the portion of the sandy-clayey materials from the sandy-loam ones constituting the substrate. In detail, it is possible to observe the presence of low-velocity materials (Vp<700 m s^{-1}), from the surface to a depth of approximately 4.00 m, where the variability of the Vp is correlated to the presence of sands and clays which are poorly differentiable from seismic tomography both for the different mechanical characteristics and the different degree of compaction. These materials are followed by a layer of more compact material with a probable sandy-gravelly component characterized by a clear increase in Vp (>1500 m s^{-1}).

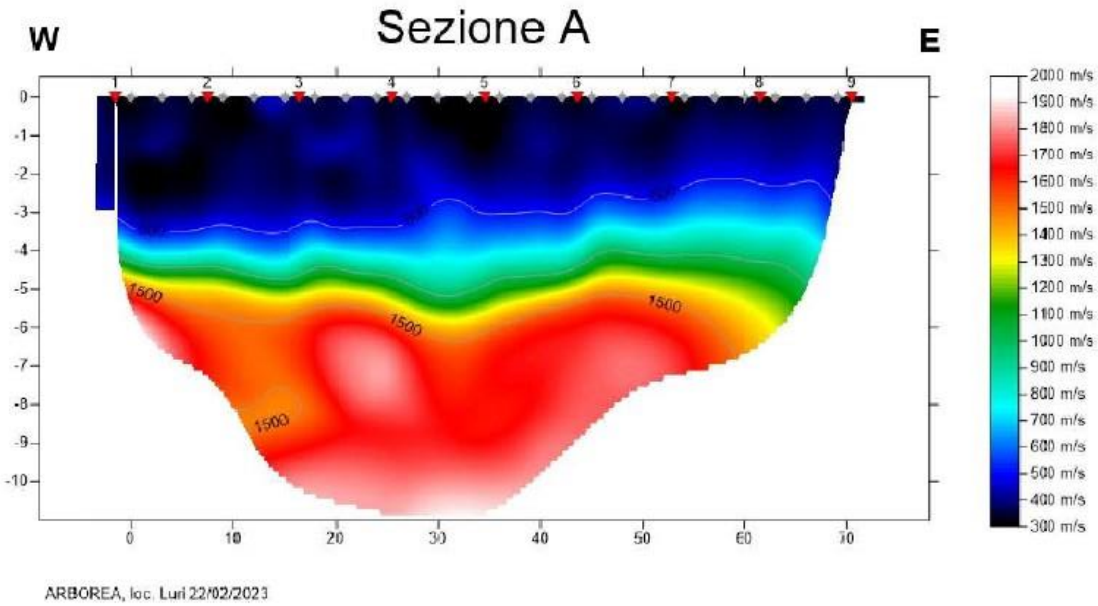


Figure 41. Tomographic seismic section A

Concerning the electrical tomography survey, the data acquisition in the field was performed using a Multichannel Electrical Imaging Systems model MANGUSTA System MC 24/144E. The apparent resistivity data were processed with software capable of reconstructing the real resistivity values by 2D numerical inversion (Res2Dinv). In the specific case of this investigation, the Wenner-Schlumberger quadripolar electrode device was used with which, by exploiting the characteristics of the instrument, a greater number of measurements are acquired compared to classic devices.

The acquisition of the 6 electrical tomography sections was carried out through the creation of electrode arrays composed of 48 steel electrodes positioned at a constant distance for each section, i.e. 5.00 m in Section 1, 2.00 m in Sections 2, 3 and 4, and 1.00 m in Sections 5 and 6 (Fig. 42).

Figure 42. Location of the electrical tomography seismic sections in the pilot site

As an example, Figs. 43 and 44 show the result of the electrical tomography for Section 1, the longest (around 230 m) and Section 4, inside the FIA. Fig. 43 shows the real differences in resistivity of the materials involved in the analysis. In detail, observing the different shades of color (which represent different real resistivity values), it’s possible to note some zones near the topographic surface where more resistive materials occur, with a thickness of approximately 12.00 m, followed by a layer of low resistivity materials.

