LIFE Project Number

<LIFE +10 ENV/IT/000394/WARBO>

FINAL Report

Covering the project activities from 01/01/2012 to 31/12/2014

Reporting Date

<31/03/2015>

LIFE+ PROJECT NAME or Acronym

<WATER RE-BORN - Artificial Recharge: Innovative Technologies for the Sustainable Management of Water Resources>

<u>Annex 62</u>

Name of Deliverable:

WARBO multidisciplinary protocol and evaluation of the transferability of the protocol to other European situations

Code of associated action: 4,6,7,9

WARBO multidisciplinary protocol and evaluation of the transferability of the protocol to other European situations

1.1 Background: Artificial Recharge of the aquifer in fulfillment of the Water Framework Directive

This report provides a summary of the technical and scientific works carried out within the project WARBO in implementation of the Water Framework Directive (WFD) through the use of artificial recharge of aquifers in floodplain areas affected by severe loss of quality and quantity of water resources. Demonstration activities of artificial recharge have been applied in Upper Friuli Plain and the Po Valley, two very different contexts for topography, soil permeability, climatic conditions and quality of resources. The two selected contexts are significant for the transferability of results at European level and in this perspective, which are the goals of WARBO protocol. The report describes in detail the applied methods and provides application protocols inherent to multidisciplinary methodologies for characterizing the geological, biological and hydrological sites, to identify the causes of degradation and to assess the effectiveness of artificial recharge in achieving the objectives of the WFD in terms of protection and enhancement of water resources and improvement of the ecological conditions of water bodies. The macro- areas of the project have been selected mainly for their critical conditions associated to the depletion of water resources due mainly to the opposite peaks of climatic events observed in the last two decades; it is expected that could artificial recharge could provide appropriate mitigation measures and to develop resilience to the on-going climate change.

1.2 Artificial Recharge as part of the obligations of the EU Water Framework Directive & the Floods Directive

Human life, protection of the environment and ecosystems depend on water sustainability and unfortunately, due to climate change, human pressure and increasing pollution areas suffering from water shortages are increasingly extended and water management of areas affected by desertification involves loss of biodiversity and also limits access to essential resources. To counter the loss of resources there are two main strategies: the saving of resources and their protection and to favor the recharge by integrating A.R. plants with the ecological network. The wastes of water resources that have characterized the 900's are nowadays no more acceptable and the strategies of compatible management of resources; which have A.R as one of the most effective management tools, allow now to counter the dynamics of competitive use of water resources that put the need to supply this essential resource to the people in opposition to the needs of productive activities. The action plans designed to promote natural and artificial recharge are prepared in accordance with the numerous directives issued by the EU to promote the management of natural resources in terms of integration and management at basin and cross-border scales. The management of water resources is regulated by the European Union (EU) through the EU Water Framework

Directive and has included the implementation of the A.R. plant of Ponte San Pietro in the plans for flood management in fulfillment of the measures envisaged by the Floods Directive.

The WFD - Water Framework Directive has had an important role not only in the classification of water bodies in terms of quality and quantity but also in the definition of management plans, compatible water

resources for the various districts and Hydrographic basins. The goals have to be reached by adopting appropriate measures to decrease the pressures, to reduce impacts and especially to encourage water conservation and recharge of aquifers. The project WARBO in fulfillment of the WFD has applied artificial recharge in flood plain areas representative of the main European geo-morphological contexts (high floodplains, medium and low plain floodplains).It has addressed the problems and difficulties to manage the new extreme climatic conditions characterized by long periods of drought and / or heavy rainfall associated to a rapid surface water flow and poor infiltration in the aquifers. The project WARBO has considered situations associated flood plains to develop protocols to define for each geo-morphological and climate typology the best possible procedures for the implementation of artificial recharge. It has Identified the analytical procedures and methodologies for the characterization of the sites, to identify the causes of deterioration, the critical situations and the possible solutions for the recovery of surface and groundwater water bodies with low cost/benefits ratio. . The developed protocol defines the possible solutions and procedures for water supply according to the special problems of degradation to provide support for the management of A.R. and monitoring in the various geo-morphological, hydrological and geological scenario. The experience has permitted to evaluate the costs and problems and provides the tools to achieve the environmental objectives set by the EU for 2020.

