Postseismic changes in stream water and groundwater related to the 2016 Kumamoto earthquake

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1.Introduction
It has been well known that large earthquakes sometimes cause hydrological changes widely in and around the region of strong ground motion. In many cases of those changes, stream flow and spring flow increases in lowland and water table drops in highland. Those changes sometimes continued for a period of several months to years (Rojstaczer and Wolf ,1992; Sato et al., 2000) . Since Japan is relatively rich in water resources, people may have not paid much attention to these earthquake-related hydrological changes in Japan. But those hydrological changes are clearly one of the seismic risks and should also be examined in Japan. The 2016 Kumamoto earthquake caused severe damages in and around Kumamoto Prefecture. There were two main events of the 2016 Kumamoto earthquake, ie, the foreshock of M (magnitude) 6.5 on April 14, 2016 and the main shock of M 7.3 on April 16, 2016. The 2016 Kumamoto earthquake also caused many changes in stream water and groundwater (Sato et al., 2017; Ichiyanagi and Ando, 2017). In our presentation we will report the post-seismic hydrological changes related to the 2016 Kumamoto earthquake using the hydrological data of 2014-2017.

2.Method
We analyzed the data of stream flow and well water level in Kumamoto prefecture which are open on the internet (MLIT, 2018; Kumamoto city, 2018)). We also analyzed the data of the 11 spring waters where we surveyed 7-12 times during the period from 2014 to 2017.

3.Result
Here we show the changes in the flow rate of the stream waters. There are two main rivers in and around Kumamoto city. One is the Shirakawa river system and the other the Midorikawa river system. Mt. Aso, which the surface earthquake fault and the region of the seismic intensity upper 6 reached, is in the upper basin of the Shirakawa river system. After the 2016 Kumamoto earthquake, stream flow increased in the Shirakawa river system for a year or longer but did not in the Midorikawa river system.

4.Discussion
Three main hypotheses for the earthquake-related hydrological changes have been suggested, ie, (1) Static coseismic elastic strain changes caused by earthquake-related crustal deformation (Muir-Wood and King, 1993), (2) Liquefaction caused by strong ground motion (Manga, 2001), and (3) Permeability enhancement caused by strong ground motion (Rojstaczer et al, 1995). Recently vertical permeability enhancement of the mountain in upper river basin has been strongly suggested (Wang et al., 2010; Wang and Manga, 2015).
The hypothesis (1) seems to be denied because distribution of the coseismic volumetric strain changes caused by the foreshock and the main shock did not correspond to the stream flow changes. The distribution did not also correspond to the flow rate changes of spring waters (Sato et al., 2017). The hypothesis (2) also seems to be denied because the liquefaction area of the 2016 Kumamoto earthquake (Wakamatsu et al., 2017) existed in both of the Shirakawa river system basin and Midorikawa river system

basin. In addition, it seems difficult for liquefaction to cause stream flow increases for a year or longer because liquefaction generally ends soon after earthquake ground motion. The hypothesis (3) can explain this case. As described above, the surface earthquake fault and the region of the seismic intensity upper 6 reached Mt. Aso, which is in the upper basin of the Shirakawa river system. On the other hand, they did not reach the upper basin of the Midorikawa river system. Therefore it is considered that vertical permeability enhancement at Mt. Aso can explain the post seismic change in stream water in and around Kumamoto city.

Keywords: 2016 Kumamoto earthquake, River water, Groundwater, Permeability