Analytical Study on Groundwater Flow System With Climate Change: Case Study for Boso Peninsula in Japan - 10371[1]

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ABSTRACT

Japan Atomic Energy Agency has started to investigate a regional groundwater flow system of sedimentary rock in an area in Boso Peninsula of Japan, where the topographic and geological features are relatively simple for mathematical modeling and hydraulic data are available. Groundwater flow on a horizontal 50 km scale is analyzed by using numerical code taking into account climate change. The analytical results for current (today's) steady conditions show that the groundwater flow is mainly from south-eastern area to north-western area in the direction of dip in the stratum. With, precipitation and topographic changes caused by climate change in 80,000 years, future conditions are estimated from existing and observed data. The analyzed results of groundwater flow in future steady conditions show that travel velocities change within a range of 10%. It is indicate that variance of groundwater flow caused by climate changes will be small in this study.

INTRODUCTION

In the safety assessment for geological disposal of long-lived radioactive waste, it is important to estimate radionuclide migration to human environments through groundwater flow. Japan Atomic Energy Agency (JAEA) has been developing a safety assessment code for nuclear regulation and studies regional groundwater flow systems in order to understand regional groundwater flow on a 10-100 km scale. It is necessary in the safety assessment to validate a conceptual representation of flow system for from the recharged area to discharged area compared with the observed data. Therefore, we investigated a regional groundwater flow system in a sedimentary rock area in Boso peninsula of Japan and conceptualized the regional flow model of this area using the observed data (flow rate, chemical composition of groundwater, and isotopic ratios of hydrogen and oxygen in water samples collected from wells, rivers and springs). In addition, the safety assessment of a nuclear waste repository in Japanese archipelago may require to evaluate an influences of tectonic movement and climate change for long time period. Especially, groundwater flow may vary with changes of infiltration and landform caused by climate change for long time period

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but not much study for them has been conducted so far. In this study, the groundwater flow in present steady conditions was analyzed and the result was compared to observed data. Then, the groundwater flow in a future environment was analyzed by using estimated future conditions (rainfall and topographic changes caused by climate change in 80,000 years) and the result was compared to the modeled present conditions, in order to quantify the uncertainties of estimation of groundwater flow rate involved in the safety assessment.

HYDROGEOLOGICAL MODELLING FOR BOSO PENINSULA

Boso Peninsula is located southeast of Tokyo. Yoro River flows in the central part of Boso Peninsula towards the northwest from the southeast and flows out to Tokyo bay with flow length about 50 km. Figure 1 shows the elevation map of the area and position of main rivers and observation wells. The main geological feature of this area consists of alternating sandstone and mudstone, and the layers dip in the northwest direction slightly. Figure 2 shows a schematic representation of regional groundwater flow in Boso Peninsula (vertical cross-section of a-a' in Fig.1)[1,2]. Chemical composition and isotopic data indicate the boundary of Ca-HCO_3 type groundwater and Na-HCO_3 type groundwater and also suggests that the groundwater flow to the surface and the groundwater flow to a deep stratum which are restricted by alternation. In addition, the above results are supported by the observed data that relatively new dating of groundwater appears in sandstone stratum with high permeability and old dating of groundwater appears in mudstone stratum with low permeability. Table 1 shows the hydraulic parameters for groundwater analysis based on data from the geologic literatures.