The protocol has taken account of all the directives dealing with water in order to be inherent with the priority measures and constraints defined in the present legislation and directives and among them 2008/105 / EC on environmental quality standards; 2007/60 / EC on floods; Groundwater (2006), The Nitrates Directive and the Directive on urban waste water.

The document took into account the sustainability of the procedure in economic and environmental terms (reducing pollution and GHG emissions) by analyzing the problems of integration of artificial recharge with the constraints and vulnerabilities of the territory ,including economic activities and farming, and evaluating the advantages and disadvantages on the health of water related ecosystems. In addition the monitoring of the thermal sensitivity of aquifers to the seasonal variations has provided useful data to support the integration of A.R: with the thermal potential of geotermal plants; A.R. could be now be integrated with plants for the use of geothermal energy.

1.3 Development of WARBO Project and main activities

The main objective of the project was to develop multidisciplinary protocols of artificial recharge for the management of water resources. The multidisciplinary approach has tested the best practices to be used to integrate lower water inflows taking into consideration that a decrease of inflow is often accompanied by widespread pollution. In particular, large areas of the Po plain , as well as most of the floodplains of coastal areas bordering the Mediterranean sea are subject to salinization of aquifers and recognized desertification processes. These problems can be addressed by the introduction of artificial recharge in water management plans.

In a similar way , for the effect of changes in the thermal regime and rainfall in recent years have negatively affected the spring belt which develops at the contact between the foothills and the plain along the entire Po Valley has gradually migrated to lower altitudes and the disappearance of historical sources has alarmed the population. The project has identified in the Mereto di Tomba and Ponterosso (ZIPR) areas, two the representative sites to test the artificial recharge for the mitigation of the above problem in application of the Directive water.

In the high Friuli plain artificial recharge was aimed not only to the compensation of lower water supplies responsible for the retreat of spring belt and , but also to support the transformation of agrarian reform to transform the flooding irrigation into drop-by-drop irrigation systems necessary because of the high nitrate pollution that plagues the aquifers of the Veneto-Friuli plain. Agrarian reform by providing the water resources for the balance of shallow groundwater helps to prevent that the excess of water supplied by flood irrigation may leach nitrates and transport them into the aquifer. These lower water amounts effective in limiting the transportation of nitrates into the groundwater but determines a quantitative depletion of groundwater; this negative side effect could be mitigated by numerous small plants of artificial recharge that due to the high permeability of the subsoil can feed significant volumes of water quality to compensation lower supply from drop-to-drop irrigation.

In the Po Valley artificial recharge was aimed at achieving four objectives: 1) fight salinisation of aquifers and diffuse pollution from hazardous toxic metals , 2) to guarantee supply of water of good quality for irrigation and civil use even during 3) to make the territory resilient to climate change and to geological risk by considering the use of A.R. reservoirs in the management plans of extreme weather events, 4) strengthen the ecological network and recover the quality of gravel and sand quarry reservoirs that in the Po river delta are all affected by serious problems of salinization. 5) to verify the possibility to re-qualify for drinking water purposes the brackish aquifers through the confinement of the salt intrusion by injection of fresh water. These objectives have already been achieved in the A.R. plants of Ponte San Pietro in Copparo.

