REVIEW OF THE GROUNDWATER INFLOW IN THE HSUEHSHAN TUNNEL FROM GROUNDWATER DATING STUDY

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ABSTRACT

Due to the abundant precipitation along the Hsuehshan Tunnel, a high water table above the tunnel elevation was expected. When the TBM was boring the Pilot Tunnel of the Hsuehshan Main Tunnel, it had to go through major faults like Chingyin, Shanghsin, etc. The TBM encountered large amounts of water behind the faults and this resulted in water bursting into the tunnel. To understand the nature of the groundwater, the recharging conditions, and to evaluate the impact of the water inflow on the area in the vicinity of the tunnel alignment, groundwater samples were taken and isotope-dating techniques were used in the project. This paper begins with reviewing the hydrogeological conditions when tunneling through the faults, then briefly describes the isotope-dating technique adopted, and follows by analyzing the data and elaborating on the possible connection between the surface water and the deep-seated groundwater.

In general the age of the groundwater can reflect the rate of the groundwater cycle and its relationship to the atmospheric water and surface water. The older the groundwater is, the slower the groundwater cycling rate is. With this concept, isotope-dating techniques were adopted to date the groundwater inflow and to evaluate the possible source of the groundwater. In hydrogeological studies, the most commonly used isotope-dating technique is ^{14}C and Tritium, the former of which can date the age in a range of several hundred years to several hundred thousand years and the latter can date the age of groundwater since the nuclear test in 1952. Groundwater containing the isotope Tritium is considered to have been mingled with surface water.

From the Tritium and ^{14}C dating, it was revealed that the groundwater inflow in the west excavation faces did not show any evidence that the surface water had been seeping into or mingled with the deep seated groundwater. The groundwater inflow in the eastern section did have surface water mingled with it. However, with the data available, it is difficult to know exactly the amount of surface water seeping into the deep groundwater, and we can only confirm the water inflow in the fractured zones in the east face had direct connections to the surface water. The data also showed that the concentrations of Tritium were highly dependent on sampling locations, implying that connections of groundwater to the surface water are also site dependent.

Keywords: pilot tunnel, isotope, Tritium, ^{14}C, dating-technique,

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INTRODUCTION

The Hsuehshan Tunnel cuts through the northern end of the Hsuehshan Range and through the piedmont hills that are west of the range in a northwest-southeast direction (Figure 1). West of the watershed, there are rolling hills that extend for several tens of kilometres. These hills gradually decrease in elevation towards the west. In this area, hill ridges mostly run in a northeast-by-east to southwest-by-west direction, and are the sources of the Peishihchi and its tributaries. The eastern side of the watershed is quite precipitous, dropping rapidly towards the east to join the western rim of the Lanyan Plain. Geographically speaking, the entire line of the Hsuehshan Tunnel is located within the Hsuehshan Range's geologic province. Rock formations traversed by the tunnel alignment are mainly slightly metamorphosed sedimentary rocks.

The hill or mountain areas stretching along the alignment of the tunnel are high in precipitation, and thus groundwater in the area is quite abundant. The groundwater table elevation is several hundreds of meters above the elevation of the tunnel alignment. A number of immense groundwater influxes occurred in the course of tunnel excavation; this triggered doubt among local residents whether this frequent water ingress in the tunnel was the direct cause of the abrupt drying up of mountain creeks in the area and was responsible for the decrease in groundwater yields. Such doubts led to several incidences of protests from local residents. To resolve the issue on whether tunnel construction imposed any adverse effects on the local groundwater system, the Taiwan Area National Expressway Engineering Bureau (TANEEB) initiated a study project involving the use of radioactive isotopes as dating tools in unravelling the issue whether tunnel construction did cause any change in the groundwater system.

RADIOACTIVE ISOTOPE DATING METHOD

Prevailing methods for the dating of groundwater are mainly the Tritium dating method and the Carbon isotope ^{14}C dating method. The Carbon dating method covers a range of several hundred years to several tens of thousands of years, while Tritium dating will identify age of the groundwater since the first detonation of the first atomic

