Japan Geoscience Union Meeting 2015
(May 24th - 28th at Makuhari, Chiba, Japan)

ACG08-01 Room:301A Time:May 24 15:15-15:40

Relationship between groundwater discharge and catchment area in considering small-scale variability

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In forested catchments, most of the rainfall infiltrates into the ground, is influenced by evapotranspiration, passes through various pathways, is stored in soil and bedrock layers, and finally discharges to streams. The flow pathways and locations of storage sites regulate the chemical evolution of groundwater. Therefore, to predict stream water discharge and chemistry in forested catchments, it is necessary to acquire a sufficient understanding of the groundwater dynamics. Many studies, including model calculations and empirical research, have targeted the relationships between groundwater dynamics and catchment area. Most of these studies indicted increases in both groundwater discharge and the contribution of deeper groundwater with catchment area. However, few studies have considered the spatial variability of groundwater discharge among small catchments. In addition, there have been few studies with multiple observations of water discharge and chemistry. Therefore, it remains unclear how the relationships between groundwater and catchment area differ among groundwaters with different flow pathways and whether there is a disconnection of groundwater discharge processes between small and large catchments. Inokawa catchment (5.07 km^2), with bedrock consisting of Neogene age sedimentary rock, was examined. Stream water discharge and chemistry were observed at multiple points, and soil water and groundwater chemistry were observed in a hillslope (0.01 km^2). Using end-member mixing analysis (EMMA), stream water was separated into a shallow groundwater component, which mainly passes through and is stored in the soil layer, and a deep groundwater component, which mainly passes through and is stored in the bedrock layer. The deep groundwater was further divided into three types, $CaHCO_3$, $NaHCO_3$, and NaCl types, based on the chemical characteristics. The relationships between groundwater discharge and catchment area were then examined. Shallow groundwater discharge decreased with catchment area, while deep groundwater discharge increased with catchment area. In addition, the contributions of $NaHCO_3$ type and NaCl type groundwater, which were thought to pass through deeper bedrock than $CaHCO_3$ type groundwater, increased largely with catchment area. Both shallow groundwater discharge and all types of deep groundwater discharge showed large variability in small catchments (<0.1 km^2). The observed values in larger catchments were all within the range of observed values in small catchments. The results indicated that a disconnection of groundwater discharge processes did not occur at this site. However, the $NaHCO_3$ and NaCl types of groundwater were observed at fewer sampling points than $CaHCO_3$ type groundwater. Therefore, if deeper groundwater pathways become dominant, the disconnection of groundwater discharge processes between small and large catchments would be expected to become more obvious.

Keywords: groundwater discharge, catchment area, water chemistry, EMMA, scaling

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UNCERTAINTY OF DIRECT RUNOFF ESTIMATION FOR FLOOD PREDICTION BASED ON TOTAL RAINFALL-TOTAL RAINFALL LOSS RELATIONSHIP

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One of the main objectives of research in hydrology is to improve the accuracy of direct runoff estimation for enhancing flood prediction. Rain water falling to the ground surface will infiltrate into the soil and the excess rainfall (effective rainfall) will be direct runoff. Rainfall loss which is defined as the difference between the observed rainfall and effective rainfall consists mainly of infiltration with some allowance for interception and depression storage. A previous study applied total rainfall-total rainfall loss relationship to many catchments in Japan for estimating effective rainfall intensity to simulate direct runoff, and results showed that the runoff parameters (a and b) consists of standard deviation values. The standard deviation value of parameter a is to show the range of the uncertainty of obtained parameter a which represents the effects of evaporation that affects the initialization of soil moisture, interception by vegetation cover, or depression storage on the land surface. The purpose of this study is to estimate the uncertainty of direct runoff by using different sets of runoff parameters.