The project has helped to reduce the environmental impact of hydraulic management of the territory by providing the opportunity to insert the numerous abandoned quarries ponds , area affected in general by salinization, in the plans of construction of expansion basins in order to optimize the land use and upgrade the r surface and groundwater waters by recharge with fresh water. The project activities pointed out that this promiscuous use of expansion ponds and A.R. systems can be adopted without any risk of pollution in quarries ponds existing in areas with low human impact and where feeding channels supply high quality waters so that the A.R. could be done with waters complying with the characteristics defined in the Water Directive. The opportunity to design the expansion basins in areas with low human impact redesigning the irrigation canals with plantations of plants useful for phytoremediation allows to strengthen ecological corridors, to counter the salinization of the reservoirs, to increasing biodiversity and to supply large volumes of water that by that infiltrating into the subsoil will slow down the peaks of floods with great benefits for recharge of groundwater system in all its components, from the choice of the methodology of recharge, the selection of water supplies, water treatment, selection of infiltration method, monitoring and finally evaluation of the effectiveness of the method. It was necessary to abandon direct injection method since the earthquake of May 2012 highlighted the critical actions of forced injection in semi-confined aquifers located at less than 15 meters in areas where seismic events with PGA (Peak Ground Acceleration) greater than 0.15 g could occur. It must be avoided that the induced overpressure caused by the by forced injection could favor the effect of sand liquefaction. ARPA's monitoring stations have in fact detected a significant rise of groundwater immediately after the major earthquake of 20 and 29 May with increase depending on the distance from the hypocenters. For that while forced injection can be critical and should be applied with caution and only in areas located at a safe distance from urbanized areas and sensible infrastructure. At the contrary A.R. recharge through infiltration basins in seismic areas has no contraindications because it does not induce excess pressure in aquifers.

A.R. can be used in the eastern Po valley for the recharge of aquifer A2, when it hosts freshwater. The considerable depth of this water body does not involve risks of co-seismic effects; also the A1 can be recharged in the areas where it behaves as a unconfined body hydraulic communication with the riverbeds. During the 2012 earthquake it was possible to verify that the aquifers in communication with the sediments of the riverside areas have the opportunity to discharge along the rivers the excess of pore pressure induced by the earthquake. That happened along the River PO, The Cavo Napoleonico and the Panaro where no liquefaction phenomena occurred along the current levee even in areas proximal to the epicentral area, while the proximal alluvial plain was heavily affected by a system "en échelon" of fractures that allowed the eruption of water and sand for the effect of liquefaction. to . The monitoring of water levels in the section between the stations of Sermide, Pontelagoscuro and Cavo Napoleonico during the main shock of May 20, 2012 showed an increase in the level of groundwater about 8 cm; this was maintained for several hours and then disappeared in 6 hours.

The geometry of hydrometric curves cannot not be justified by the propagation of the free wave generated during the earthquake because this type of signal runs out very quickly, this increment seems much more related to the pumping of groundwater from below the river bed. For the above reasons the A.R. system of Ponte San Pietro is designed to recharge by infiltration. Its efficiency is favored by the presence of sandy sediments belonging to palaeo-channel d in communication with the multi-aquifer hydraulic system A0 which in turn has interactions with the confined aquifer A1 too.

Monitoring of geophysical, geochemical and biological data for a full seasonal cycle preceded the activities of A.R providing useful references about the dynamics of natural recharge; on this basis to the evaluation of the effect of artificial recharge in upgrading the quality and quantity of water resources r and biodiversity has been done; it has also allowed to develop the conceptual model for recharges in alluvial plain areas. The integration of geophysical methods and geochemical data has permitted to produce 2D thematic maps providing the elements for the understanding of the migration in space and time of the freshwater/saltwater interface during the recharge. This indirect and cheap approach by geophysical methods has proved successful to define the effectiveness of recharge also in areas not equipped by piezometers. . Project activities were carried out in a period of time between the two climatic extreme peaks of 2012-2013. This period was considerably warmer than the average both globally and in the project areas. 2012 was the 21st consecutive year with an average temperature higher than normal and the average number of tropical nights, (minimum temperature higher than 20°C) , was the second highest in the series since 1961, second only to 2003 . These thermal conditions do not allow surface water bodies and soil to cool overnight so in 2012 the evaporation and evapo-transpiration caused a very strong stress on water resources and ecosystems . At the contrary the year 2014 was characterized by a anomalous summer season , characterized by the reduced occurrence of high-pressure conditions with the consequence of short periods of good weather in June only, thermal values below average and rainfall above normal especially in the month of July. The Azores anticyclone and the African one have steadily expanded on the Central Mediterranean feeding frequent Atlantic frontal systems from west to southern Europe and the Mediterranean. These conditions have favored an important natural recharge of aquifers so that the effects of A.R. have been amplified by these favorable wet climatic conditions. The institutions having the management and ownership of the sites will continue the charging and monitoring activities even after the closure of the WARBO project; the multi parametric probes installed in test sites will be left and will be maintained inf unction and in the test site of Ponte San Pietro, the consortium of Land Reclamation will install additional monitoring stations. The effectiveness of the recharge and the application procedures are described below in this final technical report of produced jointly by UNIFE and all Partners.

