ANALYSIS OF BEDROCK GROUNDWATER AND ITS INTERACTION WITH BASEFLOW IN A FORESTED HEADWATER CATCHMENT

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Introduction

The stable of bedrock groundwater is importance for runoff generation because this deep groundwater has been proven to be the significant generator of runoff. For instance, Kosugi et al. (2006) estimated that 65 to 70% of total runoff from a 0.09 ha catchment consisted by exfiltration from weathered granitic bedrock in Japan. Kosugi et al. (2011) reported the 3 days and 2 months delayed after the peak of rainfall for double and triple peak hydrograph were mainly generated by deep bedrock groundwater. The higher contribution of bedrock groundwater to base flow compared to storm flow was also reported by Oda et al. (2013) based on tracer analysis in 5 to 48 ha catchments underlain by sedimentary rock.

Deep groundwater level response was more attenuated and delayed within a daily or weekly timeframe, while runoff has been reported to respond quickly to rainfall with runoff peak corresponded to rainfall peak (Kosugi et al., 2006). For instance, the lag time from rainfall peak to the highest levels of bedrock groundwater at 35 to 38m depth was 4 to 14 days in a 1.87 ha granitic catchment because of low permeably of bedrock and the deep depth to bedrock groundwater water table (Katsura et al., 2008). The broad peak lagged behind the storm events of bedrock groundwater level may have the significant impact on the response of the stream hydrograph after rainfall ceased (Kosugi et al., 2008).

The contribution of bedrock groundwater to delayed peak and base flow has been reported in previous studies (Onda et al., 2001; Kosugi et al., 2011; Iwaski 2015). However, these studies mainly focused on the rainfall, bedrock and runoff response, while the response of discharge to the changing in bedrock groundwater level in the no rain period has not been discussed. Indeed, the direct observation of bedrock groundwater and runoff is necessary to reveal the runoff generation processes in the dry condition. The understanding of groundwater flow response from base flow is essential for regional water supply and food securities in watersheds especially in the dry period.

The primal objective of this research was examining the role of bedrock groundwater in base flow generation processes. We conducted bedrock groundwater and runoff analysis based on the detailed hydrometric data, then investigating the relationship between bedrock groundwater to base flow.

Study site and monitoring

This study was conducted in a 5-ha headwater catchment (named K2-4) within FM Karasawa-yama in Tochigi prefecture Japan (36°21’N, 139°36’E). The catchment is covered by 30 to 60-year-old Japanese Cypress (*Chamaecyparis obtusa*) and Cedar (*Cryptomeria japonica*) plantation. Climate is moist and temperate with mean annual precipitation and annual temperature are 1240mm and 14°C, respectively. The elevation ranged from 155 to 271m with 45° of mean hillslope gradient was 45-degree. The underlying geology consists of sedimentary rock.

Two groundwater wells at 15m and 30m in depth were located at 215m in elevation at the ridgeline within the catchment. The well is consisted of 6 cm diameter PVC at 4 to 15m in slit opening for 15m depth and 15 to 30m slit opening for 30m. Groundwater level and temperature were measured using data loggers (Onset, U20L-04) every 10-minute interval. Air pressure from 2m above ground was also measured using data logger (HOBO, U20L) for calibration. Climate condition including precipitation, temperature, wind speed, wind direction, and humidity radiation (HOBO U30-NRC Weather Station; Onset Computer Corporation, MA, USA) was measured on an open area at 250m in elevation. Discharge of the catchment outlet was measured using 5-inch Parshall flume and 45-degree box V-notch. Water levels in Parshall flume and V-notch were monitored using capacitance water-stage data loggers (TruTrack, WT-HR 1000) every 5 minutes.

To evaluate the effect of previous precipitation on the response of bedrock groundwater, the antecedent precipitation index (API) for 6 hours, 20 days, and 30 days were calculated (Padilla et al., 2014). For examining the effect of bedrock groundwater at different depths to based flow, runoff was separated into stormflow and baseflow following the method of Hewlett and Hibbert (1967) with a time-based separation line of 0.0055L/s/ha/h. Baseflow then was divided into base flow in storm event (including the rainy days and two days after the events) and base flow in the no rain day. The data of daily rainfall, stream discharge, and groundwater levels at 15m depth and 30m depth from January 2020 to February 2021 were processed.

Result

Daily rainfall ranged from 0.2 to 60.0mmday^{-1}, groundwater level at well 15m varied from 196.3 to 197.3m while the height of groundwater at well 30m exhibited larger fluctuation between a minimum of 185.7 to a maximum of 189.2m (Fig. 1). The average daily drainage rate of well 15m and well 30m were 0.01 and 0.04m, respectively. In both two wells, groundwater levels increased in response to rainfall events larger than 10mm. The differences between well 15m and well 30 were also detected in the shape of the hydrograph. The shallower well responded faster to rainfall however the peak was short and quickly decreased, whereas, groundwater level at the deeper well showed the long peak with the prolonged recession limb (Fig.1).

