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PILOT DESCRIPTION AND ASSESSMENT

Marecchia river alluvial fan

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[Geological, Seismical and Soli Survey of Emilia –
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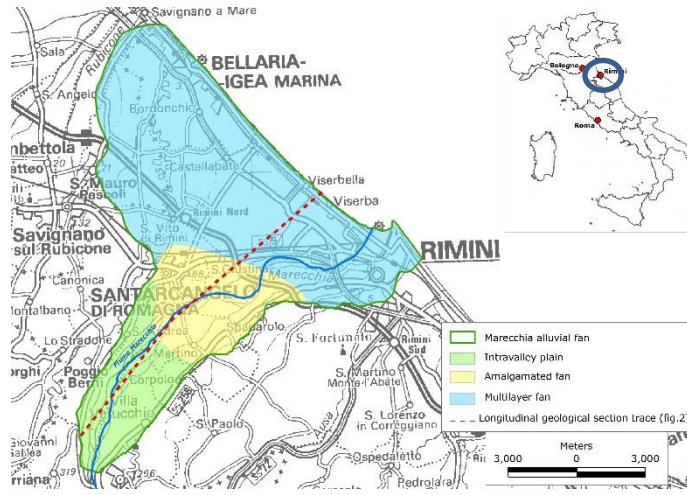
LIST OF ABBREVIATIONS & ACRONYMS

CC	Climate Change
GC	Global Change
LULC	Land Use and Land Cover
SWI	Sea Water Intrusion
GSO	Geological Survey Organisations
MAR	Managed groundwater recharge

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1 EXECUTIVE SUMMARY

Pilot name	Marecchia river alluvial fan	
Country	Italy	
EU-region	Mediterranean Region	
Area (km ²)	About 125	
Aquifer geology and type classification	Alluvial fan gravels, sands and silts; complex of porous phreatic to confined aquifers.	
Primary water usage	Drinking water and irrigation	
Main climate change issues	Higher temperature, drought	
Models and methods used	3d geological and geotechnical modelling of aquifers (Leapfrog) integrated with piezometric and salinity monitoring data; Managed aquifer recharge	
Key stakeholders	Local municipality, tourism operators, enviromental heritage authorities	
Contact person	SGSS . Paolo Severi (paolo.severi@regione.emilia-romagna.it)	

The study area of this pilot is located in northern Italy, in the Emilia-Romagna Region in the province of Rimini and it is about 125 km² large. From a geological point of view, it is an alluvial fan consisting of alternations of coarse and fine deposits that form complex of porous from phreatic to confined aquifers, well described in the chapter 3.

The study concerns the water resources of the Marecchia River alluvial fan which have a strategic importance for the drinking water supply and irrigation of the entire Rimini area, which is an important truistic location. In fact, about 28 million cubic meters of water a year are taken from aquifers of this alluvial fan, 19 of which are used for drinking water. A series of some very hot and dry summers since 2007 has led the Emilia-Romagna Region to establish a technical committee for the management of recurrent water crises. One of the practicable actions to prevent and mitigate future water crises is managed groundwater recharge (MAR), which would increase the availability of groundwater and also contrast land subsidence and salt-water intrusion, due to exciding in groundwater withdrawal. The MAR project is a specific measure to contrast drought due to climate changes, included the Management Plan done by Emilia-Romagna Region and the Po River Authority in compliance with the 2000/60 EU Directive; it



consists of putting water from the Marecchia River into an infiltration basin (site of a former quarry) in the maximum recharge area of the alluvial fan. To dimension the project and evaluate its functioning, we assess the structure of the subsoil with a series of cross-sections and with a 3d geological modelling of aquifers, integrated with piezometric and salinity monitoring data. A first trial period produced the expected effects: an increase in the volume of water in the lake induced a rise in the water table and a groundwater quality improvement. So the MAR project is going on. The great attention paid during these years to this natural area has also helped the development of an important green ecosystem and a large wetland area which is already subject to observation and protection for biodiversity and for the particular ornithological species that have found here the suitable environment for nesting. At the present time this area has therefore become a natural area that can also be available for the local population. This project has therefore proved to be a valid measure to contrast the drought due to climate change and also as a valid recovery and return to the population of and old quarry area.

2 INTRODUCTION

Climate change (CC) already have widespread and significant impacts in Europe, which is expected to increase in the future. Groundwater plays a vital role for the land phase of the freshwater cycle and has the capability of buffering or enhancing the impact from extreme climate events causing droughts or floods, depending on the subsurface properties and the status of the system (dry/wet) prior to the climate event. Understanding and taking the hydrogeology into account is therefore essential in the assessment of climate change impacts. Providing harmonised results and products across Europe is further vital for supporting stakeholders, decision makers and EU policies makers.

