Hydrogeological impact of wellpoint dewatering upon unconfined coastal aquifer of the municipality of Cervia (Ravenna – Italy)

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Abstract The sample area is located in Cervia (Province of Ravenna Italy), nearby the coast. In the last few years the construction of basements, that involve the ground water table drainage (dewatering) by the use of the wellpoint techniques, has become more and more common. Particularly, all the new buildings comprise basement used as parking areas, cellars and storage areas for technological equipment. These constructions, nowadays, are made without any hydrogeological inspections and no limitations or survey are regulated by municipalities for assessing possible effects and risks. It has been possible, indeed, notice that the digging techniques based on groundwater pumping may produce a modification and an increment of the groundwater salinity, due to the water flow from the sea (salt water intrusion) and from the bottom of the fresh waters upconing. Obviously, the salinity increment may compromise the quality and quantity of the water resources and cause serious effects on the actual vegetation. For assessing the risk a hydrogeological survey on a sample area has been set up in order to verify the effects of the intervention both in water extraction stage and in abandonment stage. In particular, it is important to determine the recovery time for both the head and the water salinity. · Determine alternative solutions for reducing the environmental impact. · Define a technical prescriptive plan for the release of the intervention authorizations. Besides the geognostic and hydrogeological analysis, the survey plan also involves the use of a mathematical 3 D model based SEAWAT that uses the finite difference approximation for the variable density flow equation., in order to provide a useful predictive tool to verify the proposed interventions effects.

I. INTRODUCTION

The coastal area of the Emilia Romagna region, which extends for more than 100 Km from Goro (province of Ferrara) to Cattolica (province of Rimini), has been characterised, especially in the last few years, by a large increase in housing construction and development due to economic and social factors.

Figure. 1 Location

This has caused considerable infrastructural impact in areas which were already strongly affected by human activities, resulting in the decrease of permeable surfaces and, above all, the introduction of forms of construction which largely use dewatering techniques for excavation under the water table.

In the past the construction of underground spaces was practically non existent because of the operating difficulties caused by the presence of groundwater situated at a depth of 1-2 metres, but over the past few years there has been a large development of underground constructions based on the technique of dewatering the aquifer through the use of well-point systems. In coastal areas in particular, all the new buildings have underground spaces which are used as garages, utility rooms, storage of technological equipment etc.

For this kind of construction large amounts of ground water

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are being extracted in a hydrogeological situation which is already very delicate due to the presence of thin layers of fresh water (about 4-5 metres or 10 metres at the most) with underlying layers, which are in contact with the sea, containing salt.

From the tests carried out, it was observed that the construction of a building of average dimensions requires the extraction of around 25,000-30,000 cubic metres of ground water over a period of 3-4 months.

If one considers that every year a municipality, such as the one in question in our research, issues about 100 new planning permissions requiring the use of wellpoint systems, one can easily understand the consequent impact of the extraction of millions of cubic metres of subterranean waters on the hydrogeological balance of the area.

In order to quantitatively evaluate the effect of the dewatering process, the level and vertical profile of electrical conductivity of the water in the piezometres on a standard building site was monitored before, during and after the extraction of groundwater.

The final aim of this work is not only to describe the problem, but also to give technical support to public authorities in order to regulate the construction of underground spaces and the use of dewatering techniques. With the use of in-depth hydrogeological testing, indications will be given about the areas where this is possible and where it should be avoided. In addition, mitigating or alternative solutions with less environmental impact will be proposed

II. METHODOLOGY OF THE ANALYSIS

A. Description of the study area:

The studied area is situated in the municipality of Cervia (province of Ravenna) in the Emilia Romagna Region, along the Adriatic coastal zone.

This zone is characterised by the presence of an urbanised area (Milano Marittima) at a short distance from the pinewood of Cervia and 1,500 metres from the coastline.).