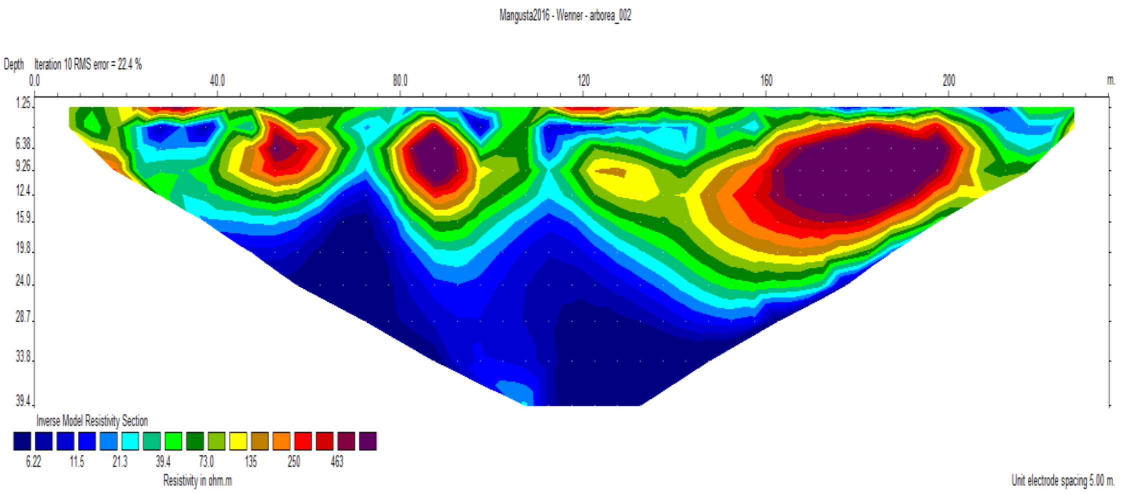


Figure 43. Real resistivity distribution in Section 1

More precisely, from the analysis of this tomographic section with a thickness of investigation of around 50 m, it can be noted that:

- the topographic surface consists of an alternation of materials with variable resistivity with a thickness of a few meters;
- below, some zones of resistive materials occur and become more evident in the final part of the section; in lithological terms, they could constitute more or less cemented sands; the thickness, initially about 10 m, reaches about 20 m in the final part;
- the deepest part of the section is made up of low-resistivity material (10-15 ohm/m) typical of clayey deposits.

Section 4 was acquired parallel to the southern part of the FIA fence, with a depth of investigation of 18 m. Fig. 44 shows that:

- the most superficial portion is made up of sandy +/- clayey materials with a resistivity of approximately 150-200 ohm/m; the thickness is around 4.00 m but it does not extend for the entire length of the section;
- from 4.00 to approximately 10.00 m, there is a layer with resistivity values typical of clays that extends for the entire length of the section; within this poorly resistive layer, between the pgr. 32-58, there is a zone where an increase in resistivity is noted, which could be attributed to the occurrence of pockets of sandy-gravelly deposits.

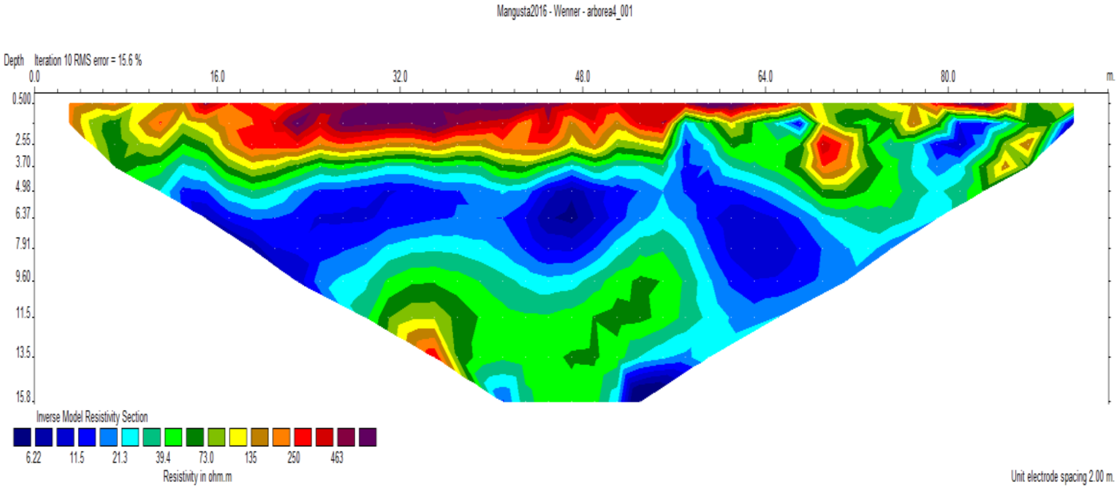


Figure 44. Real resistivity distribution in Section 4

5.1.2. Geognostic survey

Based on the results of the geophysical survey, a campaign for geognostic investigations was carried out in May 2003. It consisted of the realization of:

- 3 geognostic test-pits;
- 7 continuous core drillings;
- 6 piezometers;
- Granulometric analyses of more than 30 samples collected from the cores.