The Geological Survey Organisations (GSOs) in Europe compile the necessary data and knowledge of the groundwater systems across Europe. In order to enhance the utilisation of these data and knowledge of the subsurface system in CC impact assessments the GSOs, in the framework of GeoERA, has established the project “Tools for Assessment of Climate change Impact on Groundwater and Adaptation Strategies – TACTIC”. By collaboration among the involved partners, TACTIC aims to enhance and harmonise CC impact assessments and identification and analyses of potential adaptation strategies.

TACTIC is centred around 40 pilot studies covering a variety of CC challenges as well as different hydrogeological settings and different management systems found in Europe. Knowledge and experiences from the pilots will be synthesised and provide a basis for the development of an infra structure on CC impact assessments and adaptation strategies. The final projects results will be made available through the common GeoERA Information Platform (<http://www.europe-geology.eu>).

The present document reports the TACTIC activities in the pilot Marecchia River alluvial fan, located in the Adriatic coast of Emilia-Romagna Region, Italy.

It is a detrital alluvial fan aquifer, which extends for about 125 km². The shape and the dimension are indicated in figure 1; along the Adriatic coast the length is about of 20 km and the alluvial fan starts out of the catchment basin almost 15 km far from the coast. Rimini is the main town present in the area. This Pleistocene – Holocene aquifer is unconfined in the upper part (see green and yellow portions in figure 1) and consists of amalgamated gravel with a silty sandy matrix. In these portions the thickness goes from 10 to 80 metres, from the SW toward the Adriatic Sea. In the blue portion (figure 1) the aquifer is composed by a multilayer fan, formed by alternating gravelly levels and mainly fine levels, for the maximum thicknesses along the Adriatic coast (up to 250 m and more). All this geological information has been taken first of all from a National Geological Mapping Project (Progetto CARG, Foglio Geologico n. 256 “Rimini”), and they were used to implement a 3D geological model (software Leapfrog) in the surrounding area where a MAR project was realised. Hydrogeological information results from a local monitoring network composed by almost 35 wells, with four time per years level measure since 2001.

In the last decades during many hot and dry summer, the availability of drinking water decreased because of the poor presence of water inside the local dam located in the mountain areas. At the same time the demand for drinking water increases, because of the tourist presence. For these reasons the abstraction of groundwater in the alluvial fan aquifer of the Marecchia strongly increased, with potential problems for subsidence and saltwater intrusion.



The overall objective of this study is to use all the geological available information to implement and keep active over time a MAR project, in order to contrast the impact of climate change in water availability, and the reduction of natural groundwater recharge in the Marecchia river alluvial aquifer.

3 PILOT AREA

Overall introduction to the site and its challenges

The Marecchia River is 70 km long and has a catchment basin of about 600 km²; its average annual flow at the entrance of the alluvial fan is estimated at about 6 m³ per second (Basin Authority of Marecchia - Conca, 2004). The Marecchia alluvial fan (Figure 1) develops at the end of a mountain basin and it is divided, from a geological point of view, into three different areas: an intramountain plain, formed by a thickness of not more than 10 m of mostly gravel deposits directly flat on the marine substrate; an amalgamated fan, also comprised of prevailing gravels, for a maximum thickness of up to 80 m above the sea clays; and a multilayer fan, formed by alternating gravelly levels and mainly fine levels, for thicknesses up to 250 m and more, above the coastal marine deposits of the Imola Sands (Severi et Al., 2014, Geological Survey of Italy - Emilia-Romagna Region, 2005; Emilia-Romagna & ENI-AGIP, 1998;). From the hydrogeological point of view, the intramountain plain corresponds to a phreatic aquifer, as well as the amalgamated fan, although there can be local confinement conditions inside it. The amalgamated portion corresponds to the area of maximum recharge of the entire fan, which is mainly due to effective infiltration of rainwater and dispersion from the Marecchia River. The multilayer fan is formed by a system of superimposed confined and semi-confined aquifers. Above them, in direct contact with the surface, there is a phreatic aquifer about 10 meters thick, mainly made of sandy silt deposits.

These geological knowledges permitted to find the recharge areas of the overall Marecchia river alluvial fan, which area indicated in yellow in figure 1 (amalgamated fan). Thanks to this information it has been possible to locate the best place to implement a MAR project, in order to fight the natural groundwater recharge reduction due to climate change.

3.1 Site description and data

- Location of pilot area (Figure 1): Pilot area is located in the south portion of Emilia-Romagna Region coastal area, in the Rimini Province. Colours in figure 1 are described in paragraph “Geology/Aquifer type”.

