International Journal of GEOMATE, Oct., 2017, Vol.13, Issue 38, pp.79-88
Geotec., Const. Mat. & Env., ISSN:2186-2990, Japan, DOI: http://dx.doi.org/10.21660/2017.38.2k

TUNNEL CONSTRUCTION IMPACT ON GROUNDWATER CHARACTER OVER 25 YEARS OF OBSERVATION AT MATSUMOTO TUNNEL, MATSUMOTO CITY, JAPAN

*Hiroyuki Ii

Faculty of Systems Engineering, Wakayama University, Japan

*Corresponding Author, Received: 15 Sept. 2016, Revised: 2 March 2017, Accepted: 30 March 2017

ABSTRACT: Over 25 years, approximately 11 million m^3 of water inflow in the Matsumoto tunnel at the north of Matsumoto city was drained. Water inflow in the tunnel during tunnel construction varied from 1 to 8 m^3 per minute decreasing to 1 to 0.6 m^3 per minute between 1993 and 1995. At present, inflow maintains a rate of 0.6 m^3 per minute. Currently, it remains at 0.6 T.U. (Tritium Unit) and the age of water in flowing into the tunnel has been estimated to be over 30 years old from initial ^3H concentration for surface water which varied from 4 to 10 T.U. As oxygen stable isotope values and HCO_3^- concentration of water inflow in the tunnel were uniform for 25 years, the source of water inflow in the tunnel is not thought to have changed. Roughly 14 to 39 million m^3 water was still stored in rocks above the tunnel in the plateau from 10 % porosity measured by rock sample. When only 3 million m^3 groundwater, less than one tenth of porosity coincided with effective porosity (0.48 %) or specific yield (0.6 to 1.2 %) was drained, groundwater level decreased widely. Drained water after over 25 years of tunnel construction was derived from unsaturated small pore water excluding main pores or cracks. Therefore, total pore volume was used for slow groundwater migration (flow velocity is 3 to 7 m per year). Cracks or main pores connecting with many pores were important for fast groundwater migration (flow velocity is over 100 m per year).

Keywords: Tunnel construction, Long term drainage, Groundwater level, Tunnel seepage, Groundwater chemistry

1. INTRODUCTION

Many tunnels have been constructed in Japan. Before the construction of a tunnel, groundwater conditions are researched in detail for evaluating the consequences of tunnel construction. However, following tunnel construction, no long term ongoing studies regarding environmental conditions were reported despite a huge number of tunnels being constructed across the country. In contrast to this, studies focusing on the disposal of radioactive waste using deep underground tunnels were conducted in which groundwater flow and water chemistry over a long term were investigated for Miocene marine sedimentary rock at Horonobe in Hokkaido and for granite at Tono in Gifu [1]. However, it was determined that groundwater condition depended on each area's unique geological and topographical features [1] so information regarding how groundwater flow and water chemistry may have been influenced by tunnel construction over a long period was insufficient. Therefore, in this paper, groundwater condition due to tunnel construction starting in 1990 was researched and studied for over 25 years using water chemistry, groundwater level and flow of water inflow in the tunnel.

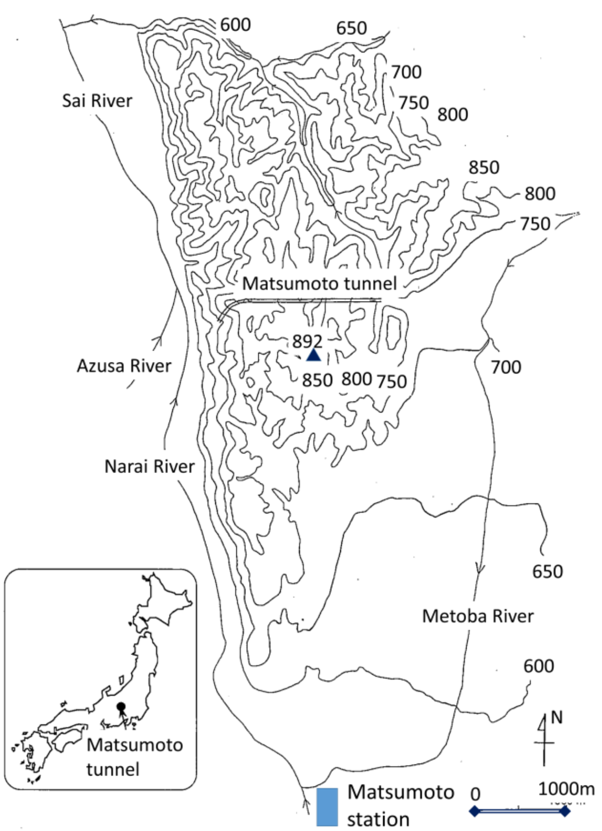

Fig. 1 Study area, Matsumoto tunnel at the north of Matsumoto city

2. STUDY AREA

The Matsumoto tunnel, approximately 2000 m in length, was constructed within a plateau north of Matsumoto city in central Japan as shown in Fig.1. Tunnel construction began in October 1990 and the tunnel was completed in November 1992 [2]. A Quaternary Period river terrace sedimentary layer is found on the top of the plateau which mainly consists of andesite tuff breccia and sandstone formed in the Miocene period. Water analysis around the tunnel revealed that oxygen and hydrogen isotopes and main soluble

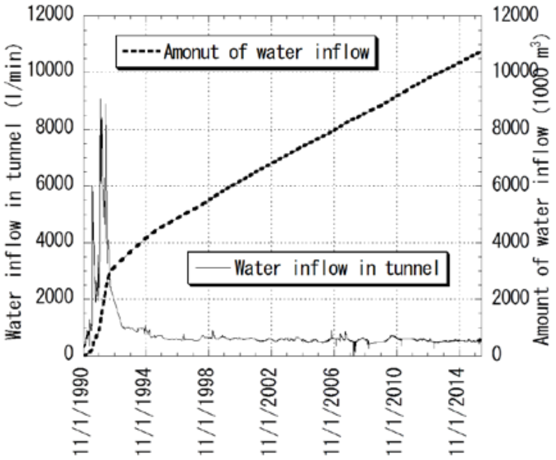

Fig. 2 Water inflow in tunnel and amount of water inflow

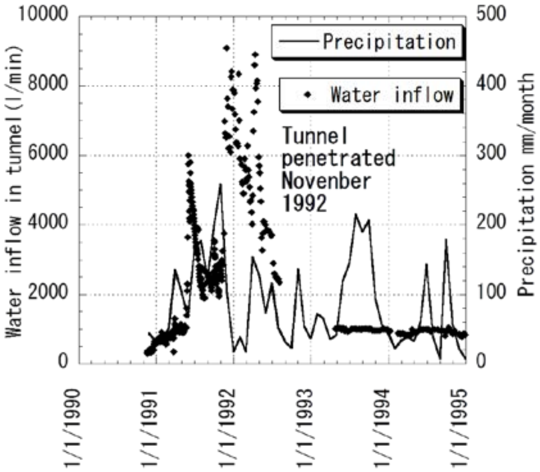

Fig. 3 Water inflow in tunnel and precipitation (1990 to 1995)

