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Water Circulation Rates in Arid Regions of Xinjiang, Western China, from the Viewpoint of Tritium*

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Abstract: *Tritium concentrations are used to trace water circulation in the Urumqi and Turfan basins in the Xinjiang, western China. Tritium analyses were made for 77 water samples of river waters, groundwaters, spring waters, lake waters and glacier ice collected in summers in 1992 and 1994. The tritium concentrations in the waters are in a wide range from 0 to 125 TU, most of which are considerably high compared with those of most waters in Japan, because tritium levels in precipitation in the area are over ten times as high as those in Japan. River waters originating in glacier regions contain melt glacier, the proportion of which is over 0.5 to river water. The mean residence time of circulating meteoric water in the mountain regions is estimated to be about 15 years. Most groundwaters and spring waters in the flat regions are mainly derived from river waters originating in glacier regions. The groundwater of greatest tritium concentrations in wells in Urumqi City is derived from Urumqi River about 25 years ago. It takes several ten years for river water to pass the underground to many springs. Some groundwaters and spring waters have taken a long time more than 40 years to travel under the ground. Enrichment of tritium in lake water by evaporation is considered to estimate the contribution of groundwater flow to the recharge of lake. Various contributions of groundwater to lakes are inferred for the various type of salinity in closed or semi-closed lakes. The inflow rates of groundwater to salt lakes are small as against fresh water lakes.*

Keywords: *Urumqi, water circulation, tritium, residence time*

1. Introduction

Urumqi and Turfan basins are situated in Xinjiang, western China, extending for over 500 km^2 with several closed salt lakes. The area is essentially flat and semi-arid, surrounded by the lofty Tianshan Mountains with perpetual snow and glacier. The chemical characteristics of river water,

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spring water and lake water in the area have been investigated by Watanabe *et al.* (1995). It is noted that various qualities of water in closed lakes change depending on the salt concentration. Main factors to effect to the water quality of closed lakes are evaporation, precipitation and morphological conditions (Watanabe and Horiuchi, 1996). The main sources of groundwater in the flat region are considered to be river water originating in perpetual snow and glacier regions, as the annual precipitation in the flat regions is less than 100 mm.

Tritium is created naturally in the upper atmosphere by the interaction of nitrogen with cosmic radiation, and is transported into groundwater systems by meteoric water. The tritium concentration in precipitation in many part of the world rose after a series of thermonuclear detonation tests in the 1950's, and by 1963 had reached a peak concentration two orders of magnitude above the previous natural level. The relatively short half-life (12.43 a) makes this isotope a valuable tracer of water movements occurring over time spans of a century or less. The tritium content of groundwater can thus give useful information on the circulation of water. In some cases, it is a good indicator of the residence time of water in the groundwater system.

Tritium concentrations are used to trace water circulation in the Urumqi and Turfan basins. Water samples for tritium measurement were collected from rivers, wells, springs and lakes in summers in 1992 and 1994. Fortunately, in 1986, tritium concentrations in precipitation, glacier, river water, groundwater and spring water in this area have been measured by the Chinese Academy of Science (Shi and Cai, 1997). The precipitation data can be referred to estimate the variation of tritium concentration in precipitation in the past in the study area. The data for various types of water in 1986 will be compared with new data from the hydrological viewpoint in the present paper.

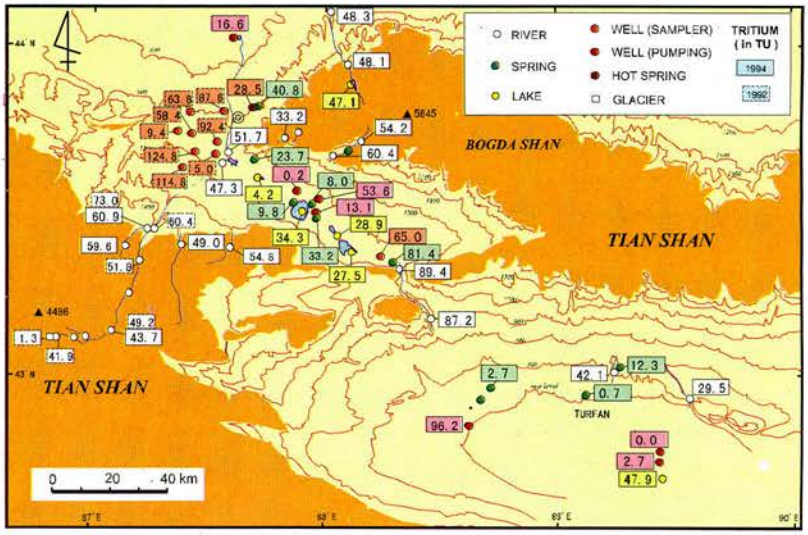

Fig. 1: Sampling points of river, spring, lake and well in Urumqi and Turfan areas in 1992 and 1994

2. Sampling and results

Samples of river water, groundwater, spring water and lake water in the area were taken twice, from 14 to 16 July in 1992 and from 27 June to 16 July in 1994. A total of 77 water samples (20 samples in 1992 and 57 in 1994) were collected for tritium and chemical analyses. The locations of sampling points are shown with sample numbers (or symbols for samples of 1992) in Fig. 1.

Tritium analyses were made using the method of liquid scintillation counting (Aloka LSC-LB-III). The accuracy of this counting procedure is 0.5 TU for tritium concentration lower than about 5 TU. The term TU (tritium unit) denotes the number of tritium atoms per 10^{18} atoms of hydrogen. The results of tritium analyses are shown in TU at the sampling points in Fig. 2.