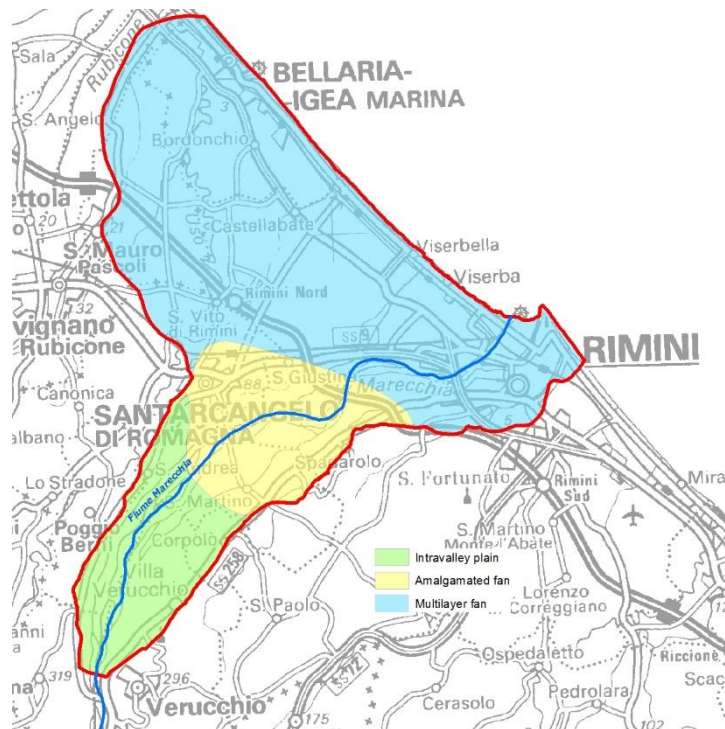


Figure 1 – Location of pilot area

- **Climate**
 - climate type is sub-continental/temperate type, with moderately cold winters (the average seasonal temperatures are about 5° C) and hot summers, with temperatures that stand at average values around 23° C. The average temperature in Rimini is about 13.6 °
 - precipitation and evapotranspiration: The average annual rainfall is about 750 mm. Rain falls throughout the year in Rimini. Most of the rain falls around October, with an average total accumulation of 75 millimeters. The least amount of rain falls around January and July, with an average total accumulation of about 42 millimeters.
 -
- **Topography (Figure 2)**: the territory is quite flat and low, with altitude between 0.5 m along the coastal strip and 100 m towards the hinterland, where the hills begin (Villa Verucchio area in the southern portion of Figure 2). There aren't areas below sea level.



Figure 2 – Topography of the pilot area

- Land use (Figure 3): most of the territory consists of areas for agricultural use and/or green areas and parks; the urban areas include the city of Rimini with its large tourist reception area and all the smaller touristic towns that develop along the whole coastline. Shrubby areas, wooded areas and orchards are shown in green. Along the course of the Marecchia River there are some active and inactive quarries, one of which is used as an infiltration pond in this MAR experience.

