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Recharge mechanism using electromagnetic ground conductivity survey and tritium concentration analyses of groundwater in salt affected area, Northeast Thailand

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Abstract: Hydrogeological survey and geochemical analysis were carried out in Phra Yun area, Northeast Thailand, which is a typical salt-affected area for an understanding of hydrogeological groundwater behaviours. Geological survey reveals the presence of G1 and F1 faults. Electromagnetic ground conductivity prospecting shows that the high conductivity zones of 15 mS/cm or more are distributed at underground of the G1 and F1 faults where saline groundwater is discharged. The distribution patterns of tritium concentration show that high tritium concentration zones of groundwater were recharged from pond and river. On the assumption that the annual average tritium concentration of precipitation in Northeast Thailand is same as tritium concentration of precipitation in Tokyo and groundwater flows as piston flow, the age of recharging precipitation of groundwater with 15 TU in 1997 could be estimated at 1967-1970 years. The velocity of groundwater flow was calculated to be 5.3×10^{-7} m/s and 2.1×10^{-6} m/s respectively from a duration time of 30 years and distance of groundwater flow 500m -2000m from the pond and river to the investigation wells. Because the estimated values of velocity of groundwater flow are compatible with the hydraulic conductivities, it is considered that 30 years is a reasonable period for recharging groundwater.

1. Introduction

Soil salinization in northeast Thailand is not a new problem and is not entirely induced by human activities. Some of it is a natural phenomenon, which is related to the climate and the rock salt that widely underlies this region. Because of the widespread salinity problem in northeast Thailand, much research had been undertaken to explain the causes of the problem, estimate its extent and suggest measures to be taken. The main controversy on salinization in northeast Thailand lies in the explanation of origin and how salt reaches the surface. Identifying recharge and discharge areas is one of most important item for groundwater management in salt affected area because saline groundwater and affected soil tends to be distributed in discharge area. The identifying recharge and discharge areas is examined based on the data of the hydrogeological structure, data of monitoring piezometers and geochemistry at 16 investigation well stations in the Phra Yuen area, which is a typical salt-affected area.

2. Geography and Geology

Phra Yuen area is located 30 km southeast of Khon Kaen town. The study area, which is located in the Phra Yuen area and covers 9 square kilometers (3 km × 3 km) (Fig.1), is mainly used for paddy fields with some upland fields and residential areas. The physiography of the study area is classified as rolling hills. Elevation ranges from 175 meters to 190 meters above sea level.

Northeast Thailand is mainly composed of Mesozoic sediments called the Korat Group and Quaternary deposits. The Mahasarakham Formation is composed of claystones and shales interbedded with two to three layers of evaporites (halite, gypsum, anhydrite, carnallite and sylvite) varying in thickness from 10 to 170 m (Japakasetr and Suwanich, 1984). According to boring data collected at Raonady village by the Department of Mineral Resources, there is a rock salt layer about 80 m thick at a depth of 180 m (JICA, 1991). The rock salt layer seems to be at the same depth in the study area (Fig.2).

3. Stalinization of Soil

Various maps of the salt-affected areas were compiled by the Land Development Department (1991). In these maps, salt-affected soil is divided into 5 classes based on the area of bare land (Salt Patches) formed by the salinization. Salt-affected soil of Classes 2-5 is irregularly distributed in study area (Fig.1).