The groundwater temperature at well 15m showed very slight thermal changes from 13.8 to 14.1°C with a mean value of 13.9°C, whereas, the temperature at well 30m remained stable during the monitoring time at 13.8°C (Fig.1). The temperature at both two well were comparable to the local mean air temperature. The was a lag of 6 months between the valley and the peak of groundwater temperature at well 15m and air temperature. The temperature of groundwater at 15m depth was observed to decrease during the period of high water level.

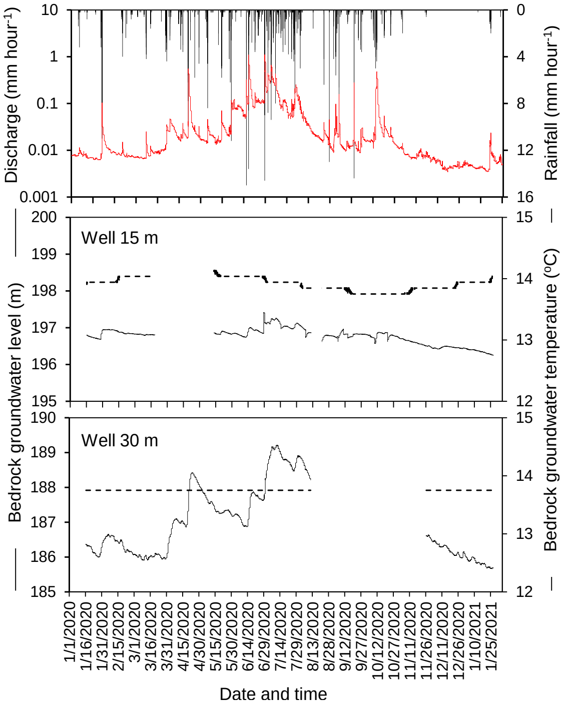

Fig.1. Hourly rainfall, discharge, groundwater level and groundwater temperature.

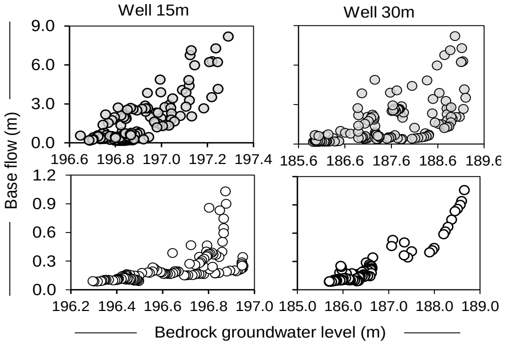

Fig. 2. Scatter plot of daily base flow and groundwater during rainfall event (closed circle) and dry period (open circle).

The amount of discharge varied from 0.1 to 16.2mmday^{-1} with the total discharge of observation and runoff coefficient in turn were 391.4mm and 34% (Fig.1). Base flow remained high during the rainy season. Discharge response corresponded with rainfall and the amount of discharge was correlated with the total amount of rainfall for each event (R^2=0.85). Compared to well 30m, the groundwater level at well 15m was more correlated with the response of base flow in the rainfall event (R^2=0.66), whereas bedrock groundwater at well 30 showed the stronger correlation with base flow in the dry condition (R^2=0.87) (Fig. 2). During the rainless hours, the recession of discharge corresponded to the larger decrease in the height of bedrock groundwater at well 30m.

Discussion

The dissimilar responses in the hydrograph of bedrock groundwater in two wells indicate the different flow systems that could influence the generation of base flow. The rapid response of well 15m to rainfall generated the pressure wave that caused the exfiltration of groundwater (Wenninger et al., 2004). Furthermore, the height of groundwater at 15m in depth have relatively small fluctuation within 1m and have never been exceeded 197.3m. This response possibly related to the presence of fracture flow which led to the evacuation of groundwater thus increasing the contribution to base flow during the event (Padilla et al., 2015). In contrast, the increment of bedrock groundwater in well 30m to rainfall was substantial, longer, and slower. This response allowed the deeper groundwater to support the baseflow in the no rain period. The gradual decrease of groundwater level during the dry time also indicating the continuous support of deep groundwater during the long dry condition.

Conclusion

The contribution of groundwater flow to the base flow of stream channel were influenced by the different responses of bedrock groundwater in bedrock aquifer at 15 and 30m depth. Our findings suggested specific depth of bedrock groundwater likely affect the base flow runoff. For further research, we will conduct the hydrometric and geochemical analysis of groundwater using ion concentration and stable isotopic composition to determine the contribution of bedrock groundwater flow to base flow.

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