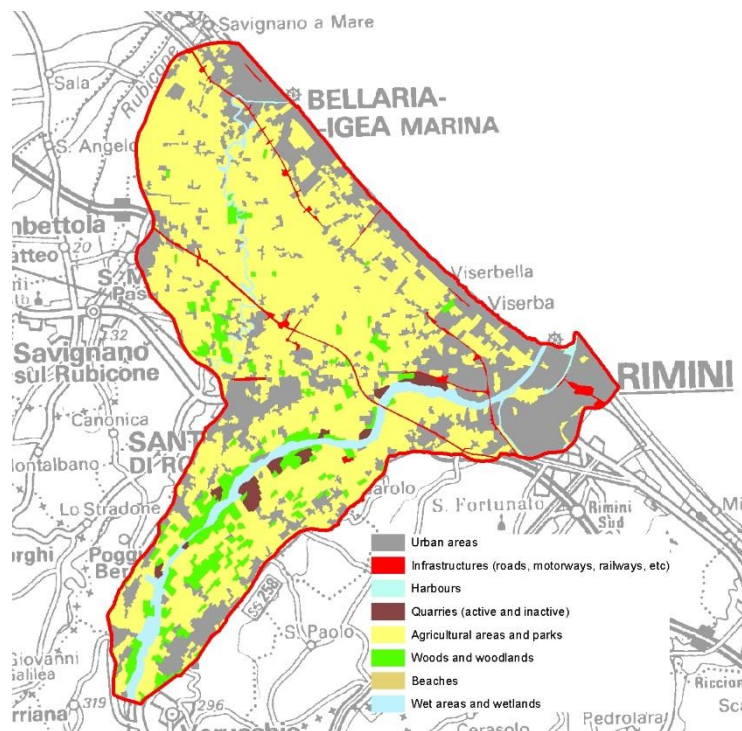


Figure 3 – Land use

- Soil types (Figure 4):** Soils in this area are mainly calcareous-moderately alkaline except the 3Cb type, which are not calcareous but neutral-moderately alkaline, the 4Ba type, not calcareous - from neutral to high alkaline, and the 5Bb type, moderately alkaline. 1D type are soils of the coastal plain and they have a coarse texture; 2C are soils in morphologically depressed areas of the alluvial plain and they have a fine texture; 3A and 3B type are soils in morphologically higher areas of the alluvial plain and they have a medium texture; also 3C are soils in morphologically higher areas of the alluvial plain and they have a medium texture, but they are not calcareous; 4B are soils of Appennine edge with a fine texture; 5B and 5C are both soils of the lower Appennine but very different from each other: 5Bb soils are rocky, with an average texture and locally they are saline in the deepest part; 5Cc are soils with a fine texture. The AVL polygon represents the ordinary flood plain.

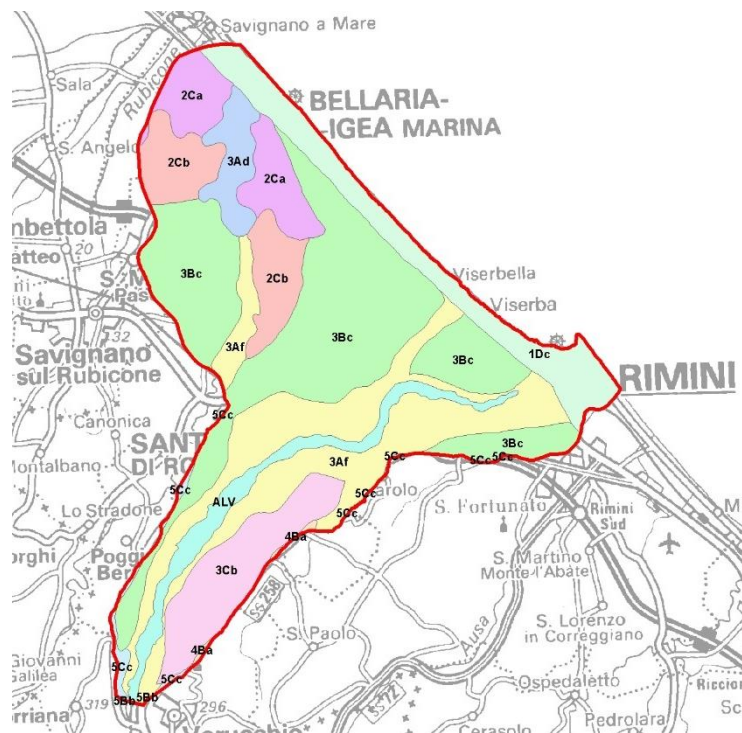


Figure 4 – Soil Types

- Geology/Aquifer type (Figure 5a, 5b and 5c):** alluvial deposits characterize all of this pilot area, except the coastal area where geology consists of coastal cord and wind dunes deposits (Figure 5a). In the subsoil, the Marecchia alluvial fan develops at the end of a mountain basin and it is divided, from a geo-hydrogeological point of view, into three different areas (Figure 5b): an intramountain plain, formed by a thickness of not more than 10 m of mostly gravel deposits directly flat on the marine substrate (green area in figure 5b) ; an amalgamated fan, also comprised of prevailing gravels, for a maximum thickness of up to 80 m above the sea clays (yellow area in figure 5b) ; and a multilayer fan, formed by alternating gravelly levels and mainly fine levels, for thicknesses up to 250 m and more (blue area in figure 5b) , above the coastal marine deposits of the Imola Sands (Severi et Al., 2014, Geological Survey of Italy - Emilia-Romagna Region, 2005; Emilia-Romagna & ENI-AGIP, 1998;). The intramountain plain corresponds to a phreatic aquifer, as well as the amalgamated fan, although there can be local confinement conditions inside it. The amalgamated portion corresponds to the area of maximum recharge of the entire fan, which is mainly due to effective infiltration of rainwater and dispersion from the Marecchia River. The multilayer fan is formed by a system of superimposed confined and semi-confined aquifers. Above them, in direct contact with the surface, there is a phreatic aquifer about 10 meters thick, mainly made of sandy silt deposits. A geological cross-section shows in a more detailed way the subsoil distributions of coarse and fine alluvial deposits, and different type of aquifers in the Marecchia river alluvial fan (figure 5c).



