Groundwater level changes in Switzerland following large, distant earthquakes

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Large earthquakes can produce sustained water level changes in certain distant wells (more than hundreds of kilometres away). Well-known examples include observations from California (Brodsky et al., 2003), Japan (King et al., 1999), and Germany (Schenk & Krauss, 1972). Following the great Mw9.0 2004 Sumatra earthquake, we observed groundwater level changes of several centimetres in two wells in Switzerland. We took these observations as motivation to look for groundwater level changes following other large earthquakes in the past. Since 1990, we found in total eight earthquakes, including the 2004 Sumatra earthquake, that caused groundwater level changes for the same two wells. In this study, we will present these observations. We further compare the observed groundwater level changes with seismic waveforms recorded at nearby stations of the Swiss Seismological Service to investigate a possible correlation between ground velocity and induced groundwater level changes. We found that, for the two studied wells in Switzerland, at least a ground velocity of 1 mm/s is needed to cause observable changes in the groundwater level.

The Federal Office for the Environment (FOEN) continuously monitors groundwater levels in selected wells across Switzerland. Groundwater levels are measured either with a float that is connected to an analogue recording drum (groundwater level recorder), or with a pressure transducer that is connected to a digital data logger. On the recording drum, groundwater level is graphically recorded on a sheet of paper. The resolution in time is 1 mm per 2 hours, which does not allow exact timing of the onset and the duration of the observed changes in groundwater level. Following the great Mw9.0 2004 Sumatra earthquake we found groundwater level changes of up to 6 cm and 4 cm at the sites Schaffhausen, Roggenäcker (SH) and Davos, Boden (GR), respectively. Both stations, Schaffhausen and Davos, are situated in unconsolidated gravel deposits and in a confined aquifer. The groundwater level changes occurred as short-lived disturbances of about 1-2 hours length. A review of all available groundwater level data revealed that at these two sites similar short-lived disturbance of about 1-2 hours length with amplitudes between 4 cm and 7 cm were observed for seven other large earthquakes since 1990 (Table 1). There are also several large earthquakes since 1999 that did not cause changes in groundwater level, although magnitudes were similar (Table 1).

The Swiss Seismological Service operates a nationwide seismic network to monitor ongoing earthquake activity in Switzerland. Since 1999, the network consists of 34 stations, of which 26 stations are equipped with broadband, three-component STS-2 seismometers. These sensors show a nearly constant sensitivity to ground velocity over the range from 120 s to 50 Hz, which allows precise recording of low-frequency, large-amplitude surface waves generated by large earthquakes. Prior to 1999, the network was equipped short-period sensors, that could not record these surface waves due to limitations in the dynamic range and in the sensitivity of these sensors. We use recorded ground velocities of the two stations, SLE and DAVOX, to compare it against recorded groundwater level changes (Table 1). Both stations are within a few kilometres of the FOEN stations, that monitor groundwater.

Many researchers suggest that seismic waves interacting with aquifers produce the sustained changes in pore pressure, or steps, hundreds of kilometres from an earthquake. Simultaneous monitoring of water level data and seismic data at a high sampling rate (1 Hz) revealed that changes in groundwater level start with the arrival of low-frequency, large-amplitude surface waves (Brodsky et al., 2003). Thereby, the amplitude of groundwater level oscillations relative to the seismic ground velocity is amplified depending on the hydrologic parameters of the aquifers. This implies that a certain threshold may exist above which groundwater level changes can be detected. Our data suggest that for the two sites studied a seismic ground velocity of at least 1 mm/s is needed to produce observable groundwater level changes. All earthquakes that produced observable groundwater level changes showed ground velocities > 1 mm/s; earthquakes with ground velocities < 1 mm/s did not cause detectable groundwater level changes (Table 1).

Earthquake			Groundwater level change (max)				Ground velocity (max)	
			Schaffhausen		Davos		SLE	DAVOX
Location	Date	Mw	Amplitude	Duration	Amplitude	Duration		
Pakistan	08.10.2005	7.7	0 cm	0 h	0 cm	0 h	0.2 mm/s	0.2 mm/s
Sumatra	28.03.2005	8.6	0 cm	0 h	0 cm	0 h	0.4 mm/s	0.5 mm/s
Sumatra	26.12.2004	9.0	6 cm	≈1.5 h	4 cm	≈1.5 h	1.0 mm/s	1.5 mm/s
Macq. Is.	24.12.2005	8.1	0 cm	0 h	0 cm	0 h	0.2 mm/s	0.2 mm/s
Japan	25.09.2003	8.3	5 cm	≈2 h	7 cm	≈2 h	1.1 mm/s	1.6 mm/s
Alaska	03.11.2002	7.9	0 cm	0 h	0 cm	0 h	0.2 mm/s	0.2 mm/s
Peru	23.06.2001	8.4	0 cm	0 h	0 cm	0 h	0.3 mm/s	0.4 mm/s
Izmit	17.08.1999	7.8	6 cm	≈1 h	5 cm	≈1 h	n/a	2.1 mm/s
Xizang	08.11.1997	7.9	2 cm	~1 h	2 cm	~ 1h	n/a	n/a
Indonesia	17.02.1996	8.2	4 cm	~1 h	no data	no data	n/a	n/a
Japan	28.12.1994	7.8	10 cm	~1.5 h	4 cm	~1.5 h	n/a	n/a
Japan	04.10.1994	8.3	5 cm	~1.5 h	no data	no data	n/a	n/a
Phillipines	16.07.1990	7.8	5 cm	~1.5 h	2 cm	~1.5 h	n/a	n/a

Table 1: Observed groundwater level changes and ground motions for selected earthquakes since 1990. Ground motion data is not available (n/a) before 1999.

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