



Deliverable 5.3

PILOT DESCRIPTION AND ASSESSMENT

Ravenna phreatic aquifer

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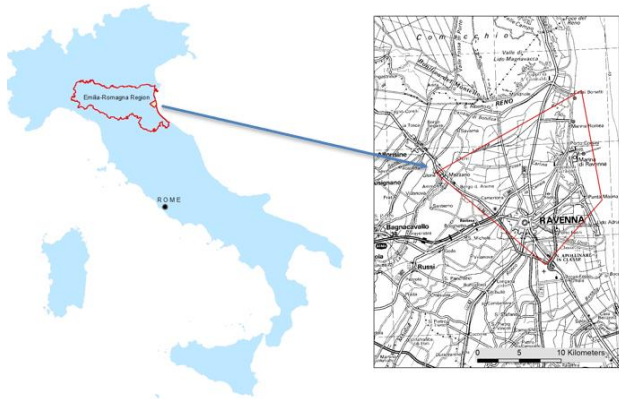
LIST OF ABBREVIATIONS & ACRONYMS

CC	Climate Change
GC	Global Change
LULC	Land Use and Land Cover
SWI	Sea Water Intrusion
GSO	Geological Survey Organisations
EC	Electric Conductivity

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1 EXECUTIVE SUMMARY

Pilot name	Ravenna phreatic aquifer	
Country	Italy	
EU-region	Mediterranean Region	
Area (km ²)	About 200	
Aquifer geology and type classification	Strand plain and delta front sands and silts; porous semi-confined to phreatic coastal aquifer	
Primary water usage	domestic use, coastal ecosystem maintenance	
Main climate change issues	Drought, Sea level rising	
Models and methods used	3d geological and geotechnical modelling of aquifers (Leapfrog) integrated with piezometric and salinity monitoring data	
Key stakeholders	Local municipality, tourism operators, enviromental heritage authorities	
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The study area of this pilot is located in northern Italy, in the Emilia-Romagna Region in the province of Ravenna and it is about 200 km² large. From a geological point of view, it is a porous phreatic aquifer composed by amalgamated medium to fine sand of beach/dune complexes and delta-front. The project for monitoring the salt-water intrusion into this sandy phreatic aquifer began in 2009 and is still active today. The intrusion of the saline wedge is a phenomenon that must be monitored because it can damage crops, as well as the delicate ecosystems that make the coastal territory a reserve of biodiversity.

The monitoring network consists of 10 piezometers which pick up the entire thickness of the aquifer and which are currently measured twice a year. At each control point the water level is measured and, starting from this, for each meter of depth, the specific electrical conductivity (EC) and temperature are measured. The comparison between the trend of these parameters in the different measurement campaigns allows to verify the possible progress of the salt - water intrusion into the shallow aquifer.



Within this pilot project a 3D model with the lithological distribution was created and then, in order to include the EC distribution into the 3D model of the aquifer, we selected from our dataset the four most complete measurement campaigns (October 2009, March 2010, September 2013 and October 2019) and we determined for each campaign an average piezometric level. This model, created using sw Leapfrog, represents the changes of the EC in the groundwater of the coastal phreatic aquifer in this area. Until now, no clear trend in salt-water intrusion in this aquifer has been observed in the last decade. These models could be used in future groundwater numerical model to evaluate water availability in future climatic change contest.

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 called Ravenna phreatic aquifer, located in the Adriatic coast of Emilia-Romagna Region, Italy.

It is a sandy coastal aquifer, which extends for about 200 km². The shape and the dimension are indicated in figure 1; along the Adriatic coast the length is about of 16 km, and the pilot area enters towards the alluvial plain of the Po river for 15 km.

The pilot consists in a porous phreatic aquifer composed by amalgamated medium to fine sand of beach/dune complexes and delta-front, deposited during the progradational phase of the Holocene transgressive-regressive sedimentary cycle. Aquifer thickness varies from 7 until 21 meters. Thanks to hundreds of geognostic tests (CPT, CPTU, corings, water-wells), it has been possible to produce a detailed geological and hydrostratigraphic reconstruction of the aquifer limits and characteristic (top and bottom surfaces; thickness). Five different geological units were recognised and mapped in a 3D model (using the sw Leapfrog), corresponding to the main depositional environments present in the area (marine shallow water/deltaic to alluvial systems). Sand of the delta-front and strand plain constitutes the Coastal Phreatic Aquifer.