1.4 Characterization Plan and hydrogeological geochemical and geophysical conceptual models

The characterization of the test sites of occurred through the collection litho-stratigraphic data available in the archives of the Municipalities involved , the Civil engineer and the Geological Survey institutions of the two regions of the Project The available data have been integrated and validated through boreholes drilled for the realization of piezometers and for the recovery of samples for sedimentologic, chemical, petrophysic and geophysical analysis. A rich database of stratigraphic data regarding the Friuli test sites was made available by the University of Udine; at the contrary in the Copparo site, due to the non exploitability of aquifers, only a few boreholes were available and among them only a few had useful data to correlate stratigraphy geochemical parameters with water bodies.

The project was a great opportunity to create a well organize allowing a good definition of stratigraphic and geochemical characteristics of the aquifers filling the gaps in this area of knowledge due to the fact that most of the water monitoring networks in Italy are focused on analysis of data regarding protection of health more than on environmental protection. Data have been processed into hydrogeological thematic maps to be used to define the program of drilling of piezometric wells for monitoring of the aquifer in view of A.R. The data in addition to responding to the needs of the project also comply with the Plans for protection of water resources in fulfillment of / EC Directive 2000/60 PA. The study permitted to verify the presence of salt water in the first confined aquifer highlighting that pollution is not related to the intrusion of sea water but it is generated by the mentioned fossil waters. . The relationship that has emerged from the project between salinization of aquifers and underground presence of major tectonic structures pointed out that for a proper protection and improvement of water resources, it would be necessary to reconsider the existing monitoring networks in the areas where tectonic generates interferences between the deep structures and the surface. In situations of low geothermic gradients, the upward movement along these structures of fossil waters rich in salts and hazardous toxic metals is not always associated to thermal anomalies.

Two non-destructive methods: geoelectric tomography and thermography were used to study the process of infiltration in the A.R. test site of Mereto Tomb (UD) .. The first one is based on measurements of electrical conductivity and induced polarization of the soil and is was to map the movements in the depth of the recharge water by the study of the variations of electrical conductivity determined by the passage of water. Thermography is based on measurements of temperature of the soil and has allowed to obtain an accurate mapping of the degree of humidity and saturation of the ground surface during the infiltration process. . The measurements were by for every few minutes at the beginning of infiltration and later every half hour. The geoelectric measurements with array on the bottom of the pit have been made for the entire night until the next morning for 24 hours, with an interval of one hour for the geoelectric and with an interval of 20 minutes for the thermography. Because of the short length of geoelectric array permitted by the dimension of the basin , the maximum depth reached by the geoelectric measurements was 8 m from the bottom, about 13 from ground level. The next day, the measurements were repeated on the side of the basin outside of the , with a longer array permitting to reach a depth of about 20 meters: In this case too measurements were made continuously for 20 hours. To verify the presence of water leakage from the nearby irrigation canal, some geoelectric measurements have been done on the bottom of the channel with a special submersible cable with graphite electrodes for underwater measurements. Thermal images have provided an excellent picture of the progress and shrinking of the area flooded by water, saturated and then dried during and after infiltration process. The correlation of surface data obtained by thermography with electrical section, has allowed to obtain a pseudo 4D map considering time and portion of soil involved in , the progress of infiltration down to a depth of about 20 meters. The arrival and transit of the plume of infiltration, and the interactions with the strata of the subsoil can be precisely mapped and correlated with the contraction of the flooded/water saturated area at the surface. Since there are no leaks from the nearby canal, all electrical variations of the subsurface are surely determined by the infiltration process. In the of Copparo (FE) site the main application of thermography was to check the extension of the water inflow from the channel into the small pool for fito-remediation and then from here into the main basin. Due to the difference in temperature of the water in the three units, it was possible to observe the entire process of propagation and mixing from one unit to another.