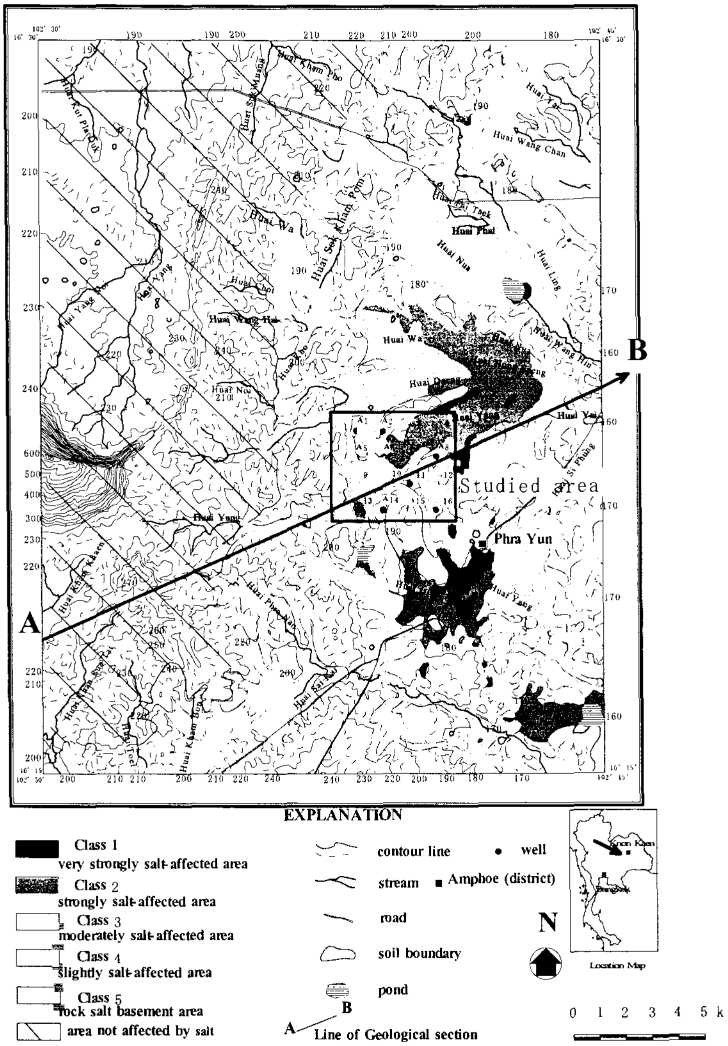

Fig. 1. Salt-affected soil map around the study area (from DLD, 1991).

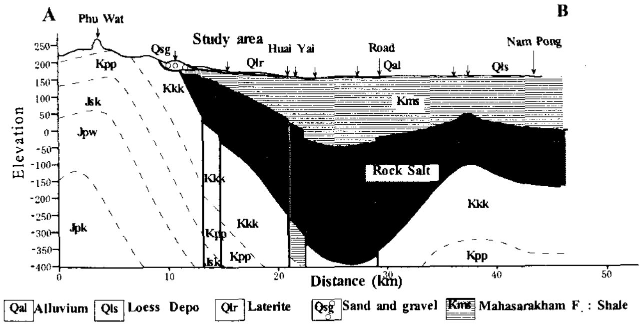

Fig. 2. Geological section (modified from Surisuk, 1994).

4. Methodology

In the study area, piezometer nets cover 3 km in the N-S direction × 3 km in the E-W direction. Piezometers were installed at every intersecting point of a regular 1 km grid for a total of intersecting points (A1-A16) (Fig.1). At each intersecting point (A1-A16) 3 investigation wells were dug and the stratigraphical profiles were described at 5, 10 and 15 meters in depth. After the investigations, 3 piezometers (hereafter, 5 m well, 10 m well and 15 m well) which had a screen (1 meter bottom) were set up for monitoring the groundwater level (potential head) and electrical conductivity (hereafter, EC) which were measured every month. This report examines data covering a period of about 2 years. The electromagnetic ground conductivity prospecting of vertical diople mode(McNeill, 1986) was carried out along the survey lines of A5-A7 and A10-A12 to verify the inferred faults. The instrument can be operated at transmitter: receiver spacings of 10, 20 or 40 m, and has theoretical depth penetrations of 0.75 times the spacing when the coils are operated in horizontal positions so as to vary the depth of exploration: 7.5 m, 15 m and 30 m, respectively. The transmission frequencies are fixed at 6.4, 1.6 and 0.4 kHz of the 10, 20 and 40 m separations respectively. The chemical composition of groundwater in each borehole and river and pond water was analyzed by ICP-Mass spectrometry. These samples were taken in March, 1997. Tritium concentrations also were analyzed using Kimura's method (Kimura, 1971). Tritium is reported in tritium units (TU). A precision of ±5% to 10% of estimated value was obtained by routine analysis.