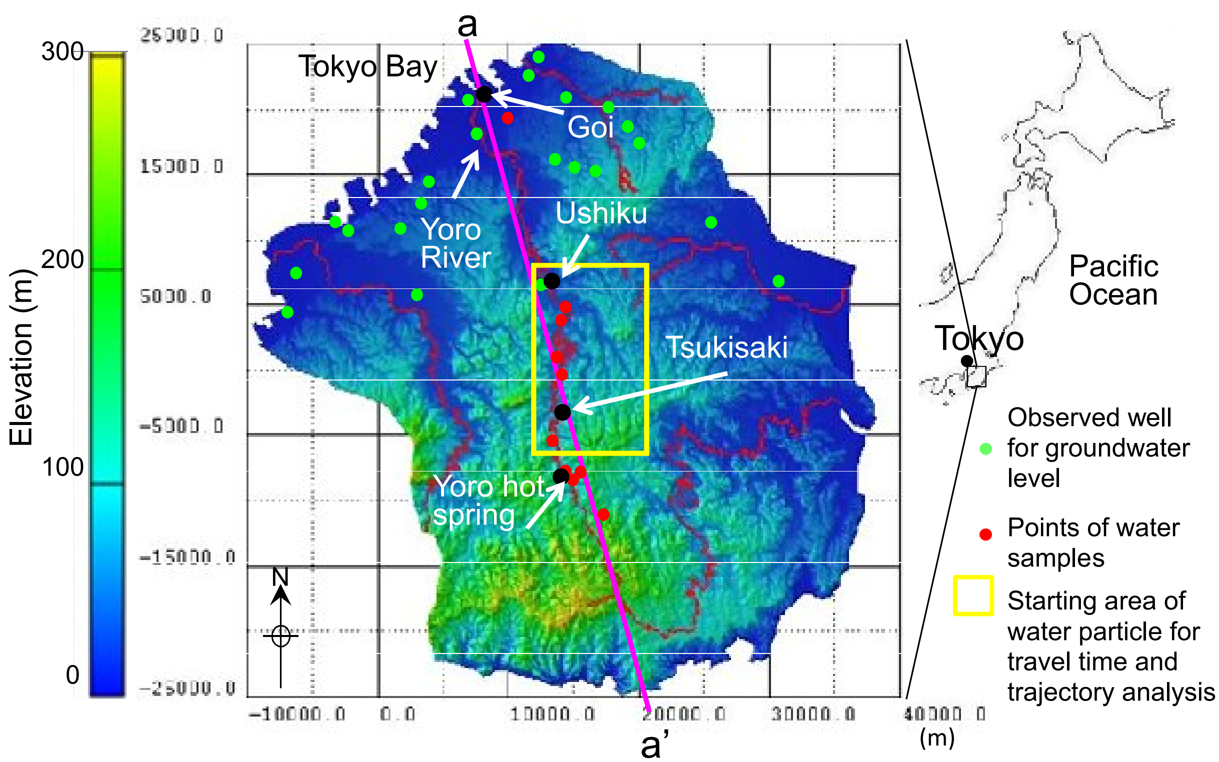

Fig. 1 Elevation map of Boso Peninsula. Red lines show rivers.