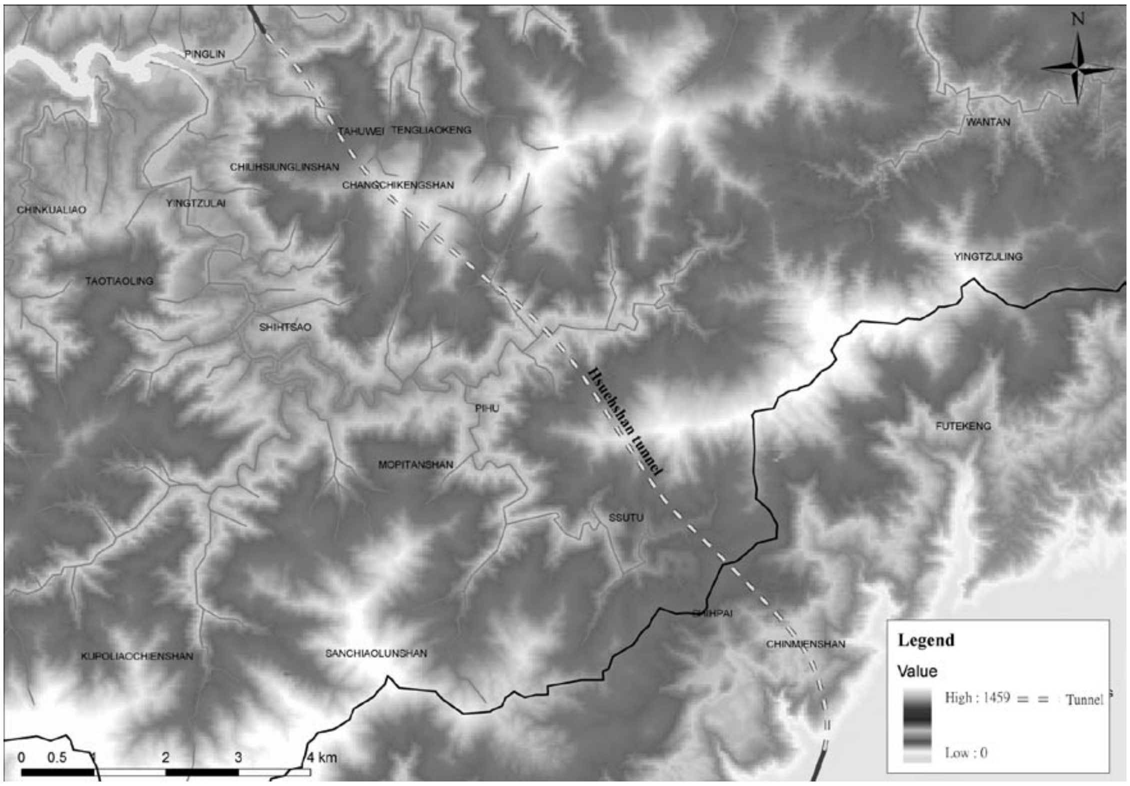

Figure 1 Drainage systems in the immediate vicinity of the Hsuehshan Tunnel

bomb test approximately 40 years ago. The following presents a brief description of the dating methods.

Tritium Dating Method

Tritium (T) is a radioactive isotope of hydrogen (H). There are two types of Tritium occurring in natural water: natural Tritium and artificial Tritium. The Tritium concentration in natural water is expressed using the "Tritium unit, TU". One TU is defined as having one tritium atom in 1018 hydrogen atoms.

Natural tritium occurs 10~20km high in space in the upper part of the atmosphere. Occurrence of natural tritium is quite steady. Prior to the effects from the atomic bomb explosion tests, natural tritium had reached a natural state of equilibrium. Artificial tritium mainly occurs as a result of nuclear weapons test explosions. The first atomic bomb test explosion happened at the end of 1952. Large quantities of artificial tritium occurred distinctly in the beginning of 1953 (Figure 2).

Tritium forms a part of the water molecule, and enters into water circulation directly. The fact that tritium is a radioactive isotope means that it observes the law of half-life decaying. Once it is no longer in contact with the source, its mass decreases with time. In the course of natural water circulation, it will leave behind signatures registering effects from environmental factors, thus making it an excellent tracer for the tracking of various hydrogeological processes. The half-life decaying period of tritium is rather short at 12.43 years, thus it is especially useful in studies on seepage of meteoric precipitation into the ground, the recharging of recent groundwater into a source groundwater body, the flow rate of groundwater, and the reservation of groundwater.

Tritium dating commonly employs the qualitative method. This involves identifying whether the groundwater has been signified by Tritium from a nuclear weapons test explosion, distinguishing ‘new groundwater’ that contains, or is mixed with, meteoric water after 1953 from the total bulk of old groundwater that formed prior to nuclear explosion tests. In practice, the standard for identifying old groundwater older than 40 years is <1TU for low latitude areas such as Taiwan; and <2TU for high latitude areas. For example, Groundwater formed through seepage of precipitation from year 1952, with tritium concentration 10 TU, would have a Tritium concentration of ≦1TU through half-life decaying reduction process. Thus if the measuring of collected groundwater samples indicated a tritium concentration value smaller than this value, this groundwater can be regarded as having an age older than 40 years. If the value is greater than 1.5TU, the groundwater is‘new water’ formed after the nuclear tests, or this groundwater is an older one that had been mixed with some groundwater formed after nuclear tests.