The overall objective of this study is to use all the geological and hydrogeological data available to obtain a 3D geological model and a 3D EC distribution model of the aquifer during time.

These models could be used in future groundwater numerical model to evaluate water availability in future climatic change context.



3 PILOT AREA

Overall introduction to the site and its challenges

In the coastal area of the Emilia-Romagna region many different and precious environments, where ground, fresh water and sea water live together in a delicate balance, are influenced by the characteristics of natural depositional systems and morphological setting of this sector. The rapid urbanization of the coast has mobilized this balance and created numerous water-supply problems that involve coastal aquifers. The increased water demands by expanding population, the increased water requirements for commercial and agricultural purpose and the development of extensive drainage networks for disposal of excess water have added the magnitude and complexity of these problems.

Salt water intrusion and contamination into the phreatic shallow aquifer, could lead to very critical consequences as deterioration of water quality, salinisation of soils, desertification of the coastal plain, with damages for the agricultural and tourist sectors.

We consider that the knowledge framework founding on the reconstruction of geometry and lithological features of the aquifer body is the basic tool to understand flow pattern and processes and to support the actions for mitigation of the nowadays criticisms and planning the future management of water resources.

3.1 Site description and data

- Location of pilot area (Figure 1): Pilot area is located in the eastern margin of Po Plain, facing the Adriatic Sea. It belongs to the Emilia-Romagna Region and it is included into the Ravenna Municipality. The aquifer is located on the coastal territory characterized by a huge articulated deltaic plain.

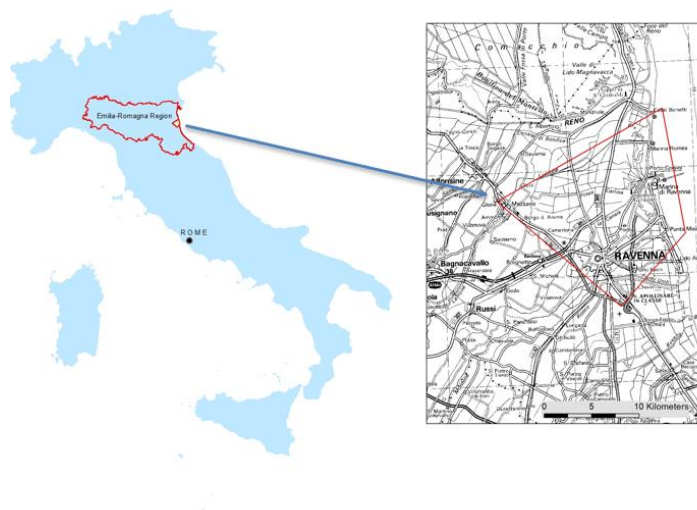


Figure 1 – Location of pilot area

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- A topographic map of the Ravenna area in Italy. The map shows the Reno river flowing through the landscape, with several towns and villages marked. A red line traces a path through the area, starting from the northwest, passing through the Reno river valley, and ending near the coast. The map includes labels for towns like Mantova, Ferrara, Ravenna, and Classe, as well as the Reno river and the Adriatic Sea.

- Land use (Figure 3): The southern sector of the pilot area is developed around the city of Ravenna and its harbour and it is characterized by urban area (grey colours, red); the central and northern sectors are mainly agricultural areas (mainly light yellow and orange) as in the eastern margin wet areas are widespread (light blue) with extensive pine forests (green colours) towards the sea. The coast is low and sandy, characterized by local touristic towns and a continuous dune/beach system.

