Managed aquifer recharge in the Marecchia alluvial fan (Rimini, Italy): trial and early results

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Among the actions designed to manage the water crisis that have taken place in the summers of recent years in the Emilia-Romagna Region (Italy) is a launched trial of managed aquifer recharge in the alluvial fan of the Marecchia River (Rimini). This test consists of conveying water through an existing channel into a quarry lake located in the recharge area of the alluvial fan. The increase in the volume of water in the lake should result in a rapid increase in the availability of water in the aquifers. Managed recharge of the aquifers can fit in the redevelopment of quarry lakes in plain areas aimed at improving the quality and quantity of groundwater bodies.

Parmi les actions projetées pour faire face à la crise (problème du déficit d'eau) qui s'est développée, ces derniers étés, en région d'Emilie-Romagne, il a été lancé un test de recharge de l'aquifère à hauteur du cône alluvial du fleuve Marecchia (Rimini). Ce test consiste à acheminer l'eau, par l'intermédiaire d'un canal, jusque dans un lac artificiel (de carrière) situé dans l'aire de recharge du cône alluvial. L'augmentation du volume d'eau au niveau du lac devrait s'accompagner d'une augmentation rapide de l'eau disponible dans les aquifères. Une gestion contrôlée de la recharge des aquifères peut concorder avec le redéveloppement des lacs de carrière en zones de plaine, destiné à améliorer la qualité et la quantité des réservoirs souterrains.

Una de las acciones diseñadas para gestionar las crisis del agua que occurieron en los veranos de los últimos años en la región de Emilia-Romagna (Italia) es un ensayo de recarga de los acuíferos en el cono de deyección del río Marecchia (Rimini). Esta prueba consiste en el transporte de agua a través de un canal existente a un lago, originado por una cantera, ubicado en el área de recarga del cono de deyección. El aumento en el volumen de agua en el lago debe dar lugar a un incremento rápido en la disponibilidad de agua en los acuíferos. La gestión de la recarga de acuíferos puede reconvertir el uso de los lagos de cantera ubicados en llanuras destinadas a mejorar la calidad y cantidad de las masas de agua subterránea.

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). A series of some very dry summers since 2007 has led the Emilia-Romagna Region to establish a technical committee for the management of water crises, which are particularly significant for Romagna region. The committee is coordinated by the Civil Protection and constituted by relevant technical bodies. One of the practicable actions to prevent and mitigate future water crises is managed ground-

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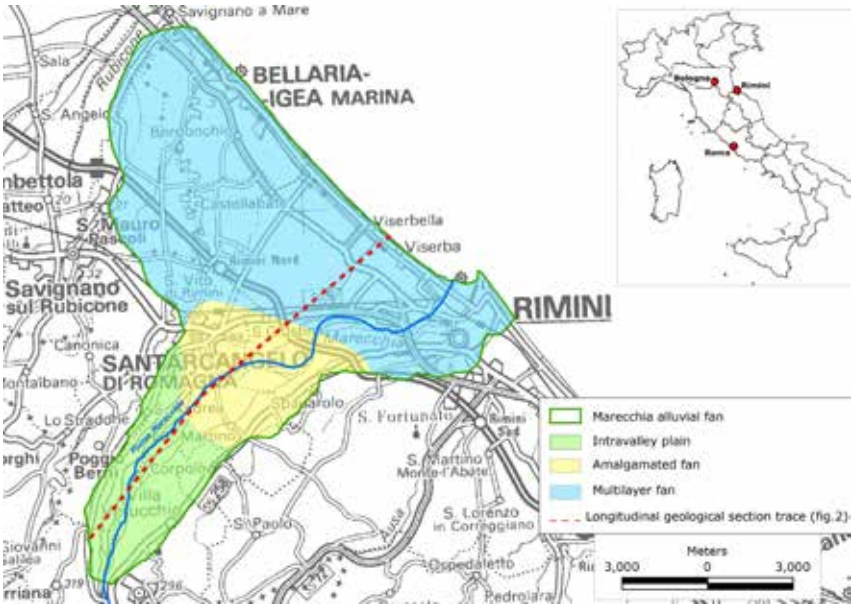

Figure 1: Marecchia River Alluvial fan and its different areas (intravalley plain, amalgamated fan, multilayer fan).

