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Managed aquifer recharge by using spreading basin methods on alluvial fans: a general overview of the situation in Japan

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ABSTRACT

In this paper, the author reviews the present situation of managed aquifer recharge (MAR) by using basin method as of 2009 in Japan. Most of the MAR basin is carried in the area of alluvial fans. The enhancing groundwater resources in the *Rokugo* alluvial aquifer has resulted in sustainability for the groundwater environment, especially in the distal fan. As a recent tendency, the MAR basin contributes to sustainable aquifer management in alluvium and is spreading in Japan.

Key words: alluvial fan, artificial recharge of groundwater, basins, MAR, Rokugo

Recarga artificial mediante balsas en abanicos aluviales: situación general en Japón

RESUMEN

En el presente artículo, el autor hace una revisión de la situación actual de la recarga artificial mediante balsas en Japón. La mayor parte de las experiencias tienen lugar en abanicos aluviales. La mejora de la disponibilidad de recursos hídricos subterráneos en el caso del acuífero aluvial de Rokugo se ha traducido en un aumento de la sostenibilidad medioambiental, especialmente en el abanico distal. Las tendencias actuales muestran que, en Japón, la recarga artificial mediante balsas contribuye a una gestión sostenible de los acuíferos, y se está extendiendo por todo el país.

Palabras clave: abanico aluvial, balsas, recarga artificial, Rokugo

Introduction

Regarding managed aquifer recharge (MAR), there are various methods (Thoa *et al*., 2005; Luck *et al*., 2006). Methods using a basin or pond and wells are generally spread. In the case of the well method, pure water must be injected into aquifers, but the basin method does not always need pure water. The water may be polluted to some extent, such as due to turbidity. The basin method is used not only for enhancing groundwater resources, but also for purifying water through the process of percolation (BMI, 1985; O'Hare *et al*., 1986).

In Japan, MAR using injection wells was introduced from the middle of 1950's to 1970's in Japanese big industrial areas such as Tokyo, Osaka and the neighborhood (Yamamoto, 1972). Main purpose was focused on preventing subsidence caused by over pumping. However, the injection wells disappeared in 1980's, because subsidence stopped and well management about handling of clogging was difficult in particular (Hida, 2002).

In recent years, however, the MAR basin has attracted attention. Why is this? In this paper, the author reviews the present situation of the MAR basin as of 2009 in Japan. The main subject of this paper was written on Hida (2007), while adding some new informations. In addition, a part of Hida *et al.* (2009) was supplemented.

Models of the mar basin

As for the MAR basin, it is operated mainly in two topographical locations. One is on the river or lakeside and the other is on the alluvial formation.

River or lakeside type

In this type, the MAR basin is installed in the bank of

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a river or lake. It pumps up subsurface water again which is mixed with original groundwater and underflow water created from the bank filtration basin (Holzbecher, 2005).

Alluvial fan type

An alluvial fan is a place suitable for the MAR basin. Utilizing the characteristic of a groundwater cycle in an alluvial aquifer, a recharge basin is installed in the proximal and center fans, and groundwater is pumped again into the distal fan (Hida, 2002). The main subject of this paper focuses on this method.

The MAR basin operating in alluvial fans

The MAR basin operating in Japan in 2009 is present in the *Rokugo* alluvial fan in Akita Prefecture, in the *Umamigasaki* alluvial fan in Yamagata Prefecture and in the *Shou River* alluvial fan in Toyama Prefecture. In addition, for the MAR basin, there are some experimental examples in *Showa-machi* Town in Akita Prefecture and *Oono-shi* City in Fukui Prefecture. In this paper, only operating examples are selected.

The Umamigasaki alluvial fan in Yamagata Prefecture

The MAR basin of the Umamigasaki alluvial fan was set up at the proximal fan (38° 14′ 38″ N, 140° 21′ 37″ E) (Yamagata-shi, 1988). The operation began in September, 1991. The basin area is 62 m^2. The basin draws source water from an irrigation canal (Sasazeki canal) for paddy fields. In the beginning, water was supplied only in the non-irrigation period from September to April. Starting in 2005, water was supplied year-round.