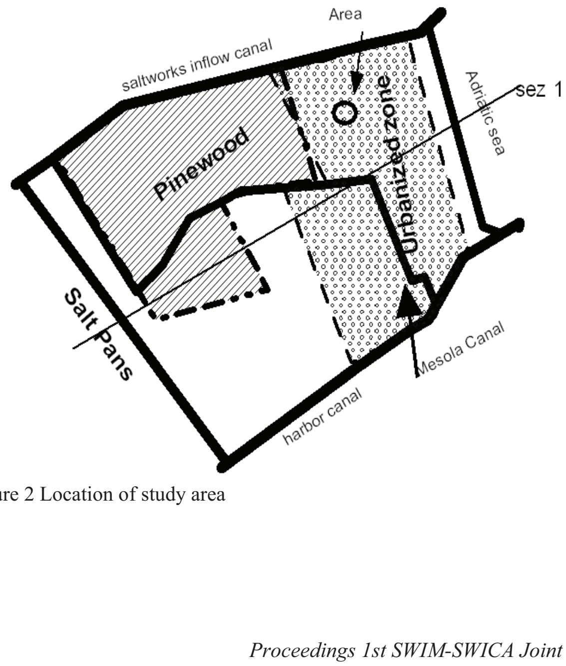

Figure 2 Location of study area

This situation can cause a modification and an increase in the salinity of groundwater, due to water being drawn from the sea and from the fresh ground water source (up-coning phenomenon). As can be clearly seen, an increase of salinity can compromise the qualitative, as well as the quantitative state of the water resources and have negative effects on the existing vegetation and coastal pinewoods, hence compromising future reforestation plans of.

Evident signs of deterioration in some areas of the pinewood of Cervia can already be observed because of the increase of salinity of the aquifer, a topic which has already been studied by the author. Moreover, the presence of groundwater exposes houses to the danger of flooding in the event of high water (marine incursions) or overflowing of rivers.

The terrain consists of a sandy stratum which settled during the Flandrian transgression (about 6,000 years ago) and which, in the area of study, is about 16 metres thick with underlying continental clayey silty sediments .

The section in figure 3 illustrates the structure of the subsoil: it is possible to observe that the sandy layer grows thinner westwards and ends at the Cervia saltworks.

In this zone the grain size of sand becomes coarse (gravel) and this testifies the ancient coastline of the Roman period.

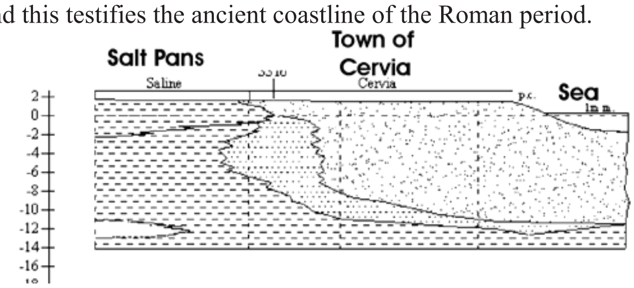

FIgure 3: Geological section of the study area

This sandy layer, which has thin silty levels, is the site of a phreatic aquifer confined at the base by silty clays, bordering eastwards on the Adriatic Sea, and delimited westwards, as already mentioned, by the saltworks of Cervia, based, on the other hand, on clayey grounds.

The whole area is intersected by canals with different functions: the harbour canal in the south, the saltworks inflow canal in the north and the canal Mesola for drainage in the central area. However, all the canals are connected to the sea and have therefore a high degree of salinity.

During the study some samples of sediments from the upper part of the aquifer, where the two piezometers were installed, were taken at a depth of 1, 2 and 3 metres from the walls of the excavation.

Figure.4 Section of the walls of the excavation

The sediments are mainly of a sandy nature with some thin peaty levels about 20-25 cm thick. The grain size analysis is illustrated in the following table:

TABLE 1: GRAIN SIZE ANALYSIS

		gravel %	sand %	silt %	clay %	AGI/S Classification
P1	sample 1 m		95	5		sand
	sample 2 m	3	91	6		silty sand
	sample 3 m		94	6		silty sand
P2	sample 1 m		96	4		sand
	sample 2 m		98	2		sand
	sample 3 m		96	4		sand

As can be observed the sediments are almost the same with a low level of silty components. The grain size can be described as belonging to fine sands.