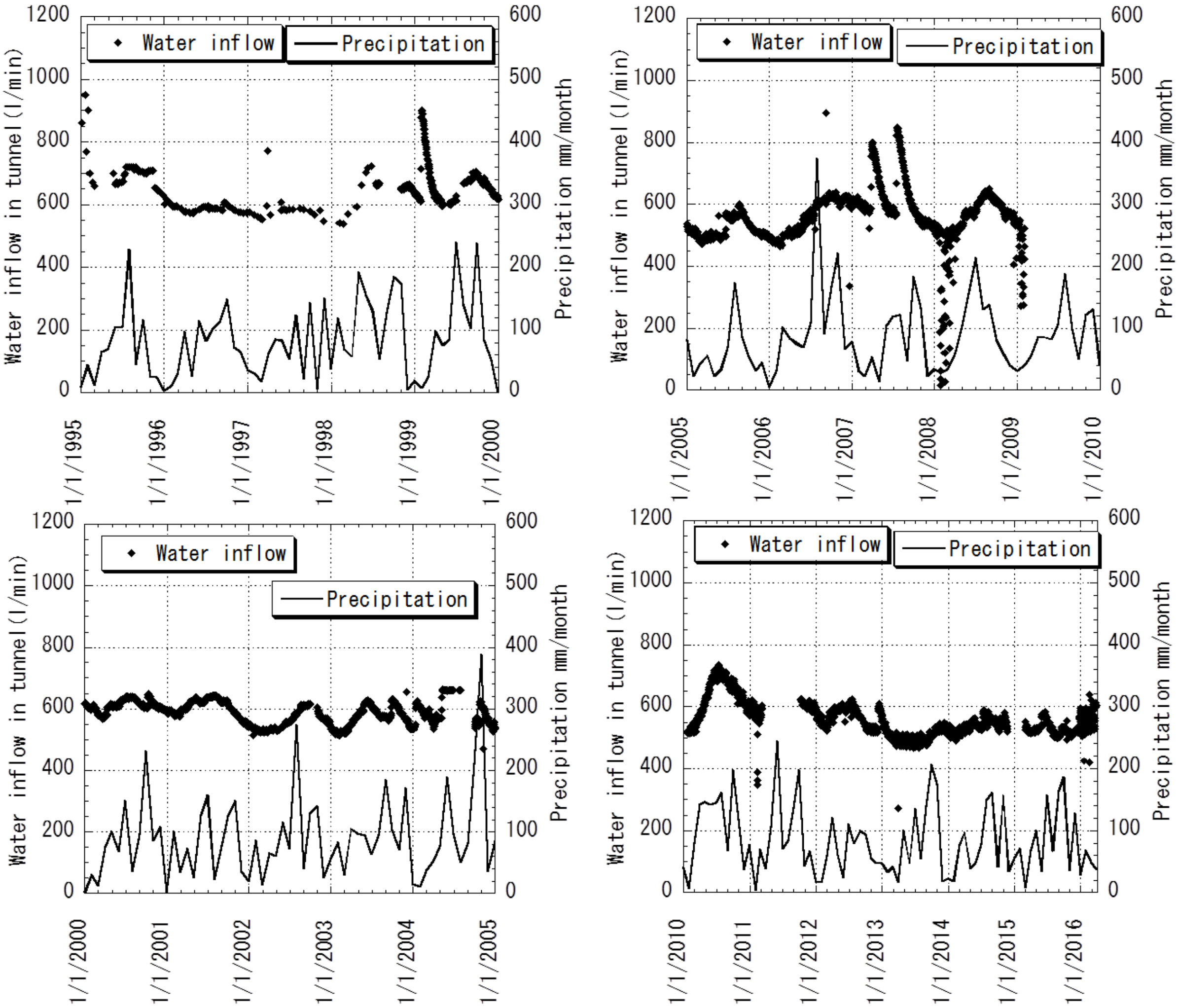

Fig. 4 Water inflow in tunnel and precipitation (1995 to 2016)

substances between water inflow in the tunnel and a dried up spring and well were the almost same [1]. On the other hand, isotope values and main soluble substances for an undried well and spring on the tunnel were different from those for tunnel inflow in the tunnel. Subsequently, water chemistry analysis was able to predict the influence of tunnel construction on the spring and well [2]. During tunnel construction, a tracer test was performed by Br^- injection into a borehole and sampling in the tunnel determined effective porosity to be 0.48 % using a three dimensional FEM transport analysis. The effective porosity value was very low relative to porosity, 7 to 15 % for Miocene sedimentary rock [3]. On the other hand, before tunnel construction, effective porosity was measured at 10 % using ^3H concentration for water inflow in the tunnel [4]. Groundwater level and water inflow in the tunnel were studied for 5 years [5].

3. METHOD

Around the Matsumoto tunnel, spring, river, well and cutting face water was sampled during tunnel construction. After the tunnel penetrated was completed, total water inflow in and along the tunnel was sampled. Flow rate for water inflow in and along the tunnel was measured from the beginning of tunnel construction.

Main soluble substances, NO_3^-, Cl^-, Ca^{2+}, and SO_4^{2-} concentrations were measured by ion exchange chromatography. HCO_3^- concentration was measured by titration and ^3H concentration was measured by liquid scintillation counter. The stable hydrogen and oxygen isotopic ratio were measured by mass spectrometer (Sercon Geo Wet System).