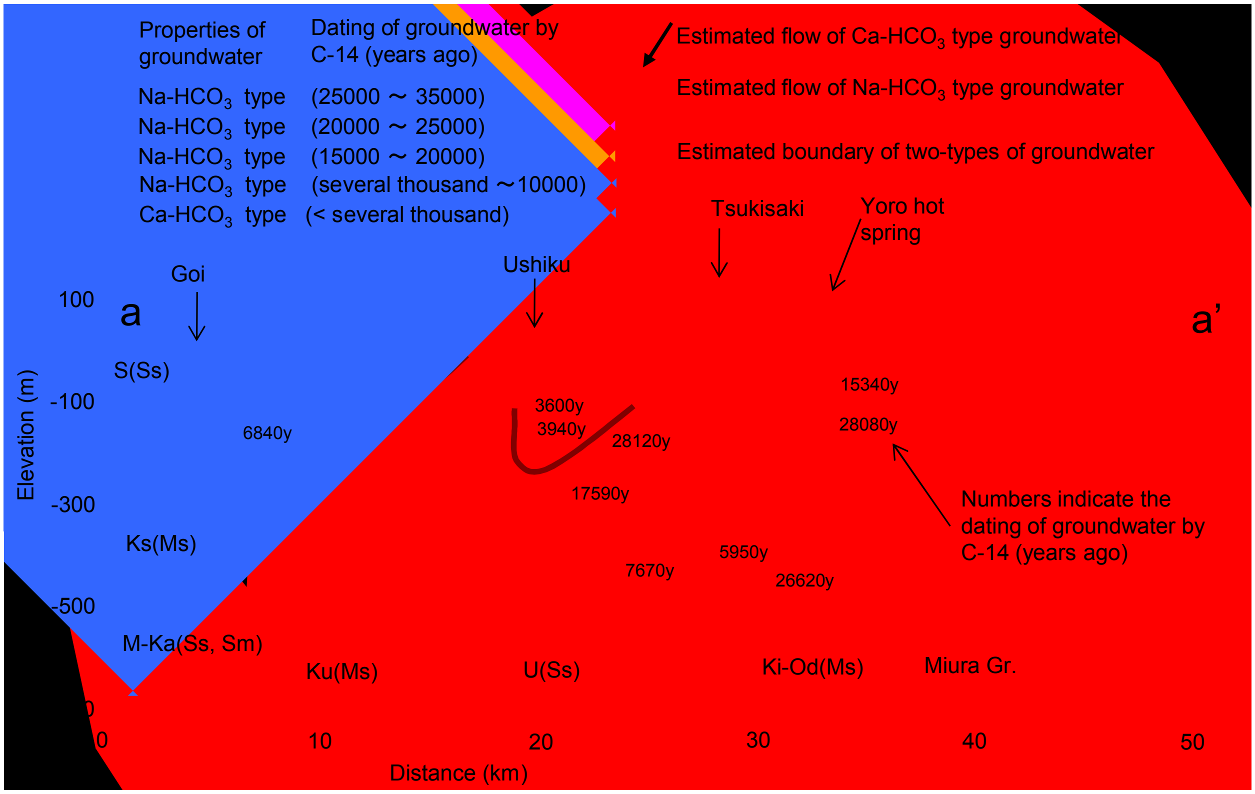

Fig. 2 Schematic representation of regional groundwater flow in Boso Peninsula (vertical cross-section of a-a' in Fig.1).

Table 1 Hydraulic Parameters for Groundwater Analysis Based on Data of Geologic Literatures.

	Facies	Hydraulic conductivity (m/sec)	porosity
Shimousa Group S(Ss)	Sandstone	3×10^{-5} [6]	0.5 [6]
Kasamori formation Ks(Ms)	Mudstone	1×10^{-7} [3]	0.5 [7]
Matano, Kakinokidai formation M-Ka(Ss, Sm)	Sandstone - Sandy Mudstone	4×10^{-5} [3, 4]	0.46 [7]
Kokumoto formation Ku(Ms)	Mudstone	1×10^{-7} [3, 8]	0.47 [7, 8]
Umegase formation U(Ss)	Sandstone	1×10^{-5} [3, 5]	0.4 [7]
Kiwada, Ohtadai formation Ki-Od(Ms)	Mudstone	5×10^{-7} [3]	0.45 [7]
Miura Group Miura Gr.	Sandstone, Mudstone, Conglomerate	3×10^{-7} [4]	0.4 [9]

ANAYSIS OF REGIONAL GROUNDWATER FLOW WITH CLIMATE CHANGE

In order to quantify uncertainty included in the result of safety assessment of geological disposal, it is important to evaluate groundwater flow under environmental conditions in a future with climate change. From the viewpoint of evaluation of groundwater flow velocity in the future, we focus on two factors caused by climate change. One is a change of precipitation with the climate change. The other is a topographic change caused by uplift and erosion. In this study, it is assumed that the temperature falls 8 degrees Celsius from the current temperature and infiltration is reduced 30% in 80,000 years (Figure 3(a)). Also, a change of topography in 80,000 years is estimated by using data of uplift [10] and erosion in Boso peninsula using topography simulation [11]. Figure 3(b) shows the estimated landform in 80,000 years along the cross-section (a-a') in Figure 1. Future landform in 80,000 years is estimated from differences between uplift data of Figure 3(d) and erosion data of Figure 3(d) for 500 m square grids.