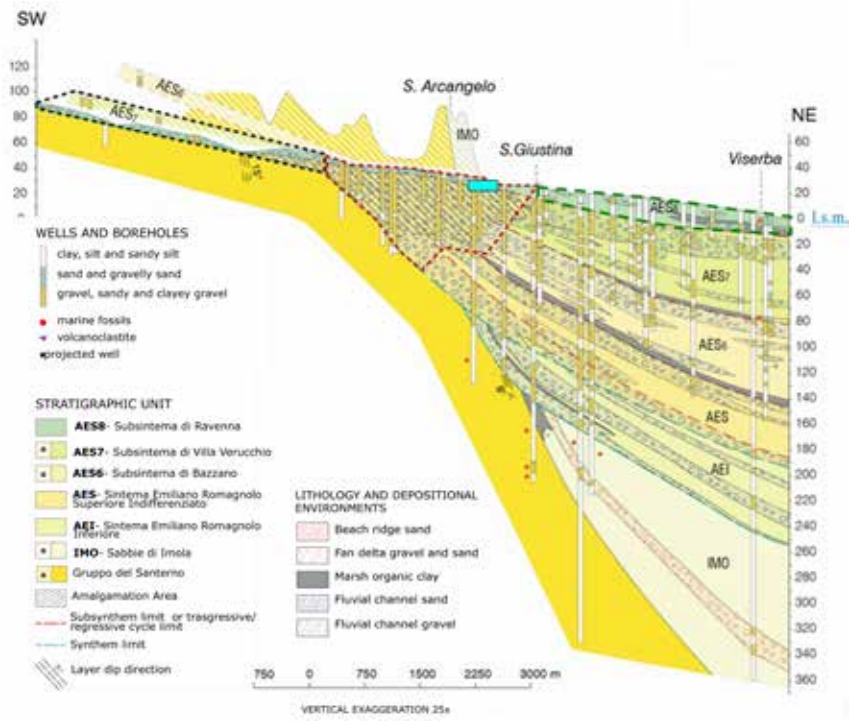

Figure 2: Longitudinal geological section of Marecchia River fan with aquifers scheme and site of the Incal System recharge lake (blue rectangle). Indication of the different areas: intramountain plain (black dashed area), amalgamated fan (red dashed area), multilayer fan (downstream) and phreatic plain aquifer (green dashed area) (from Servizio Geologico d'Italia – Regione Emilia-Romagna 2005, modified).

water recharge, which would increase the availability of groundwater. After several meetings between the various stakeholders, in January 2014 a managed recharge experiment began on the alluvial fan of the Marecchia River.

Aquifers of the alluvial fan of the Marecchia River

The Marecchia River is 70 km long and has a catchment basin of about 600 km^2; its average annual flow at the entrance of the alluvial fan is estimated at about 6 m^3 per second (Basin Authority of Marecchia - Conca, 2004).

The Marecchia alluvial fan (***Fig. 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 semiconfined aquifers. Above them, in direct contact with the surface, there is a phreatic aquifer about 10 meters thick, mainly made of sandy silt deposits (***Fig. 2***).

The piezometric level of the Marecchia alluvial fan is constantly monitored thanks to a network of more than 70 measuring points, managed by the province of Rimini and existing since 2001. ***Figure 3*** shows the average piezometric surface of the aquifer called A1, for a period between 2001 and the spring of 2012 (Severi *et al.*, 2014). The groundwater level is between a maximum of 91 m m.s.l. and a minimum of 1 m m.s.l.. The piezometric gradient, rather high in the intramountain plain area, decreases proceeding towards the distal portion of the fan. In the area of Santarcangelo we clearly see the recharge of the river and its hydraulic connection with the phreatic aquifer of the amalgamated fan, which ends near the A14 highway, where the fan becomes multilayered and A1 aquifer is confined.