4. RESULTS

4.1 Flow rate of water inflow in tunnel

Measurement of water inflow in the Matsumoto Tunnel began from the beginning of construction and has continued until present. Measurements were performed over 25 years with the amount of water inflow in the Matsumoto Tunnel reaching approximately 11 million m^3 as shown in Fig.2. During tunnel construction, storage water in rocks from the cutting face was drained and high water inflow was observed. In November 1992 at the tunnel penetrated (when the tunnel went through completely), the amount of water inflow reached 3 million m^3 when 1 million m^3 per years was continually drained as water inflow.

Although, uniform flow rate for water inflow in the tunnel as shown in Fig.2 was recognized after the tunnel penetrated, small changes of water inflow in the tunnel were observed as shown in Fig.3. Water inflow in the tunnel varied from 1 to 0.8 m^3 per minute from 1993 to 1994 but decreased to 0.6 m^3 in 1995. Currently, water

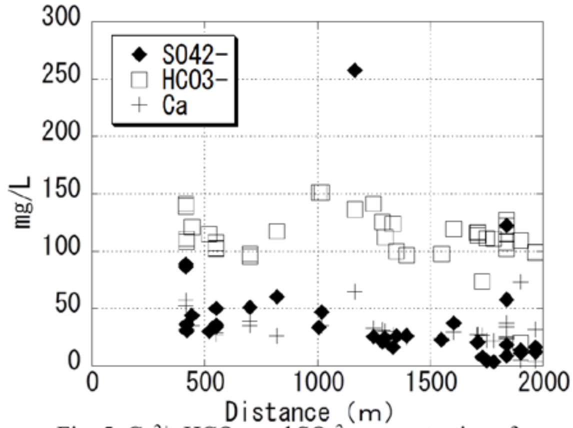

Fig. 5 Ca^{2+}, HCO_3^- and SO_4^{2-} concentration of cutting face

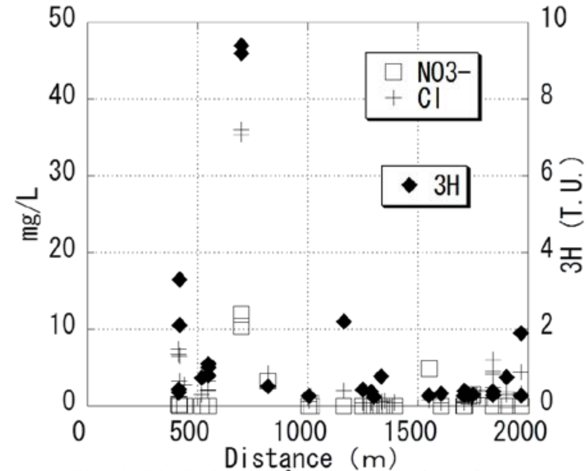

Fig. 6 Cl^-, NO_3^- and ^3H concentration of cutting face

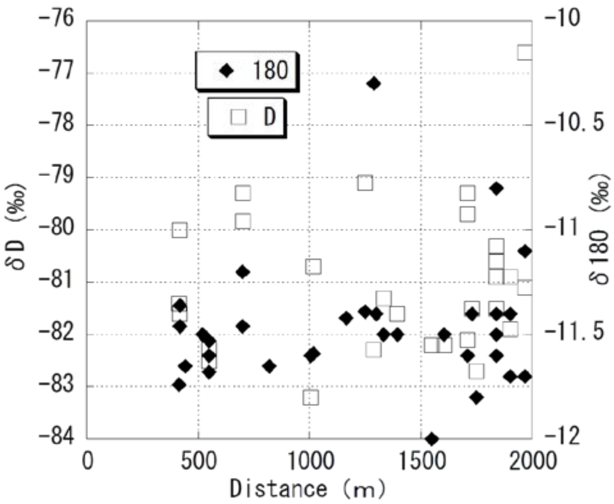

Fig. 7 δD and $\delta^{18}O$ of cutting face

inflow is stable at 0.6 m^3 per minute. However, after 1993, a small change for water inflow in the tunnel was recognized. A time series for water inflow in the tunnel and monthly precipitation are shown in Fig.4. Monthly precipitation varied from 0 to 400 mm and water inflow was mostly between 0.5 and 0.7 m^3 per minute. Peaks and bottoms for precipitation sometimes seemed to coincide with those values in following months for water inflow although abnormal values due to machine trouble for flow mater were sometimes observed.

4.2 Cutting face water during construction

The tunnel was dug from both the east and west with both cutting faces water sampling. Main soluble substances, Ca^{2+}, HCO_3^-, and SO_4^{2-} concentrations were shown in Fig.5. The left side was the west entrance and the right side was the east side with 2000m of total tunnel length. SO_4^{2-} concentrations around the entrance of the east side were lower than those at other areas and were observed to be extremely high (1200 m) from the west side, HCO_3^- and Ca^{2+} concentrations in contrast were almost the same value.

As farm houses, rice fields and fruit trees were observed on the plateau, surface water contaminated with NO_3^- and Cl^- was suspected. ^3H concentration was an indicator of water age. NO_3^-, Cl^- and ^3H concentrations are shown in Fig.6. Most ^3H concentrations for water inflow in the tunnel were less than 0.3 T.U. (Tritium Unit) therefore it was thought to be old groundwater reserved in rocks. If ^3H concentration for the recharge water is assumed to be 10 T.U., the traveling time for water inflow in the tunnel is over 50 years. Therefore, as the recharge area was thought to be on top of the plateau because the plateau was divided and isolated by a valley and river, surface water on the plateau infiltrated and gradually migrated into the tunnel level. In this process, NO_3^- and SO_4^{2-} were thought to be decomposed under a reductive condition and NO_3^- concentration for old groundwater was thought to be under the detection limit and SO_4^{2-} concentration was thought to remain at 50 mg /L [2].

On the other hand, in some locations, ^3H concentrations were over the detection limit of 0.3 T.U. At a point 700 m from the west side, ^3H concentrations were over 9 T.U. which was the same as surface water, and NO_3^- and Cl^- concentrations were extremely high. Thus surface water on the plateau was thought to flow directly into the tunnel. Similarly at points 450, 1200 and 1900 m, ^3H concentrations were over 2 T.U. At 1200 m from the west side, SO_4^{2-} concentrations were 250 mg/L and at locations 450 and 1900 m from the west side Cl^- concentrations were over 5mg/L relatively higher than the other areas. SO_4^{2-} was also thought to be of agricultural origin because the main fertilizer was $(NH_4)_2SO_4$. Therefore, at specific points 450, 1200 and 1900 m, surface water was thought to mix with old groundwater and the mixed water was thought to flow into the tunnel.