The water table was studied in the past by the author and these studies have allowed to draw a general picture of the current situation.

Some studies concerned the pinewoods, other studies dealt with land planning for drawing up the town planning schemes.

In Figure 5 it is possible to observe the distribution of the electric conductivity in the study area, which represents a part of the coastal area of the municipality of Cervia.

Northwards there is the Cervia saltworks inflow canal which conveys sea water to supply the saltworks. Because of the level of this canal, sea water infiltrates towards the pinewood due to the presence of a water scooping system which drains water in the pinewood.

This situation creates a large area of salt water which saturates the below-ground ìecosystem.

Southwards there is the harbour canal which links the sea to the inland areas.

The study area is also intersected by the Mesola Canal which, in the event of intense rainfall, discharges surface runoff. In normal conditions it suffers the effects of high water and the salt wedge, which causes an increase in the salinity of the surrounding wells.

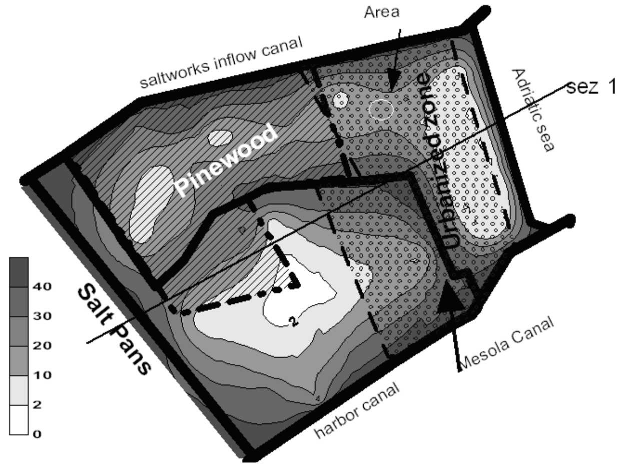

Figure 5: Distribution of the electric conductivity in the study area.

Figure 6 shows the fence representation of the conductivity distribution along the coastline and in the study area.

It can be observed that fresh water with values lower than 2mS is limited to a small area, while there is a prevalence of water with higher values of conductivity, brackish water and what is undoubtedly salt water both in the fresh ground water resource as well as in the saltworks area and the pinewood.

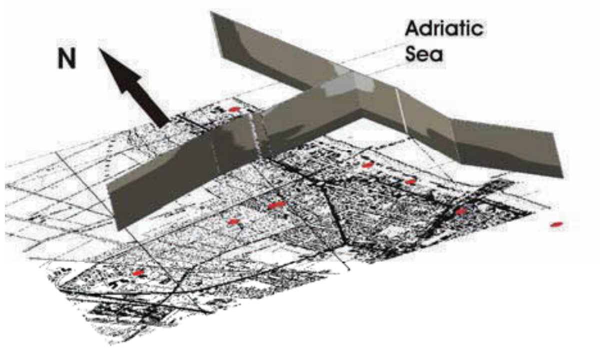

Figure 6: Fence representation of the conductivity along the coastline and in the study area

This situation creates a delicate balance between fresh and salt water and leads to the risk of an increase of salinity in the event of disturbances, such as :

-reduction of permeable surfaces due to intense urbanization, which limits the infiltration of rainwater

-pumping and extraction of phreatic water

external physical events such as subsidence or variations of the sea level.

In this case the consequences of the extractions carried out for excavations under the water table were studied as it is a problem which has been underestimated by public authorities. So far it has been little documented even though, considering its large dimension, it can cause a progressive increase of salinity of the whole aquifer.

B. Description of the experimental building site

The area of the intervention is situated in the district of Milano Marittima near the municipal pinewood of Cervia and at a distance of about 1,5 Km from the coastline (see fig.7).

Figure 7: Detail of the area of study

In this area a multi-storey car park with four floors and an underground floor will be built. The site has a surface area of 1,000 square metres.

The underground floor will be built with an excavation 3.5 m in depth and with the use of a wellpoint situated at a depth of 1.5 m below ground level for dewatering the water table.