The flow direction the intramountain area is basically constant towards the north-northeast direction, except for the draining of the river, not visible in the figure for reasons of scale. Even in the amalgamated fan the flow direction is towards the north-northeast, while in the multi-layered alluvial fan, the situation is more complex: in the northern portion the flow is towards east- northeast and this is most likely due to the recharge coming from the Rubicone and Uso Rivers; in the area between the A14 Highway and the coast the flow direction

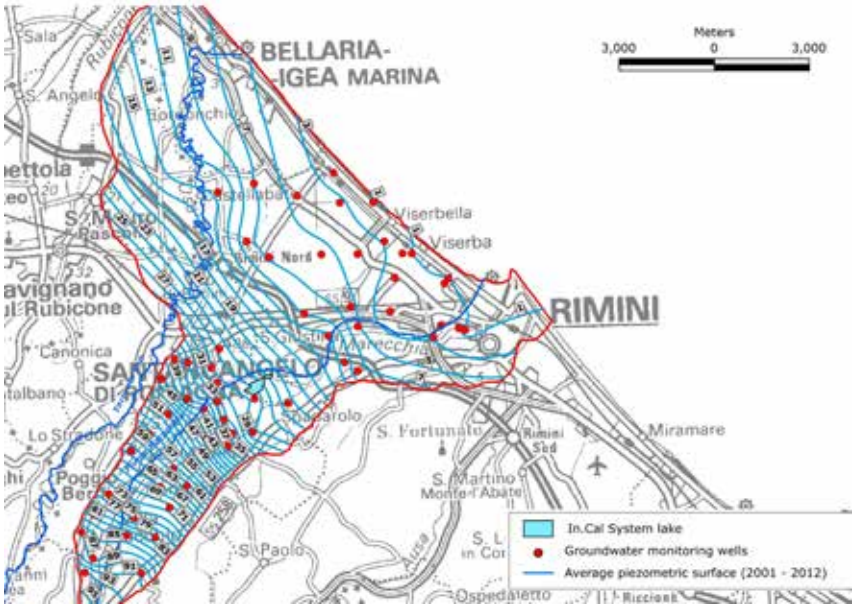

Figure 3: Average piezometric surface of the Marecchia fan (2001-2012).

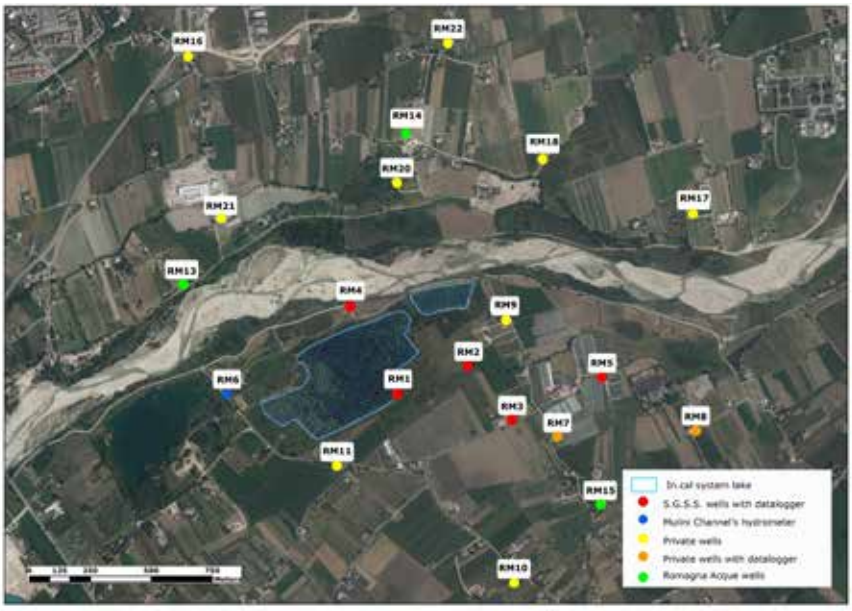

Figure 4: Monitoring network to verify the managed aquifer recharge efficacy.

is northeast with some variations, probably due to water withdrawals.