5. Results and Discussion

Stratigraphy and geological structure

The boring columns indicate the geology of the study area consists of Mahasarakham Formation (hereafter, M.F.) and Quaternary (Fig.3). M.F. consists of red to brown hard shale. The M.F. is unconformably overlain by Quaternary laterite deposits, which consist of a clay layer, gravel layer, laterite layer and sandy loam layer in ascending order. The thickness of the Quaternary laterite deposits is less than 10 meters except at A2 where the M.F. is not found below a depth of 15 meters. Shallow groundwater occurs in Quaternary laterite deposits, especially in the gravel layer and surface of unconformity. Deep groundwater in the fracture of the M.F. is considered to be unconfined or semi-confined by the clay layer based on monitoring data of the groundwater level. Lineament analysis, upper structure of the M.F., and distribution level of the gravel layer in the Quaternary literate deposits revealed the presence of G1, F1, F2 and F3 faults (Fig.3).

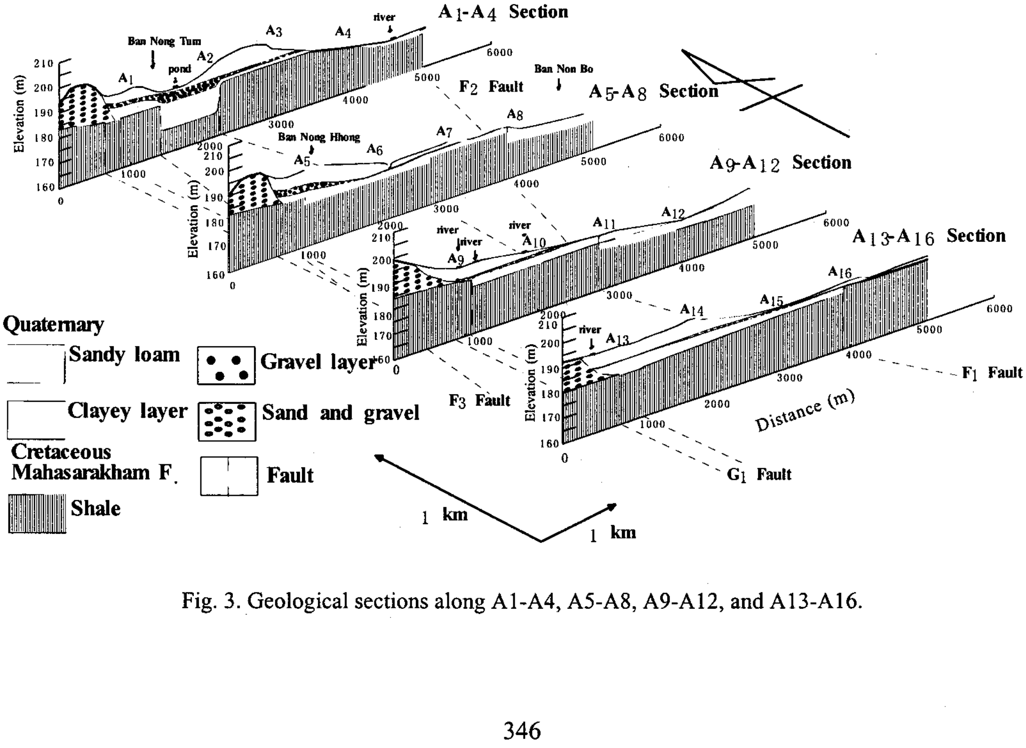

Fig. 3. Geological sections along A1-A4, A5-A8, A9-A12, and A13-A16.