On the other hand, oxygen isotopic ratio values for cutting face water were -11.3 to -11.7 ‰ as shown in Fig.7, uniform although hydrogen

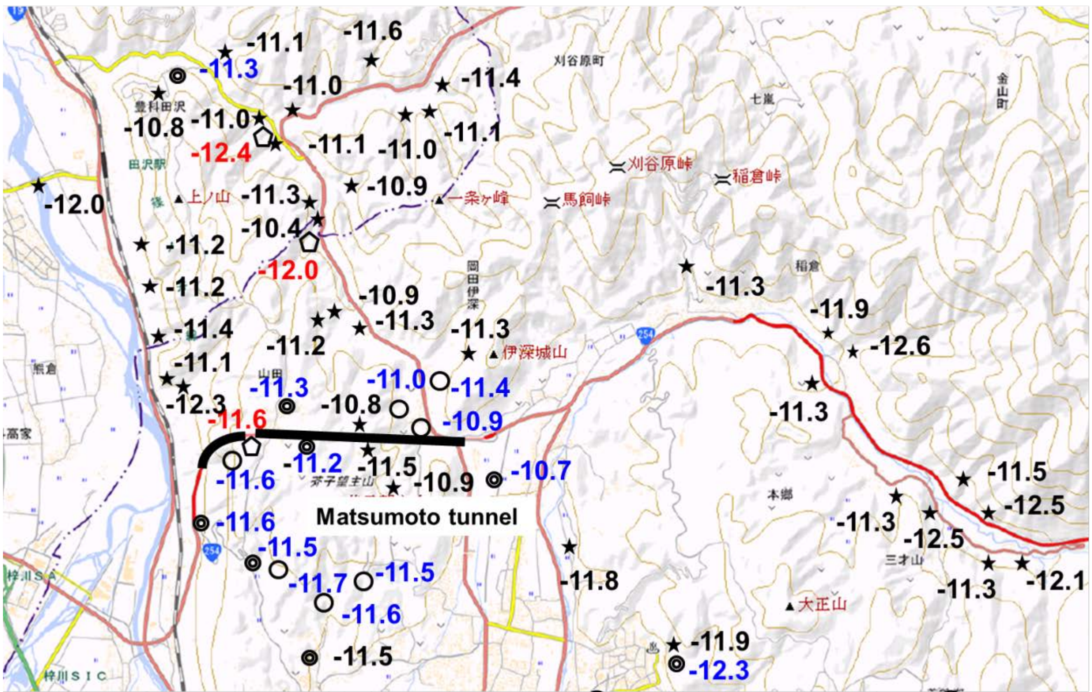

Fig.8 δ18O values for dried up spring and well ○, non-dried up spring and well ◎, river ★ and deep borehole ⬠

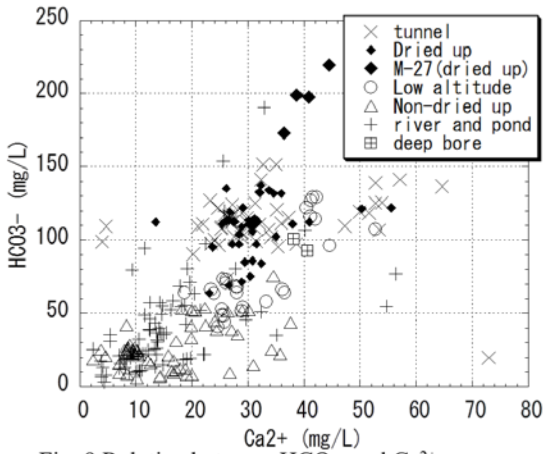

Fig. 9 Relation between HCO_3^- and Ca^{2+} concentrations

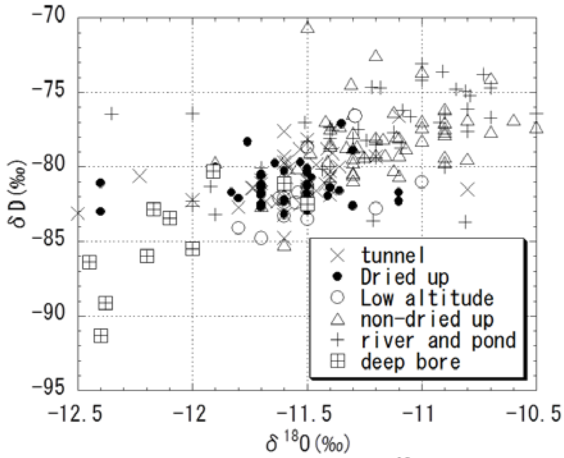

Fig. 10 Relation between δD and $\delta^{18}O$

isotopic ratios were between -79 and -83 ‰. In general, hydrogen isotope values included a large margin of error, but isotope values for cutting face water were uniform.

4.3 Dried up spring and well

After the tunnel was completed, some springs and wells around the tunnel dried up. Dried up was confirmed by several samplings and water sampled before drying up was used for analyzing. Fig.8 showed wells, springs, rivers and dried up wells and springs around the tunnel with their average oxygen isotope values. Dried up springs and wells were observed within 1.5 km from the tunnel and the altitude was higher than the tunnel level. However, some wells and springs above the tunnel were not dried up. The average oxygen isotope values for river, spring and well varied from -12.4 to -10.8 ‰. In particular, the oxygen isotope values for the dried up springs and wells were -11.7 to -11.3 which coincided with the average value of -11.6 for water inflow in tunnel.

As shown in Fig.6, water inflow in tunnel contained high concentration of Ca^{2+} and HCO_3^-. Ca^{2+} and HCO_3^- concentrations for the accumulated water inflow in the tunnel after tunnel construction (tunnel), dried up spring and well, non-dried up spring and well, and spring and well at the lower altitude than tunnel level (low altitude) are shown as in Fig.9. Although HCO_3^- concentration for dried up spring, M-27 at the north of tunnel was over 150 mg/L (extremely high), HCO_3^- concentrations for most dried up springs and wells were the same as those for the tunnel. On the other hand, most HCO_3^- concentrations for non-dried up springs and wells on the plateau were less than 50 mg/L and Ca^{2+} concentration was also low. HCO_3^- concentration increased three times with Ca^{2+} concentration. The ratio was 2:1 in mole. Weathering of Ca feldspar in andesite produces $2HCO_3^-$ and Ca^{2+} in mole [2]. The plateau mainly consists of andesite tuff breccia and sandstone formed in the Miocene period [2]. Therefore water inflow in the tunnel and dried up spring and well water were thought to be in contact with rocks for a long time.