The infiltration rate of the basin was maintained at 18.4 cm/h at a level of about 100,000 m^3 annually until 2001. After 2002, the infiltration rate of the basin declined to 9.2cm/h at a level of about 50,000 m^3 annually (Kakubari, 2006). It may be said that the rate is still considered substantial.

The Shou River alluvial fan in Toyama Prefecture

Station of the promoting division in Toyama Prefecture (Enomoto, 2007)

The promoting division in Toyama Prefecture operated a basin system for MAR in 2004. The system existed on the right bank of the *Shou River* situated in the center of the fan (36° 37′ 23″ N, 137° 0′ 38″ E). Two MAR basins are of about 1,000 m^2 (19.5 m × 56 m) were installed on a contour line, and are used in turn while repeating removal of sedimentary solids waste from the basin bed. These basins are covered by a building with a roof.

The source water for the basins is drawn from the *Wada-gawa Kyoudou* waterway (irrigation canal for paddy fields). Pre-treatment is not carried out. The maximal amount water, 8,200 m^3/day, is supplied in

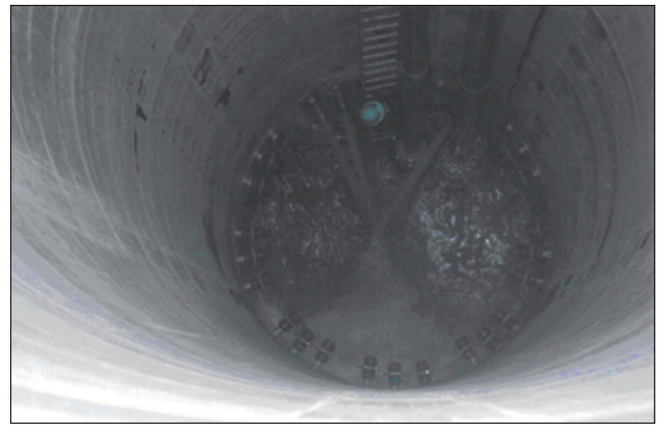

Figure 1. Receiving well with radial horizontal collector drains, Sept. 09, 2007
Figura 1. Pozo de recepción con drenes radiales horizontales. Septiembre 2007

Figure 2. Toyama Prefecture's infiltration basin No.2, Oct. 08, 20093. The Rokugo alluvial fan, Akita Prefecture
Figura 2. Balsa de recarga nº 2 en la Prefectura de Toyama. Octubre 2009. Abanico aluvial de Rokugo, en la Prefectura de Akita

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theory. Groundwater is pumped up by a receiving well with radial horizontal collector drains (Figure 1), which is installed about 250 m downstream from the basin and is used for industrial purposes.

Station of agriculture and forestry division in Toyama Prefecture (Tonami- Nouchirinmu-Jimusho, 2006)

In the agriculture and forestry division, Toyama Prefecture's infiltration basin was built in autumn of 2006. This basin was designed for flood control and not for enhancing groundwater resources. However, the form is the same as in MAR basins. While it operates, it should lead to the enhancement of subsurface water as well. The infiltration basin was installed in three places in the west of Tonami City.

The three basins are lined up along 3 km stretch of the *Suwagawa* irrigation and drainage canal. The canal flows in a northwest direction in the center of the *Tonami* alluvial fan Basin No. 2, midway among the three, is installed at 36° 39′ 06″ N and 136° 55′ 08″ E (Figure 2). The capacity of each basin is about 8,000-9,000 m^3.

Operation is limited to flood times, because the basin is aimed for flood control along the *Suwagawa* irrigation and drainage canal. Flood water is highly turbid, so clogging is a major problem.

The *Rokugo* alluvial fan is the place where the author studies MAR basins. In this paper, he focuses on the *Rokugo's* case, among other examples.

Paddy field and unpaved irrigation canals with MAR function

Paddy fields are a place for growing rice. At the same time, paddy fields possess a function that is the same as the MAR basin in that the fields also effectively recharge groundwater (Hida, 1989).

