2012 EMILIA EARTHQUAKES

Effects on the groundwater levels of the May-June 2012 Emilia seismic sequence

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1. Introduction

A variety of phenomena were observed in the groundwaters in concomitance with the May-June 2012 seismic sequence that occurred in the Emilia Romagna area. In particular, phreatic wells close to the epicentral area were affected by a sudden increase in water level of up to 4 m. In some cases, the sands of aquifers were ejected outside wells, and >700 liquefaction phenomena were recorded [Bertolini and Fioroni 2012, this volume]. Some automatic stations of the regional well network recorded variations in well levels. These data can be considered useful to understand the relationships between seismic events and the local groundwaters [see also Italiano et al. 2012, this volume].

2. Hydrogeological features

The Po sedimentary basin is filled by sediments of Alpine and Apennine origin [Ori 1993]. The sedimentation processes have filled the sedimentary basin with alternate layers of sands and clay [Ori 1993, and references therein]. Gravels are present near the Apenninic chain front in the alluvial fan areas, while the bottom of the Quaternary sediments is at depths of 100 m to 700 m. These multilayered sequences constitute the Po aquifer system [Regione Emilia-Romagna and ENI-AGIP 1998]. In the part of the basin close to the Apenninic chain front (the belt of alluvial fans), the aquifers are located in undersaturated sediments and are subject to seasonal variations in their recharging processes. North of this area, fine sediments host confined or semiconfined aquifers that are characterized by low circulation velocities. Isotopic data indicate that deep groundwaters in this area are of Alpine origin, while ^{3}H and ^{14}C data indicate ages of 15000 to 30000 years [Martinelli et al. 1998, and references therein]. At depths shallower than 50 m, load fluctuations are observed in connection with rainfall, although lenses of confined aquifers that are poorly sensitive to rainfall are known to be at shallow depths too. The May-June 2012 seismic sequence occurred in the low plain area in the provinces of Modena and Ferrara, where fine sediments generate multilayered confined aquifers, and phreatic aquifers are limited to the first 10 m to 30 m in depth.

3. The monitoring network

In 1976, a regional network composed of 330 wells was set up with the purpose of monitoring the groundwater levels using manual techniques. These data have been used for environmental purposes and for water management. In recent years, the monitoring network managed by Agenzia Regionale Prevenzione e Ambiente (ARPA) has increased the number of wells (to about 600), and chemical analyses are also periodically carried out for environmental monitoring activities. In the past three years, an automatic monitoring network composed of 40 stations was set up and this has allowed the monitoring of the water levels and the temperatures, at a rate of one measure per hour, and to broadcast the data to the host center located in Bologna (Figure 1a).

4. Recorded data

Most of the stations located in the whole of the Emilia-Romagna region did not record significant signals that are attributable to seismic events, while some stations located in the provinces of Modena and Ferrara (Figure 1b) recorded sudden water uprising phenomena, of up to 1.5 m (Figure 2).

The internal clock of the monitoring stations was synchronized according to Coordinated Universal Time (UTC). In this way, the first measures after the M 5.9 and M 5.8 shocks were recorded about 1 h after these seismic events. Figure 2 shows that a decay of the water level signal was seen, and the higher water levels probably occurred in concomitance with these seismic events, although they were not recorded here (Table 1).

Figure 3 gives the water level variations observed at three selected monitoring stations of the Emilia-Romagna