Keywords: Uncertainty of Direct Runoff, Flood Prediction, Total Rainfall-Total Rainfall Loss

Japan Geoscience Union Meeting 2015
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ACG08-03 Room:301A Time:May 24 16:15-16:40

Estimation of bedrock groundwater contribution with a distributed rainfall-runoff model and Time-Space Accounting Scheme

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Recent field studies with deep groundwater wells in headwater catchments have demonstrated the importance of groundwater in weathered bedrock in mountainous regions for controlling the dynamics of streamflow. On the other hand, currently used distributed rainfall-runoff models typically simulate for flows in subsurface soil and on surface by assuming impermeable bedrock. This may hamper the reasonable representation of rainfall-runoff process at a catchment scale, especially in terms of temporal and spatial source of water.

This study proposes a simple Boussinesq-type distributed rainfall-runoff model simulating for groundwater in weathered bedrock and unsaturated, saturated subsurface flow in a soil layer as well as overland flow. We apply the model in a Japanese catchment in Rokko mountain region underlying by weathered granite bedrock. We introduce also Time-Space Accounting Scheme (T-SAS) for analyzing temporal and spatial sources of water in simulated hydrographs. In particular, this study extends the original T-SAS algorithm to evaluate flowpath within the model to quantify the contribution of bedrock groundwater. The case study suggested the importance of the interaction between bedrock groundwater and saturated subsurface flow and the considerably high ratio of groundwater contribution especially during a low flow season. The developed model with T-SAS can be a useful tool to understand hydrologic processes including bedrock groundwater in mountainous catchments.

Keywords: groundwater, bedrock, Boussinewq equation, storage, granite, flowpath

Japan Geoscience Union Meeting 2015
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ACG08-04 Room:301A Time:May 24 16:40-17:05

Uncertainty Estimate in Runoff Analysis Based on Theory of Stochastic Process

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The aim of this paper is to provide a theoretical framework of uncertainty estimate on rainfall-runoff analysis based on theory of stochastic process. In this study, we applied SDE (stochastic differential equation) and Fokker-Planck equation to estimate uncertainty of rainfall-runoff analysis. SDE (stochastic differential equation) based on this theory has been widely used in the field of mathematical finance due to predict stock price movement. Meanwhile, some researchers in the field of civil engineering have investigated by using this knowledge about SDE (stochastic differential equation) (e.g. Kurino et.al, 1999; Higashino and Kanda, 2001). However, in the field of civil engineering, there have been no researches about uncertainty estimate by using correspondence relationship of SDE (stochastic differential equation) and Fokker-Planck equation. The Fokker-Planck equation is a partial differential equation that describes the temporal variation of PDF (probability density function), and there is evidence to suggest that SDEs and Fokker-Planck equations are equivalent mathematically.

In this paper, therefore, the uncertainty of discharge on the uncertainty of rainfall is explained theoretically and mathematically by introduction of theory of stochastic process. The rainfall data is generally used as input data for rainfall-runoff analysis. The lumped rainfall-runoff model is represented by SDE (stochastic differential equation) due to describe it as difference formula, because the temporal variation of rainfall is expressed by its average plus deviation, which is approximated by Gaussian distribution. This is attributed to the observed rainfall by rain-gauge station and radar rain-gauge system. Moreover, we obtained the time evolution of PDF (probability density function) of water level or discharge from correspondence relationship of SDE (stochastic differential equation) and Fokker-Planck equation.

As a result, this paper has shown that it is possible to evaluate the uncertainty of discharge by using the relationship between SDE (stochastic differential equation) and Fokker-Planck equation. Moreover, the results of this study show that the uncertainty of discharge increases as rainfall intensity rises and non-linearity about resistance grows strong. These results are clarified by PDFs (probability density function) that satisfy Fokker-Planck equation about discharge. It means the reasonable discharge can be estimated based on the theory of stochastic processes, and it can be applied to the probabilistic risk of flood management.

Keywords: uncertainty, runoff analysis, lumped model, SDE, Fokker-Planck equation

ACG08-05 Room:301A Time:May 24 17:05-17:20

Estimation of catchment scale water storage using high frequency and long-term tracer information

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In forested catchments, streamwater runoff process and streamwater chemistry are related catchment water storage. To investigate the mechanisms of water flow in forested headwater catchment, water sources, pathways, transit time and water storage have been estimated using chemical tracer information. Recent studies have modeled catchment streamflow and the response of isotopes and chemical composition during storm events using a conceptual model and estimated the water storage and transit time distributions within the flow regime and the relationship to the water source and flow paths.