Wakasa *et al.* (2006) studied infiltration from May to August, 2005, using unpaved irrigation canals for

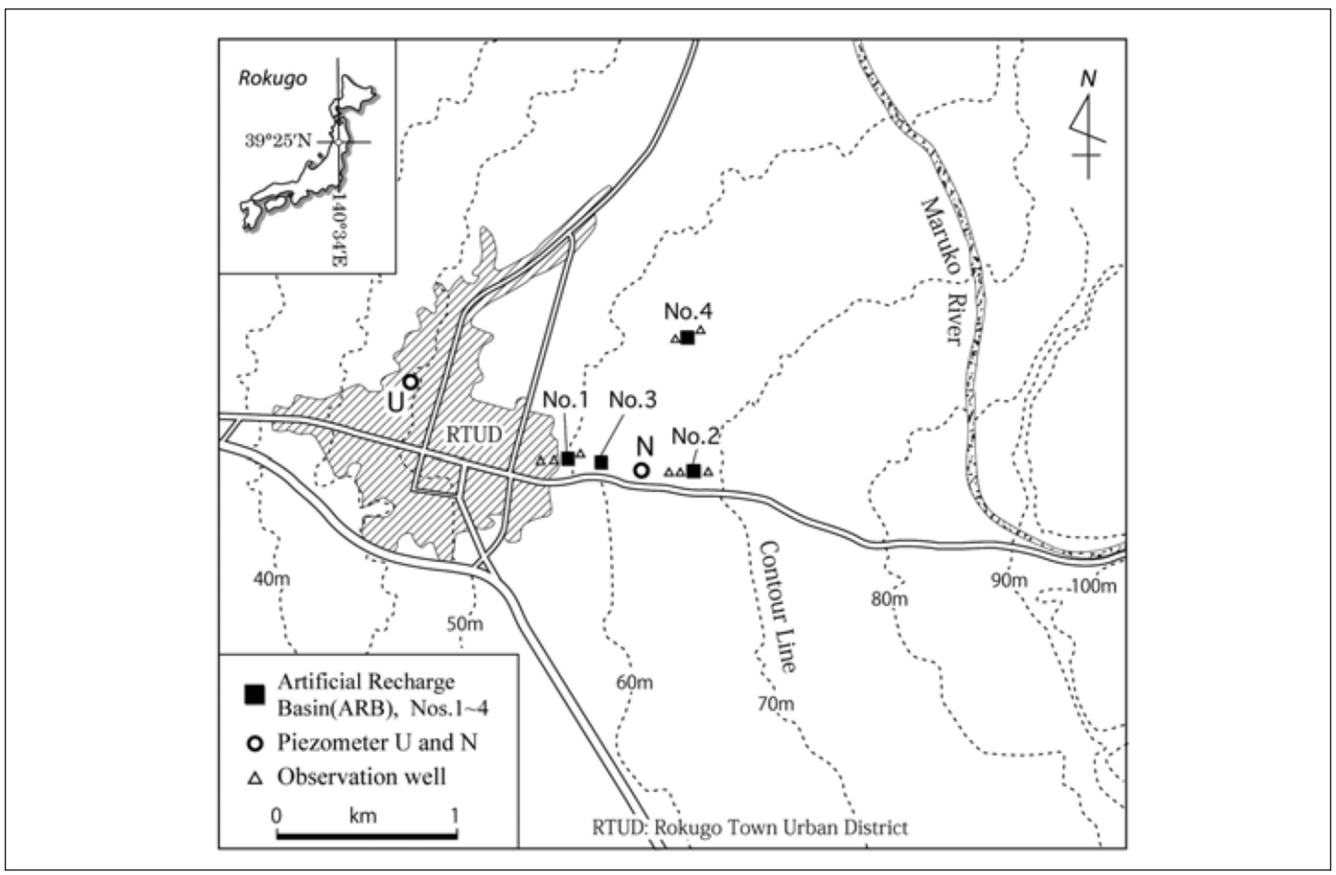

Figure 3. Study area, the Rokugo alluvial fan and the instruments
Figura 3. Area de estudio, el abanico aluvial de Rokugo y su instrumentación

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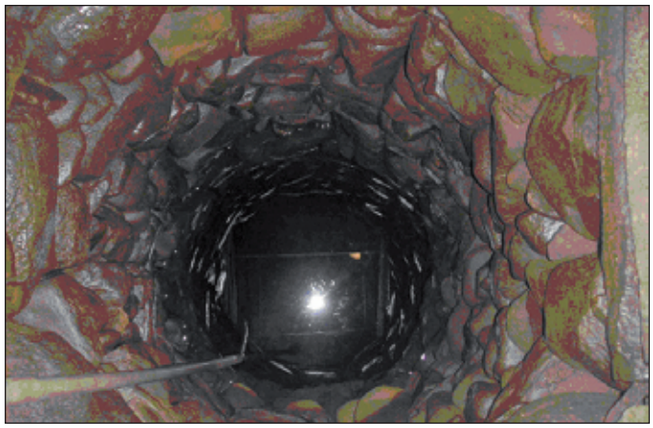