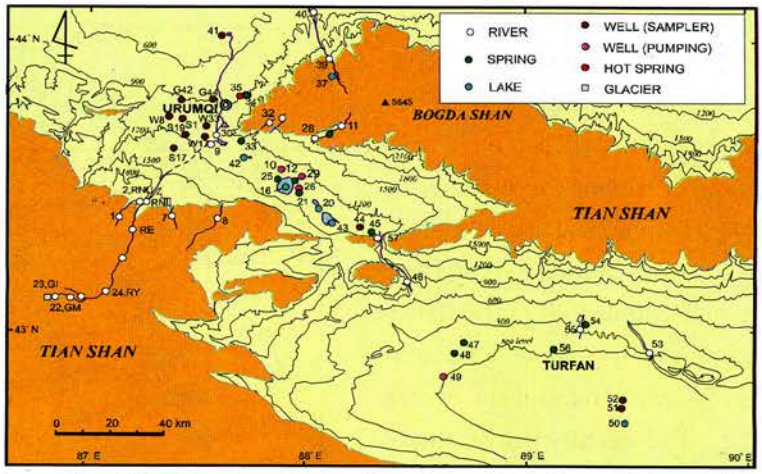

Fig. 2 Tritium concentrations in waters from river, spring, lake and well in 1992 and 1994

The tritium concentrations in water samples fall into a wide range of 0 to 125 TU, most of which are considerably great, compared with those of most waters in Japan.

It is noticed that the tritium concentration of river water at the source point of Urumqi River (at the glacier end: GM in Fig. 1) has already become higher, which is nearly same as that in the middle stream of the river (RY, RE and RNL), although tritium concentration in glacier ice (GI) is very small. The tritium concentrations in Urumqi River water have a tendency to increase with distance towards downstream. According to data in 1986, 1992 and 1994, the tritium concentrations in the Urumqi River water seem to decrease gradually with time as a whole.

Tritium concentrations in most spring waters were relatively small compared with those of river waters. In most lakes, tritium concentrations in waters were similar to those of river waters. However, tritium concentrations of waters from springs or pumped-wells near lakes are very small. An exception was in a case of Shaiwopu Lake (No.16 in Fig. 1), where tritium concentration in waters from springs and pumped-wells near the lake were not so small.

On the other hand, it is conspicuous that great tritium concentrations over 100 TU occurred in groundwaters collected from wells by a sampler in Urumqi City in 1992. The great tritium concentration occurred also in 1994 in a big spring (No.45) located near the water divide between Urumqi and Turfan basins, and in river (No. 46, 57) originating from the spring.

3. Estimation of tritium concentration in precipitation in the area

Interpretation of tritium concentrations measured in river waters, spring waters, groundwaters and lake waters requires an estimation of the natural variation of tritium concentration in precipitation in this area. IAEA World Survey Network Stations monitor tritium concentration in monthly precipitation at many points in Eurasia.

The tritium monitoring in precipitation began at Ottawa in the earliest stage in 1953. Monitoring at Tokyo started in 1961 by IAEA. From 1980 onward, the tritium concentration in monthly precipitation has been monitoring at Chiba near Tokyo by National Institute of Radiological Sciences. There is a good correlation in annual means of tritium concentrations in precipitation between Tokyo and Ottawa. Then the annual means of tritium concentration at Tokyo before 1960 can be estimated by using Ottawa record. There are also correlations in the annual means among stations located in the Northern Hemisphere at each other. The distribution of annual mean of tritium concentration in precipitation in Eurasia obtained in this manner is shown in the Fig. 3. Number indicated in the Fig. 3 denotes a factor to be multiplied by the annual mean at Tokyo. We will represent the factor by a symbol *M*.

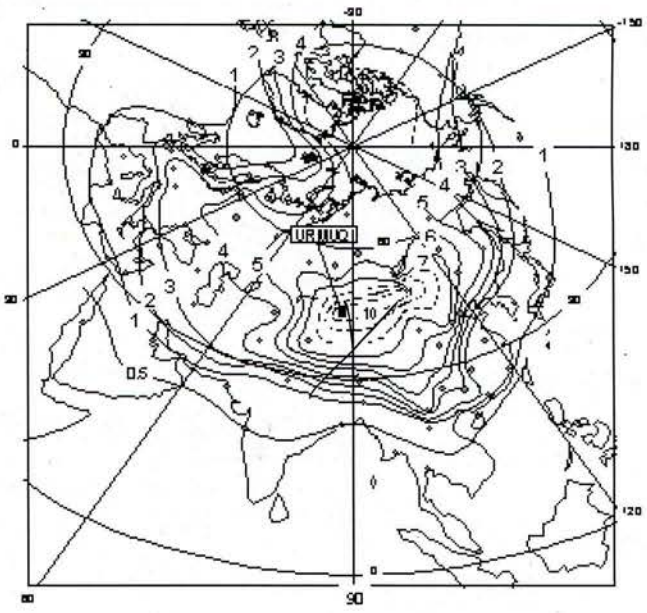

Fig. 3 Distribution of annual mean tritium concentration in precipitation in Eurasia. Fig. is the factor (*M*) of tritium concentration when *M*=1 at Tokyo.

The greatest factor of 10.3 is found at Ulan Bator. The average of the factors *M* among 8 IAEA stations around Urumqi (Omsk, Enisejsk, Novosibirsk, Irukutsk, Tashkent, Ulan Bator, Hetian and Lhasa) is 6.0.