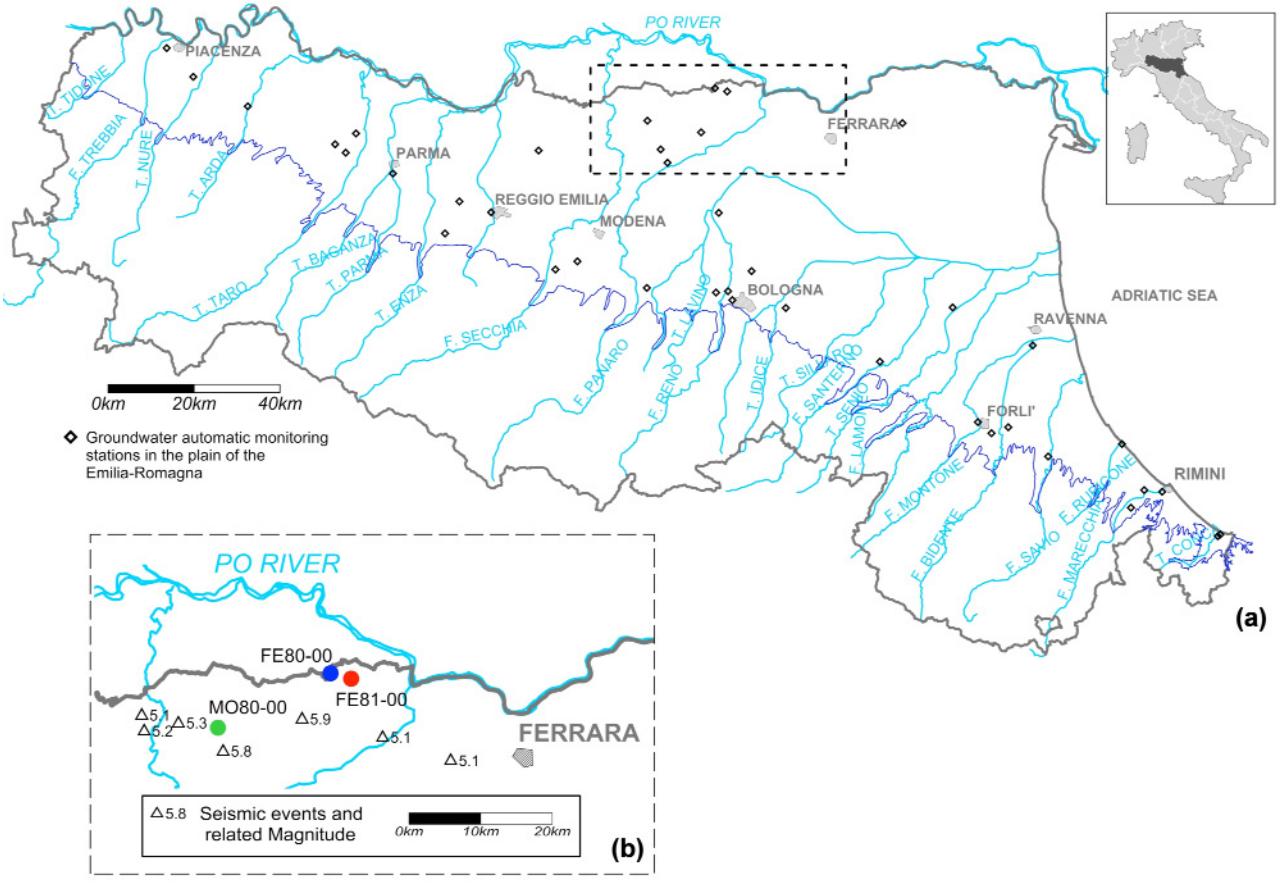

Figure 1. (a) Geographical sketch of the Emilia-Romagna region showing all of the groundwater automatic monitoring stations managed by ARPA Emilia-Romagna. (b) Monitoring stations considered and epicenters of the most relevant seismic events, as characterized by 5.1 ≤M ≤5.9 [INGV 2012].