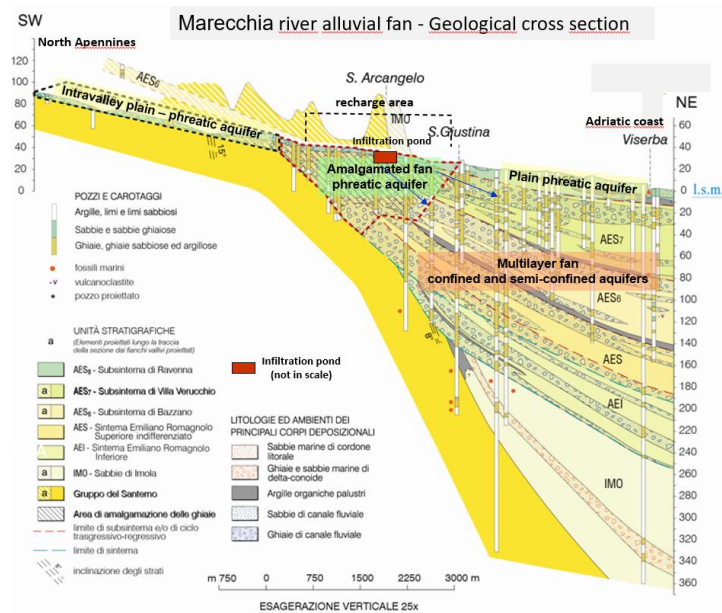


Figure 5c – Geological cross-section, with indication of the infiltration pond used for MAR project.

- Surface water bodies (Figure 6): besides the Marecchia river, the main surface water bodies of the area are the Torrente Uso which flows in the northern part and the Marecchia River which crosses the entire pilot area. The rest of the surface waters bodies are artificial channels and minor watercourses.

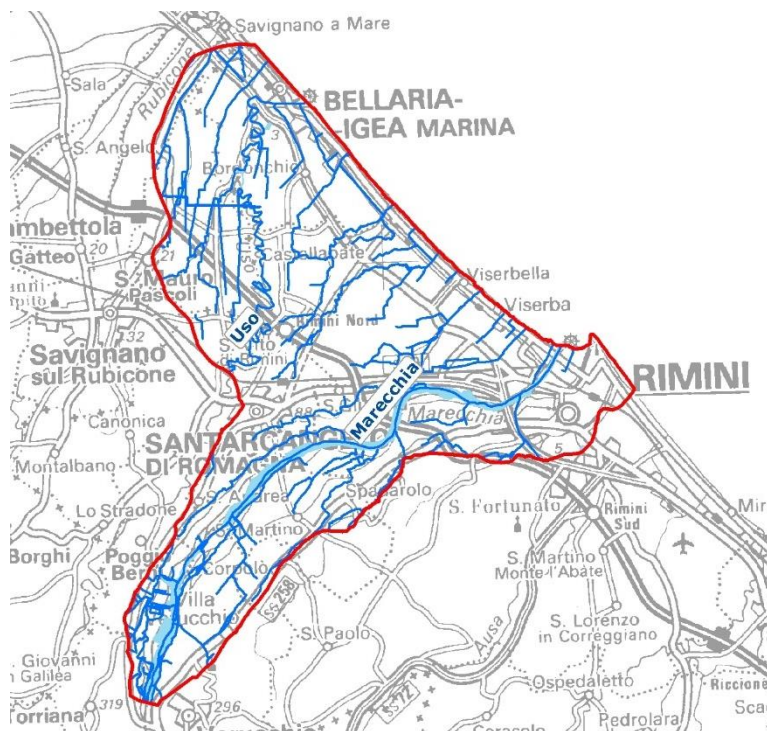


Figure 6 – Surface water bodies

- **Abstractions/irrigation:** Water resources of the alluvial fan of the Marecchia River have strategic importance for the drinking water supply of the entire Rimini area. In fact, about 28 million cubic meters of water a year are taken from aquifers of this alluvial fan, 19 of which are used for drinking water (Emilia-Romagna Region, 2005). Water for irrigation comes from some well and from the channel network, but it's not so considerable so the drinking water use of groundwater. Abstraction for domestic use and for industrial use are quite low.

3.2 Climate change challenge

In accordance with the EEA map the main expected issues due to climate change in this case study are those described in the Figure 7 for the Mediterranean regions, with strong rising in summer temperatures, rainfall reduction with a result of drought increasing and salinization of soils and groundwaters, and strong reduction of natural groundwater recharge and water availability. The main challenge is to find adaptation measures to obtain water availability for all uses, and to maintain a good status in the related water ecosystem or to promote their controlled and sustainable transformation; it's important to support a dynamic management of groundwater bodies through a in-depth knowledge of balance between subtraction of fresh water and recharge of the aquifer throughout the future climate change conditions.