Considering the field-based water source and time relationship, for example, previous studies have estimated the bedrock groundwater contribution using the mean transit time (MTT) of bedrock groundwater and streamwater during baseflow. However, the studies that estimated the MTT using tracer information were usually in the baseflow condition. The transit times during storm events are not clear, as field observations have not been made to test the model results. A newer methodology and observation system are needed to determine the high spatial and temporal variation in the water time and the source in forested catchments. In this study, to estimate the catchment scale water storage and the contribution on the water runoff, we considered a data collection strategy using a case study involving long-term high-frequency tracer measurements using the signal of an entire clear-cut catchment in the Fukuroyamasawa Watershed in the Tokyo University Forest, Chiba, Japan. A time series of Cl concentrations during each flow condition was used to estimate the MTT for various flow regimes. The estimated MTT was 300 to 400 days during high flow, and more than 1200 days during baseflow. From the MTT, the water storage in the catchment could be estimated. The water storage in the catchment could not be explained by the storage capacity of the soil layer alone; the bedrock water storage might contribute to water runoff and streamwater chemistry. This suggests that long-term high-frequency tracer data and focusing on the variation in tracer composition in each flow condition could be used to express the relationship between the water source and time in the flow regime.

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ACG08-06 Room:301A Time:May 24 17:20-17:35

Estimation of bedrock groundwater movements using multiple investigation methods at a weathered granite mountain, Japan

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Introduction

Previous studies have noted that bedrock groundwater is one of the important factors influencing stream discharge and streamwater chemistry. However, most previous studies were conducted not by direct measurement of bedrock groundwater but by using indirect methods, such as solute tracers and water budget analysis. Thus, the movement and flow path of bedrock groundwater remain incompletely understood based on direct measurements of bedrock groundwater. To better understand the dynamics of bedrock groundwater, we evaluated the flow path of bedrock groundwater based on groundwater table movement, water chemistry of bedrock groundwater and elution experiment of bedrock using dense borehole wells at a small catchment in a mountainous area.

Methods

The study was performed at the Fudoji Experimental Watershed located in the Tanakami Mountains in the southeastern part of Shiga Prefecture, central Japan. Precipitation was monitored using tipping-bucket rain gauges, and discharges were observed at eight small catchments, ranging in area from 0.1 to 2.3 ha. Seven small catchments (subcatchments) were included in the largest catchment (2.3 ha), within which we installed 61 borehole wells. The water table of bedrock groundwater was then observed at these borehole wells. Rainwater, streamwater from the small catchments and bedrock groundwater from the borehole wells were sampled, and the concentrations of major ions and SiO_2 as well as the water stable-isotope ratios $d^{18}O$ and dD were measured in the Graduate School of Agriculture, Kyoto University. The elution experiment of bedrock obtained by borehole excavation was conducted to evaluate the elute potential of rock itself. The elution water was analyzed by chemical analysis as described above.

Results and Discussion

The results of the analysis of the groundwater table of bedrock groundwater indicated that there were several fluctuating characteristics and that these characteristics of groundwater table change had locality. At the area having higher altitude in the ridge, the bedrock groundwater-table changes were gradual but the ranges of fluctuation were larger than those of the lower wells. At the lower-altitude points, although the bedrock groundwater table responded rapidly, the ranges of fluctuation of the groundwater table were small relative to those of the higher points. Some areas responded only to peak rainfall over a short time. Based on the groundwater flux analysis, bedrock groundwater moves across the surface divide. A catchment inflowed by a neighboring catchment showed a high specific discharge.

The relationships among chemistries derived from the chemical weathering of bedrock indicated that although the weathering processes were similar in the catchment, the weathering level varied among the borehole wells. The chemistries of bedrock groundwater at each catchment and of streamwater at each catchment showed large variability. The results of elution experiment and chemical variability of bedrock groundwater suggested that the concentrations of Na^{+} were high when the bedrock depth was shallow and the degree of hardness of bedrock was low. In addition, the concentrations of Ca^{2+} were high as the bedrock depth deep and the hardness degree of bedrock was high. The concentrations of Na^{+} and Ca^{2+} with local characteristics may be explained by specific flow path and different flow paths of bedrock groundwater across the surface divide. Our study indicated that groundwater movements assumed by the groundwater table were different with those estimated by chemical characteristics, suggesting that complex processes of groundwater flow path and chemical dynamics occur in the weathered bedrock.