^{14}C Dating

^{14}C that formed in the atmosphere can’t survive for a very long period; instead, it will rapidly oxidise to form carbon dioxide. Since the chemical properties of $^{14}CO_2$ are identical to the chemical properties of $^{12}CO_2$, $^{14}CO_2$ will then rapidly mix with carbon dioxides in the atmosphere, and enter into exchange circulation of carbons in the natural environment. The ^{14}C dating method thus involves identifying the ‘Before Present’ (BP) number of years since a carbon containing material ceased carbon exchange with the atmosphere.

In groundwater, there are two sources for ^{14}C: (1) Directly from CO_2 in the atmosphere; (2) From CO_2 in pores in the soil. In rain water, there is dissolved atmospheric CO_2 that performs CO_2 exchange with the soil. As atmospheric precipitation enters into the ground and moves in the phreatic zone, it absorbs considerable amounts of CO_2. The sources of this CO_2 are the respiration of roots and stems of plants, and decaying and decomposition of organic materials in the soil. As these water molecules enter into the saturated zone, they are confined within a comparatively closed environment, and are cut off from the source of ^{14}C, the ^{14}C in the groundwater will then decrease in time, following the law of half-life decaying of radioactive isotopes. Hence through measuring the concentration of the remaining ^{14}C it is possible to calculate the time the groundwater stayed or remained after leaving the phreatic zone, and thus obtain the age of the groundwater.

RESULTS

In the construction of the Hsuehshan Tunnel, the excavation of the western portal at the Pinglin end went comparatively more smoothly, whereas tunnel excavation at the eastern end at Toucheng encountered more difficulty, and construction was seriously delayed as numerous collapses due to the ingress of large quantities of groundwater occurred. What was worse, the many occurrences of groundwater influxes aroused local residents’ suspicions that such large quantities of