Managed recharge of the fan

In the portion of the amalgamated fan, on the right bank of the Marecchia, there are three lakes, remaining from previous quarrying activities, whose water level corresponds to the phreatic water table. These lakes are located in the maximum recharge area and so they are hydraulically connected with the entire alluvial fan. The possibility of using these lakes for managed recharge of the alluvial fan was proposed several years ago (Rimini District, 1992; Giulietti, 1993; Emilia-Romagna Region, Municipality of Rimini, Municipality of Santarcangelo, 2004), and more recently it was the subject of a further specific study designed to assess the efficacy of an intervention of managed recharge through a flow mathematical model (ARPA Emilia-Romagna, 2008).

The ongoing trial, taking into account previous studies, provides a certain amount of water to be added to the quarry lake called Incal System, which has an area of 15 hectares and is owned by the municipality of Rimini (***Fig. 3***), through the consortium Mulini Channel (whose use is leased to the Land Reclamation Consortium of Romagna). The channel takes water directly from the river, runs parallel to it for about 9 km, and finally reaches the lake, located in the recharge area of the fan, where the aquifer is amalgamated and outcropping. Under these conditions, an increase in the volume of water in the lake should be translated quickly into an increase in the groundwater level of the aquifer, meaning higher availability of water in the subsoil.

To verify the efficacy of the recharge operation, implemented a special monitoring network (***Fig. 4***) was implemented, made up of 20 measuring points, including 5 wells drilled specifically. In 9 of these points a data logger was installed for continuous monitoring of the level, temperature and specific electric conductivity at 20 °C. A data logger only for the level was also positioned in the channel through which the water flows to the lake.

Water began to enter the lake from the channel on 25 February 2014, after about a month of measuring the water table level without recharge to better assess the expected increase following the increase in the volume of water in the lake.

First results

The monitoring data collected in the period from January to April 2014 are illustrated and commented on below.

Figure 5 shows the water level measured in the intake channel and allows us to view the points at which water was flowing to recharge the lake and those at which, for various reasons, the recharge was interrupted. As we see, in fact, from 25 February to 30 April 2014 the inflow of water to the lake was not continuous; for example, the recharge was stopped from 5 to 11 March due to bad weather and from 28 March to 15 April because an excessive rise in the lake level had led to the risk of flooding the adjacent bicycle path and to compromising the ecosystems depending on the lake. Within the surroundings of the lake there are some protected bird species of Community interest, which require a precise environmental balance for nesting and survival.

Thanks to the collaboration with ARPA Emilia-Romagna some flow measurements of the Mulini Channel have been carried out and it was thus possible to draw up a flow scale for calculation of the total volume of water entering the lake, which was approximately 600,000 m^3.

Figure 6 shows the trend of groundwater level continuous monitoring in the wells closest to the lake. As can be seen from the graphs, in these points there is a direct and very clear relationship between the start of recharge and the increase in the groundwater level and between subsequent closing