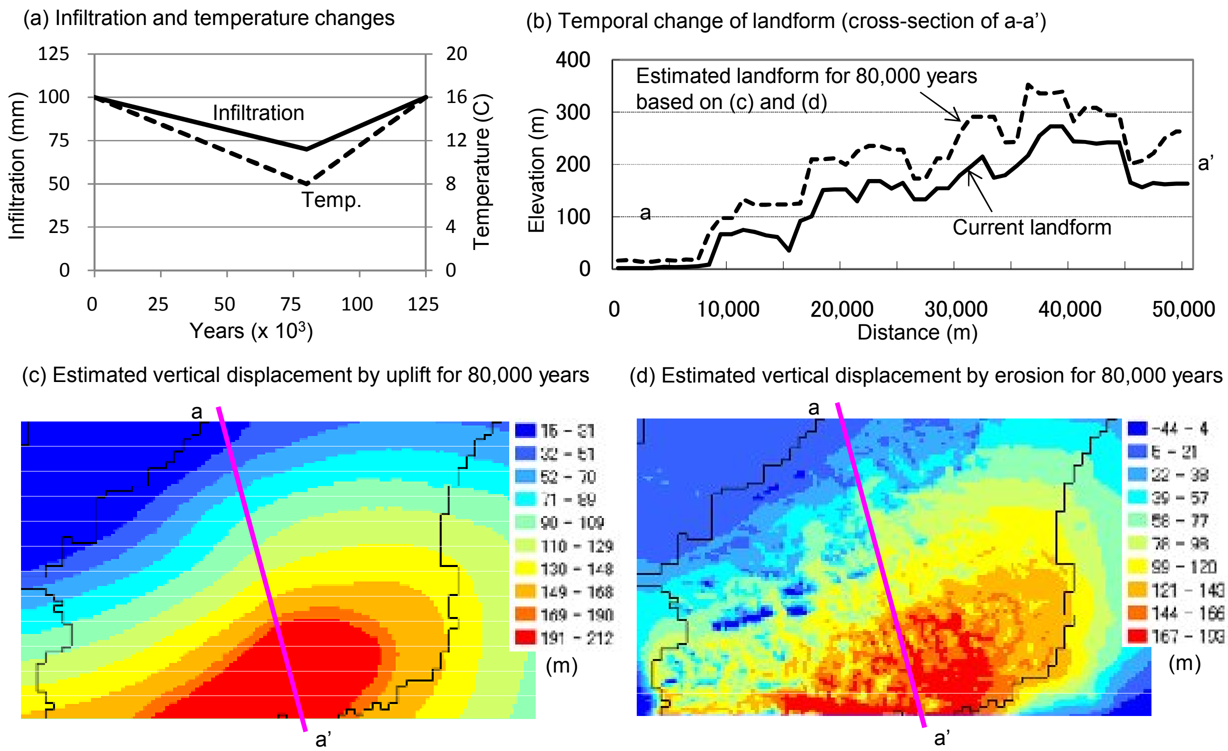

Fig.3 Models for infiltration and temperature changes and temporal change of landform.

JAEA has developed the 3D-SEEP code for regional groundwater analysis, which is a three-dimensional, finite element code for simulating saturated-unsaturated groundwater flow in porous media, taking into account temporal change of landform caused by climate change, uplift and erosion. The 3D domain evaluated has dimensions 50 km x 50 km x 3 km, and was modeled using 2 million finite elements.

Two steady state simulations were performed for the current environmental condition (case 1) and the estimated conditions in 80,000 years (case 2). The simulation of case 1 uses infiltration of 100 mm/year and the current landform and the simulation of case 2 uses infiltration of 70 mm/year and the estimated landform in 80,000 years. Sea level change caused by climate change was not considered because of difficulties of definitions for domain in these simulations and also the positions of the rivers in that future environment may not change. The boundary conditions for the analysis were assumed that the bottom of the domain at depth of 3 km was a no flow condition and the pressure head in the rivers on the surface was zero, and the infiltration rate (100 or 70 mm/year) was applied to the other area on the surface. In addition, no flow was assumed to cross the boundary of north-eastern and south-western side. The boundaries that face Tokyo bay and Pacific Ocean were set as the current sea water level. Figure 4 show the results of total head distribution for the current environmental conditions (case 1) and the future environmental conditions (case 2;80,000 years). The analyzed results in current steady conditions (case 1) show that the groundwater flows mainly from south-eastern area to north-western area in the direction of dip in the stratum. The distributions of total head appear almost the same between case 1 and case 2, however, the results of case 2 indicate an increased hydraulic gradient caused by topographic changes on the domain.