The geognostic test-pits were realized by an excavator reaching a depth from the ground level up to 3.00 m. Table 2 summarizes their characteristics while the box includes the lito-stratigraphic description.

Table 2. Main characteristics of the geognostic test-pits

ID geognostic test-pits	Depth from the ground level (m)	Groundwater (if any) depth from the ground level (m)	Coordinate Gauss Boaga N	Coordinate Gauss Boaga E
P1	3,0	NO – Humidity at 2,50 m	4396453,10	1462022.80
P2	3,0	YES – Groundwater at 2,10 m.	4396457,0	1462086,50
P3	2,80	NO – Humidity at 2,00 m	4396504,40	1462075,32

Fig. 44 shows their location with respect to the FIA area.

P1 – Depth reached equal to 3.0 m from ground level. Impossibility of continuing the excavation due to the presence of inconsistent materials.
Diffuse root system up to 1.30 m deep.
From 0.0 m to 0.4 m: Light brown sand for the first 40 cm;
From 0.4 m to 0.9 m: Cohesive dark brown-black sand with a thickness of approximately 50 cm. Widespread root system;
From 0.9 m to 1.3 m: Sandy clay
From 1.3 m to 2.10 m: Light brown loose sand.
From 2.10 m to 3.0 m: Dark gray sands with silty matrix. Humidity found at -2.50 m depth

P2 – Depth reached equal to 3.0 m from ground level. The excavation is more stable than P1 due to the presence of cohesive materials.
Diffuse root system up to 1.30 m deep.
Water table at 2.10 m depth.
From 0.0 m to 0.7 m: Light brown sand with root system.
From 0.7 m to 2.7 m: Dark brown cohesive sand with root system for the first 50 cm.
From 2.7 m to 3.0 m: Light gray sand

P3 – Depth reached equal to 2.8 m from ground level. Impossibility of continuing the excavation due to the presence of inconsistent materials.
Diffuse root system up to 0.50 m depth. The excavation tends to collapse from 0.50 m to 1.50 m deep.
From 0.0 m to 0.5 m: Light brown sand with root system.
From 0.5 m to 2.0 m: Loose light brown sand.
From 2.0 m to 2.8 m: Light brown – cohesive green sand