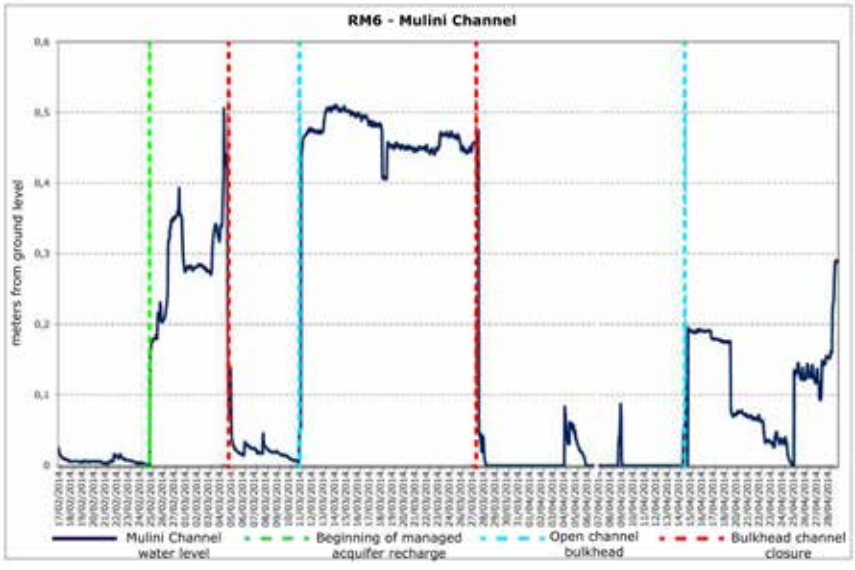

Figure 5: Water level of the channel bringing water to the lake.

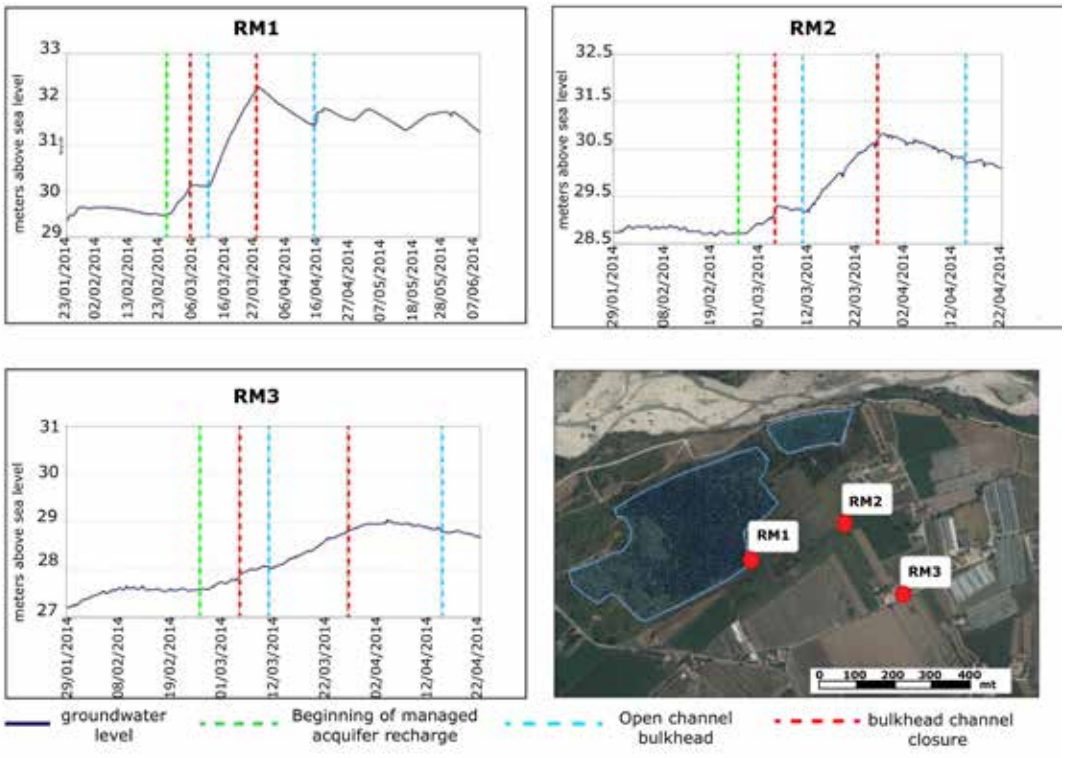

Figure 6: Piezometric level trends at three points near the recharge lake.