At Urumqi, the values of tritium concentration for 4 precipitations measured in 1986 by Shi and Cai (1987) were 105.7, 56.5, 108.0 and 84.2 TU. The average of these values is corresponded to a factor *M* of 12.5 as against the annual mean in 1986 at Tokyo. Although the number of the precipitation data measured at Urumqi is not sufficient to take correlation with those at Tokyo, the factor is the only instance. The value of this factor is not inconsistent with the general distribution in the central part of Eurasia (Fig. 3).

Thus, it can be recognized that the tritium level in precipitation at Urumqi is highest over the world.

4. Effect of evaporation to tritium concentration in lake water

A water sample from Ayding Lake (No. 50 in Fig. 1) was the greatest tritium concentration in lake waters collected in 1994. The site for collecting the water sample was in the muddy swamp. Water sampled was saturated with salt in puddle. The tritium concentrations in groundwater from wells near the sampling point of the Ayding Lake were very small (Fig. 2). The recharge amount by

groundwater may be small, even if groundwater supply to the lake exists.

Tritium in the lake water from the swamp seems to be enriched by evaporation of recent precipitations. In order to estimate the evaporation effect to the tritium concentration in lake water, a model describing isotopic fractionations between liquid water in the lake and vapor in the atmosphere above the lake surface is required.

The fractionations accompanying evaporation can be understood by subdividing the process in steps according to Craig and Gordon model (Gonfiantini, 1986). That is, the isotopic fractionation factor is composed of an equilibrium separation factor between liquid and vapor at the surface, a kinetic factor transporting vapor from the surface to the atmosphere, and the relative humidity in the atmosphere.

The kinetic factor is approximated by the square root of the ratio of diffusion coefficients of H_2O to HTO in air. The kinetic factor in fractionation process is estimated to be 1.016. The relative humidity in the atmosphere may be approximated to be zero in the arid condition. The relative vapor pressure of HTO to H_2O is 0.90 to 0.92 in a temperature range of 20 to 40 ℃(Jacobs, 1968). The equilibrium separation factor, which is the reciprocal of the relative vapor pressure, is 1.086 to 1.111. We will use a value of 1.099 as the equilibrium separation factor. After all, the fractionation factor α of tritium at the lake surface estimated to be 1.116.

A water balance equation for closed lake in a steady state is as follows,

$$\frac{dV}{dt} = Q_P + Q_G - Q_E = 0$$

where Q_P, Q_G and Q_E are precipitation, recharge rate by groundwater and evaporation rate. V is water volume of lake, and t is time. If it is assumed that the water in a shallow lake mixes rapidly, the mass balance equation will be expressed as follows,

$$\frac{d(CV)}{dt} = C_P Q_P + C_G Q_G - C_E Q_E - \lambda(CV)$$

where C is the tritium concentration in lake water, and λ is the radioactive decay constant of tritium ($0.0558a^{-1}$).

The total flow rate Q passing through the lake is equal to evaporation rate Q_E for closed lakes with no inflow river. We will introduce here a parameter β defined as: $\beta = Q_P/Q$, which means the proportion of direct precipitation to the total flow rate Q. Thus, the proportion of groundwater recharge rate is expressed as $1-\beta$ ($= Q_G/Q$). The mean residence time of water (turnover time of water) in the lake can be defined as $T=V/Q$.

By combining these equations, we get the differential equation for C:

$$\frac{dC}{dt} + \left(\lambda + \frac{1}{\alpha T}\right) \cdot C = \frac{1}{T} \cdot [\beta \cdot C_P(t) + (1-\beta) \cdot C_G(t)]$$

where α is the fractionation factor: $\alpha = C/C_E$.

Integrating the above equation, we obtain the expression for the variation of tritium concentration $C(t)$ as:

$$C(t) = \int_0^{\infty} [\beta \cdot C_P(t-\tau) + (1-\beta) \cdot C_G(t-\tau)] \cdot \frac{1}{T} \cdot \exp\left[-\left(\lambda + \frac{1}{\alpha T}\right)\tau\right] \cdot d\tau$$

In order to apply this equation to natural lake waters, tritium concentrations of precipitation and groundwater are required as input. For the Ayding Lake (No.50, in Fig. 1), the tritium concentration in groundwater can be zero for the reason mentioned above. The residence time of water in such the swamp condition might be less than a few years at longest.

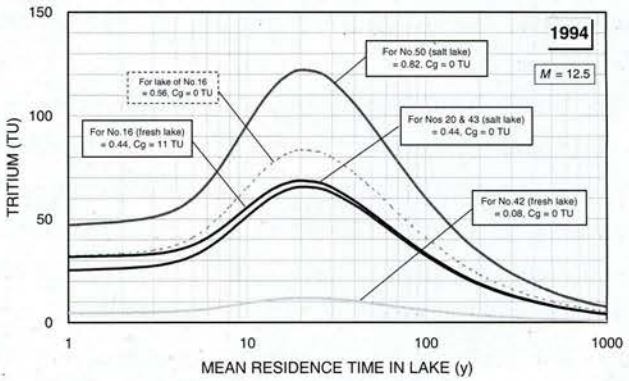

Fig. 4 Calculated relationship between tritium concentration influenced by evaporation in 1994 and mean residence time in lake

At first, we will estimate the lower limit of tritium concentration in precipitation in the area by applying the above equation to the tritium data of 47.9 TU of the lake water in 1994 under the extreme condition of $\beta = 1$ (zero contribution of groundwater). As the result, we can confirm that the factor M of tritium concentration in precipitation should be a value greater than about 10 to satisfy the tritium data in the lake water for a mean residence time less than a few years.