The wellpoint system consists of 68 extraction points at intervals of 2.5 m at a depth which reaches 5 m. They are connected to their own pumps through two separate pipes, as shown in figure 8.The water coming out of the two final pipes is delivered to the municipal sewer system.

The piezometers were located on both sides as indicated in fig. 8 and consisted of two PVC pipes, with a diameter of 5 cm, inserted at a depth of 10 m with micro-slits along the whole column.

Piezometer number 2 was equipped with the Hydrolab multiparametric drill situated at a depth of 4.5 m for the constant monitoring of data regarding the level and electric conductivity of the water as well as its temperature.

C. Monitoring activity.

The monitoring consisted of:

- periodic (weekly) measurement of the vertical profile of salinity, the temperature in piezometer 1 and the water table level;
- Constant monitoring of piezometer 2 with the Hydrolab drill
- Measurement of the flow and salinity of the water coming out of from the wellpoint pipes
- Monitoring of two other piezometers, one situated in the municipal pinewood at a distance of 300 m from the excavation area and the other near the coastline at a distance of 1,500 m.
- Rainfall measurements during the monitoring period

The pumping started on 26th May 2006 and ended on 7th August 2006 (total 73 days).

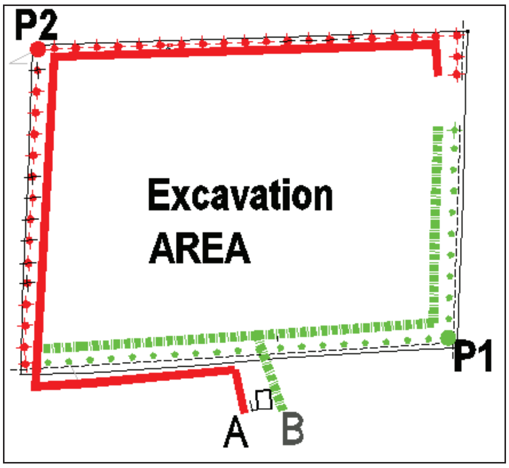

Figure 8: Arrangement of the wellpoints

III. Discussion of the Results

A. Monitoring results

Before activating the well-point system, the vertical profile of the electric conductivity and the temperature in the two piezometers was measured in order to determine the initial situation.

The graphs are shown in figure 9.

As can be observed, even though the two piezometers were situated at a short distance from each other (about 40 m), they showed some differences.

The piezometer located eastwards (2) showed a thicker layer of freshwater than the piezometer located westwards (1).

Approximately, in piezometer n. 1 the layer of fresh water was about 8 m thick and was followed by a transition-zone down to –10 m.

In piezometer n. 1 water with a lower degree of salinity is to be found only –3m below ground level. The transition zone was included between depths of 3 and 7 metres. Beyond this, the water was definitely salty. This fact can be attributed to the distribution of phreatic water in the area: westwards, towards Cervia pinewood. The presence of salt water is principally due to a network of surface drainage forced by water-scooping pumps, which draws salt water from the Cervia saltworks inflow canal.

Eastwards, in the direction of the coastline, there is a lens of fresh water supplied only by rain.

This different salinity was confirmed by taking measurements of conductivity from the pipes coming out of the wellpoints. In actual fact, the part which drains water on the east side shows more fresh water, while the part which drains the western section shows more salt water.

Figure 9 illustrates the results of conductivity measurements carried out on the drainage water discharge pipes..