Figure 4. Well used for domestic purpose, Aug. 22, 2007
Figura 4. Pozo para uso doméstico. Agosto 2007

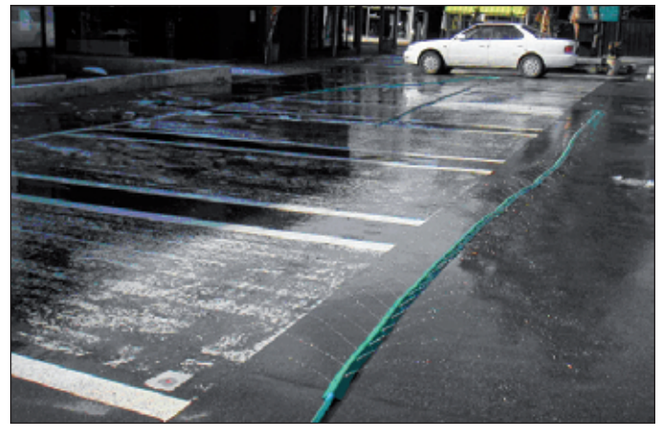

Figure 5. Groundwater used for the melting snow on a parking lot, Jan. 07, 2004
Figura 5. Agua subterránea utilizada para fundir la nieve en un aparcamiento. Enero 2004

paddy fields. The total length of the canals was 21 km. The canals were distributed in the central part of the *Narusegawa* River alluvial fan in Northern Japan. As a result, average infiltration rate during the observation period was estimated at about 18.8 cm/h. As a numerical value, unpaved irrigation canals in this district have a superior groundwater recharge function.

Case study. Rokugo alluvial fan

Hydrological environment of the Rokugo alluvial fan (Hida et al., 2005; 2006)

The *Rokugo* alluvial fan lies around 39° 25′ N and 140° 34′ E in northern Japan. The distance between the proximal fan, at 90 meters above sea level, and the distal fan, at 45 meters, is about four kilometers (Figure 3).

The unconfined aquifer of the *Rokugo* alluvial fan consists mainly of gravel, which hydraulic conductivity is 10 – 10^{-2} cm/sec and specific yield is over 20%. The depth of the aquifer is over 100 meters around the center of the fan. Annual mean precipitation is 1653 mm and annual mean potential evapotranspiration is estimated at 660 mm. Maximum snow depth occurs during a period from mid-January to mid-February. It averages 130 cm in the distal fan and 150 cm in the proximal fan.

The annual groundwater level changes regularly. The level is high during the period of paddy field irrigation from May to August and low during the non-irrigation period. As for land use, the paddy field accounts for 70 per cent of the total surface of the fan.

The urban district of *Rokugo* town is located in the distal fan. The inhabitants living there own well and water supply plant in every house (Figure 4). Groundwater is used for their domestic purpose and for the melting snow on parking lots in the winter season (Figure 5).

Mar basins

Four MAR basins (Nrs.1 - 4) (figures 6 to 9) are installed in the fan (Figure 3). The source water supplying each basin comes from the irrigation canal water, which is drawn from the *Maruko* River.

Table 1 shows the site of each basin, the constructing year, the basin area, the basin depth and the figure number of each basin.

Observation equipment

Two piezometer nests were installed as the main observation equipment. One is at *Nonaka* (N) station in the center of the fan (39° 25′ 02″ N, 140° 33′ 55″ E) and the other is at *Umamachi* (U) (named, *Yukawa* as well) station (39° 25′ 18″ N, 140° 33′ 03″ E) in the distal fan. Each nest consists of three pipes, drilled to depths of ca. 20, 50 and 100 m. Table 2 shows the specifications of the N and U piezometers. The geologic column section of each one is shown in Figure 10.

In addition, some observation wells were installed in the alluvial fan.