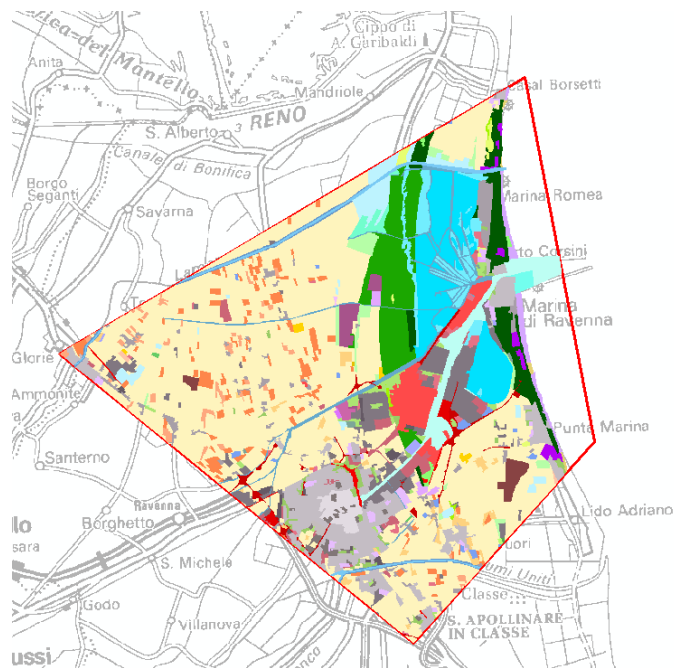


Figure 3 – Land use

- **Soil types (Figure 4):** Soils in this area are mainly calcareo-moderately alkaline; 1D type are soils of the coastal plain and they have a coarse texture; 2A type are soils in morphologically depressed areas of the alluvial plain and they have a fine texture; 3A type are soils in morphologically higher areas of the alluvial plain and they have a medium texture. Polygons indicated with CA correspond to a superficial body of water.

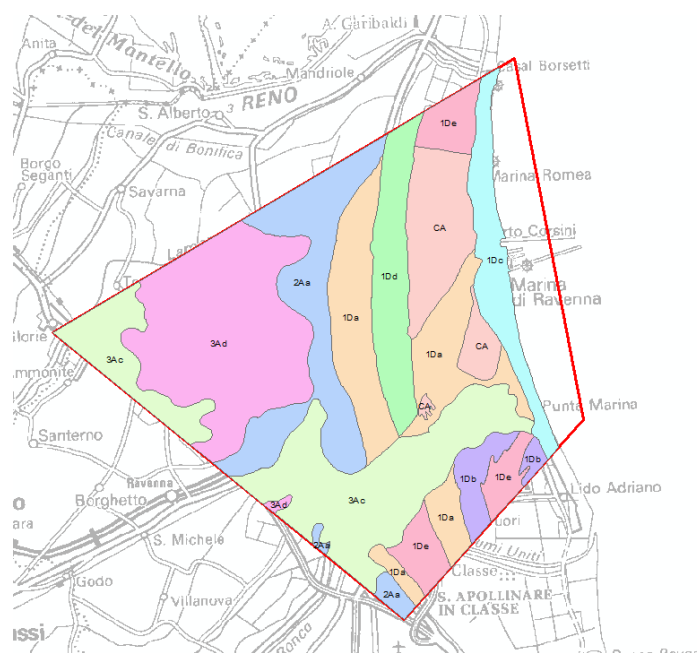


Figure 4 – Soil Types



- Geology/Aquifer type (Figure 5): in this pilot area, alluvial deposits characterize the western sector (yellow to rose) while coastal dune (blue) and lagoonal and swamp deposits outcrop in the eastern sector. Aquifer is porous, phreatic in the eastern sector where it reaches maximum thickness (about 15 m) as pinches out westward, where it becomes semi-confined; it's mainly composed by medium to fine sand of beach/dune complexes and delta-front, deposited during the progradational phase, since 6 ky BP, of the Holocenic transgressive-regressive sedimentary cycle.