Electromagnetic ground conductivity prospecting

Fig.4 shows the conductivity sections along survey lines of A5-A7 and A10-A12 by electromagnetic ground conductivity prospecting. The A5-A7 section shows the vertical distributions of high conductivity zone around the inferred G1 and F1 faults. The A10-A12 section shows high conductivity parts of 15 mS/cm or more thrusts from the underground to ground-surface at the survey line 2400 m and 3500 m. It is clear that the distributions of high conductivity shows the upward movement of the salt from the following filed observations: ① The soil with salt is distributed near the survey line 2400 m. ② The salt crust occurs along survey line 3500 m - 3800 m where topography is a small valley that is a discharge area. An area of 15 mS/cm or more projects from underground to 15m in depth at survey line 3000m coincides with the inferred F1 fault.

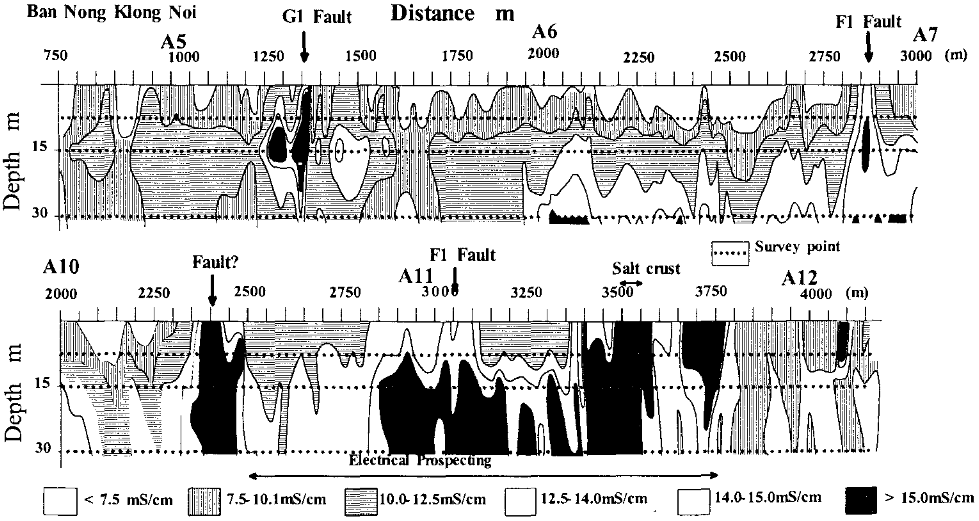

Fig. 4. Sections of iso-conductivity value along A5-A7 and A10 - A12 survey lines.

Data from monitoring piezometers

The fluctuation range of the groundwater level at each station is about 3 meters. The fluctuation patterns of the 5 m well, 10 m well and 15 m well at each station show one cycle per year, which relates with precipitation pattern (Fig.5). Fluctuation patterns of groundwater level (potential head) in the 3 wells at each site can be classified into the four types (Table 1). Type 1 corresponds to a potential pattern associated with the recharge area of groundwater. Type 3 corresponds to a pattern associated with the discharge area. Type 4 that shows reciprocal change of the

Table 1. Classification of fluctuation patterns of groundwater level in the 3 wells at each station.

Type	Characteristic	Location
Type 1	Potential head in the 5 m well is the highest.	A1, A2, A7, A8, A9, A10, A11
Type 2	Potential head in the 10 m well is the highest.	A14
Type 3	Potential head in the 15 m well is the highest	A4, A12, A16
Type 4	The well with the highest potential head reciprocally changes	A3, A5, A6, A13, A15