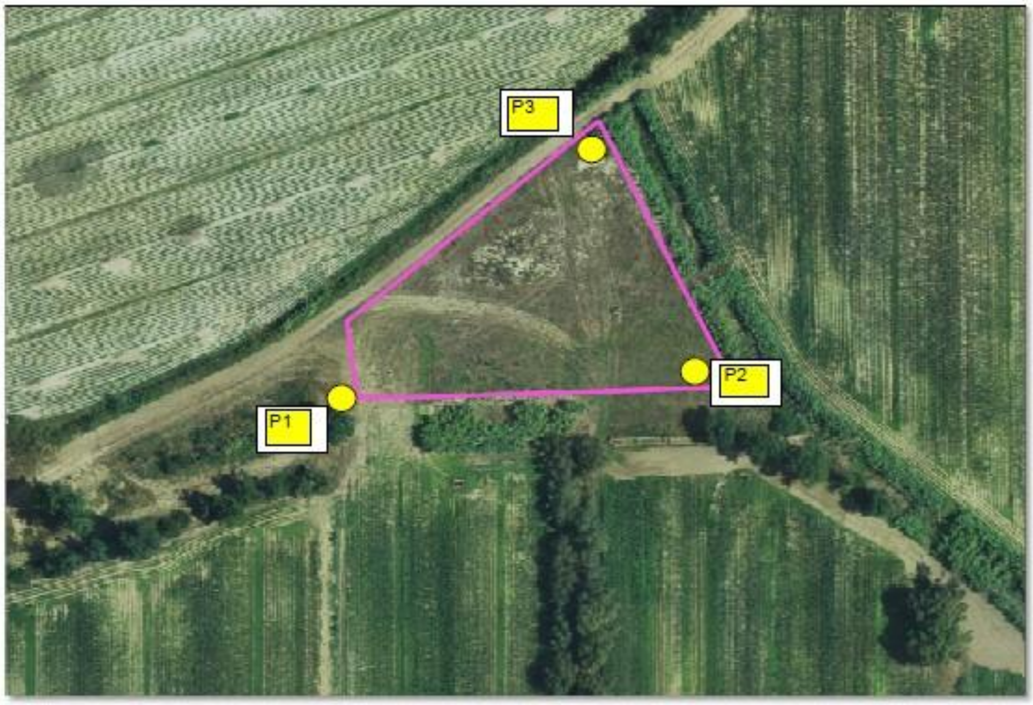


Figure 45. Location of the geognostic test-pits

Figure 46. Realization of the geognostic test-pit P1

Figure 47. Geognostic test-pit P1

The continuous core drillings were realized by a rotary drill machine model MK900D 1 MV. Fig. 48 shows the location of the 7 drillings.

Figure 48. Location of the continuous core drillings

The depths reached during drilling are indicated in Table 3:

Table 3. Depth reached for the drillings

ID Continuous core drilling	Depth reached from the ground level (m)
S1	5.00
S2	5.00
S3	5.00
S4	5.00
S5	4.00
S6	9.00
S7	25.00

As an example, Figs. 49, 50 and 51 show the realization of the core drilling S1, the cores collected and the log-stratigraphic report, respectively.