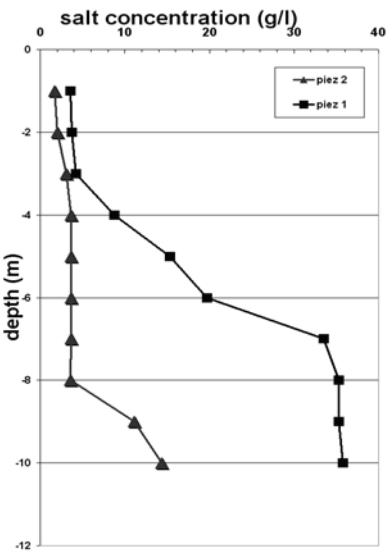

Figure 9: results of conductivity measurements

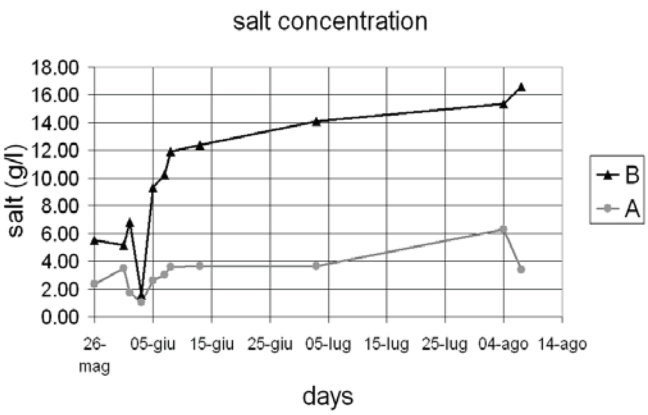

Figure 10 Temporal change of conductivity of the discharge waters of the wellpoint

As we can observe, the eastern part shows a lower degree of conductivity, starting from a value of about 2 mS, while the western part shows a higher degree of conductivity with values of about 6mS.

As the pumping continued, the conductivity increased progressively to reach values of more than 16mS for the western part and of 6mS for the east side.

The effect of the extraction drew water from the bottom as a consequence of the up-coning phenomenon causing an increase of salinity and water head in the uppermost part of the aquifer that contains water which is fresher on the east side and saltier on the west side towards the pinewood. The mixing of this water leads to the final value of the conductivity of the water coming out of the well-point.

The results of the periodic measurements of the flowrate of water coming out of the wellpoint system showed that the initial rate of 7.9 l/S fell to 3.8 l/S at the end of the operations.

The rate progressively decreased as the excavation continued.

About 35,000 cubic metres of water were extracted altogether.

During the phase of extraction and the rising of the water table Piezometer 2 was constantly monitored, with the Hydrolab drill situated at a depth of 4.5 m below ground level. Piezometer 1 was periodically monitored.

The graph of figure 11 shows the data of piezometer 1.

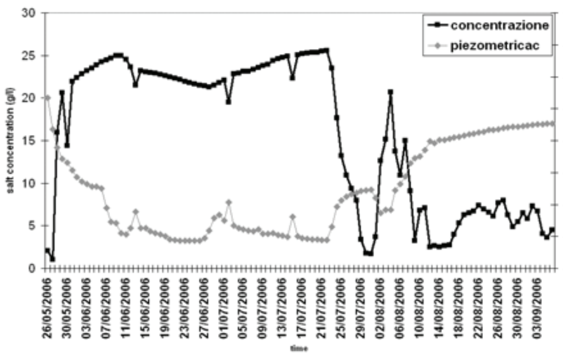

Figure 11:Temporal change of conductivity in the constantly monitored piezometer no. 2

As one can observe, the lowering of the water table led to the immediate increase of conductivity: the normal values of fresh water rose to very high values (more than 25mS) in just a few days.

During the whole excavation period the conductivity became stable remaining at the same values.

The decreasing values which were sometimes registered were caused by power cuts which led to the immediate recovery of the levels.

At the end of the extraction the immediate decrease of the conductivity and the progressive rise of the phreatic level could be observed.

The values observed afterwards indicated resumption of pumping for brief periods for technical reasons.

On the other hand, the piezometers were situated along the same line as the well-points and for space reasons it was not possible to use check points other than those situated in the pinewoods of Cervia .

The results of the periodic monitoring of piezometer 1 are shown in figure 12.

In this case the vertical profile of conductivity during and after extraction of the water was monitored.

It can be observed that the thin layer of fresh water was immediately removed and during extraction the water showed a degree of conductivity which constantly exceeded 45 mS.

At the end of extraction there was a progressive rise of salinity which was much slower than in piezometer 1.