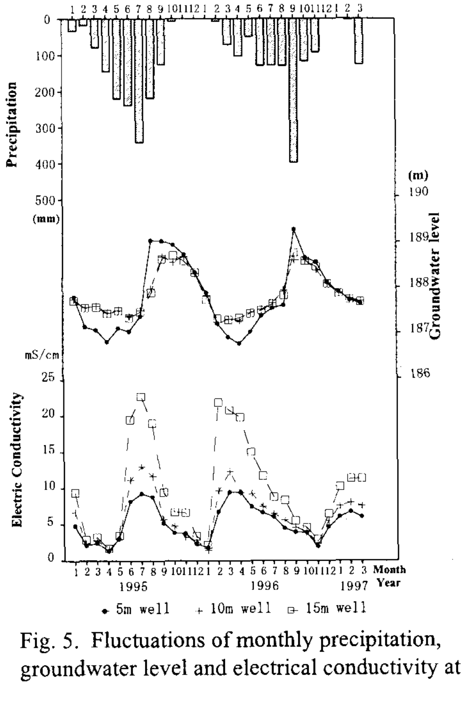

Fig. 5. Fluctuations of monthly precipitation, groundwater level and electrical conductivity at A5

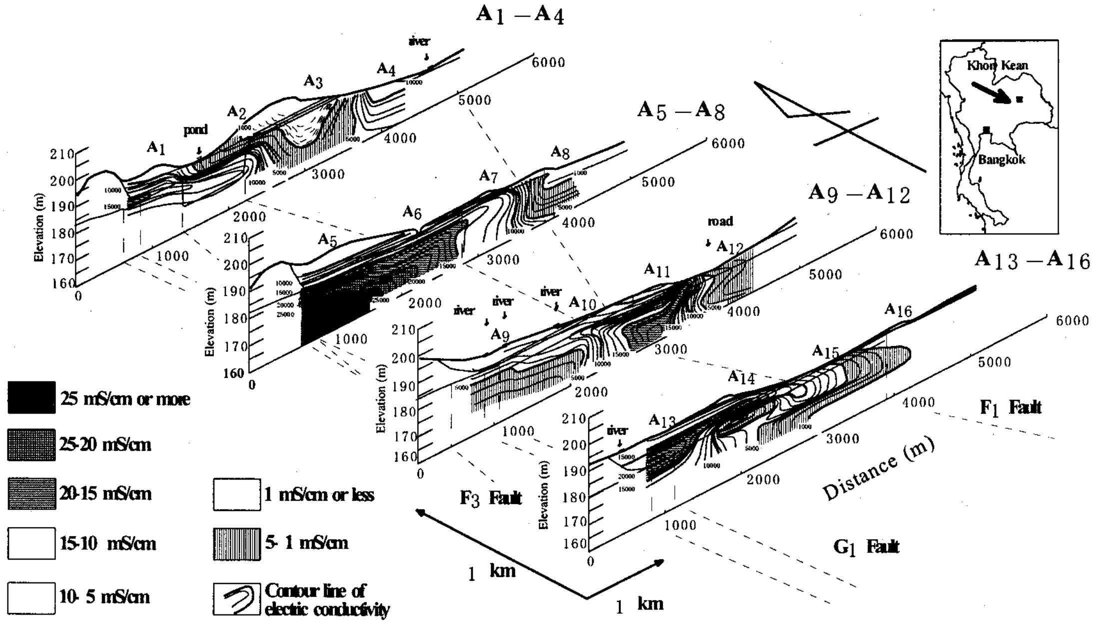

Fig. 6. Distributions of Electric conductivity in geological sections in April 1995.

highest potential well, corresponds to a pattern intermediate between the recharge area and discharge area. The sites of Type 4 are usually found in the vicinity of the faults. Type 2 is a type that is not related with a conception of recharge and discharge. Further discussion on Type 2 is excluded due perhaps to a faulty casing rather than to genuine groundwater movement.

Fig.5 shows the typical annual cyclical fluctuations of monthly precipitation, groundwater level and EC at A5 in the vicinity of the G1 fault. Two periods alternately appeared. In one period, the groundwater level of the 5m well was higher than at of the other wells, while in another period, the groundwater level of the 5 m well was lower than the others. EC rose rapidly when the groundwater level of the 15m well was the lowest. It should be noted that the saline water groundwater rises in the period of positive differential of groundwater levels between 15m well and 5m well.