Figure 49. Realization of the core drilling S1

Figure 50. Collection of the cores for the drilling S1

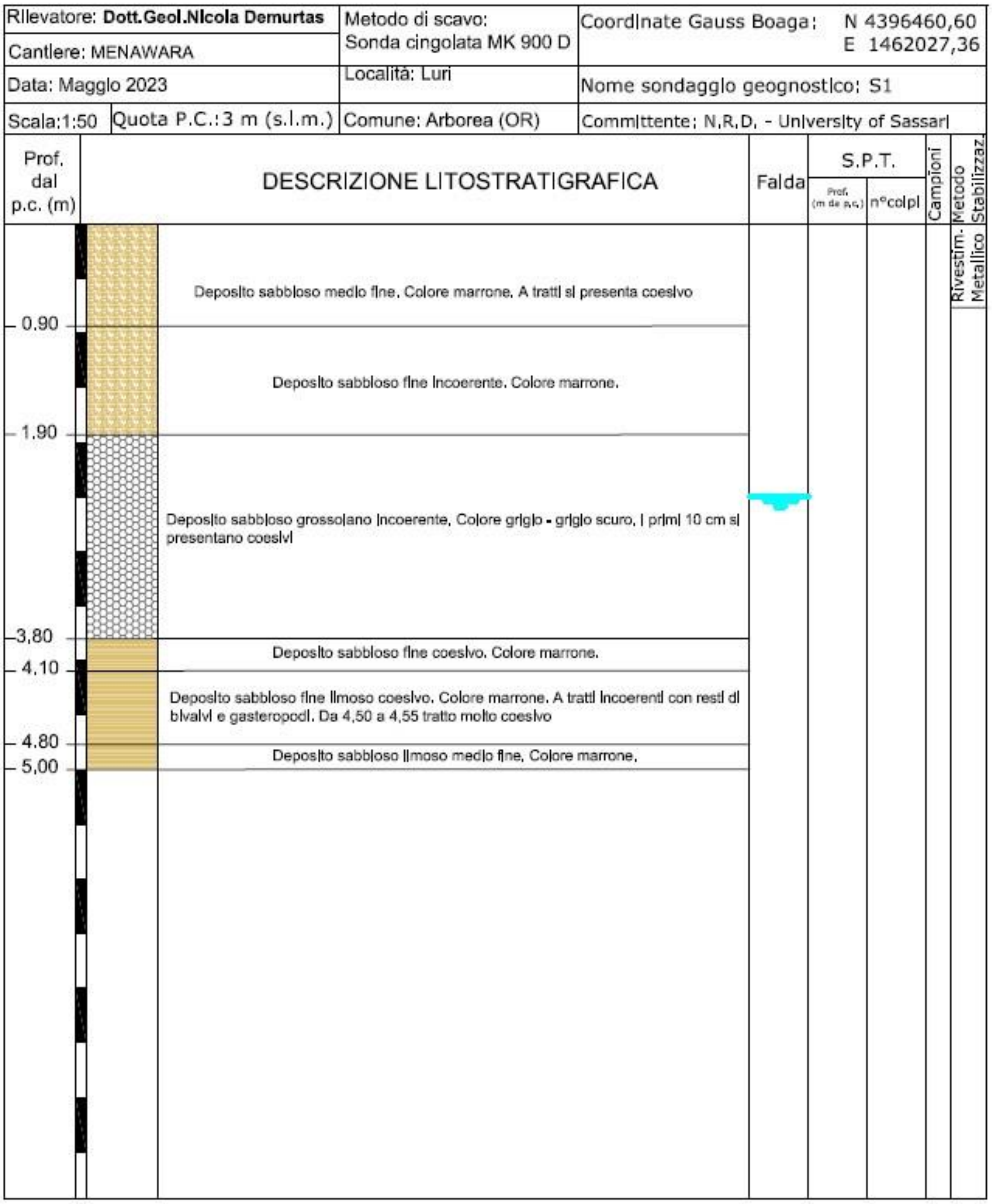


Figure 51. Log-stratigraphic report for the drilling S1

Except for the 25 m deep drilling, the other ones were equipped with a piezometer. In Table 4, the main characteristics of the 6 piezometers are reported.

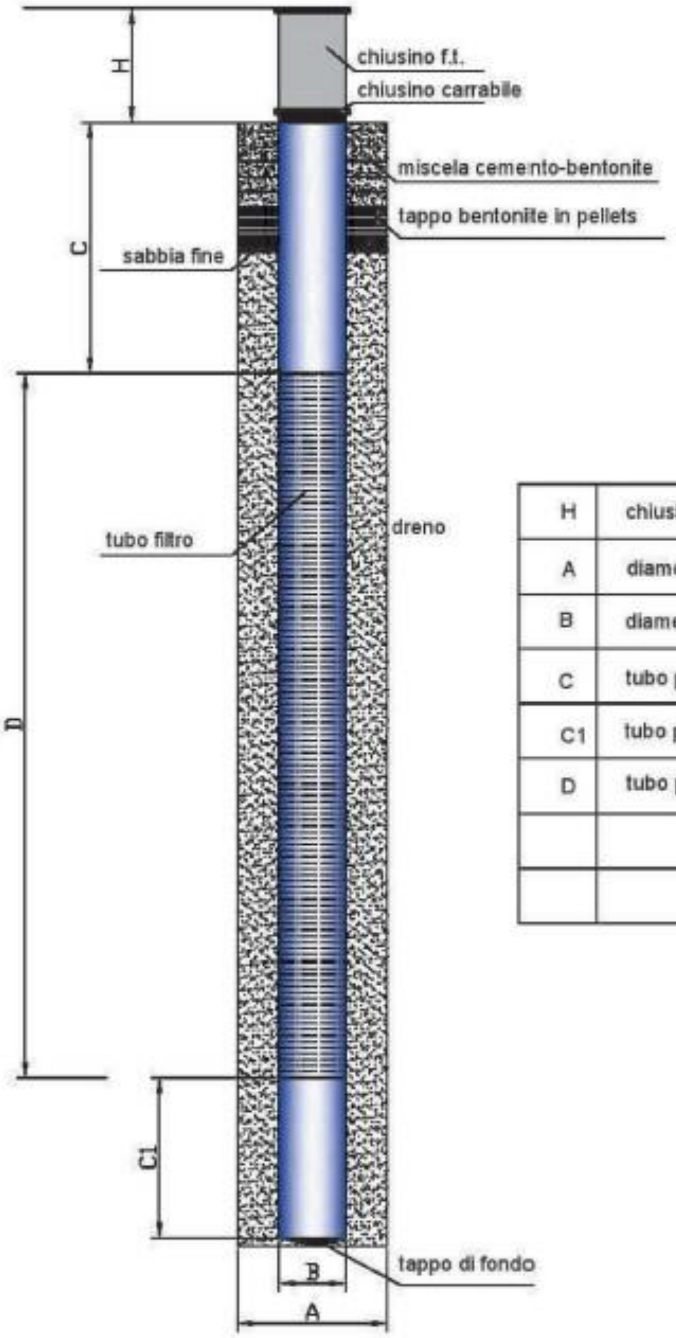
Table 4. Main characteristics of the piezometers