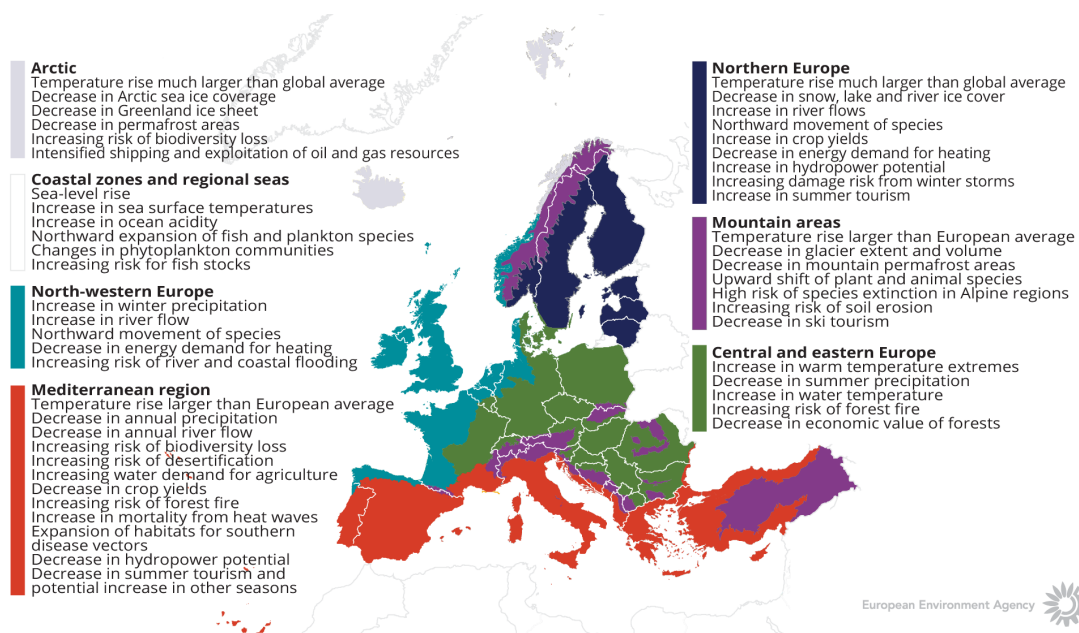


Figure 7 - Climate expected change in Europe. The European Environment Agency map

4 METHODOLOGY

4.1 Methodology and climate data

4.1.1 Tools/ model description

Due to the succession of particularly hot and dry summers, in relation to the climate changes in the Rimini area, a MAR project has been active since 2014. The MAR project consists of putting surface water from the Marecchia River into an infiltration basin in the recharge area of the alluvial fan (Figure 8, and 5c). This MAR project is a specific measure of the Management Plan done by Emilia-Romagna Region and the Po River Authority in compliance with the 2000/60 EU Directive.

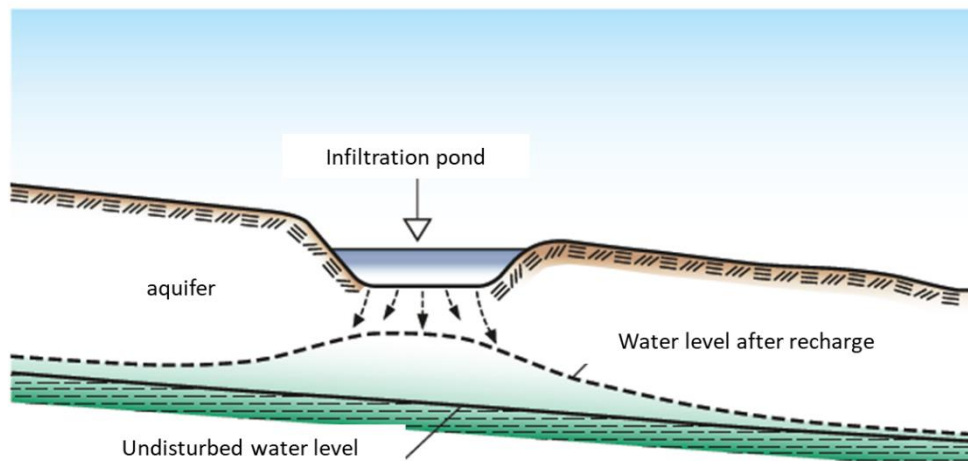


Figure 8 – MAR scheme applied on Marecchia alluvial fan

Within this pilot, we kept on with the piezometric level measures campaigns (four per year), with the groundwater quality monitoring (two per year) and with the quality monitoring (two per year) of the lake used as a pond for our MAR project.

A numerical groundwater model is not available. Nevertheless since 2014, in five years of MAR, 5.8 million cubic meters of water were introduced into the infiltration basin. It is in medium 1.15 million cubic meters per year, which represent the 4% of the overall groundwater abstraction in the Marecchia aquifer.