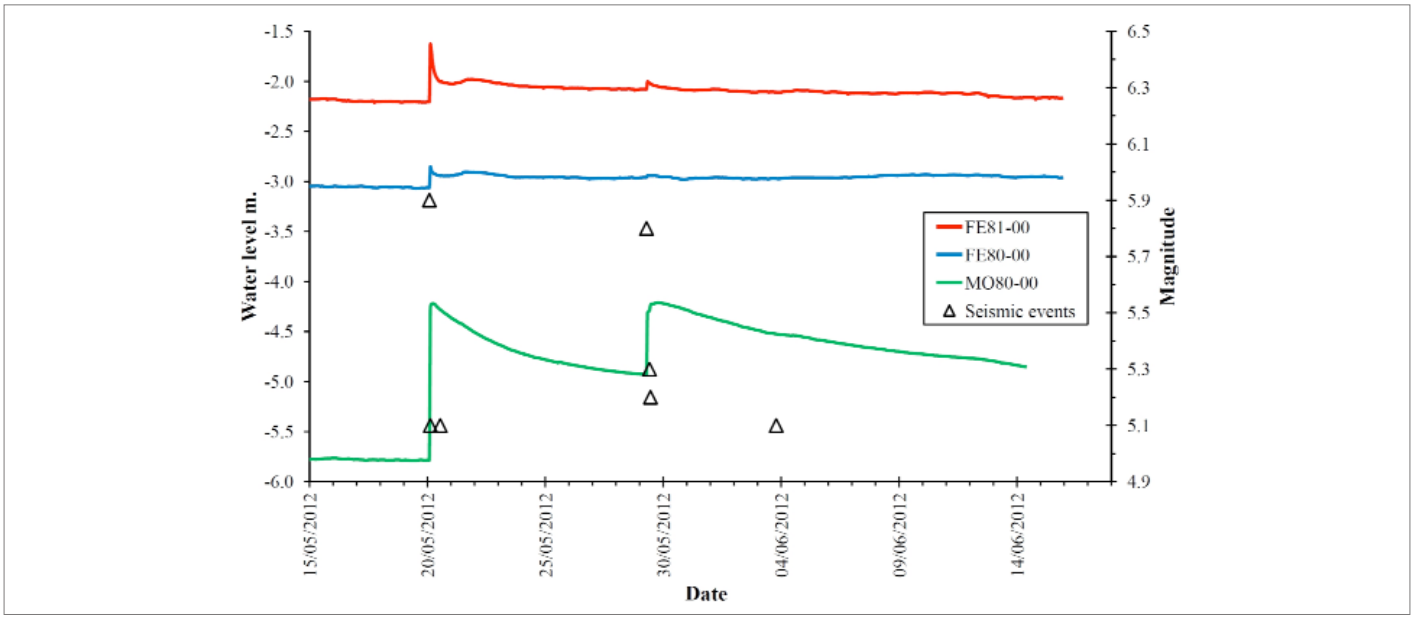

Figure 2. Water-level changes in concomitance with some significant seismic events. The events characterized by 5.1 ≤M ≤5.9 were considered.

Relevant seismic events (magnitude)	Seismic events occurrence date	Seismic events occurrence time (UTC)	Pre-seismic recording time (UTC)	Post-seismic recording time (UTC)
5.9	20/05/2012	02.03.52	02.00.00	03.00.00
5.8	29/05/2012	07.00.03	07.00.00	08.00.00

Table 1. Occurrences of the two most relevant seismic events, with the pre and post recording times.