If we adopt a factor M of 12.5, which is obtained by averaging the tritium data in precipitation observed at Urumqi in 1986 (as mentioned above) as the input C_P (assuming $C_G = 0$), the best fit of β value for the data of the Lake is estimated to be 0.82 (Fig. 4).

The estimated proportion β of direct precipitation to the total recharge of lake seems, however, to be too great, because the annual precipitation of the area is less than 50 mm and the potential evaporation rate might be greater than 3 000 mm per year. As the number of tritium data in precipitation in this area are very limited, we will use reluctantly the factor M of 12.5 in this paper.

Applying the theory by the similar way to a small lake (No.42 in Fig. 1) whose water is fresh with low tritium concentration, small β value of 0.08 is estimated.

The lake water may be supplied mainly by groundwater with small tritium concentration. In the case of salt lakes (Nos 20 and 43 in Fig. 1) in the Urumqi basin, the estimated β is 0.44.

By the way, for the relatively large lake of fresh water (Chaiwopu Lake: No.16 in Fig. 1), spring waters and groundwaters near the lake contain relatively high tritium content in a range from 8.0 to 13.1 TU. If zero tritium content in the inflow groundwater is supposed, β of 0.56 is estimated. If the tritium content of recharge groundwater is assumed to be 11 TU during these recent several

years (the mean residence time is supposed to be roughly less than ten years), β of 0.44 is estimated (Fig. 4). The β value is similar as that estimated for salt lakes. However, the β value estimated on the lake should be recognized to be an upper limit, because the lake is not closed completely.

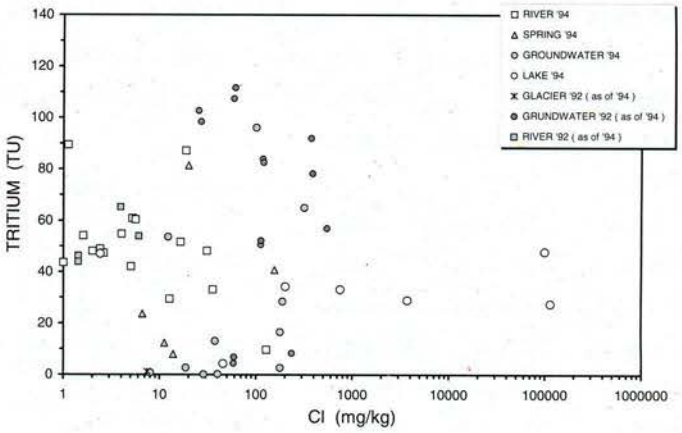

Fig. 5 Tritium concentration versus Cl concentration in waters from river, spring, lake, groundwater and glacier in 1992 and 1994. TU values in 1992 are revised as of 1994 by radioactive decay.

As a whole, it seems that the proportion of direct precipitation to the total recharge of lake has a tendency to increase with salt concentration of lake water.

The chloride concentration of these lakes is as follows, lake of No. 42: 45.6 ppm, No. 16 (Chaiwopu Lake): 202.0 ppm, No. 20 (Small Salt Lake): 3 700 ppm, No. 43 (Salt Lake): 115 000 ppm and No.50 (Ayding Lake): 100 000 ppm. From the above tritium analyses, we could suppose some conditions that salt lakes are formed.

The main condition for forming salt lakes might be whether the lake is closed or not. The fresh lakes of No. 42 and 16 are not closed completely.

The second condition related to the formation of salt lakes may be whether the groundwater is fresh or salty. Although the salinity in groundwater is not always related to its tritium concentration as seen in Fig. 5, water qualities may be related to the residence time of water. The tritium content in groundwater provides a useful information on residence time of water under the ground. The residence time, which is inversely proportional to the flow rate, is connected to the discharge rate of groundwater to lakes.

As discussed above, salt lakes seem to receive relatively large contributions of direct precipitation as against the groundwater supply, in comparison with fresh water lakes.
Thus, the discharge rates of groundwater to the salt lakes are considered to be relatively small.

5. Tritium concentration in discharge water

5.1 Modeling of tritium concentration in discharge water

To interpret the measured tritium concentrations in river waters, there is a need for model describing water behavior in the drainage region with respect to meteoric water infiltrated from the surface.

If the subsurface water system is an ideal condition, the subsurface water will follow such as the pattern sketched in Fig. 6 (in the downside figure). The shape of the tritium-versus-depth profile (if obtained) in the unsaturated and saturated zones will reflect the time history of tritium concentration in the precipitation and the recharge rates.

In a mountain region, the water table may be deep in rock formations. The tritium concentrations of water reaching the water table will be influenced by dispersion during infiltrating processes through unsaturated zones in the fractured system. The infiltrating water is supposed to pass fast the media because of its poor porosity.

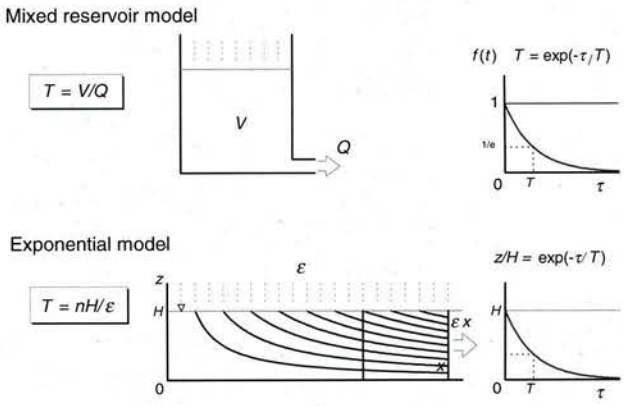

Fig. 6: Mixed reservoir model and exponential model

For transport of tritium in a groundwater body, it can be assumed that advective transport predominates over macroscopic dispersion, except near the upper boundary of flow (Kitaoka, 1988).