The stratigraphic - geological-geochemical conceptual model has been prepared on the basis of hydrogeological characteristics, geophysical and geochemical data and with the involvement the responsible institutions. The model in addition to the direct applications to A.R. is an important tool for planning interventions and for the definition of policies of protection and sustainable use of water resources as required by Directive 2000/60 / EC. The A.R. project at both sites had been subjected to EIA procedures and these procedures were reviewed by a technical committee to verify any critical point .. The process of characterization and monitoring has been defined in the technical reports of the project and complies with legislative the 2000/60 / CE del 23/10/2000.

1.5 Water supply and territorial impact of the management of A.R.

The supply of resources for charging is one of the most critical of the methodology as it must meet the following conditions:

a) water resources for A.R. to recharge must have excellent quality as they do not have to compromise the characteristics of water bodies. These conditions must be guaranteed through appropriate monitoring systems: this condition must be maintained even when recipient aquifers are salinated as A.R. has the scope to induce the gradual rehabilitation of underground water reserves.

b) the activities of A.R. should not create competitive scenario for water resources and the supply must fit with the plans of resource management at basin scale. In the project WARBO supply was provided by the land reclamation and in full accordance with the water distribution for irrigation.

c) The supply of resources must be part of the management plans of both the irrigation and runoff catchment network to operate without or with minimal energetic costs, which is essential to operate without increasing GHG emissions.

d) the use of water resources for A.R. must ensure the minimal vital flow of water streams g and treatment of water resources for the achievement of the quality characteristics laid down in Directive water must be pursued through the insertion of the areas interested by A.R. recharge in the plan of river corridors

e) The volumes of water dedicated and delivered to A.R. should not trigger geological risks; for that it should be necessary to consider if the increase of pore pressure may trigger landslides, to increase in case of seismic events the site effect and to increase the risk of flooding in morphologically sensitive areas. The test area of the project WARBO, Ponte San Pietro, lies in an morphologically depressed area; for that the Municipality of Copparo in collaboration with the Consortium of Reclamation Ferrara has evaluated the impact that the provision of water resources for A.R. could have on the conservation of the hydraulic height and and efficiency of the hydraulic network. Artificial Recharge should not conflict with the outflow of surplus water under conditions of high rainfall intensity. Each territory according to the mentioned critical points should define management plans of resources for artificial recharge and to define the costs.

The plan for supply and management of water recharge has been supported by climatic analysis at local scale that confirmed the extreme vulnerability and climate sensitivity of selected macroareas. The climate trends that emerged from the project are in full agreement with the ones reported for the Italian territory by NCDC / NOAA and ISPRA confirming, for the Italian territory, average temperature anomalies significantly higher than the ones st global scale [1, 2]. The climatic and geochemical survey was carried out at the catchment scale in order to verify any critical point or risk of pollution. This activity has been particularly critical in the test area of Ponte San Pietro since the earthquake of 2012 triggered the rising of plume of fossils salty water that could contaminate the irrigation network. This approach has allowed the identification of suitable water resources to be allocated to the A.R. areas in accordance with the parameters of Directive 2000/60 / EC.

1.6 Innovative analitic methods

The project has made use of conventional methodologies integrated with innovative methods aimed at the characterization of sites, monitoring of artificial recharge and data processing. The following methodological innovations have been developed:

a) Climate Analysis compared to 'isotopic analysis in order to define the recharge