Keywords: bedrock groundwater, weathered granite, densty borehole, spatial variavility of chemistries, elution experiment

ACG08-07 Room:301A Time:May 24 17:35-17:50

Intensive monitoring of bedrock groundwater level for estimating water storage capacity in a headwater catchment

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1. INTRODUCTION

The mechanisms of bedrock groundwater flow in headwater catchments and their significant contribution to catchment hydrology have been emphasized in recent studies, involving the direct monitoring of bedrock groundwater in intensively drilled bedrock wells in granitic regions (e.g., Kosugi et al., 2011). The principal goal of these investigations was to clarify the contribution of bedrock groundwater to water storage capacity of a watershed and a discharge hydrograph. In this study, we observed bedrock groundwater levels from monitoring nested bedrock wells and estimated the amount of bedrock groundwater storage in a mountainous watershed.

2. METHODS

Observations were conducted in the Fudoji Experimental Watershed, underlain by Cretaceous granite. The whole study watershed is referred to as F0, the area of which was 2.3 ha (Figure 1a). Discharge was measured at a V-notch weir at the outlet of the watershed. Groundwater levels were measured at 67 bedrock wells with depths of 2-42 m. In each well, bedrock groundwater storage was calculated by multiplying the amount of elevation in groundwater level by local porosity, which was estimated from weathering class and fissure distribution in each core sample. Within whole watershed, groundwater storage was estimated by interpolation of wells using kriging method.

3. RESULTS AND DISCUSSION

Figure 1b shows the 2D contour map of the groundwater level (annual average in 2013). In general, the groundwater surface shows a main valley line, which roughly corresponds to the ground surface topography (Fig. 1a). On the slopes on both sides of the main valley line, however, the groundwater surface across the slope is mostly planar and does not correspond to the relief of the ground surface topography. Thus, the bedrock groundwater in both side slopes flows towards the main valley line, mostly independent of the ground surface topography.

The amount of bedrock groundwater storage showed gradual variation and ranged approximately 80 mm from minimum to maximum in a year. The waveform of the groundwater storage corresponded to the base flow of discharge hydrograph. The base flow can be fitted well by quadratic function of the groundwater storage. However, after the heaviest rainfall event during observation period (total: 328 mm), the volume of observed base flow was lower than that of estimated from groundwater storage. This trend lasted for a month after the rainfall event. During that period, the contour map of the groundwater level showed a characteristic shape indicating that a considerable amount of groundwater flows out from F0 across the watershed boundary. Future studies should analyze long-term data to further clarify the effect of bedrock groundwater on the water budget of specific watersheds.

Keywords: bedrock groundwater level, water storage capacity, groundwater flux, base flow

ACG08-07 Room:301A Time:May 24 17:35-17:50

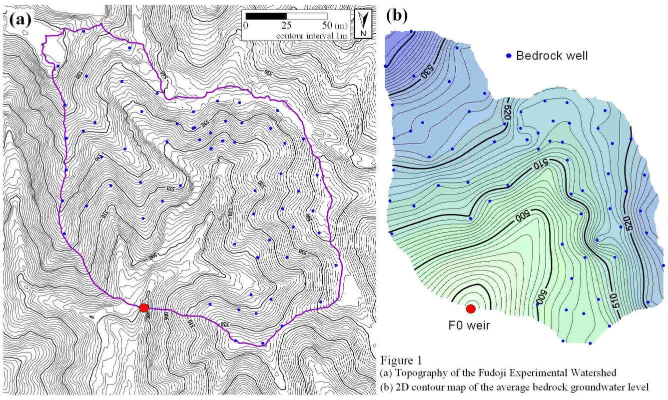

Figure 1
(a) Topography of the Fudoji Experimental Watershed
(b) 2D contour map of the average bedrock groundwater level