Fig.6 shows EC distribution in July 1995 when EC showed the maximum value for the observation period. EC values at A1, A5, A11, and A13 where G1 and the F1 fault are distributed show 10 mS/cm or more, which generally increased with depth.

Geochemistry

Fig.7 shows the distribution of hexadiagrams. The geochemical characteristics of groundwater in the study area show a Na-Cl type except groundwa-

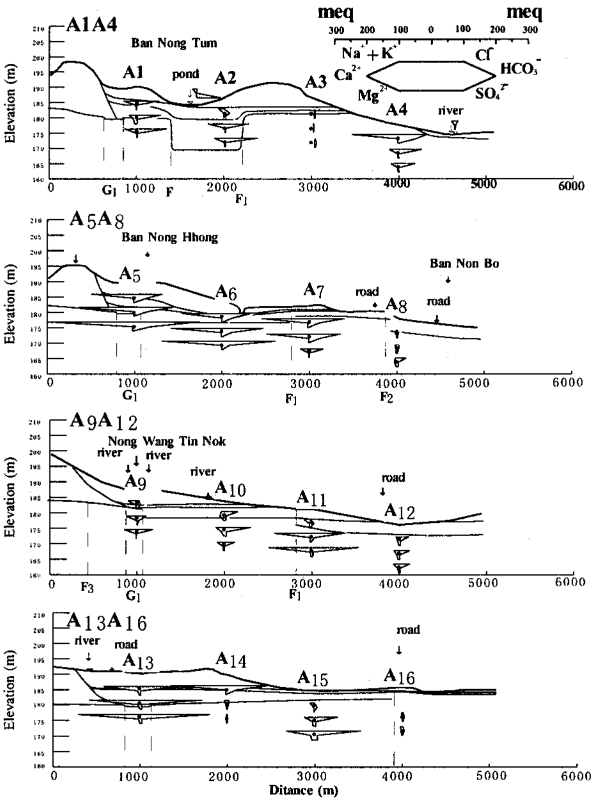

Fig. 7. Distribution map of hexadiagrams at each investigatio well.

ter at A3, A8 (10 m well, 15 m well), A14 (10 m well, 15 m well) and A16, where the type is ambiguous due to low ion concentrations.

The Cl/Br ratio was used as a parameter to identify the origin of the salt because Br^- and Cl^- are conservative elements. According to the review of the Cl/Br ratio in rock and water by Holser (1966), the distribution of Cl/Br is divided into four general groups; Cl/Br of the igneous rock, sedimentary rock and meteorites show about 100. Cl/Br of seawater (average: 288), halide in the atmosphere and connate water ranges from 200-400, while that of geothermal water is about 900 and that of rock salt is 5000 or more. Fig.8 shows the Cl/Br ratios of groundwater and surface water in the study area. The maximum Cl/Br ratio was 8799 at the 15 m well at A13. The minimum was 43 at the 10m well at A3. The Cl/Br ratio of the pond water, which has the lowest chlorine concentration and is used for drinking water, is 104. Most Cl/Br ratios ranged from 1500-3000, larger than the Cl/Br ratio of normal seawater. The ratios of Cl/Br can be classified into three types: rock salt type (2500 or more of Cl/Br ratio), secondary salt type (288-2500) and rain water type (288 or less) (Fig.8). The rock salt type has a Cl/Br ratio of 2500 or more. Data from geochemical studies, as well as geological studies, indicate that the main origin of NaCl in groundwater at A5, A11 and A13 is a solution from salt rock.