Table 2 Boundary Conditions for the Regional Groundwater Flow Analysis.

Boundary	Conditions
Bottom	No flow at -3 km.
Surface	Infiltration (mm/year); 100 (case 1) or 70 (case 2). Pressure head on the rivers; 0.
North-eastern and south-western side	No flow.
The side boundary that faces Tokyo bay and Pacific Ocean	Water levels that are the same as current sea water level.

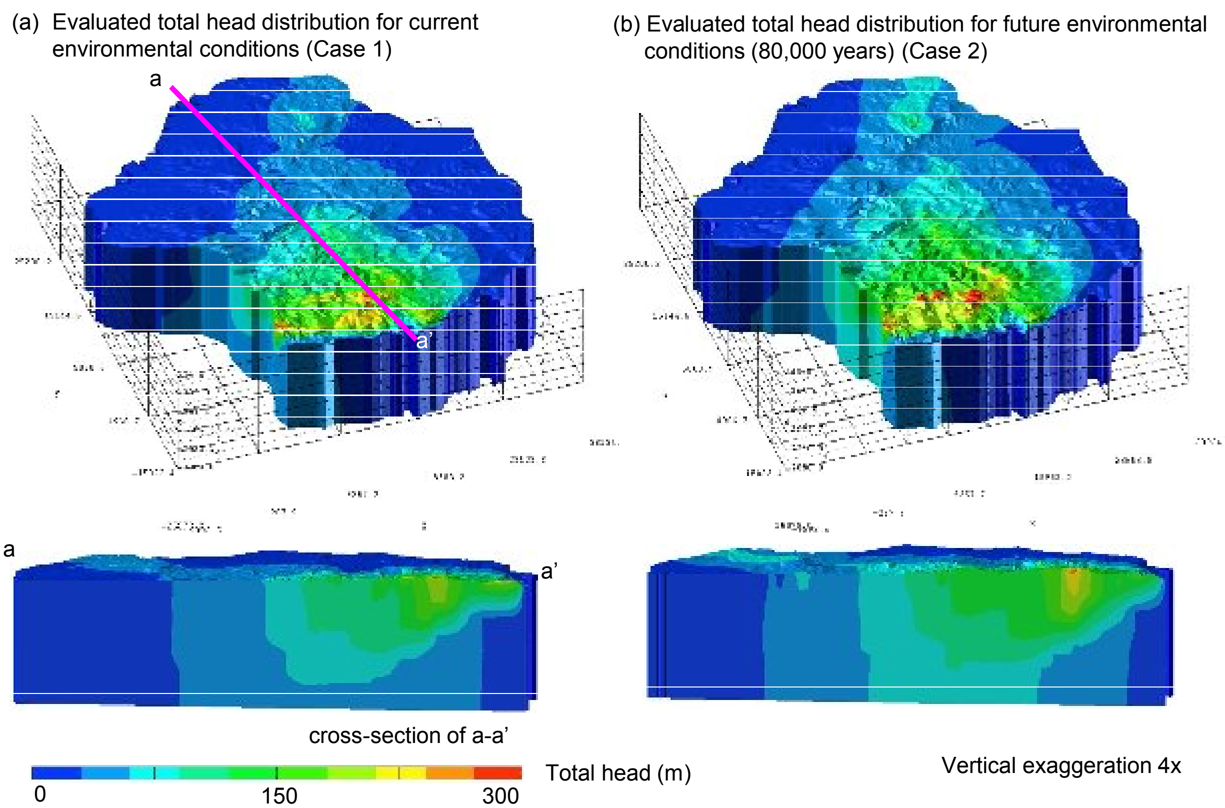

Fig.4 Total head distributions of the results of (a) case 1 and (b) case 2. upper figures show outlook from south western direction and lower figure show the cross-section along the a-a'.