During the last year, the recharge had been stopped because of the damage of the weir used for the water transfer, caused by an extreme river overflow in the last winter season, but we know that during the last recharge period (October 2018 - April 2019), 2.3 million cubic meters of water were introduced into the recharging lake, which represent the maximum value respect all the precedent years.

At the end of 2020, a new weir has been built and now we are going to install a multiparametrical datalogger, useful for improve monitoring and for the early warning in case of the passing of alert levels of some parameters.



The great attention paid during these years to this natural area has helped the development of an important green ecosystem and a large wetland area which is already subject to observation and protection for biodiversity and for the particular ornithological species that have found here the suitable environment for nesting.

At the present time this area has therefore become a natural area that can also be available for the local population.

4.1.2 Future scenarios. Climate and land use data

In this case study no modeling was developed for a quantitative assessment of the changes in groundwater due to climate change. However, it is possible to already have an idea of how the climate will vary in the future in Emilia-Romagna and foresee a clear deterioration of the water resources in question.

Arpae-Emilia-Romagna Region has conducted several studies on the impact of the climate on the environment at a regional and local scale; in particular, the effects of rising temperatures on the water resource have been investigated (EU Interreg IVC Water CoRe Project). The results show that in the climatic projections predict an increase in the average annual temperature for the Italian peninsula, between 1.5 and 2 ° C, in the period 2021-2050. In the same period, for the Emilia-Romagna region there is a signal of 2 ° C increase for both the minimum and maximum temperatures. The change in the last part of the century, 2071-2100, will be much more marked, in which an even more marked increase in the average annual temperature will occur, around 3.5-4 ° C and for the summer season an increase in the maximum number of consecutive days without precipitation is expected. There will therefore be an increase in both mean and extreme values. This means that very hot (with positive anomalies of 3-4 degrees) and relatively prolonged periods, which today are extreme events, will be more frequent in the 2021-2050 period and will be the norm at the end of the century.

In the Emilia-Romagna Region in recent years there is evidence of the impacts of climate change on natural areas and cities, but ecosystems, such as forests and wetlands, biodiversity, the availability of drinking water resources and the agriculture are also affected by climate change. In this scenario, the MAR project implemented could be a reasonable methodology to contrast the loss of natural groundwater recharge due to climate change.

5 RESULTS AND CONCLUSIONS

Thanks to the availability of geological and hydrogeological data, it has been possible to reconstruct the subsurface geology of the Marecchia river alluvial aquifer and to recognize the recharge area of this aquifer. The presence of an old quarry located in the recharge area, and the presence of an artificial canal that brings superficial water from the Marecchia river to the quarry, permitted since 2014 to implement a MAR project. In five years of project activity 5.8 million cubic meters of water were introduced into the infiltration pond, distributed in time as in table 1. No MAR activities were realised in 2016-2017 (because of realization of the Environmental Impact Assessment) and in 2019-2020 (because of the damage of the weir used for the water transfer). The MAR project is active only during fall – spring seasons (October – April), because during the other seasons the water from the canal is used only for irrigation. The medium amount of water introduced in the infiltration pond is 1.15 million cubic meters, which represent the 4% of the overall groundwater abstraction in the Marecchia aquifer.

2014:	1.283.000 m³
2014 - 2015:	677.000 m³
2015 - 2016:	488.000 m³
2016 – 2017:	//
2017 - 2018:	1.105.000 m³
2018 - 2019:	2.250.000 m³
2019 – 2020:	//
Total	5.803.000 m³

Table 1: water amount introduced into infiltration pond with MAR project.

In order to evaluate the MAR efficiency, a specific groundwater monitoring network has been realised, that permitted to measure the rising of piezometric level after a period of recharge, (Figure 9).