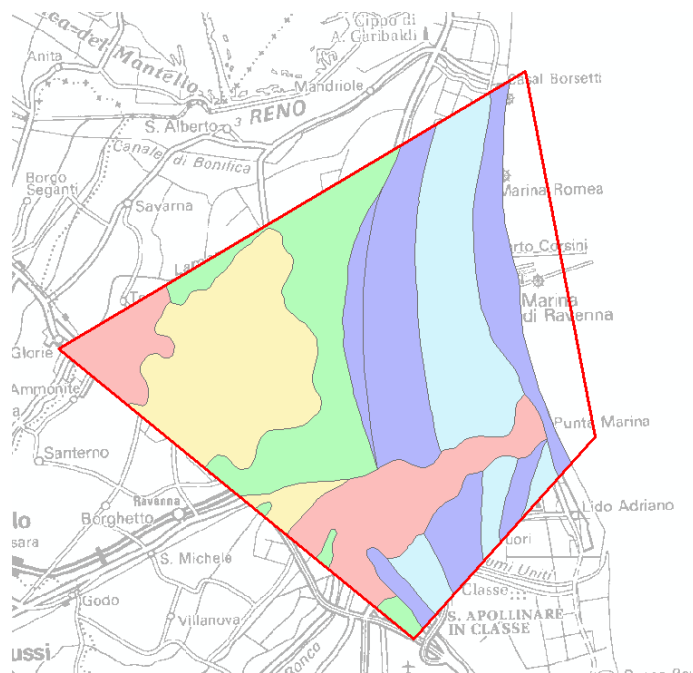


Figure 5 – Surface geology at 1:250.000 scale

- Surface water bodies (Figure 6): The territory is characterized by a dense network of artificial channels (green lines), used for irrigation purposes and for the drainage of surface waters. In the southern margin there is the major river of the area, the Fiumi Uniti River (blue). In the north-eastern area there are large wetlands (blue and light blue polygons), mainly brackish.

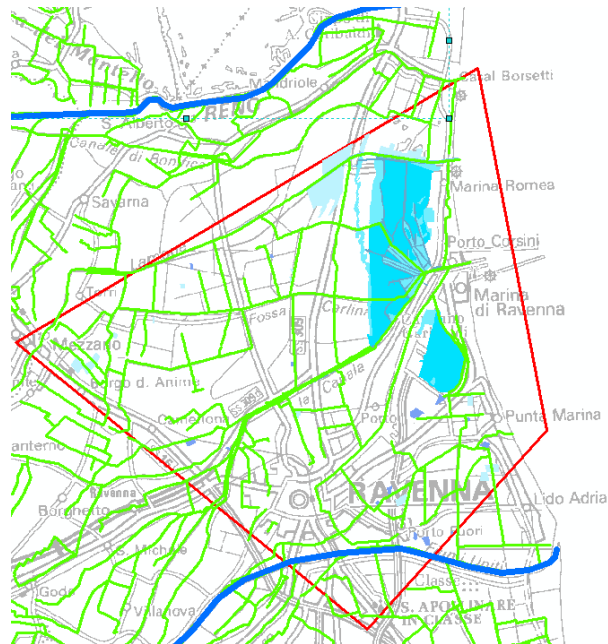


Figure 6 – Surface water bodies

Abstractions/irrigation: in this area only few withdrawals of water from the subsoil are allowed through deep wells because of a great subsidence occurred in the past few years; the large part of the wells existing in this area are very shallow (less than 10 m) and have only a domestic use. Water for irrigation comes only from the channel network presented in Figure 6.

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.

The main challenge is to find adaptation measures to maintain a good status in the related 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.

In this context, we consider that the geological reconstruction of the aquifer could be one of the basic tools to support the necessary actions to mitigate the changes in the availability of surface and groundwater induced by climate change.