ID Piezometer	Drilling	Dept from the ground level (m)	Casing pipe (depth from the ground level m)	Screen filters (depth from the ground level m)
Pz1	S1	5,0	from 0 to -1 m	from -1 to -5 m
Pz2	S2	5,0	from 0 to -1 m	from -1 to -5 m
Pz3	S3	5,0	from 0 to -1 m	from -1 to -5 m
Pz4	S4	5,0	from 0 to -1 m from -4 to -5 m	from -1 to -4 m
Pz5	S5	4,0	from 0 to -1 m	from -1 to -4 m
Pz6	S6	9,0	from 0 to -2 m from -8 to -9 m	from -2 to -8 m

The following steps were carried out for the piezometer installation:

- water-reaming of the hole up to a diameter of Φ 178 mm;
- installation of the 4" PVC pipe (casing pipe and screen filters) with the relative bottom cap, once the hole was reamed to its entire depth;
- installation, in correspondence with the screen filters, of a filter layer made of clean and selected quartz gravel reaching a height of 1.00 m above the screen pipe section;
- creation of a bentonite plug with a minimum thickness of 1.00 m to protect the groundwater above the filter layer and in correspondence with the casing pipe. Specifically, bentonite pellets were used;
- installation of a cement mix composed of cement, and water added with bentonite, according to technical specifications, starting from the bentonite cap and up to the ground level. Cementation was carried out starting from the bottom upwards using special small tubes;
- insertion of a sealed cap and installation of an above-ground manhole cover to complete the piezometer.

Finally, piezometers were cleaned using the airlift technique. The resulting water was stored in tanks. The cleaning was continued until clear water free of suspended material and/or sediments was obtained.



H	chiusino f. t. = 0.50m / chiusino carrabile p.c.
A	diametro perforazione = 135mm
B	diametro tubo piezometro = 4"
C	tubo piezometro cieco = 4" = 2.0m
C1	tubo piezometro cieco = 4" = 1.0m
D	tubo piezometro finestrato = 4" = 7.0m

Figure 52. Scheme of the piezometer

Figure 53. Installation of the piezometer

Figure 54. Piezometer completed

6. Conclusion

Compared to the original proposed design in the preliminary technical report, there were only very few modifications done for the FIA system implementation. Initially, in the preliminary design, an outflow trench connecting the outlets of the recharge trenches to collect the excess water flowing out from them was foreseen. This part was replaced, in the executive design, by pipelines in PVC connecting the different trenches through prefabricated concrete calm pits at the end of each trench. This choice allowed to obtain a close system for the FIA to optimize water supply and management of the levels in the trenches.

The installation of the PTS in each trench of the FIA has allowed a significant reduction of the nitrate concentrations in the recharge water and groundwater, even if this was not observed in all piezometers and disk lysimeters of the monitoring network. The results achieved so far are described in detail in the report "Output 3.5: Report on the efficiency of the implemented pre and post treatments and MAR systems".

Due to the delay accumulated during the process for obtaining all the necessary authorizations for the realization of the FIA and during the implementation works, the time available for the *post-operam* monitoring aimed at evaluating the efficiency of the FIA was reduced to just 4 months. Therefore, this situation did not allow us to carry out a full assessment, highlight the critical issues and implement the necessary corrective measures. Since April 1st, 2023, the Arborea pilot site has become the case study of the project "NATMed - Nature-based Solutions on existing infrastructures for resilient Water Management in the Mediterranean", funded by the PRIMA Programme, of which NRD-UNISS is a partner. The project will end in 2026. This further opportunity will allow NRD-UNISS to continue the monitoring through the network created in MENAWARA, with some possible integration, and therefore it will be possible to demonstrate that the FIA can be considered a best practice for the mitigation of groundwater nitrate pollution. Furthermore, the experiment will be taken at the real scale, by the SARNITRO project, recently funded by Sardinia Region, which will maximize and enlarge FIA's results, utilizing, for filtering the groundwater, the existing drainage channels and the eucalyptus trees' windbreaks band of the plain.