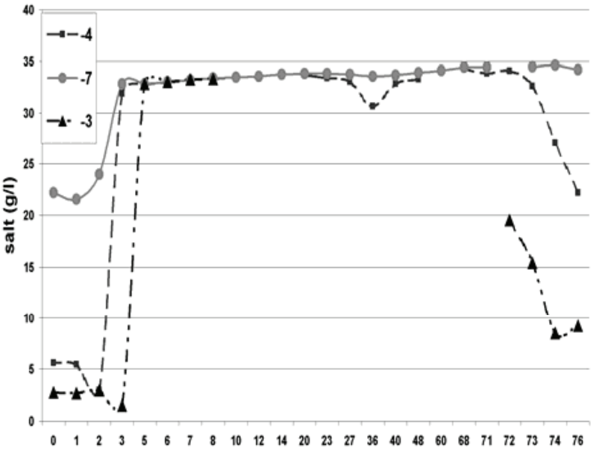

Figure 12: vertical profile of conductivity in piezometer 1

The piezometer situated at a greater distance (coastal area) did not show significant variations compared to the pumping phase, while the piezometer situated in the pinewood showed a higher degree of conductivity in the upper part compared to existing data. This may suggest that the extraction also influenced the area near the pinewood.

The monitoring which is still ongoing will possibly confirm this.

B. Simulation of mitigating hypotheses

In a hydrogeological situation such as the one on the coast of the Emilia Romagna Region, the dewatering techniques cause local effects that persist for a short period, and which could produce short or long term changes due to the increase of housing projects in nearby areas. The present study tried to analyse possible solutions to mitigate these effects.

However, this problem has already been addressed in other areas, for example, Versilia in the Province of Lucca, where the re-injection of the water extracted from the subsoil has been proposed in order to avoid the impoverishment of the water resource and to limit seawater intrusion.

The hydrogeological situation in this part of the region of Emilia Romagna does not allow the application of such a solution because of the lack of space and due to a greater complexity and fragility than the one mentioned. In actual fact, the water coming out of the wellpoints reaches high values of salinity so rapidly that it allows nothing but the re-injection of salt water.

Some mitigating hypotheses have been suggested: for example, the use of barriers or partitions, or an external solution could be to prohibit any excavation work below the water table, at least in the more vulnerable areas.

In order to evaluate the possible benefits of using hydraulic barriers some preliminary simulations, still in progress, have been carried out. This concerns a theoretical case, similar to the one observed, which has yet to be assessed, as a forerunner of a specific model to be applied to the study area.

The simulations have been carried out using Visual Modflow Pro software with the specific application package SEAWAT 2000 which allows to create a model with a variable density flow similar to the flow which occurs during seawater intrusion or upconing phenomena. SEAWAT combines the MODFLOW code of flow modelling with the code for solute transport modelling.

In this way the programme can solve the associated flow and transport equations.

The flow equations are formulated using the conservation of mass instead of the volume conservation as occurs in Modflow 2000.

The simulations carried out concern the situation without the suggested adoption of mitigating measures and solutions such as the use of barriers at different depths.

As regards the simulation without the adoption of any preventive measures, the hydrogeological situation is shown in figure 14: it is possible to observe the dual emptying cone due to the wellpoint line and to the up-coning phenomenon. The simulation figure refers to samples taken over a period of 30 days. The quantity of water extracted is about 19,000 mc which is consistent with the observation made during the first month of extraction. Figure 15 shows the hydrogeological situation in the event of barriers being inserted into the ground down to a depth of about 6 meters.

It is possible to observe that there is a reduction of the area involved in the up-coning phenomenon, which is, however, more accentuated locally in the area of intervention. With the same drawdown, the volume of extracted water is equal to 10,000 cubic metres: so the quantity was halved with a consequent reduction of the impact on the hydrogeological balance of the area.If the barriers are inserted at a depth of 10 meters, as shown in figure 16, the extraction of water is further limited: in 30 days it is equal to 8,000 cubic metres.

As regards the phenomenon of the up-coning of water with a higher degree of salinity, we can observe that outside the area delimited by the barriers, the curves with the same degree of salinity are undisturbed, compared to the initial situation.

In this way, therefore, the problem is limited within a defined area.