To determine the recharge area of water inflow in the tunnel, oxygen and hydrogen isotopic ratios for water samples around the tunnel were measured. Fig.10 showed δD and $\delta^{18}O$ values for sampled water. Isotope values for dried springs and wells coincided with those for water inflow in tunnel. However, isotopic ratios for deep borehole water and non-dried up springs and wells above the tunnel level were different values. Isotopic ratios for non-dried up springs and wells coincided with those for rivers and ponds around the tunnel and these values were higher than those for dried up springs and wells. Dried up springs and wells and water inflow in the tunnel were thought to be uniform values because of mixing and no

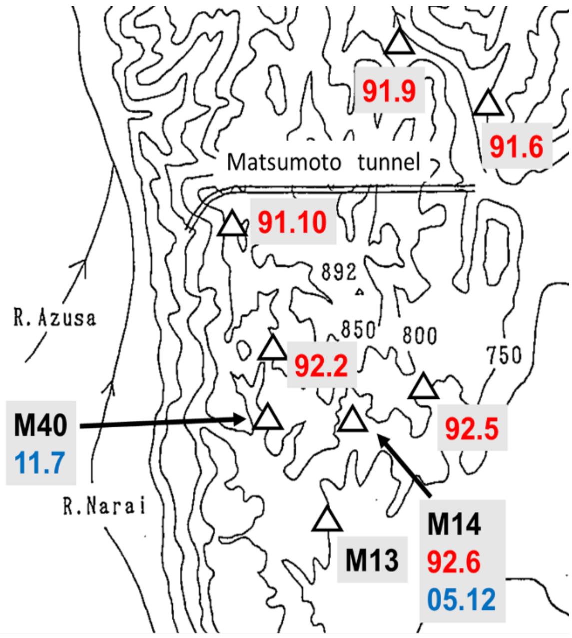

Fig. 11 Dried up springs and wells with the dates of their drying up (the number is year and month)

evaporation. On the other hand, river, pond and no dried up spring was variable values because of seasonal change and evaporation. Isotopic ratios for deep boreholes were lower than those for the dried up springs and wells. From Figs.1 and 8, there are higher mountains at the north east of the tunnel and isotopic ratios for river water at the area were lower than those around the tunnel. From isotopic ratios, the recharge area for water inflow in tunnel and dried up spring and well waters were thought to be the mountain area at the north east of the tunnel. The recharge area for deep borehole water was the higher mountain area at the north east of the tunnel.

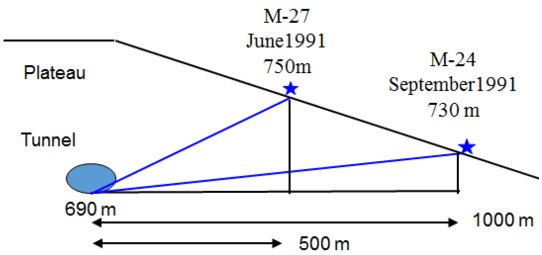

Fig. 12 Estimated groundwater level using spring and well condition at the north of tunnel

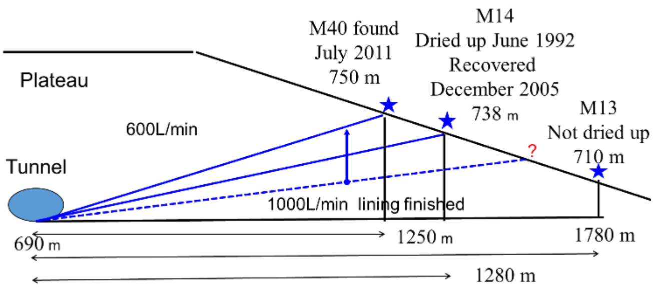

Fig. 13 Estimated groundwater level using spring and well condition at the south of tunnel

4.4 Groundwater level and porosity

Fig.11 showed dried up springs and wells with the dates of their drying up. Tunnel construction started on the east side in October 1990 and on the west side in November 1991. At the north of tunnel, two wells dried up in June 1991 and in September 1991 as is shown in Fig.12. At the south of the tunnel, three springs and one well dried up in October 1991, February, May and June 1992 as shown in Fig.13. However the spring M13 did not dry up. Groundwater level was estimated from dried up spring and well points and drainage along the whole tunnel line as shown in Figs.12 and 13. The slope of the groundwater level at the N-S direction was 40m/1000m = 0.04 at the north of tunnel and 48m/1280m = 0.038 at the south of tunnel. M14 spring in the south of the tunnel was recovered in May 2005. M40 bore hole was found in July 2011. Probably the new bore hole was dug after tunnel construction. The altitude of M40 bore hole was about 750 m and higher than that of M14 spring. Therefore, groundwater level gradually was recovered. From Fig.2, water inflow in the tunnel was 1000 L/min when most springs dried up in 1992 however since 1995 water inflow in the tunnel has remained at 600 L/min. Following 2005, some springs recovered, and a decrease of water inflow into the tunnel was thought to bring about spring recovery.

The total volume for the unsaturated zone was estimated to be 250 million m^3 (2,000 m × 2,500 m × 50 m) to 500 million m^3 (2,000 m × 2,500 m ×100m) from the geographical features and the groundwater level. M14 spring, the farthest dried up spring, dried up in June 1992 and at that time the amount of water inflow into the tunnel reached about 3 million m^3 and specific yield was 0.6 to 1.2 % from volume for the unsaturated zone and total drainage water during that time [6], [7]. On the other hand, effective porosity for rocks at the Matsumoto Tunnel was determined to be 0.48 % by field tracer testing during tunnel construction [3]. Therefore, effective porosity and specific yield values were almost the same [8], [9]. Porosities measured from rocks sampled at the Matsumoto Tunnel area were about 10 % [3], [4]. As a result, effective porosity was less than one tenth of porosity and effective porosity was thought to be due to cracks and main pores connecting with the tunnel. The amount of pore water for the unsaturated zone was calculated to be 25 to 50 million m^3 from 10 % pore value and the volume of the unsaturated zone. At present, the amount of water inflow into the tunnel reaches 11 million m^3. If drainage water from the tunnel is assumed to come from pore water for the unsaturated zone, 56 % ((25-11)/25 = 0.56) to 78 % ((50-11)/50 = 0.78) of pore water still remains in the unsaturated zone.