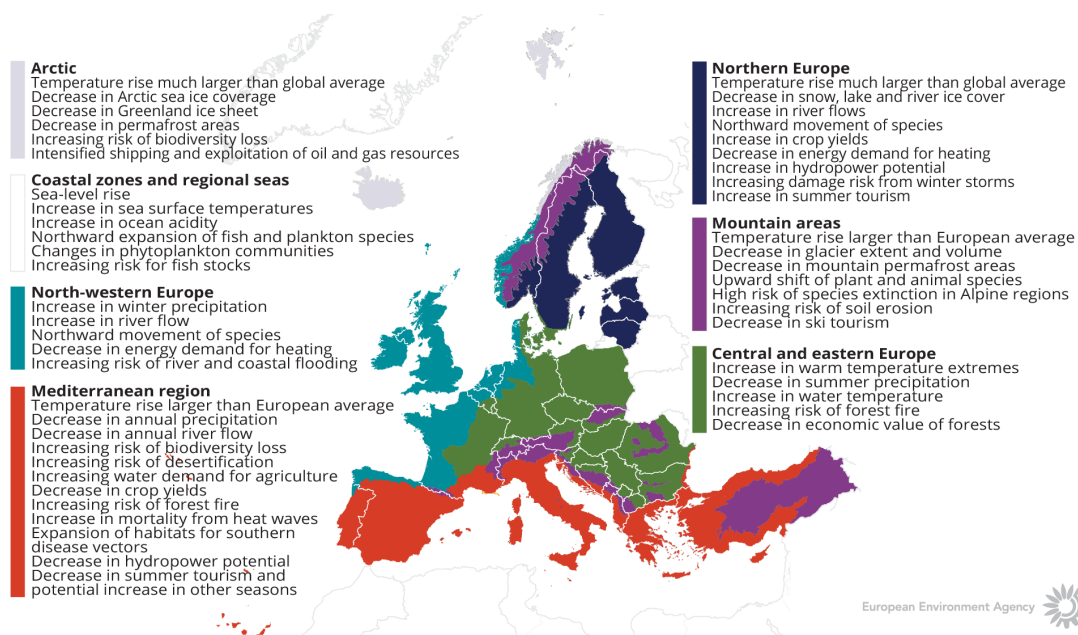


Figure 7 - Climate expected change in Europe. The European Environment Agency map

4 METHODOLOGY

4.1 Methodology and climate data

4.1.1 *Tools/ model description*

The approach to the impact and adaptation assessment started from the characterization of hydrogeological dynamics on the base of historical data.

Therefore, the activity focused on the reconstruction of the physical, lithological and hydrogeological features of the coastal phreatic aquifer and on the integration of the three-dimensional model created with the geological and hydrogeological monitoring data available. Five different geological units were recognised and mapped in 3D (with sw Leapfrog) in the pilot area, corresponding to the main depositional environments present (marine shallow water/deltaic to alluvial systems, figure 8a); the orange unit includes delta-front and strand plain sands and constitutes the Coastal Phreatic Aquifer.

The groundwater monitoring started in 2009 and is still in progress; it is carried out with a probe that measures water level, temperature and electrical conductivity every meter in piezometers with a depth between 7 and 21 meters. An example of how we collect the data is shown in figure 8b, where the trend of EC, temperature and piezometric level are illustrated with reference to one of the monitoring points.

The Holocene succession has been studied for the creation of the 3D model, with a particular attention to the upper sandy portion, where the coastal phreatic aquifer develops, consisting of prograding dunes, beach ridges and delta front deposits.

The data were integrated, and it was possible to identify the groundwater bodies for each survey and the three-dimensional variation of the parameters mentioned above. With reference to September 2013 survey, the EC 3D and 2D distribution are represented in figure 9 a, b and c. In the reported example EC varies from < 2.5 ms/cm to > 30 ms/cm; only a little portion of the aquifer is saturated in fresh water (blue area in left upper portion), while a large amount of the costal phreatic aquifer is saturated by salt water (green areas). We consider that this could be the natural distribution of the EC, due to the equilibrium from the recharge in fresh water from the rain, rivers and irrigation, and the salt intrusion from the Adriatic Sea and from the canals where marine water enters during storm and tide.

The aim is to provide a solid base-knowledge, when the data and models will be available to develop future scenarios. At the moment, in fact, no new tools have been produced nor those proposed within the project have been used due to the lack of fundamental necessary information, first of all the quantification of the contribution of the various factors in the flow balance. It is hoped that these data will be available in the future.