Effect of MAR basin No.2

As an example, the following is one of the result of MAR using basin No.2. (Figure 11). The approximately 60-70 L/sec water was supplied in the basin from

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Basin	Site	Elevation, m	Bain Area, m^2	Basin Depth, m	Construction Year	Photo No.
No.1	39°25′05″N, 140°33′35″E	58.0	1,192	1.0	1991	5
No.2	39°25′00″N, 140°34′05″E	68.0	2,120	3.4	1992, 1994	6
No.3	39°25′01″N, 140°33′44″E	61.0	212	2.9	1998	7
No.4	39°25′27″N, 140°34′05″E	62.0	1,045	3.0	1998	8

Table 1. MAR basins in the Rokugo alluvial fan
Tabla 1. Balsas de recarga en el abanico aluvial de Rokugo

April 8 to May 2, 1998. The water temperature in the basin was 4-5 degrees Celsius during the period.

The following points were confirmed by the every 10 minutes record at *Nonaka* and *Umamachi* piezometers. The scales of the vertical axis of Figures 12 and 13 are different.

Nonaka piezometers (Figure 12): **First,** the rise of the hydraulic head appeared on the 1st day after

Figure 6. Basin No.1 Apr. 24, 2004
Figura 6. Balsa nº 1. Abril 2004

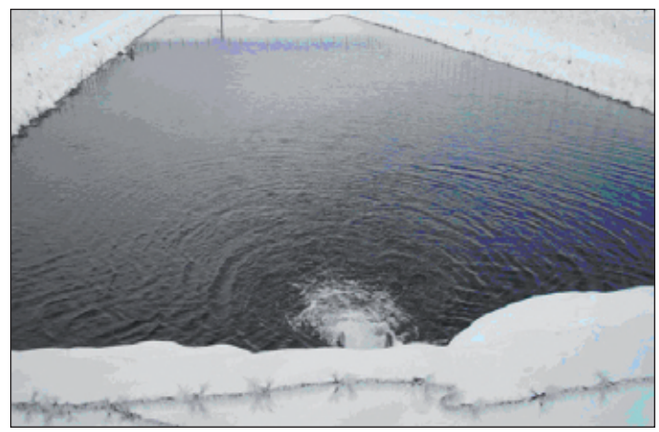

Figure 7. Basin No.2 Dec. 08, 2008
Figura 7. Balsa nº 2. Diciembre 2008

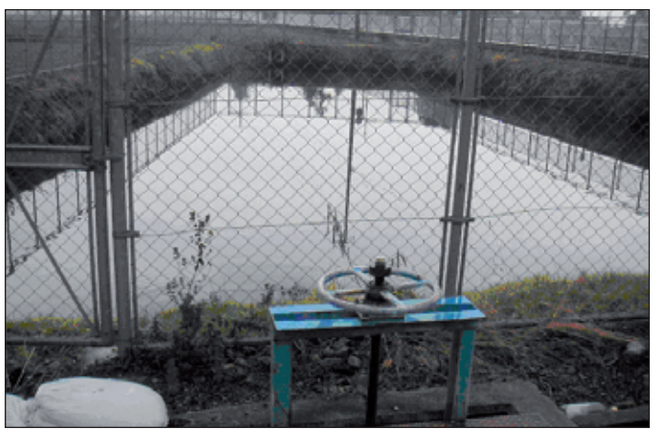

Figure 8. Basin No.3 Dec. 25, 2003
Figura 8. Balsa nº 3. Diciembre 2003

Figure 9. Basin No.4 Feb. 28, 2003
Figura 9. Balsa nº 4. Febrero 2003

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	N-20m	N-50m	N-100m	U-20m	U-50m	U-100m
Site	See: Figure. 1					
Head/Piz, (m) (1)	64.56	64.59	64.57	48.88	48.85	48.86
Ground level, (m)	64.19	64.19	64.19	48.37	48.37	48.37
Depth, (m) (2)	24.0	55.0	107.0	25.0	55.0	106.0
Screen (m) (3)	19-21	46-49	100-103	19-21	47-50	99-102
Diameter, (m/m)	150	150	150	150	150	150
Water level gauge	all NDR					
Recorded from	all 1991					
Year of const.(4)	all 1991					
GCS (5)	See: Figure 2					