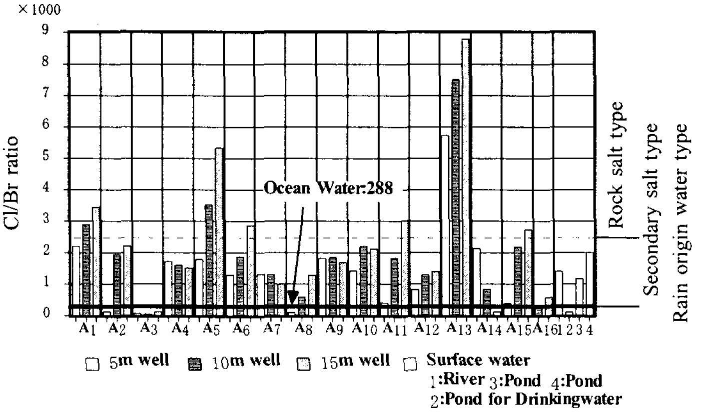

Fig. 8. Cl/Br ratios of groundwater and surface water in the study area.

Tritium concentration

Trends in tritium in precipitation are now fairly well known; the natural tritium concentration in the precipitation was presumed to be about 10 TU. After nuclear testing in 1952, the tritium concentration abruptly increased, reaching its maximum value in 1963. Afterwards, the tritium concentration continually decreased. It has now almost returned to its natural level.

Fig.9 shows the distribution of tritium concentration. Tritium concentration in groundwater ranged from 3.1 (A11 15 m well) to 15.0 (A8 15 m well), river water has 9.1 TU and the pond water for drinking shows 8.6 TU, which may indicate an average trit-

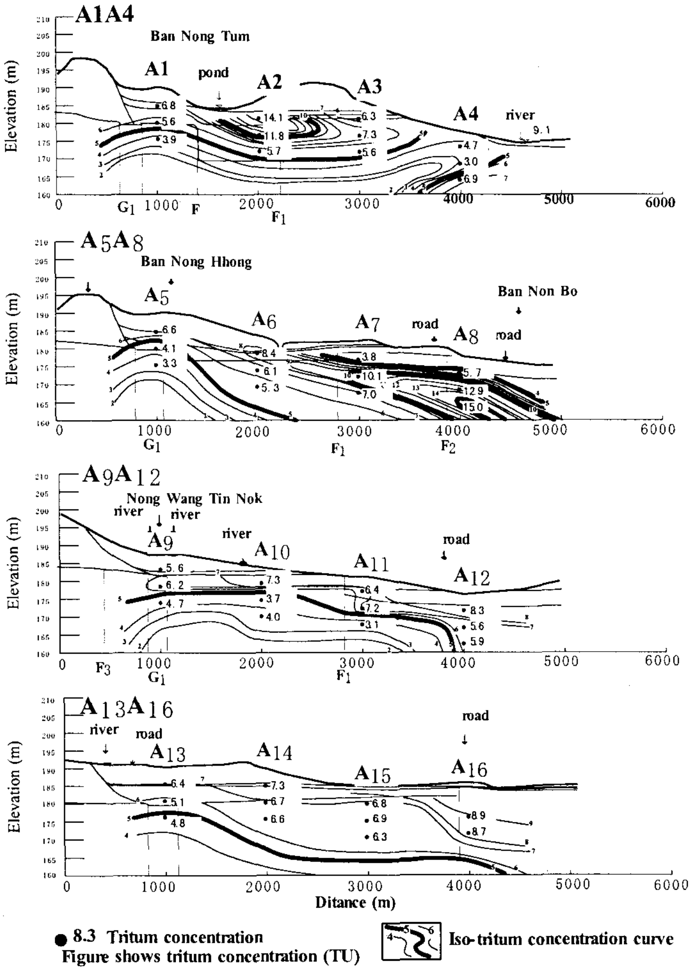

Fig. 9. Distribution map of tritium concentration at each investigatio well.

ium concentration of the latest precipitation. The distribution patterns of tritium concentration in sections A1-A4 and A5-A8 show that high tritium concentration zones of groundwater (14.1 TU:A2 5 m well and 15.0 TU: A8 15 m well) were recharged from pond and river.