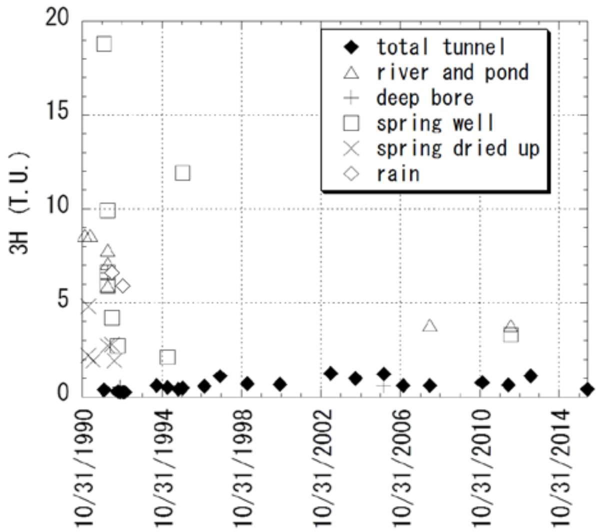

Fig. 14 Time series of ^3H concentration

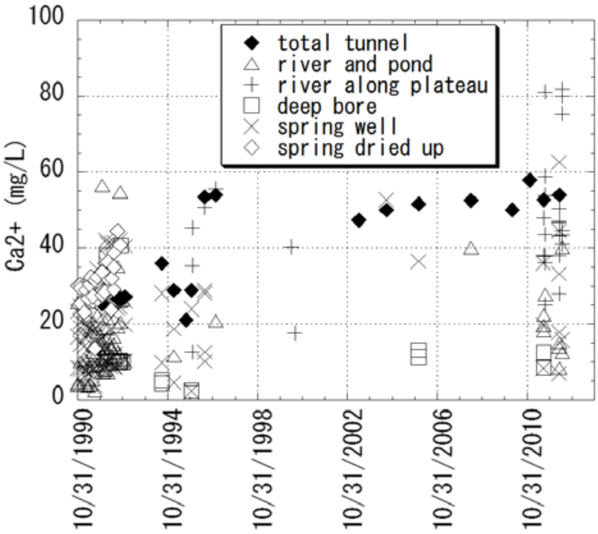

Fig. 15 Time series of Ca^{2+} concentration

4.5 Long term changes of water chemistry

For 25 years, ^3H, Ca^{2+} and SO_4^{2-}concentrations and $\delta^{18}O$ values for water around the Matsumoto Tunnel were measured. Fig.14 showed a time series of ^3H concentrations. Although ^3H concentrations at the cutting face were variable, ^3H concentrations at the tunnel remained low, less than 0.6 T.U. The ^3H concentrations of surface water decreased from 10 T.U. to 4 T.U. over 25 years. Furthermore, ^3H concentrations decreased after hydrogen nuclear bomb experiments [10]. Therefore, the age of water inflow into the tunnel was estimated to be over 30 years old from initial ^3H concentration for surface water which varied from 4 to 10 T.U. From the cutting face result, some cracks were connected tunnel with surface and at specific points 450, 1200 and 1900 m, surface water was thought to mix with old groundwater and the mixed water was thought to flow into the tunnel during tunnel construction. However after tunnel construction, ^3H concentration remained low and the age of water inflow into the tunnel was old. Therefore, after tunnel construction, surface water is not thought to be drained directly from tunnel through some cracks. After tunnel construction, groundwater level went down and then rocks above the tunnel level was unsaturated. Therefore, pore water confined in unsaturated zone for long term still has been drained from the tunnel after over 25 years of tunnel construction and then the drained water maintained low ^3H concentrations.

Figs.15 and 16 show a time series of Ca^{2+} and SO_4^{2-} concentrations. Ca^{2+} and SO_4^{2-} concentrations for water inflow in the tunnel increased from 25 to 55 mg/L (0.63 to 1.38 mol/L) and 40 to 100 mg/L (0.42 to 1.04 mol/L). Both values increased between 1992 and 1994 when the tunnel concrete liner was finished. The concrete contained CaO and $CaSO_4$, so the solute of the tunnel concrete liner was thought to have increased Ca^{2+} and SO_4^{2-}concentrations for water inflow in tunnel.

Fig.17 shows a time series of $\delta^{18}O$ values. $\delta^{18}O$ values for water inflow in the tunnel were uniform over 25 years. Therefore the water source for water in the tunnel was thought to not have changed but to have remained the same over 25 years.

5. DISCUSSION

Judging from water chemistry around the tunnel, flow rate for water inflow in the tunnel and spring and well conditions, groundwater level and groundwater sources were estimated as shown in Fig.18. Before tunnel construction, rock above the tunnel was saturated with water. 2 years later, about 3 million m^3 of groundwater was drained