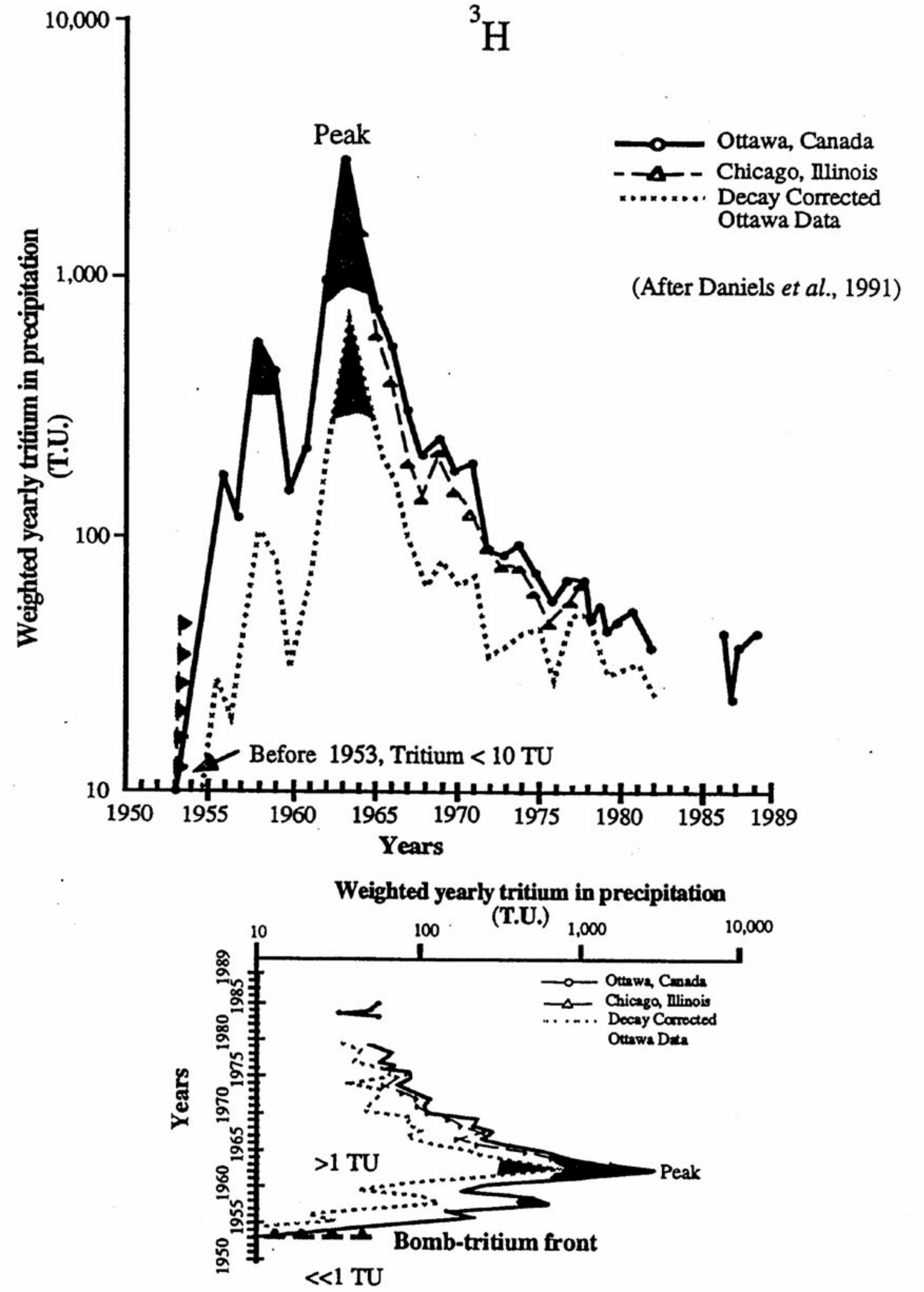

Figure 2 Variations of Tritium Contents in the Atmosphere after Nuclear Explosion Tests.

groundwater flooding the tunnel were the main cause of the sudden decrease in water that ran in the gullies in the area, or the major cause of the area's abrupt decrease in groundwater yield. In view of these, TANEEB contracted Sinotech Engineering Consultants, Ltd. to conduct a study project "Investigation and Evaluation Study on Groundwater Ingress in the Pinglin Tunnel (now named Hsuehshan Tunnel)". The duration of this study project was three years from 1997 to 2000. This project was followed and supplemented by a monitoring project launched in 2001 and completed in 2002. The core theory of these projects was that the older the groundwater body, the poorer would be its circulation. Thus, through identifying the groundwater's age by measuring and analyzing ^{3}H and ^{14}C of the groundwater it would in turn be possible to attempt to estimate its source. Hence, through Tritium dating, it would be possible to unravel whether younger, recent groundwater had been mixed with the older groundwater, since detecting occurrence of Tritium in the older groundwater would indicate that the groundwater represented a mixture of young and old groundwater bodies.

During the study, 19 groundwater samples were collected between 1996 and 2002. Sample locations and analytical results are presented in Table 1. ^{3}H and 14C dating tests were entrusted to Professor C. K. Liu of the Geological Society of China. Tritium dating was undertaken by the University of Miami, USA, using samples shipped to the United States. The lower bound of the University of Miami dating accuracy can reach 0.1TU.

$$1.\delta\,({}^{0}/_{00})=\left[\frac{R(\text{sample})}{\text{R(standard)}}-1\right]\times 1000\,{}^{0}/_{00}$$

There are a number of materials that can serve as standards for isotopic references (Craig, 1957). For ^{13}C, the international standard is PDE (Peedee Belemnite, Chicago Limestone Standard).

From 1999 to 2001, six water samples were collected from the excavation faces at the west portal for analysis. The results of the 3H and 14C analysis are presented in Table 1. Water samples from one identical water emission site were collected on July 12th 2001 and on October 31st 2001. Although the samples were collected 3 months apart, the concentrations of ^{3}H and ^{14}C did not show any change. All ^{3}H concentrations were smaller than 1TU, and ^{14}C age dating showed a groundwater age of 8000 years, thus indicating the groundwater influx in the Hsuehshan Tunnel involved a body of groundwater of an older age. Another set of water samples was collected from another water influx site on July 5th 2001 and September 14th 2001 for analysis. Analytical results showed that the ^{3}H concentration at >1TU was smaller than the lower bound of analysis. ^{14}C age dating, on the other hand, showed that the groundwater was quite old at 20,000 years, thus indicating there was no mixing in of groundwater from shallow depths.

From 1996 to 2002, 13 water samples were collected from the excavation faces at the east portal for ^{3}H and ^{14}C analysis. The results of the ^{3}H and ^{14}C analysis are presented in Table 1. ^{14}C dating results revealed that influxes of groundwater in the Hsuehshan Tunnel were all from older groundwater bodies. The Tritium analysis results indicated that except for four analytical results that showed ^{3}H values smaller than 1TU (at Sta39k+150, and Sta39k+178 Pilot Tunnel groundwater ingress, 37k+251.5 eastbound main tunnel alignment, and 37k+099 westbound main tunnel alignment groundwater ingress), Tritium concentrations were all within 1~3.2TU, a tritium concentration similar to the Tritium concentration in recent rain precipitation in Northern Taiwan.