We will define the concentration C as the concentration averaged over the thickness of the aquifer along a cross-section. If the macroscopic dispersion effect associated with an inhomogeneity is due to a vertical fissure in the aquifer, waters passing across the section could mix vertically along the section. In this case, the concentration C defined above can be considered to be an adequate expression. A discharge point, such as a spring or a pumped well, can be regarded as a singular point at which vari- ous streamlines originating in the related recharge area are concentrated in a steady state.

The tritium concentration of drainage water $C(t)$ at time t can be expressed as:

$$\frac{\partial C}{\partial t}+u\frac{\partial C}{\partial x}=-\left(\lambda+\frac{1}{T}\right)C+\frac{C_P(t)\cdot r(t)}{T}$$

where x is the horizontal distance in the flow direction, u is the pore water velocity averaged over the section, $C_P(t)$ is the tritium concentration in recharge water and $r(t)$ is the weighting factor for the recharge amount at time t. The parameter T is defined as:

$$T=\frac{nH}{\varepsilon}$$

where n is the effective porosity, H is the thickness of groundwater and ε is the recharge rate per unit area.

When the start of time t is put sufficiently long before the concerned point in time, the solution of

the above differential equation does not depend on the initial value of concentration C and the pore water velocity u. The final solution is as follows:

$$C(t)=\int_0^{\infty} C_P(t-\tau)\cdot r(t-\tau)\ \cdot\frac{1}{T}\cdot\exp\left[-\left(\lambda+\frac{1}{T}\right)\tau\right]\cdot d\tau$$

Tritium concentration $C(t)$, averaged over a cross-section of the aquifer, can be approximated by an exponential distribution of residence times of water in the aquifer. From the theory, it can be seen that the average tritium concentration $C(t)$ does not depend on the horizontal position as long as T is uniform in the flow direction.

The mean residence time T is represented by the water volume nH stored in a column of unit area divided by the recharge rate ε per unit area. This is the same definition as so-called "turnover time" of a well-mixed reservoir system (in the upside of Fig. 6), because it denotes the ratio of the whole water volume V in an aquifer to the volume rate Q of water passing through the aquifer if the thickness H is constant.

It is considered that the average concentration $C(t)$ combined with the exponential model represents approximately the actual discharge processes of tritium, and that the residence time of water passing through a drainage region must have a distribution similar to an exponential function reflecting the hydrological characteristics of the drainage system.

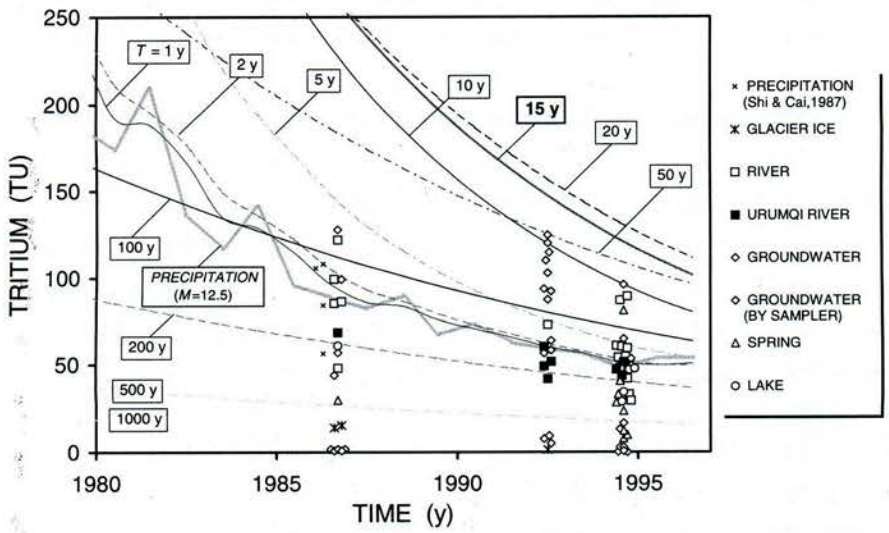

Fig. 7 Tritium data of river water, groundwater, spring water, lake water, glacier ice and precipitation. A line graph denotes the precipitation (the annual mean is assumed to be 12.5 times as great as that at Tokyo). Curves are outputs of exponential model for different mean residence times T.

In order to apply the model, one needs to know the monthly (or annual) contribution of the re-

charge amount $r(t)$ to the groundwater system. However, it is difficult to estimate the seasonal or secular change of the recharge contribution because of complex interplay of precipitation, evaporation, melt of snow and glacier ice and infiltration condition at the surface. It will be assumed that the annual recharge amount to the groundwater system in the recharge region is constant every year. We will use simply the annual mean tritium concentrations, putting $r(t)$=1 when applying the above equation.

5.2 Output of the exponential model

Fig. 7 shows the calculated output curves using the exponential model for a residence time: T = 1, 2, 5, 10, 20, 50, 100, 200, 500 and 1 000 a, assuming instantaneous recharge of precipitation (as M = 12.5) to groundwater systems. The tritium data for various type of water measured in the area down to the present are plotted in the figure. All the tritium data fall into a range of outputs from the exponential model.