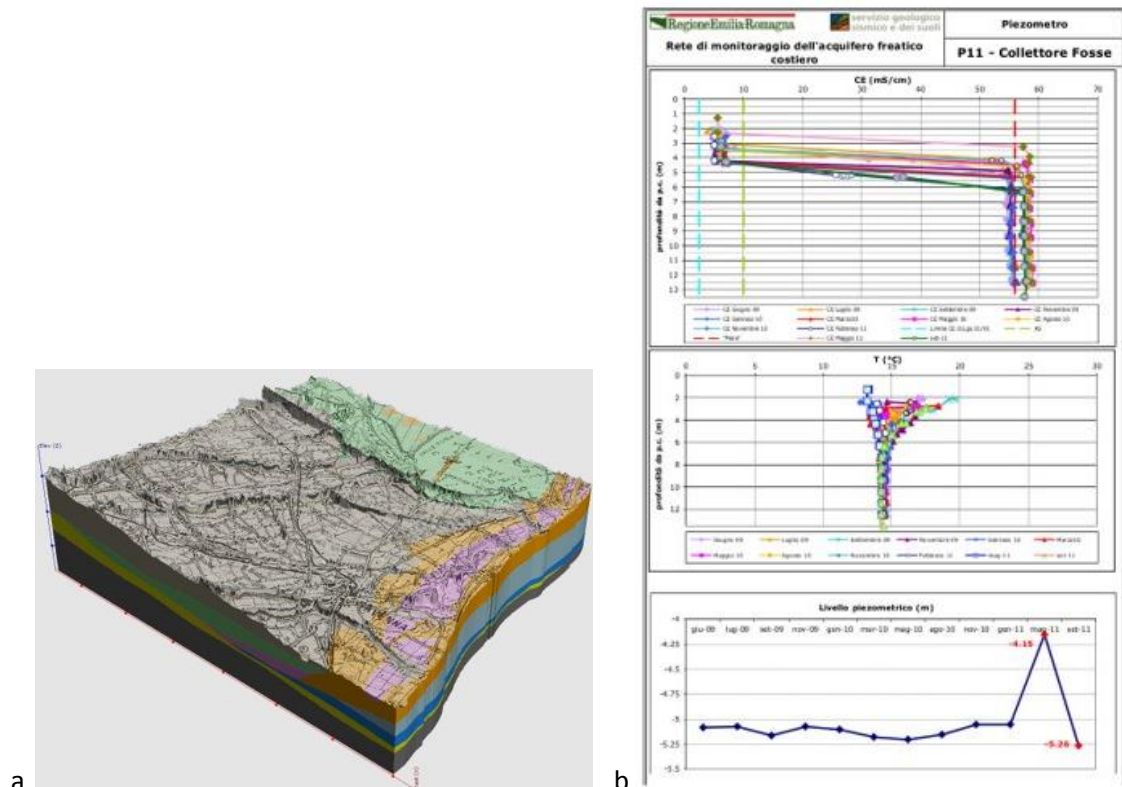
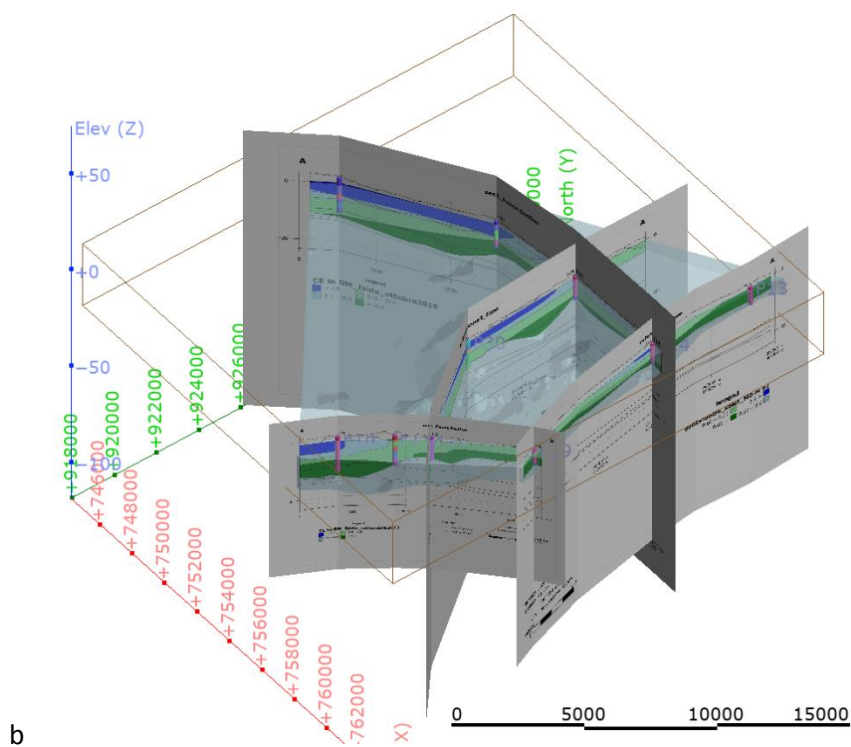