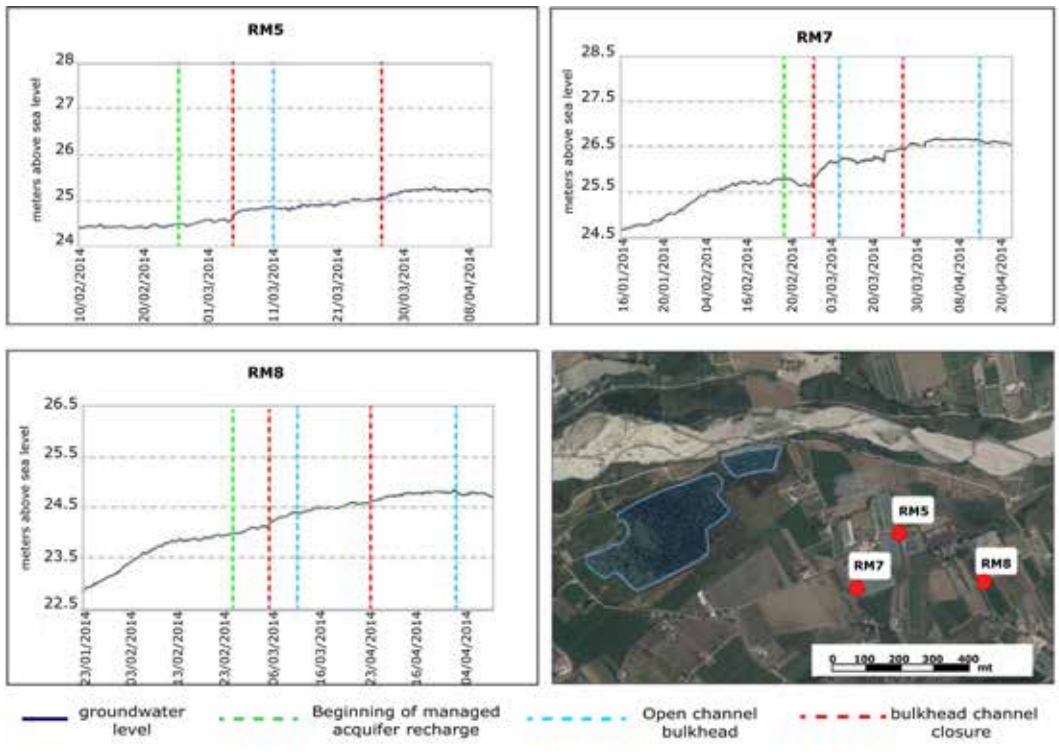

Figure 7: Piezometric level trends at 3 points far away from the recharge lake.

interventions and lower levels.

For the piezometers RM1 (located a few metres from the lake) and RM2 (200 m from the lake), the response is more immediate and evident. At point RM3 (located 470 m from the lake) there is the same relationship, but with more delayed response times and a more modest level of increase.

Figure 7 shows the trends in groundwater level in the most distant points from the lake (from 700 to 1,250 m from the lake). Also in this case it is possible to see an increase in the level, but it is less clearly correlated with recharge through the lake.

The maximum rise measured was 2.75 m by piezometer RM1, located a few metres from the lake, while the minimum elevation (0.8 m) was observed from piezometer RM5, at 800 m from the lake. The maximum elevation values were recorded between the end of March for wells closest to the lake