In the simulation of current environmental conditions, the comparison between the observed and evaluated total head is shown in Figure 5(a). The analysis shows a value slightly bigger than observed data. Figure 5(b) shows the distributions of the vertical component of flow rate in the cross-section a-a'. In Figure 5(b), the color of blue describes a flow toward the deeper area, and the color of red describes a flow to surface. It appears that the groundwater flow to surface under the area of Goi and the groundwater flow to deeper stratum under the area of Yoro hot spring agree with the results obtained by observed data in Figure 2. Therefore, it may be said that evaluated results of the regional groundwater flow for current environmental conditions reasonably explain regional groundwater flow qualitatively.

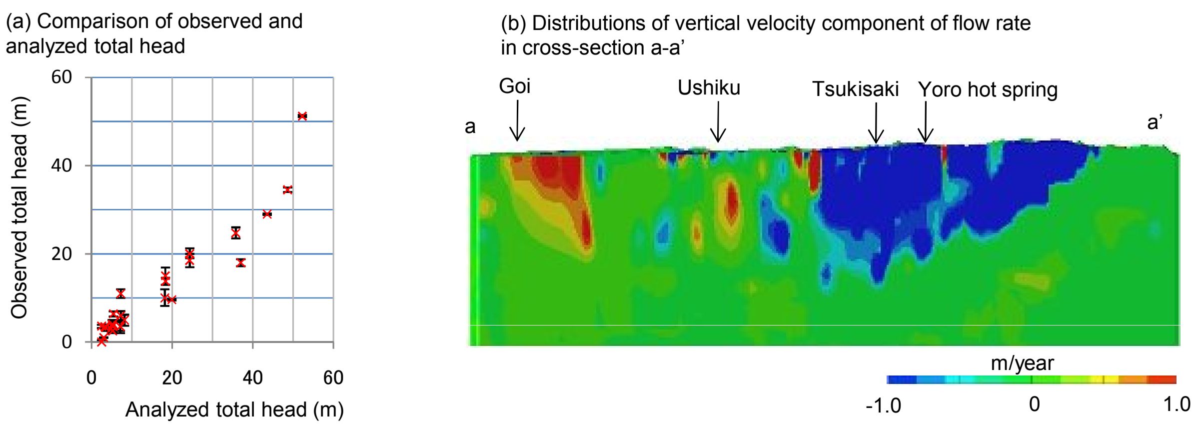

Fig.5 Verification results of (a) comparison of observed and analyzed total head and (b) distributions of vertical velocity component of flow rate in cross-section a-a'.

Using the simulation results of groundwater flow rate, travel time and trajectory analysis of water particles by particle tracking method were performed. Figure 6 shows the results of trajectory analysis for the current environmental condition (case 1) and the estimated conditions in 80,000 years (case 2). 187 Particles are used in these calculations. Particles start from points 300 m or 500 m deep, and are located along square grid points on a 11 km x 17 km area (black line). There are no large differences between the trajectory results of case 1 and case 2 in Figure 6. However, differences appear in the travel velocity shown in Table 3. Simulated results of mean values of travel velocity vary within 10% between case 1 and case 2. These results may be caused by the slight change of trajectories which are affected by topographical change and reduction of precipitation. These uncertainties can be indicated in detail by using cumulative distribution function (CDF) of travel velocities of water particles. Figure 7 shows the CDFs obtained from the simulation results. The figure indicates that variance of groundwater flow caused by changes of infiltration and landform will be small in 80,000 years. However, large variance of groundwater flow may be induced by sea level change with climate change because of drastic change of flow domain. In future work, we have to study the assessment methodology for future groundwater flow under the conditions of sea level change.