A cheap innovative method based on laser absorption spectroscopy with high resolution to determine cheap δ18O and δ D in precipitation, surface waters groundwater was applied. Isotope analyzer manufactured by American Los Gatos LWIA 24d was used.. This equipment acquired in 2012 has been calibrated via an cross comparison with mass spectrometry and excellence correspondence for samples with electrical conductivity less than 3000 mS / cm was found . Care must be taken to alternate the isotopic analysis of samples with electrical conductivity greater than 1000 mS / cm, with analysis of distilled water to wash the chamber, since the salts present in the sample can produce a matrix effect which affects the determination of the isotope ratio. For the characterization of precipitation and isotopic determination of their influx on the aquifer project WARBO has defined that sampling of rainwater must be performed within 12 hours after precipitation as a longer time makes allows the collected rainwater in rain gauges to rebalance with the atmosphere acquiring the local isotopic imprint and becoming therefore not suitable to provide the useful markers to trace rain water infiltration.

Analyses of aquifers must be conducted before and after the rainfall in order to understand the timing and effectiveness of precipitation on natural recharge; sampling times may be even longer because the exchange capacity with atmosphere are reduced.

b) Utilization of confocal microRaman to characterize the primary and secondary mineral phases characterizing the lithologies of the feeding reservoir and aquifers interested by A.R.

The survey is very useful in water bodies affected by problems of widespread contamination from toxic-harmful pollutants as it allows to determine if the pollutant is present in the primary components of the sediment (granules, clay particles and carbonate cement) or it derives by the interaction between sediment and the ground water system. In the specific case of Copparo, some problems of contamination by chloride, Cr, Ni, V, As, B, Ba, Al and Fe were observed in the aquifers . One of the goal was to figure out how much of this contamination is due to the nature of the sediments and how much is produced by the rising fossil water . Furthermore, the knowledge of the nature of the mineral phases that host contaminants allows to understand if the variations of the chemical-physical characteristics of the water induced by the recharge l (pH, T, Eh, dissolved oxygen) can promote solubilization of the mineral phases that containing these metals and thus making them bioavailable. The use of HORIBA Jobin Yvon Raman Micro-Labram HR800 with a source 632.81nm combined optical microscope Olympus in microRaman allowied ccurate analysis and permitted to identify phases present in very low percentage but containing hazardous toxic metals. This was done in alternative to the XRD mineralogy analysis on samples in powder which does not allow to identify phases in which concentration in the sediment is less than 5%. The spectra acquired with confocal microRaman have clarified some doubt about the origin of the fluvio-glacial: for the first time it was clarified that the sediments that from the A1.

The aquifer in the project area are does not derive solely from the Po basin but rather it receives contributions from the river Adige basin. Numerous ebbles of limestone and dolomite associated with porphyry with proportions similar to deposits that characterize the contributions of the Garda have been found.

Combining microRaman analysis with EDXRF analysis it was possible to verify that the glass pebbles of porphyry contains traces of arsenic and then the interaction of these pebbles in time with inter-pore waters of can release this toxic –harmful metal. Arsenic is derived as well from fossil metanifer deep waters and also by the interaction of water with the sediments of the aquifer . Being the confined aquifer recharge areas A1 away from the water trapped in the pores, have long periods of permanence and can get rich over time in Arsenic by long interaction with the sediment: The introduction of water of good quality in the aquifer as well as the induced by dilution can improve the chemical-physical and chemical properties of the aquifer and to induces a flow which will reduces the interaction time and therefore associated the dissolution process that are characteristic of underground water with long residence times in contact with sediments. The same analysis indicate that Cr, Ni, Co, V are present in high concentrations in the sands of the aquifers associated with spinel and silicate phases such as pyroxene and amphibols femic . are trapped in mineral resistant to alteration and therefore do not tend be released. . At the contrary Cr adsorbed in the clay minerals of the smectite group of chlorite inside he levels silty clay-containing can be mobilized by water rock interaction. Since the levels of clay are low permeable, A.R. should not produce contamination problems for this metal.

It was also observed that the abundance of peat K is not related to silica that shows the presence of oxides and chlorides of potassium in the peat. This abundance of potassium may result from the development in the basins of marsh fern . This that is a plant that has the propensity to trap potassium. And tend to absorb arsenic; this explains the enrichment in arsenic levels that characterizes peaty deaposits.