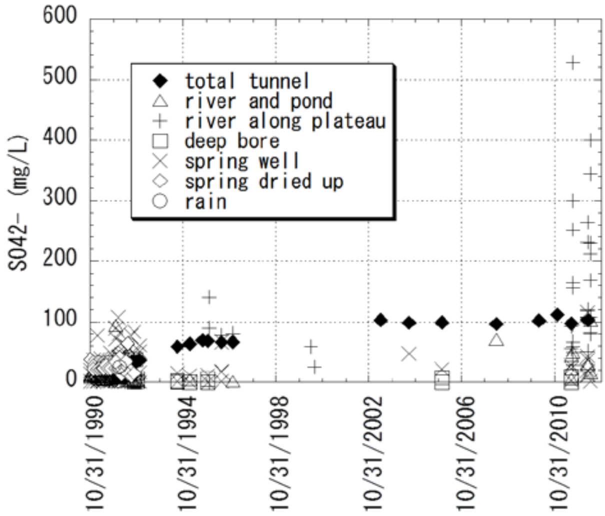

Fig. 16 Time series of SO_4^{2-} concentration

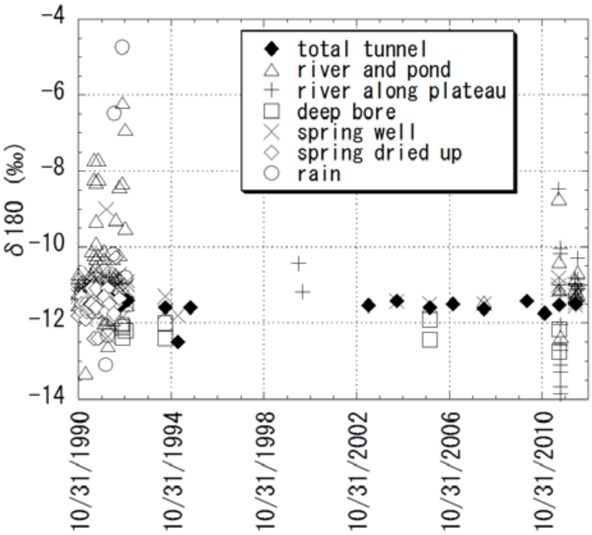

Fig. 17 Time series of $\delta^{18}O$ values

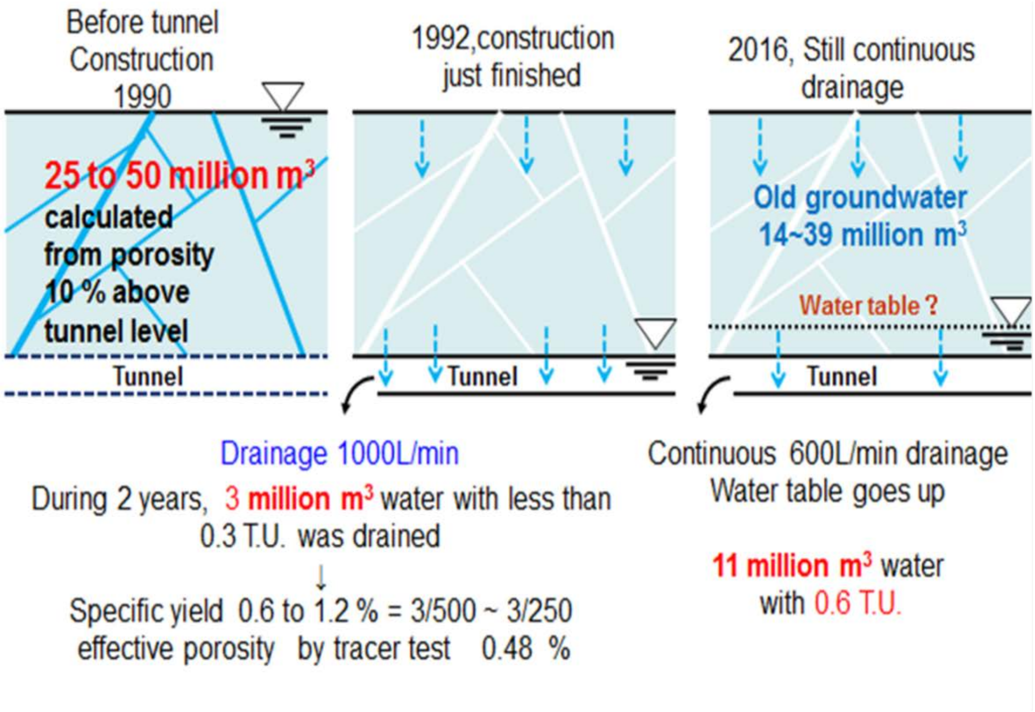

Fig. 18 Schematic diagram for groundwater level changes caused by tunnel construction

and groundwater level went down. The total rock volume of unsaturated zone was calculated to be 250 to 500 million m^3 from groundwater level estimated from dried up springs and wells. Therefore, specific yield was 0.6 % (3 million m^3 / 500 million m^3) to 1.2 % (3 million m^3 / 250 million m^3). The specific yield coincided with an effective porosity of 0.48 % as determined by tracer test during construction [3]. Effective porosity and specific yield were one tenth of porosity (10 %). Thus, effective porosity (0.48 %) and specific yield (0.6 to 1.2 %) were thought to indicate cracks or main pores connecting with many pores. Therefore, the decrease of groundwater pressure was brought about by drainage of main pores or cracks.

However, pores in the unsaturated zone still retained a lot of groundwater, 25 million m^3 - 3 million m^3 = 22 million m^3 to 50 million m^3 - 3 million m^3 = 47 million m^3 just after tunnel construction. After construction of the tunnel concrete liner, drainage flow rate decreased from 1.0 m^3 per minute to 0.6 m^3 per minute. Although groundwater level increased marginally and some dried up springs were recovered because of a decrease in flow rate of the water inflow in the tunnel, fundamentally, a big change in groundwater levels was not found [4]. Drainage water has maintained low ^{3}H concentration until now even when the total volume of water inflow in the tunnel reached 11 million m^3. The drainage water was old groundwater. Old groundwater for the unsaturated zone was less than 14 (25 - 11 million m^3) to 39 (50 - 11 million m^3) million m^3 as some groundwater was also drained under the groundwater level for maintaining the groundwater level. Therefore, the decrease of groundwater pressure was brought about by drainage of less than one tenth of total pore, effective porosity or specific yield such as main pore or crack water. However drained water after over 25 years of tunnel construction was derived from unsaturated small pore water excluding main pores or cracks.

Effective porosity before tunnel construction was measured at 10 % using ^{3}H concentration for water inflow in the tunnel [3]. ^{3}H concentrations in tunnel water were under detection limit excluding some points and fundamentally recharged water migrated slowly (flow velocity is 3 m per year) [4]. Effective porosity coincided with porosity (total pore) and total pore is used for groundwater migration when groundwater migrated slowly [5]. Similarly unsaturated pore water was drained slowly. It takes 57 years (25 million m^3 / 11 million m^3 × 25 years) to 114 years (50 million m^3 / 11 million m^3 × 25 years) to exchange old small pore water. The distance between plateau surface (800 m) and tunnel level (600 m) was about 200 m and the pore water velocity was 3.5 to 7 m per year (200 m / 57 to 114 years). Therefore total pore was thought to be used for slow groundwater migration process (flow velocity is 3 to 7 m per year).