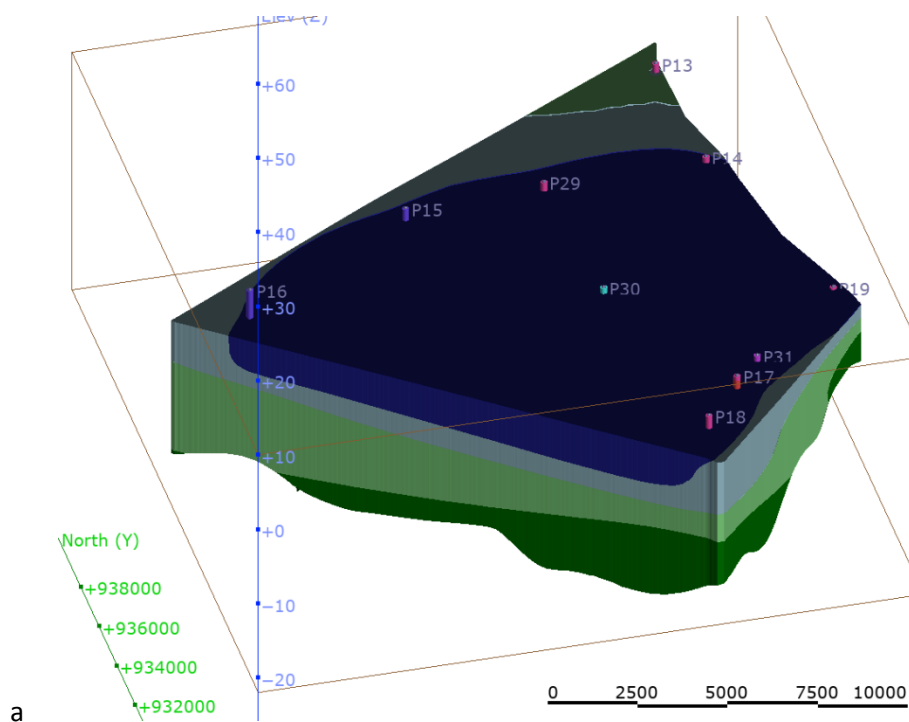
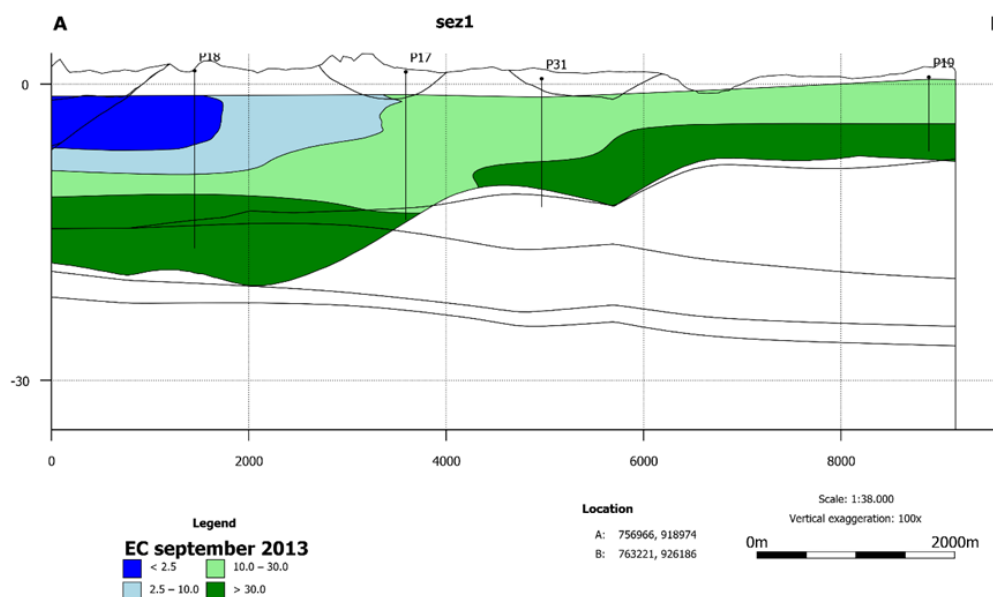