These peaty levels are also rich in iron sulphides. Fortunately being peaty levels associated to clays which are impermeable their interaction with the water does not cause pollution problems. Arsenic tends to concentrate in the iron oxides and hydroxides of (goethite) that characterize the levels of weathered clay. The only problem occur in sediment of floodplain (PI) located -2.00m below ground level affected by tillage and excavation. The micro-Raman analyses confirmed that:

- The Ba is closely linked to the presence of hydroxides of manganese arising mainly from chemical precipitation in the sedimentation basin and is also present as barite derived from the precipitation of barium sulphate from fossil methane water rich in this metal;

- Rb and Zr are highly concentrated in levels rich in volcanic products;

- Sr is thoroughly embedded in the carbonate phase - Zn and Ni appear, in the coarser fractions, closely related to the presence of oxides and hydroxides of iron; in finer one Zn, but not the Ni, seems related to the abundance of clay minerals;

- The presence of spinelli testifies the contributions from mafic and ultrafemici complexes rich in Cr, Ni, V, Co. By microRaman it was possible to verify that the anomalous concentrations of Zn and Ni are associated to the presence of sulphytes, while high concentrations of chromium testify mafic minerals such as pyroxene and amphibole and also chromite spinels.

Barium in addition to be present in carbonates is present as barite and this mineral is associated with fractures rich in sulphides. The mineralization in iron oxides (hematite and goetite) instead have abnormal concentrations of arsenic. There are clear evidences that in particular climatic and environmental conditions mineral phases rich in toxic metals that can be harmful can precipitate from methan waters and to be re-mobilized with severe impact on the environment and human health. The micro-Raman showed how clays can adsorb toxic metals such as As, Ba, Cr, Ni and V that may be released by changes of the water chemistry from reducing to oxidizing. The supply of surface water rich in oxygen needs to be conducted with caution in these sediments: In this case the infiltration by basins is more secure than direct injection into the well.

c) Biological Monitoring

Biological monitoring is applied both to the quality of water systems and to environmental systems adjacent to the basins.

To study the animal communities two different methods were applied : the study of aquatic macro-invertebrates by collection on the bottom of canals and reservoirs by a Surber net and collecting terrestrial arthropods by Malaise trap, with particular attention to the Diptera Hoverflies . The collection of aquatic macro-invertebrates was carried out in 2012 and 2013 in Mereto di Tomba Ponte Rosso and Copparo simultaneously to the acquisition of physical and chemical parameters of water. The communities of terrestrial arthropods were investigated in 2012-2013 Mereto's Tomb, Red Bridge and Copparo and in 2014, after the construction of the tank constructed wetlands, in Copparo, to have available data before and after the RA. On data from the organisms collected with both methods were calculated main biotic indices (Shannon, Pielou and Margaleff) and correlations were made with chemical and physical parameters of the water collected through a multiparameter probe.

For biological investigations were used the following instruments:

• Surbre Net;

• Malaise Trap

• Cans type Kartell, sieves, wash bottles, formalin and polyethylene glycol;

• Multiparametric Probe.

Investigations of the community of aquatic macro-invertebrates showed that:

- At Ponte Rosso the community is quite rich and diverse and there are some invertebrate bioindicators of clean water, as proof of good water quality.

- At Copparo the community is not as rich, probably because it is a relatively new habitat. There are at least a couple of bio-indicator species whose presence and abundance, however, is dependent on seasonality.

Investigation of terrestrial arthropods have shown:

- In the years 2012-2013 a community much more rich and diverse in Mereto, followed by Ponte Rosso while in Copparo environmental quality seems quite compromised, with very low values of biotic indexes ,probably because of the disruptive effect of quarrying and agriculture in the vivinity of the basin.

- In 2014, after the construction of the basin wetlands, biotic indices show a sharp recovery in the environmental quality with the presence of several species of Diptera Hoverflies, who had not been collected in previous years.

d) Methodologies and geophysical monitoring

Geophysical methods are non invasive investigations methods specifically designed to maximize the amount of information about the geometry, the depth of layers and the subsurface hydrogeology .To satisfy these requirements, it is important to apply more than one geophysical method reduce the uncertainties of each of them.