5.3 Urumqi River

In Fig. 7, solid square marks denote Urumqi River, which show to be corresponded "apparently" to the residence time of 150 to 200 a. Most river waters fall into a range between 60 a and 300 a. These residence times seem too long, as compared with those in Japan.

Many rivers flowing into the Urumqi and Turfan basins originate in the perpetual snow and glacier regions in the lofty Tianshan Mountains. The high-water season of these rivers is in high-air-temperature periods. This suggests that the main source of the river water is melt snow and ice in the mountain area.

The melt glacier may contain tritium-free water precipitated long time ago. It will be assumed that river waters can be separated simply into two parts: discharges from circulating water including melt from newly deposited snow, and discharges from melt glacier originated from very old precipitations. Here, we will call, for the convenience of simplicity, the former as meteoric water and the latter as glacier ice.

If the tritium content of glacier ice is assumed to be zero and that of precipitation is prescribed as M = 12.5, we can estimate the proportion of meteoric water to river water from the measured tritium data of river water by using the exponential model. In other words, the proportions of meteoric water accompanied with various mean residence times can be estimated by dividing the measured tritium concentration by the output concentration (at the concerned time of the data) due to the input of the prescribed precipitation, for systems with various residence times. In Fig. 8, curves drawn by thin lines (solid, dotted and broken curves) are the calculated proportion of meteoric water to river water for 8 tritium data of Urumqi River water in 1986, 1992, and 1994.

On the other hand, there were great tritium concentrations in groundwater from wells in Urumqi City in 1992, as mentioned above. It is likely that such the groundwater with great concentrations was derived from Urumqi River water when its tritium level had been high in the past. The main source of groundwater in the Urumqi City is considered to be river water from the Urumqi River,

because the infiltration from the ground surface in the flat region must not be predominant in the arid environment, even though irrigation canals are dispersed in the flat region.

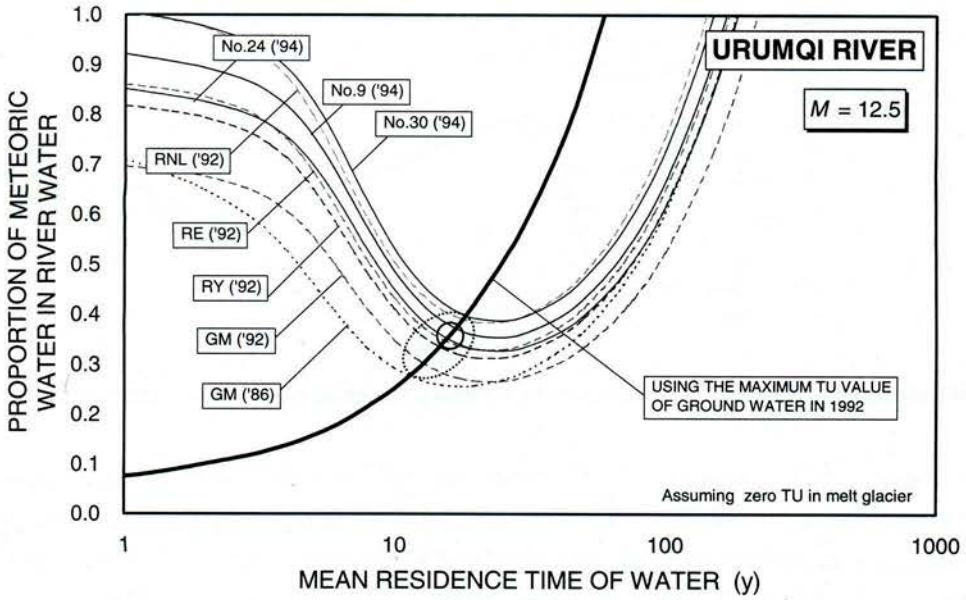

Fig. 8 Proportion of meteoric water to river water against mean residence time calculated by using tritium data measured for Urumqi River in 1986, 1992 and 1994. Also shown by using the greatest TU value of groundwater in Urumqi City in 1992. These are based on the exponential model under the assumption of no tritium content in melt glacier.

We will assume here that the greatest concentration of the groundwater corresponded to the greatest concentration of river water in the past. Then, using the greatest concentration of groundwater in 1992, we can estimate the proportion of meteoric water to the Urumqi River water for various residence times of meteoric water. A bold curve in Fig. 8 shows the proportion of meteoric water with respect to the greatest concentration of groundwater in 1992.

Thus, we can obtain the relations between the meteoric water contribution to river water and the mean residence time of meteoric water, in two different ways. Using Fig. 8, the meteoric water proportions to river water could be obtained to satisfy both the estimated relations by independent ways. As the result, the meteoric water proportions seem to have a tendency to increase with distance toward downstream from the original point at glacier end. And the mean residence times of meteoric water increases from about 11a to 18a with the proportion of meteoric water to river water. Using the tritium data in the middle stream, the proportion of meteoric water to river water is about 0.35, and the mean residence time of the meteoric water part is about 15a, as indicated in Fig. 8.