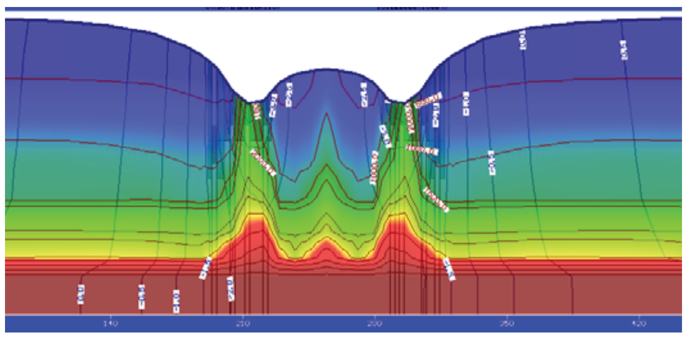

Figure. 14 simulations of the situation without the suggested adoption of mitigating measures

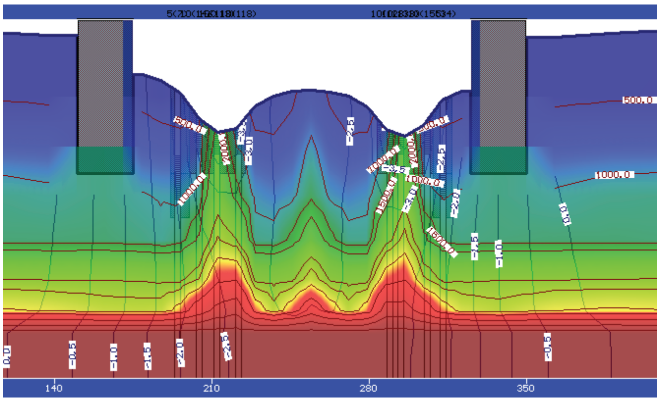

figure. 15 simulations of the situation with barriers inserted into the ground down to a depth of about 6 meters.

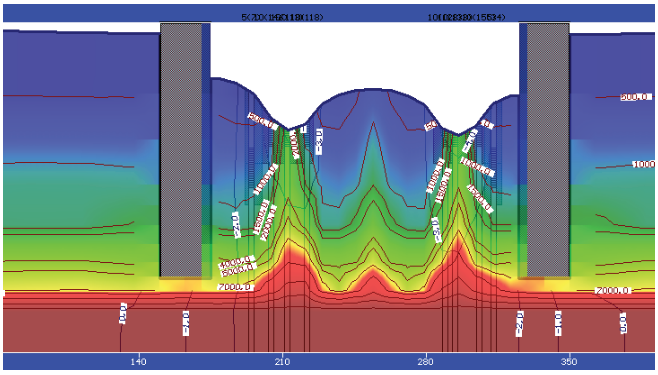

Figure. 16 simulations of the situation with barriers being inserted into the ground down to a depth of about 10 meters

IV. Conclusions

The study carried out in an area on the coast of the municipality of Cervia (Emilia Romagna Region) indicates that the process of groundwater dewatering using well points causes major local effects concerning the increase of the salinity of the aquifer, chiefly due to up-coning.

These effects are gradually reversed, but the large amount of housing construction in nearby urban areas can potentially cause overlapping of these effects and lead to salinization of the aquifer in the short or long term.

On the other hand, the quantities of water extracted every year during housing construction in the coastal area are unsustainable or incompatible with the water resources conservation.

Moreover, in parallel with these extractions there is also the progressive increased impermeability of the soil with the reduction of the surface due to infiltration of rain water which multiplies the negative effects.

The suggested solutions, which will be the object of further studies and tests, also to be carried out using models, concern the prohibition of this kind of action in vulnerable areas (thin layers of fresh waters) and the adoption of mitigating measures such as barriers or partitions, while the re-injection of water does not appear to be a feasible solution.

The first simulations carried out indicate that the adoption of these systems might reduce the quantity of water to be extracted and might lead to an improved conservation of the fresh water layer.

At the same time, water resource management actions should be adopted in order to favour infiltration into the subsoil, thus reducing the amount of impermeable surfaces so as to recover rainwater, in order to improve the water balance of the phreatic surface.

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