The zigzag line in Fig.10 shows the annual average tritium concentration in precipitation from Tokyo and Tsukuba between 1961 and 1997 (Imaizumi et al., 1999). The two straight lines show the decay lines of the precipitation of 10 TU in 1952, and 1,000 TU in 1963 calculated using the half life for the radioactive decay of the tritium: 12.35 years. The lines between the decay lines show estimated decay lines in which tritium concentrations in precipitation decay to 3 TU and 15 TU in 1997.

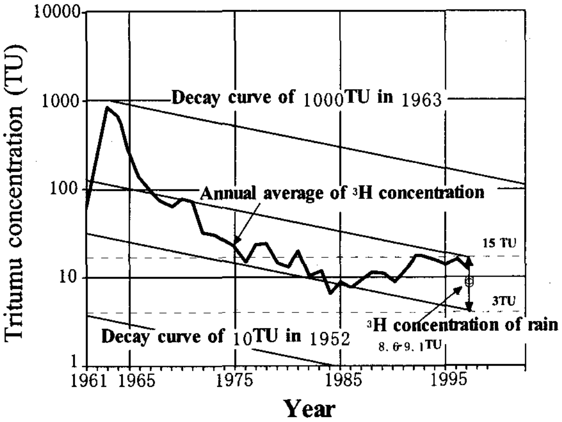

Fig. 10. Relationship between the tritium concentrations and annual average tritium concentration in precipitation from Tokyo and Tsukuba between 1961 and 1997 (Imaizumi et al., 1999).

If a mixing of precipitation (new water) with groundwater (old water) dose not occur and groundwater flows as piston flow, the age of recharging precipitation of groundwater with 15 TU in 1997 could be estimated at 1967-1970 years. The velocity of groundwater flow was calculated to be 5.3×10^{-7} m/s and 2.1×10^{-6} m/s respectively from a duration time of 30 years and distance of groundwater flow 500m from the pond to the A2 5m well and 2000m from the river to the A8 15m well.

The hydraulic conductivities range from 2.47×10^{-4} to 6.48×10^{-3} and 1.16×10^{-5} to 8.57×10^{-4} cm/sec for the Quaternary sand and gravel unit and M.F., respectively (Srisuk, 1994). Because the estimated values of velocity of groundwater flow are compatible with the hydraulic conductivities, it is considered that 30 years is a reasonable period for recharging groundwater.

Groundwater of the 5 m well at A2 and 15 m well at A8, which is recharged by the pond and river, respectively, recharge groundwater shows low EC. On the other hand, the distribution pattern of the tritium concentration shows a decreasing trend with depth at A5, A11 and A13, where groundwater of the Na-Cl type trends to show increasing EC with depth. The origin of Na-Cl in groundwater at A5, A11 and A13 is considered to be old groundwater containing a rock salt solution on the basis of the geological structure and geochemistry.. Therefore, the distribution pattern of tritium concentration may result from the mixing of new water with old water.

6. Conclusions

Hydrogeological survey and geochemical analysis were carried out in Phra Yun area, Northeast Thailand, which is a typical salt-affected area for an understanding of hydrogeological groundwater behaviours. Geological survey reveals the presence of G1 and F1 faults. Electromagnetic ground conductivity prospecting shows that the high conductivity zones of 15 mS/cm or more are distributed at underground of the G1 and F1 faults where saline groundwater is discharged. The distribution patterns of tritium concentration show that high tritium concentration zones of groundwater were recharged from pond and river. The behaviours of saline groundwater are closely related to the differential between groundwater levels in the 5m well and 15m well. Data from geochemical studies, as well as geological studies, indicate that main origin of Na-Cl in groundwater at A5, A11 and A13 is a solution from salt rock. The salinization of groundwater in northeast Thailand is mainly induced by the natural phenomenon, which is related to the rock salt that widely underlies this region. However, further consideration on human activities such as over-pumping that affect the groundwater level is necessary before we come to our final decision of the salinization of groundwater.

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