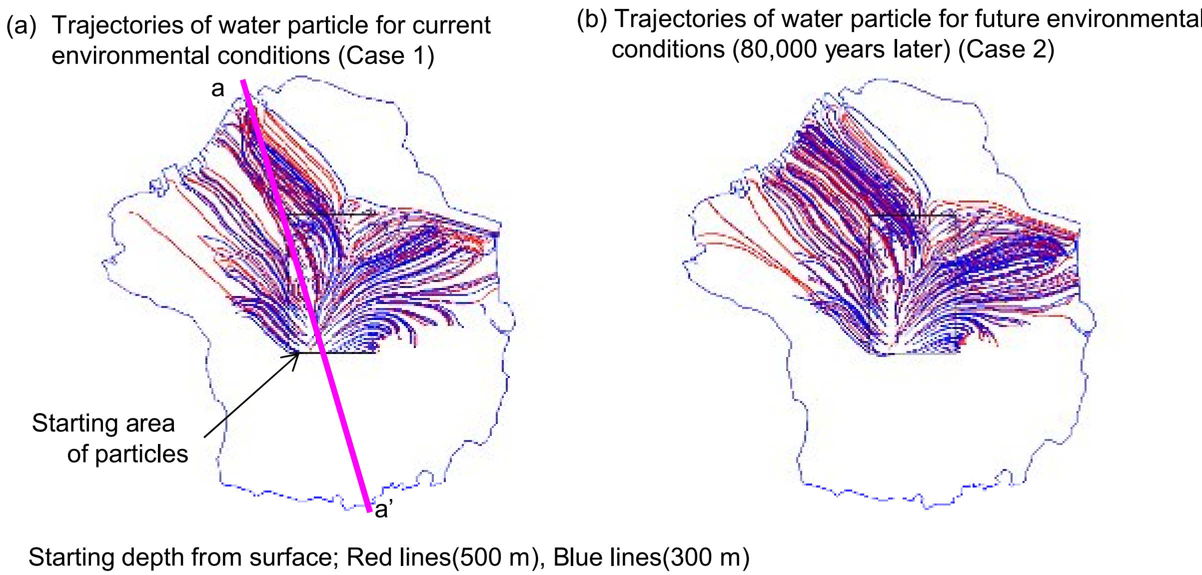

Fig. 6 The results of trajectory analysis for the current environmental condition (case 1) and the estimated conditions in 80,000 years (case 2).

Table 3 Simulated Results For Current Environmental Conditions (case 1) and for Future Environmental Conditions (80,000 years) (case 2).

Stating depth from the surface (m)		Trajectory length (m) Mean value	Travel time (year) Mean value	Travel velocity (m/year) Mean value
Case 1	300	846.4	1309	7.016
	500	886.7	1321	6.740
Case 2	300	1230	1907	7.445
	500	1462	2273	6.108

CONCLUSION

JAEA has started to investigate a regional groundwater flow system of sedimentary rock area in Boso peninsula of Japan. The analyzed results for current steady conditions show that groundwater flows mainly from south-eastern area to north-western area in the direction of dip in the stratum. The analyzed results of groundwater flow in future steady conditions shows that the mean value of travel velocity of water particles change within a range of 10%. It is indicate that variance of groundwater flow caused by changes of infiltration and landform with climate changes will be small in this study. It is indicated that uncertainties in the estimation of groundwater flow rate in the future will be able to quantify and much study is needed for the safety assessment of HLW facilities in Japan.

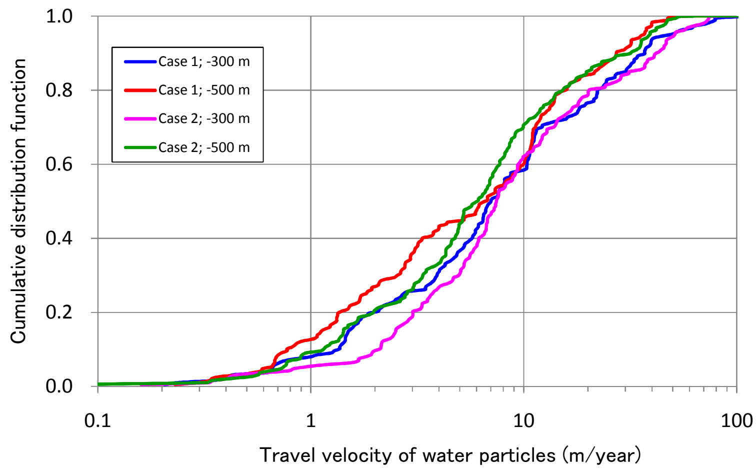

Fig. 7 Cumulative distribution functions obtained from the results of trajectory analysis for case 1 and case 2.

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