Summarizing the above data from ^{3}H and ^{14}C analysis, it can be concluded that at the west portal of the Hsuehshan Tunnel, no ingress of water in the tunnel had been found to have involved any recent groundwater or surface water. The ^{3}H signature for the groundwater ingress at the east portal indicated groundwater of younger age at <6,000 years, thus revealing the fact that the east portal groundwater ingress had involved a groundwater body that had been mixed with younger (since 1953) water. This younger water is judged to have been surface water that percolated downward along gullies and fracture zones, and replenished the groundwater in the tunnel along a vertical direction. At this moment, it is not yet known what the proportion of the new water is compared with the older groundwater, nevertheless, the quantity is quite sizeable.

The Hsuehshan Tunnel exhibits geological structures in the forms of broad, open folds and long extending faults. At the eastern section of the tunnel, faults of various scales are the main geologic structural features, and so, rock formations at the eastern section of the tunnel are mostly quite poor. These include argillite of the Kankou Formation and quartzite of the Szeleng Sandstone Formation. At the western section of the tunnel, geologic structures are mainly folds, and the

Table1 Isotope Dating Results, Vicinities of the Hsuehshan Tunnel

Sampling Date	TBM Location of Pilot Tunnel	Sample Location	^{14}C(y BP)	^{3}H(TU)
1996/04/24 (provided by RSEA)	39K+079	Pilot Tunnel 39K+070	4850±80 $\delta^{13}C=-14.28^{0}/_{00}$	3.17±0.10TU
1997/06/23N1	39K+079	Pilot Tunnel 39K+070		2.38±0.14TU
1997/06/23N2	39K+079	Pilot Tunnel 39K+070		2.64±0.17TU
1997/06/23N3	39K+079	Pilot Tunnel 39K+150		0.87±0.17TU
1997/06/23	39K+079	Tianchi, Shihpai (EL.520m)		2.60±0.20TU
1997/06/23	39K+079	Pilot Tunnel 39K+178		0.64±0.16TU
1997/07/01	39K+079	Pilot Tunnel 39K+070	4850±80 $\delta^{13}C=-14.28^{0}/_{00}$	2.52±0.17TU
1997/07/01	39K+079	Pilot Tunnel 39K+079		2.86±0.17TU
1998/12/11	39K+079	Pilot Tunnel 38K+950	5140±80 $\delta^{13}C=-14.3\ ^{0}/_{00}$	1.81±0.17TU
1999/06/07	39K+079	Pilot Tunnel 38K+902	5500±100 $\delta^{13}C=-14.0\ ^{0}/_{00}$	1.20±0.20TU
1999/10/31	39K+079	Pilot Tunnel 38K+476	5510±100	0.70±0.10TU
1999/12/26	39K+079	Pilot Tunnel 38K+409	6950±180	1.60±0.70TU
2001/03/04		Eastbound 37K+251	8450±50 $\delta^{13}C=-13.4\ ^{0}/_{00}$	2.4±0.2TU
2001/04/25		Westbound 37K+099	7430±110 $\delta^{13}C=-13.4\ ^{0}/_{00}$	1.5±0.2TU
1999/07/12	39K+079	Pilot Tunnel 29K+509	8450±50 $\delta^{13}C=-13.7\ ^{0}/_{00}$	0.60±0.10TU
1999/10/31	39K+079	Pilot Tunnel 29K+503	8600±130	0.60±0.10TU
1999/12/26	39K+079	Pilot Tunnel 29K+561	8230±110	0.90±0.20TU
2001/07/05		Pilot Tunnel 30K+688	19100±200 $\delta^{13}C=10.8\ ^{0}/_{00}$	0.0±0.1TU (<0.1TU)
2001/09/14		Pilot Tunnel 30K+688		0.0±0.1TU (<0.1TU)
2002/09/25		Westbound 33K+730	5050±150 $\delta^{13}C=-14.5\ ^{0}/_{00}$	1.6±0.2TU

rock formations are comparatively better. Radioactive isotope analysis results indicated that surface water had mixed with older groundwater. In view of the geological structural models, this mixing in of younger surface water occurred along localized fracture zones or along gullies and creeks. This is an indication that the fracture zones at the eastern end of the tunnel alignment are connected to surface water, and this model coincides well with the geologic structural model of the Hsuehshan Tunnel. Analytical results indicated that the Tritium concentrations varied in accordance with variation in sites of sample collection, affording an assumption that connection to groundwater bodies varied by locations.

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