Notes (1) Elevation of the head of piezometer column, (m)
(2) Drilling depth from ground level, (m)
(3) Screen: in depth above sea level, (m)
(4) Year of well construction
(5) Geologic columnar section

Table 2. Specifications of the N and U piezometers
Tabla 2. Especificaciones de los piezómetros N y U

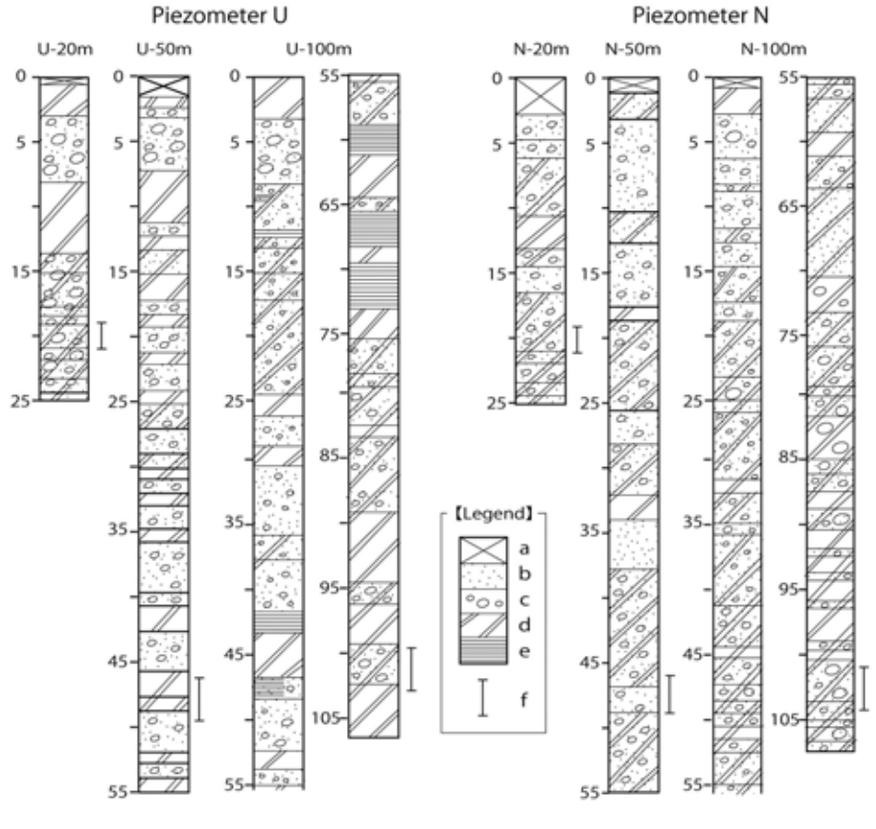

Figure 10 Geologic columnar section at the site of piezometers U and N by Hida and Kagabu (2009)
Figura 10. Columnas geológicas de los piezómetros U y N, por Hida y Kagabu (2009)