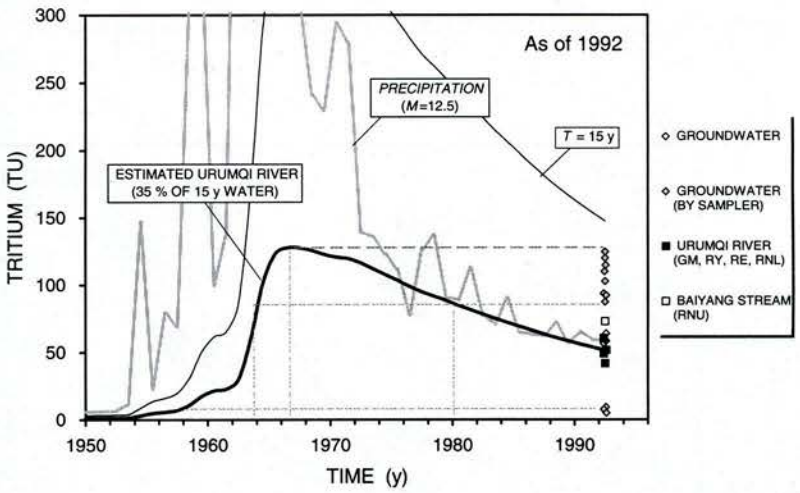

Fig. 9 Estimated tritium concentration for Urumqi River as of 1992 and tritium data in 1992.

Fig. 9 shows the variation of tritium concentration of river water calculated under the meteoric water proportion of 0.35 to river water by a bold curve. In the Fig., all the TU values of precipitations and calculated curves are converted as of 1992 by radioactive decay, in order to compare with the data measured in 1992. The data of Urumqi River are shown by solid squares. For the great tritium concentrations in groundwater, we can estimate the travel time
for the river water to pass the underground to the observed wells by using this figure, as discussed later.

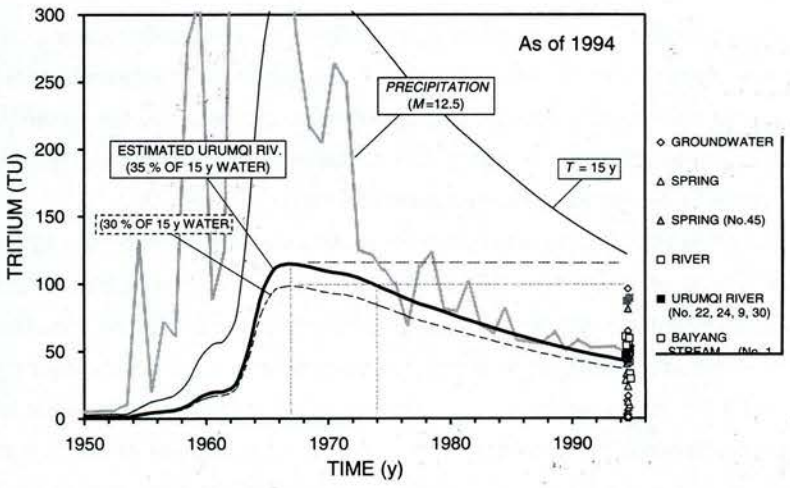

Fig. 10 Estimated tritium concentration for Urumqi River as of 1994 and tritium data in 1994.

For the data in 1994, similar results can be obtained as shown in Fig. 10. All the data are found within the maximum of concentration (in 1966) calculated for Urumqi River water (indicated by a bold curve). The data of greatest TU value measured in 1994, which is from a well (No. 49) located in western part of Turfan basin, could be corresponded that the proportion of meteoric water to recharge water is about 30 %, as shown in Fig. 10. The proportion of meteoric water is similar to that of Urumqi River.

5.4 Other rivers and springs

As discussed above, the residence time of drainage systems in the recharge area including perpetual snow and glacier regions is inferred to be around 15 a from the tritium concentrations in Urumqi River water. A thin solid curve in Fig. 11 shows the time variation of output curve for a meteoric water circulation system with residence time of 15 a. The residence time reflects hydrologic states over a wide area of the recharge regions.

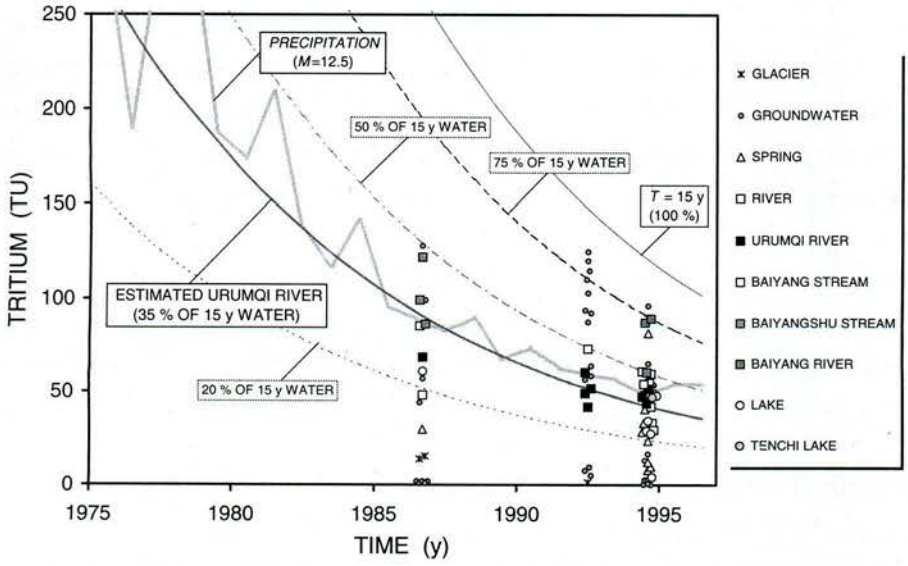

Fig. 11 Estimated tritium variations for river water and measured tritium data for various type of water. Thin solid curve represents the output from a system of 15 a mean residence time due to direct input of precipitation. Thick curve is estimation for Urumqi River water, which is on the condition of 35 % contribution of meteoric water with 15 a residence time. Dotted and broken curves are 20, 50 and 75 % contribution of 15 a water. These calculations are based on the exponential model under the assumption of no tritium content in melt glacier.