On the other hand, Br^- tracer was performed during tunnel construction and its flow velocity was 5700 m per year (130 m / 200 hours) [3].

Groundwater level went down for less than 2 years and then roughly groundwater velocity was calculated 100 m per year from 200 m and 2 years. Therefore, main pores or cracks were important for fast groundwater migration process (flow velocity is over 100 m per year).

From long term observation, groundwater level increased marginally owing to a decrease of water inflow in the tunnel and a Ca^{2+} and SO_4^{2-} concentrations for water inflow in the tunnel increased because of soluble of the concrete liner.

6. CONCLUSION

In 1980, the Matsumoto Tunnel construction at the north of Matsumoto city started at the foot of the Matsumoto Plateau which is isolated by surrounding mountains. 11 million m^3 of water inflow in tunnel has been drained until present. Water inflow in the tunnel was thought to be derived from precipitation on the plateau. Since 1980, groundwater level and flow rate of water inflow in the tunnel have been measured and then the amount of water inflow in the tunnel from 1980 reached about 11 million m^3 and groundwater level 2 km around the tunnel decreased for the first two years but has kept uniform until now.

For 25 years, water inflow in tunnel, river and spring waters around the tunnel have been sampled many times and water chemistry and isotope values have been measured. Water inflow in the tunnel for the first years during tunnel construction varied from 1 to 8 m^3 per minute and from 1993 to 1995 it decreased 1 to 0.6 m^3 per minute. At present inflow is stable at 0.6 m^3 per minute. ^3H concentration, an indicator of groundwater age during tunnel construction was less than 0.3 T.U. It increased and has stayed less than 1.0 T.U. since 2003. On the other hand, ^3H concentrations of river and well water on the plateau were 4 T.U. Therefore, age of water inflow in tunnel was estimated to be over 30 years old from initial ^3H concentrations for surface water which varied from 4 to 10 T.U. Oxygen stable isotope values and HCO_3^- concentration of water inflow in the tunnel were uniform over 25 years. Therefore, as stable isotope values for the cutting face and water inflow in the tunnel was uniform until now, the groundwater source is not thought to have changed.

Effective porosity (0.48 %) determined by tracer test and specific yield (0.6 to 1.2 %) calculated by groundwater level change were one tenth of porosity, about 10 % measured by sampled rocks. 25 to 50 million m^3 of water was storage in rocks above the tunnel in the plateau from a 10 % porosity value. However when only 3 million m^3 groundwater, about 1 % effective porosity and specific yield such as main pores or cracks, was drained, groundwater level decreased widely. Br^- tracer was performed during tunnel construction and its flow velocity was 5700 m per year [3]. Groundwater level went down for less than 2 years and then roughly groundwater velocity was calculated 100 m per year from 200 m and 2 years. Therefore, main pores or cracks were important for fast groundwater migration process (flow velocity is over 100 m per year).

As the drained tunnel water was low ^3H concentration, the drained groundwater was deemed to be old. Old groundwater in the unsaturated zone above the tunnel level was determined to be less than 22 to 47 million m^3. 11 million m^3 after over 25 years of tunnel construction was thought to be drained from the unsaturated zone above the tunnel and still less than 14 to 39 million m^3 of old groundwater was thought to be reserved. Unsaturated small pore water above the tunnel level was drained mainly after tunnel construction slowly. It takes 57 to 114 years to exchange old small pore water and the pore water velocity was 3.5 to 7 m per year. Effective porosity before tunnel construction was measured at 10 % using ^3H concentration for water inflow in the tunnel under the slow flow velocity condition, 3 m per year [4]. Effective porosity coincided with porosity (total pore) and total pore is used for groundwater migration when groundwater migrated slowly [5]. Therefore total pore was thought to be used for slow groundwater migration process (flow velocity is 3 to 7 m per year).

From long term observation, groundwater level increased marginally owing to a decrease of water inflow in the tunnel and a SO_4^{2-} and Ca^{2+} concentration increase was found because of the solubility of tunnel liner concrete.

7. REFERENCES

[1] Nakao, S, Kikuchi T, and Ishido, T, "Current status of regional hydrogeological, studies and numerical simulations on geological disposal", Bull. Geol. Surv. Japan, vol. 55(11/12), 2004, p.409 - 415,

[2] Ii H, and Misawa S, "Groundwater chemistry within a plateau neighboring Matsumoto city, Japan", J. of Environmental Geology, Vol. 24(3), 1994, pp. 166-175.

[3] Ii H, "Effective porosity and longitudinal dispersivity of sedimentary rocks determined by laboratory and field tracer tests", J. of Environmental Geology, Vol. 25(2), 1995, pp. 71-85.

[4] Ii H, Ohtsuka Y, Mori N, Inagaki T, and Misawa S, "Effective porosity and specific yield of a sedimentary rock determined a field tracer test using tritium as a tracer", J. of

Environmental Geology, Vol. 27(3), 1996, pp. 170-177.

[5] Ii H, and Kagami H, “Groundwater level and chemistry changes resulting from tunnel construction near Matsumoto City, Japan”, J. of Environmental Geology, Vol. 31(1/2) 1997, pp. 76-84.

[6] Robson S.G, ”Techniques for estimating specific yield and specific retention from grain size data and geophysical logs from clastic bedrock aquifers”, Water-Resources Investigations Report 93-4198, 1993, U.S. Geological survey.

[7] Tizro A.T, Voudouris K, and Basami Y, “Estimation of porosity and specific yield by application of geoelectrical method”, J. of Hydrology. Vol. 454-455, 2012, pp. 160–172.

[8] Stephens D.B, Hsu K.C, Prieksat M.A, Ankeny M.D, Blandford N, Roth T.L, Kelsey J.A and Whitworth J.R, “A comparison of estimated and calculated effective porosity”, Hydrogeology Journal, Vol.6, 1998, pp. 156–165.

[9] Urumovic K, and Urumovic K.Sr, “The effective porosity and grain size relations in permeability functions”, J. of Hydrol. Earth Syst. Sci. Discuss., Vol. 11, 2014, pp. 6675–6714.

[10] Duvert C., Stewart M.K., Cendón D. I., and Raiber M. ”Time series of tritium, stable isotopes and chloride reveal short-term variations in groundwater contribution to a stream”, Hydrol. Earth Syst. Sci., Vol. 20, 2016, pp.257-277.