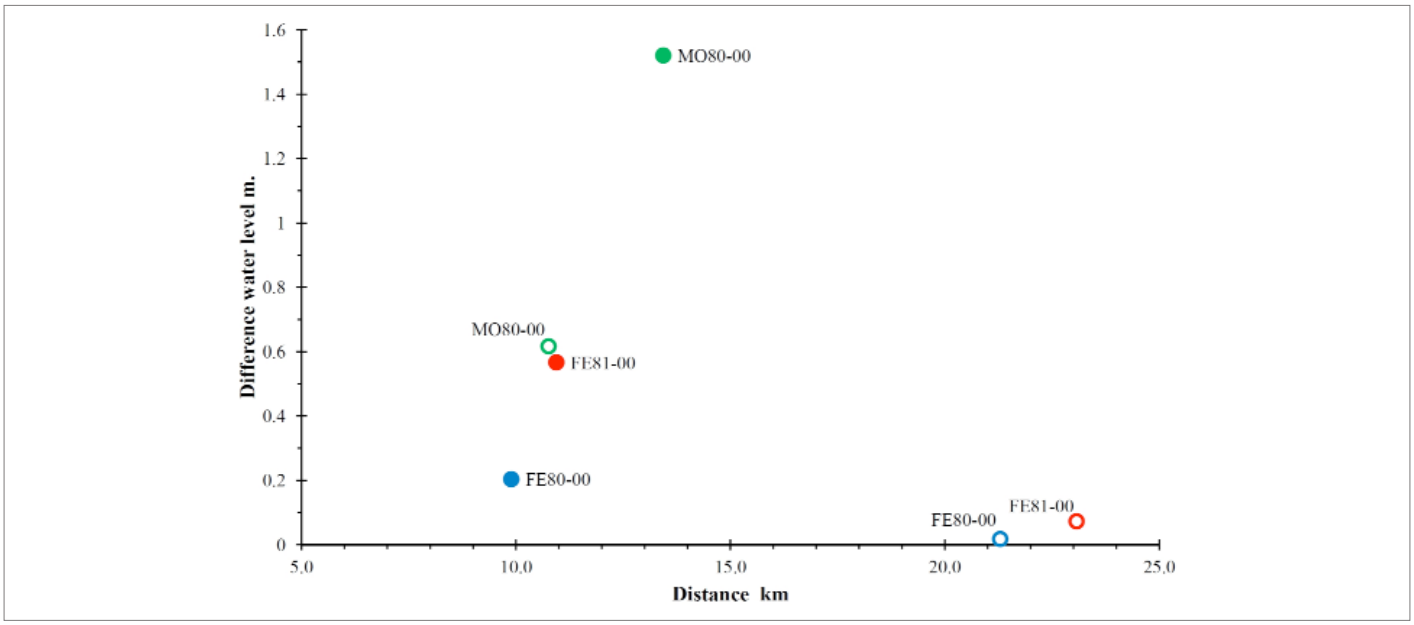

Figure 3. Differences in the water levels at the three monitoring stations, as related to the distance in concomitance with the two relevant seismic events characterized by M 5.9 (full dot) and M 5.8 (empty dot).

groundwater automatic monitoring network. In particular, for each station, two different water level variations were recorded in concomitance with most of the relevant seismic events, which were characterized by the M 5.9 (full dot) and M 5.8 (empty dot) seismic events. Water level variations were calculated according to values recorded at the UTC hours reported in Table 1.

The M 5.9, May 20, 2012, seismic event occurred at a distance of about 10 km to 14 km from the monitoring stations. The observed signal amplitude was relevant in all of the three monitoring stations considered. The M 5.8, May 29, 2012, seismic event occurred at a distance of about 10 km from the MO80-00 station, and at about 21 km to 23 km from the FE80-00 and FE81-00 stations. These distance differences might explain the higher effects recorded at the MO80-00 station (Figure 3).

Most of the relevant groundwater variations that have occurred in concomitance with other earthquakes were described by Roeloffs [1996] and by Wang and Manga [2010], while previous investigations on earthquake-related piezometric variations in Italy were carried out by Albarello et al. [1991] and Albarello and Martinelli [1994]. In the Italian historical records, earthquakes related to piezometric variations were reported by Boschi et al. [1995] and by Martinelli [1997]. As a general rule, possible water-level anomalies can be positive or negative according to the well location. If the area is subjected to compressive strain, the expected anomaly is positive [Okada 1992]. The sizes of the recorded anomalies can be tentatively related to the aquifer characteristics, to the distances of the recording station from the hypocentral area, and to the locations of the monitored aquifers in areas probably subjected to compressive strain. The step-like signals observed indicate that all of the monitoring stations in the near-field area, in which undrained consolidation is the dominant mechanism for coseismic groundwater level changes [Wang and Manga 2010], were affected by significant water-level variations.

5. Conclusions

The observed anomalies are within the characteristics previously reported in the common scientific literature relating to undrained consolidation phenomena linked to earthquake occurrence. Their sizes and shapes are probably a function of their relatively small distances from the hypocentral area and to their location in an area subjected to compressive strain. The collection and processing of all of the available data on piezometric variations during the Emilia 2012 seismic sequence will allow a better understanding of the phenomena observed.

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