If a tentative hydrologic condition such as the annual recharge of 0.4 m per unit area in the recharge regions is supposed, then the mean residence time of 15 a is corresponded to a water volume of 6 m per unit area (that is a height of water column). Assuming the effective porosity in the rock forma-

tions is 0.02 to 0.002 in the mountain region, the vertical range of groundwater flow could be corresponded to in a order of 300 m to 3 000 m. Even such the rough calculation, the estimated range of groundwater does not seem so unrealistic for the lofty Tianshan Mountains. The mean residence time of water in the mountain area is likely to be around 15 a.

Other dotted and broken curves in Fig. 11 denote the calculated outputs for river water with some other proportions (0.2, 0.5 and 0.75) of meteoric water to river water. Most river waters in the area are found in a range of proportion of meteoric water between 0.2 and 0.75 to river water.

As seen 1994 data in Fig. 11, the great tritium content at the spring of No. 45 and the river waters (No. 46, 57) originated from the spring can be corresponded apparently to a proportion of about 0.7. The spring water may be discharged from underground stream, taking about 15 to 30 a to pass the underground to the spring (Fig. 10). Except for the river originating from the spring of No.45, most river waters contain meteoric water in a proportion range of 0.2 to 0.5 from Fig. 11. That is, river waters contain predominantly melt glacier.

It is noticed in Fig. 11 that the proportions of meteoric water to river in rivers originating in relatively small altitudes in mountains (compared with Urumqi River) are relatively great as compared with that of Urumqi River. Such the rivers are Baiyang stream (No. 1, 2) and Baiyangshu stream (No. 11, 28). This may suggest the difference of relative contribution of melt glacier to river waters.

In reality, Sangong River (No. 37, 39 and 40 in Fig. 1), which originates in the lofty Bogda Shan, where glacier abounds, shows similar tritium values to the Urumqi River. Tenchi Lake (No. 37) located in the upper-reach of the river shows the same value of tritium concentration to the river water in the lower-reach.

In these circumstances stated above, tritium contents in river waters in the area are substantially influenced by melt glacier. Tritium concentration in river water may depend on the areal proportion of glacier in the upper part of drainage area. Melt glacier contributes predominantly to the water resource in the flat regions in the basins

6. Travel time of water under the ground

As mentioned above, the main recharge to the underground water in the foothills and the flat regions is due to river waters. A greater part of river water is composed of melt glacier. The transit time of river water to reach the observation point of groundwater or spring can be estimated by using Fig. 9 or Fig. 10.

In Fig. 9, the groundwater containing the greatest tritium content in 1992 is considered to be the Urumqi River water having entered the underground about 25 years ago. Most groundwaters of relatively great tritium content in 1992 may have traveled under the ground for a range of 12 to 28a. The groundwater with small tritium concentration can be corresponded to be the river water more than 35 years ago.

On the other hand, in Fig. 10, many groundwaters from Turfan basin in 1994 are corresponded more than 40 a of age, under the assumption the similar river water as Urumqi River water acts as recharge to the groundwater system. The groundwater with greatest tritium concentration in 1994,

which is from a well (No.49) in western Turfan basin, may have traveled under the ground for 20 a or 30 a.

Many spring waters are corresponded to around 30 a of age (Fig. 10), though some spring waters are corresponded to about 10 a or more than 30 a of age. The age means here the transit time for river water to pass through the underground to the spring point.

Finally, we will try to make a rough estimation for flow velocity of water under the ground in the foothills. Supposing that river water travels a distance of 20 km under the ground (actually it seems in a range of 10 to 50 km from Fig. 1), and that the travel time is around 30a based on tritium data, then the water particle velocity is around 660 m/y. Assuming the effective porosity of 0.3 for the granular sedimentary media, the velocity is corresponded to a specific discharge of 200 ton·a·m^{-2} (~ 6.10^{-4} cm·s^{-1}). If the cross-section of main flow is to be known, the total discharge will be estimated roughly by using the result.

7. Concluding remarks

(1) The tritium concentration in precipitation at Urumqi is estimated to be about 12.5 times as great as that at Tokyo, as annual means. The tritium level in precipitation at Urumqi is highest in the world.

(2) Contribution of precipitation to the recharge of closed or semi-closed lakes located in Urumqi and Turfan basins is estimated, considering the effect of evaporation to tritium concentration in lake water. The proportions of precipitation to the total recharge of lakes are various between 0.08 to 0.8, depending on the salinity of lakes. The groundwater discharges to salt lakes are relatively small to the direct precipitation amounts in comparison with fresh lakes.

(3) Many river waters contain predominantly melt glacier. For the Urumqi River, the proportion of melt glacier to the river water is about 65 %.

(4) Mean residence time of circulating meteoric water in the Tianshan Mountains is estimated to be about 15 a.

(5) Tritium concentrations in spring waters are relatively small compared with those of river waters. In many cases, spring waters originate from river waters. River waters take around 30a or more to travel the underground to springs.

(6) A big spring near the water divide between Urumqi and Turfan basins has relatively great tritium concentrations, indicating the transit time of the underground stream is 20 to 30 a.

The main origin of groundwater in the flat regions is river water originating in the glacier regions. Various ages of groundwater in the flat regions are estimated from about 10a to more than 40a.

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