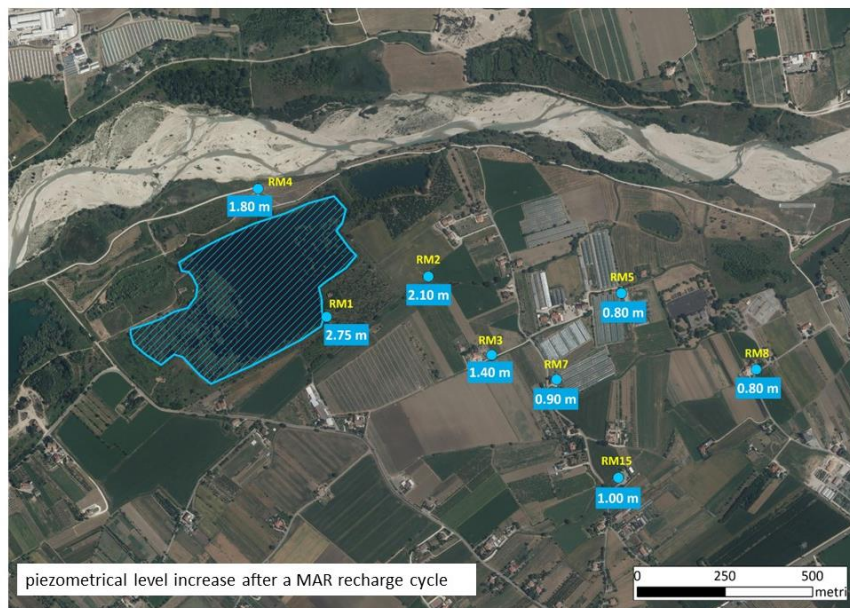


Figure 9 - Piezometrical level increase after a MAR recharge cycle (m)

At the same time it was noted that in the area surrounding the infiltration pond the water quality is better in terms of nitrate quantity than in more distant areas (Figure 10).

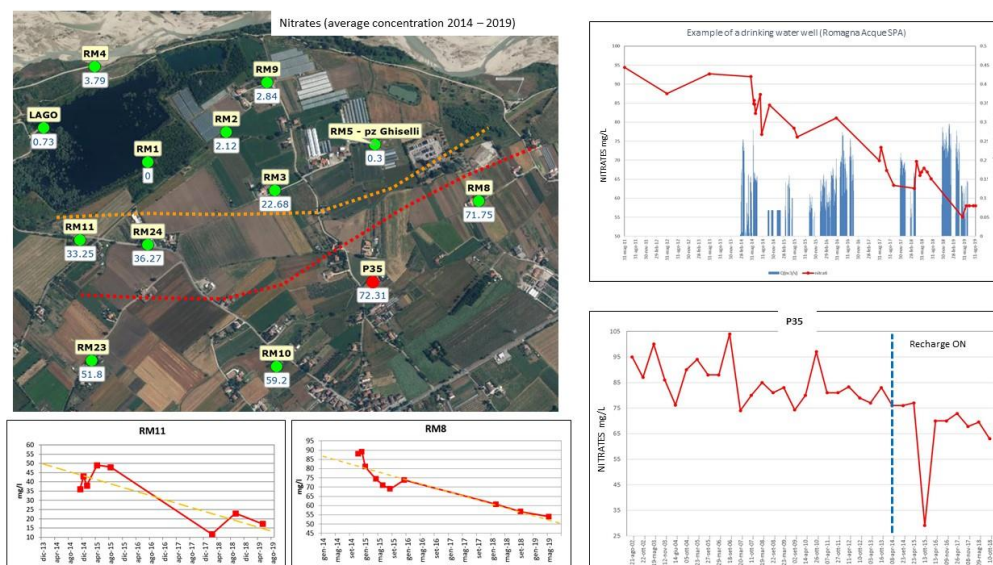


Figure 10 – Nitrates trend after a MAR recharge cycle: groundwater quality gets better.

Arpae-Emilia-Romagna Region has conducted several studies on the impact of the climate on the environment at a regional and local scale (EU Interreg IVC Water CoRe Project). The results show that in the climatic projections predict an increase in the average annual temperature for



the Italian peninsula, between 1.5 and 2 ° C, in the period 2021-2050. In the same period, for the Emilia-Romagna region there is a signal of 2 ° C increase for both the minimum and maximum temperatures. This temperature increase, associated with a different way of precipitations, will induce a reduction in natural groundwater recharge.

In this scenario, the MAR project implemented could be a reasonable methodology to contrast the loss of natural groundwater recharge due to climate change.

5.1 Performance to historical data

The lack until today of a numerical groundwater model does not allow to evaluate the quantitative and qualitative efficiency of the MAR project respect the precedent natural hydrogeological situation. However, the piezometric data indicate that with the MAR project the local recharge of the aquifer has certainly increased compared to the period prior to the start of this project (Figure 8). This means that this project could be an interesting way to contrast the water scarcity during the future predicted climate change in the Mediterranean region.

The actuation of our MAR project has been facilitated by the geological and hydrogeological previous knowledge, by the presence of a topographic depression due to an old quarry activity located exactly in the recharge area of the aquifer, and the presence of an artificial canal that can bring directly water from the Marecchia River to the topographic depression. So it was quite simple and inexpensive to implement the infiltration pond.

A MAR project like this described here (infiltration pond), is surely quite easily applicable in other places in Emilia-Romagna Region. Many other technical possibilities are proposed for MAR projects (Dillon, et al. 2018), and surely it could be possible to use those to contrast the reduction of water availability due to the climate change in Mediterranean Region.

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