Figure 8: 3D geological model of the Ravenna pilot site, orange colour represents the phreatic aquifer (a). Example of electrical conductivity (EC mS/cm), temperature, and piezometric level available from monitoring surveys (b)





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Figure 9: integration of EC data with geological model: a) 3D variation of EC within the aquifer; b) representative cross-section network; c) cross-section with geological units (black line) and EC distribution within the aquifer (coloured from dark blue to dark green).

The aquifer volume in the Ravenna pilot affected by brackish (EC from 10 to 30 mS/cm) and saltwater (EC > 30 mS/cm) intrusion varies between 79% and 61%, considering the four monitoring surveys in the period 2009-2019 (Table 1).

	October 2009	March 2010	September 2013		October 2019
Volume of total groundwater within aquifer (mc)	2.543.800.000	2.755.700.000	2.607.700.000		2.664.500.000
Volume of groundwater with EC>10 mS/cm within aquifer (mc)	2.008.530.000	1.681.840.000	1.916.780.000		1.656.360.000
% of EC>10 water	79	61	74		62
Volume of water with EC>30 mS/cm	930.530.000	608.740.000	865.480.000		657.940.000



within aquifer (mc)					
% of EC>30 water	37	22	33		25

Table 1: Volume of total and brackish to salt water within the aquifer.

The results show that the condition of the aquifer in the last ten years is quite stable with a strong natural contamination of brackish and salt water by sea. Changes in EC lateral and vertical distribution are associated to variation in total rainfall in the different years and also to groundwater flow, that influenced the intrusion of salt water (EC > 30 mS / cm) in depth.

On the basis of these results, no particular trends potentially associated with ongoing climate change for the period analyzed are observed. A long-term future projection, also in the light of the recent scenarios of the meteo-climatic forcings, could highlight important changes in the SWI. The fact remains that, due to the trend towards an increase in temperatures and drought periods (see below), an escalation of the phenomenon must be expected.

4.1.2 Future scenarios. Climate and land use data

In this case study, for the reasons mentioned above, 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.

When the SWI modelling will be applied, the use of the local scenario weather-climatic data (Arpae) or ISIMIP (Inter Sectoral Impact Model Intercomparison Project, see www.isimip.org) datasets will be evaluated, considering also the expected rising of the Adriatic Sea.

What we have done until now is to realise a 3D geological model and a 3D distribution of EC over time, which could be used in future groundwater numerical model to evaluate water availability in future climatic change contest.



5 RESULTS AND CONCLUSIONS

The SWI assessment was based on the reconstruction of the aquifer architecture and on the lithological and hydrogeological characterization. This was possible thanks to the amount of data archived in the Geognostic Database of the Emilia-Romagna Region. The aquifer has also been monitored for 12 years through a network of piezometers by which groundwater level, EC and temperature, has been measured several times a year.

The type of data favors the definition of the basic structure of the aquifer, SWI state and its evolution. Until now, on the basis of monitoring data, no particular trends potentially associated with ongoing climate change for the period analyzed are observed.

The future scenarios, on a modeling basis, was not dealt with, which would be the proper integration to the work done so far. The application of a model was conditioned by the lack of quantification of the system's water balance. The current approach in the study was: knowing the past in order to predict the future. When the SWI modelling will be applied, the use of the local scenario weather-climatic data (Arpae) or ISIMIP (Inter Sectoral Impact Model Intercomparison Project, see www.isimip.org) datasets will be evaluated, considering also the expected rising of the Adriatic Sea. What we have done until now is to realise a 3D geological model and a 3D distribution of EC over time, which could be used in future groundwater numerical model to evaluate water availability in future climatic change contest. These 3D models have been published on GEOERA web site, according to GIP-P colleagues.

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