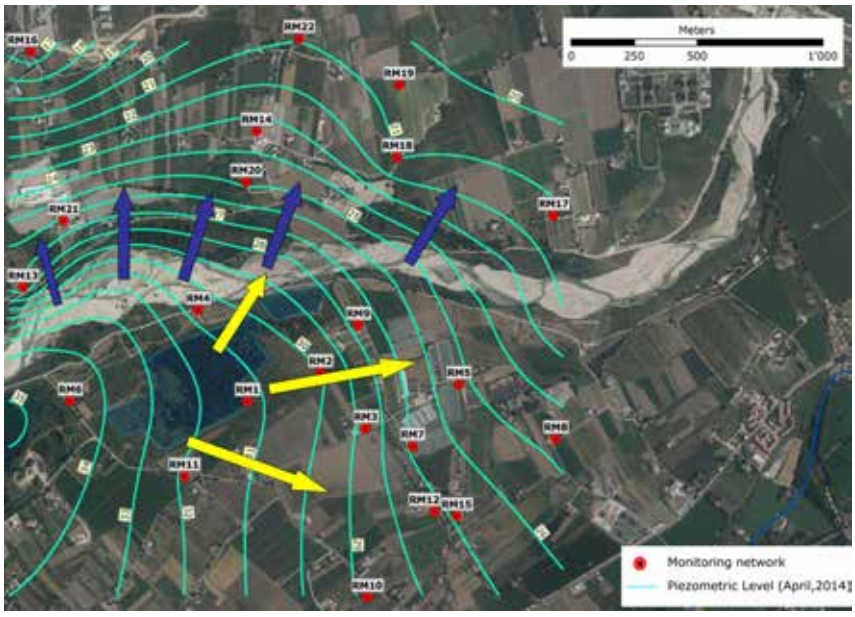

Figure 8: Piezometry near the recharge lake in April 2014. Yellow arrows show the flow from the lake to the alluvial fan, blue arrows show the flow toward the Marecchia River and the north side of the alluvial fan.

and the beginning of April for those further away. Since the intervention of recharging took place between winter and spring, the increased level observed is certainly due both to the normal aquifer dynamics during this time of the year and to the managed recharge.

As mentioned, the maximum increase in the groundwater level was 2.75 m, recorded at the RM1 point. Considering that this point is just a few metres from the lake and that here the subsoil consists of very permeable sediments (gravels are prevalent), it is likely that this increase in the level may correspond with the raising of the lake level. The surface of the lake is about 150,000 m^2, and thus the maximum increase in the lake water volume was about 410,000 m^3 which, of course, also reflects the contribution to the recharge of rainfall and the dynamics between the lake, the river and the aquifer.

The action carried out by recharging the lake is also evident from the interpretation of piezometric data detected in April 2014: the water spreads from the lake to the east, southeast and northeast, recharging the fan and partly the Marecchia River (***Fig. 8***). In order to prevent the water recharging the fan from being partially drained from the river, it will be necessary to modulate the flow rates so as to maintain the level of the lake at an appropriate altitude. However, it should be considered that during the experiment described here an important field of wells located about one kilometre from the lake (RM15 in ***Figs. 4 and 8***), was not active; its operation could certainly change the directions of groundwater flow, potentially retrieving water from the recharge lake. Therefore it will be necessary, in the near future, to carry out some checks also in this sense, in order to make the aquifer recharge most efficient.

Conclusions

The managed recharge of the Marecchia alluvial fan through the Incal System Lake (site of a former quarry) produced the expected effects: an increase in the volume of water in the lake indeed induced a rise in the water table; the increase is at its maximum close to the lake and decreases moving away from it. Part of the water that infiltrates through the lake flows also to the river. The high rise in the water level in the lake, if not properly calibrated, could create problems for the nesting and survival of some species of birds in the area. Recharging should be modulated so that no damage is done to the ecology of the area. To do this it is necessary to know the actual volumes at stake, through the most precise measurements possible of levels in the lake and river and of the flow through the channel. Thanks to the collaboration of the ARPA Emilia-Romagna Region the outflow scale of the final part of the channel was determined for calculation of the total volume of water entering the lake, which was approximately 600,000 m^3. In the near future it will be interesting to assess the influence of the nearby well field on the trends of flow lines and the possible retrieval of water from the lake. Finally, the adopted managed aquifer recharge could be considered as a sort of quarry restoration, and may serve as an example for other regions with similar needs.

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