Geophysical surveys allow the investigation of the subsoil , by measuring the surface variations in certain physical quantities. The spatial and time variability of these quantities, the nature, size and depth of buried geological formations can be reconstructed t.

1. GPR Survey - GPR (Ground Penetrating Radar). This method is suitable for the identification of shallow discontinuities down to a depth of few meters. Interfaces with different dielectric permittivity (better known as dielectric constant,), the generate refractions and reflections of the electromagnetic signal t allowing the creation of a 2D section with representation of subsurface structures.

2. Electrical resistivity tomography (ERT) - ERT is a fast, efficient and economical, with no impact on the environment and has sufficient definition for targets having a depth of 100-150m . ERT uses a DC source to obtain the so-called "apparent resistivity" amd I.P “ induced Polarisation”, which are functions of the distribution of the electric characteristics of the different materials present in the subsoil.

The model of the distribution of I.P. and resistivity provides information directly related to the effective porosity of aquifers and lithological characteristics of the deposits. It is therefore a primary method of choice to determine the position and shape of clay lenses, sand and gravel in the subsoil, and to monitor how variations of values of resistivity in time, in relation to infiltration.

3. Passive Seismic - seismic 2D-seismic reflection method, Passive seismic uses natural or artificial sources of seismic waves in opposition to conventional seismic which uses artificially generated waves. By analyzing the amplitudes and arrival times of the reflected waves, and after complex processing of the data collected, it is possible to obtain an accurate picture of the aquifers in the subsurface. The 2D seismic method has allowed the identification of the main geological formations of the areas under investigation and has defines the area of where to locate 3D survey.

6. Seismic 3D. 3D seismic acquisition uses the same methodology reflection (slap hammer, geophones and digital recording of reflections) but allows a more careful study of the variations in the properties of the subsurface (eg lateral variations of aquifers).

3D uses many more sensors, more personnel, ,longer data collection times and therefore high operating costs. This allows the definition of the stratigraphy and allows the areal "extension" of the measures collected in the wells. The seismic method has its inherent limitations in terms of vertical resolution (definition of thickness) that depends on the parameters of data acquisition and depth.

1.7. Proposal of Protocol for the characterization and monitoring of A.R. plants

A “protocol for design survey, monitoring and management of A.R." based on Project has been proposed " with the aim to induce actions to protect quality and quantity of water resources, as explicitly required by Community Directives and to provide the information needed to 'use of artificial recharge in order to facilitate the introduction of the methodology in the territorial plans of the EU” . The project has bee developed by several parallel activities for definition of the methods of investigation and cross-comparison between the results obtained with different complementary technologies useful to give uniform approach and applicability in different hydrogeological and geochemical, contexts and to assess: to assess in

- The risks and the ability to contrast of A.R.. Detailed studies and analysis were performed to define the hydrogeological, petrophysical (permeability) and geochemical analysis of aquifers useful to assess what modifications could n be induced in the chemical and physical parameters, especially on the permeability, due to precipitation of soluble phases in the pores (carbonates, sulfates, chlorides, oxides, etc.); this is the risk. Reducing the risk of mobilization of potentially hazardous toxic metals through artificial recharge, recharge effectiveness in countering the ingression of saline waters contaminated; this is the contrast capability.

- Effectiveness of A.R. to increase biodiversity in the basin and associated environment.

- Introduction of the methodology of A.R. in the on-going projects t of creation of retention/expansion basins due to increased occurrence of extreme weather events and flooding.

The implementation of the protocol is composed of a series of tasks and activities to be developed step-by-step according to the following procedures:

- Collection and processing of existing data, re-organization of data in thematic maps and integration with invasive and non-invasive methods to fill existing gaps;

- Construction of the Preliminary Model of A.R. and system design;

- Execution of bathymetric and sediment sampling of basin bottom ;

- Creation of thematic maps of the dynamic of A.R.;

- Introduction of A.R. in plans of resilience to climate change on a regional and European scale.