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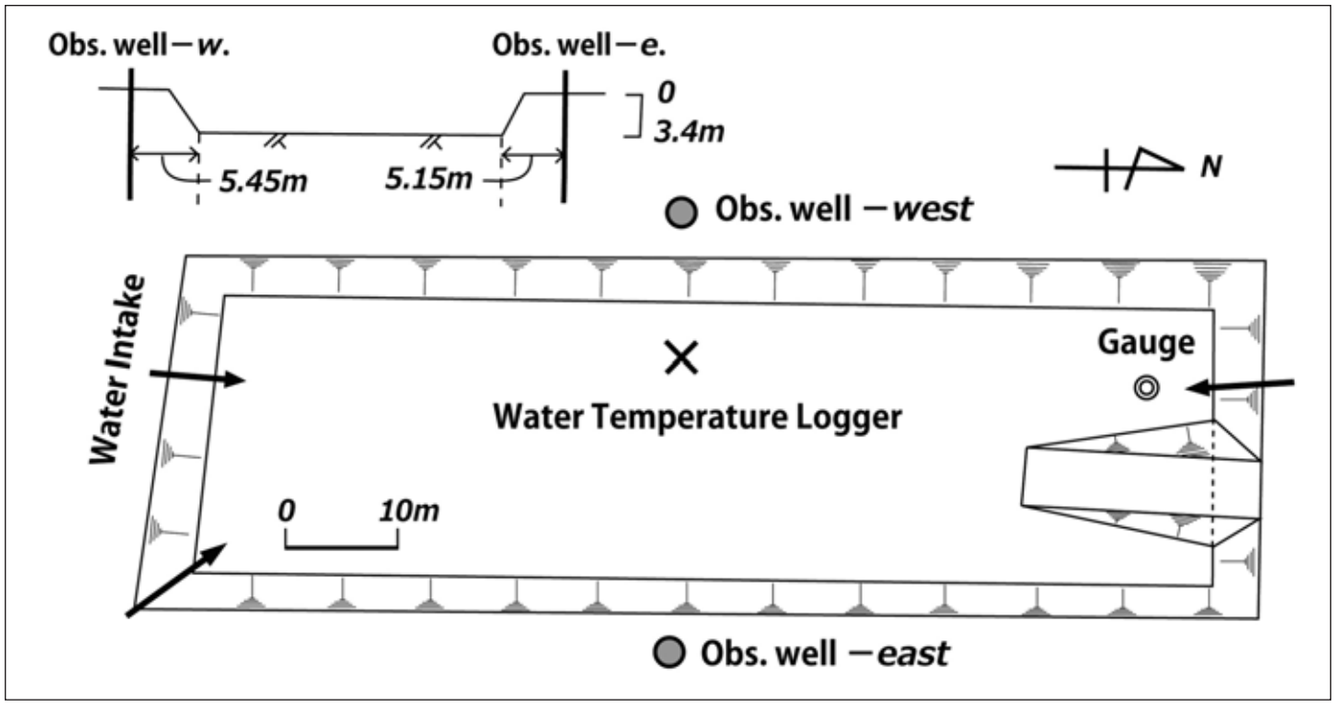

Figure 11. MAR basin No.2, water temperature logger and observation well
Figura 11. Balsa de recarga nº 2. Situación del fenómeno y el pozo de observación

starting the water supply (April 8, 1998). The recorded rise was about 80-100 cm at the depth of 20 m and about 40-60 cm at the depth of 50 m. **Second,** the fall of hydraulic head appeared approximately at the same time as stopping the water supply (May 2, 1998) at the depth of 20 m and 50 m. **Third,** the water temperature at the depth of 20 m dropped during the period from on the 2nd day after beginning water supply to the time the water supply was stopped. During the period, water temperature dropped from 11.4 degrees Celsius to 9.6 degrees Celsius. The authors are examining records from 2005 to check whether the supply of surface water with low temperature, which is four to five degrees Celsius in the basin, influences this phenomenon or not.

Umamachi piezometers (Figure 13): **First,** as an effect of this test, the rise of the hydraulic head was recognized. The rise appeared on April 22, the 14th day after starting the water supply (April 8, 1998). The recorded rise was about 10-30 cm at the depth of 20 m and about 10-20 cm at the depth of 50 m. **Second,** on May 5, after water supply was stopped (May 2, 1998), the fall of hydraulic head appeared at the depth of 20 m and 50 m. The time for the groundwater mound to decay was significantly shorter than the time to form after starting the water supply. This phenomenon is a characteristic of MAR performed in an unsaturated zone of the *Rokugo* alluvial fan. **Third,** the groundwater temperature at the depth of 20 m rose temporarily about 0.4 degrees Celsius from April 23 until May 4. The reason is clear: During the time, especially from April 23 until May 2, the groundwater of the depth at 50 m was confined, and the value of the hydraulic head at 50 m, at which groundwater has comparatively higher temperature, came close to the value of the hydraulic head at 20 m. Therefore the rise of this groundwater temperature was temporarily recorded. **Fourth,** from three points mentioned above, an effect of the MAR basin No. 2 was able to recognize at the *Rokugo* distal fan.

Results

The following points are summarized by the result of the precedent study of the MAR basin in the *Rokugo* alluvial fan (Hida, 2007; Hida *et al.*, 1999; 2005; 2006; 2009).

First, groundwater mounds were formed under the bottom of the MAR basins. In the example of MAR basin No. 2, the water supply of 60-70 L/sec raised the water table by 3-5 m in the aquifer around the basin area.

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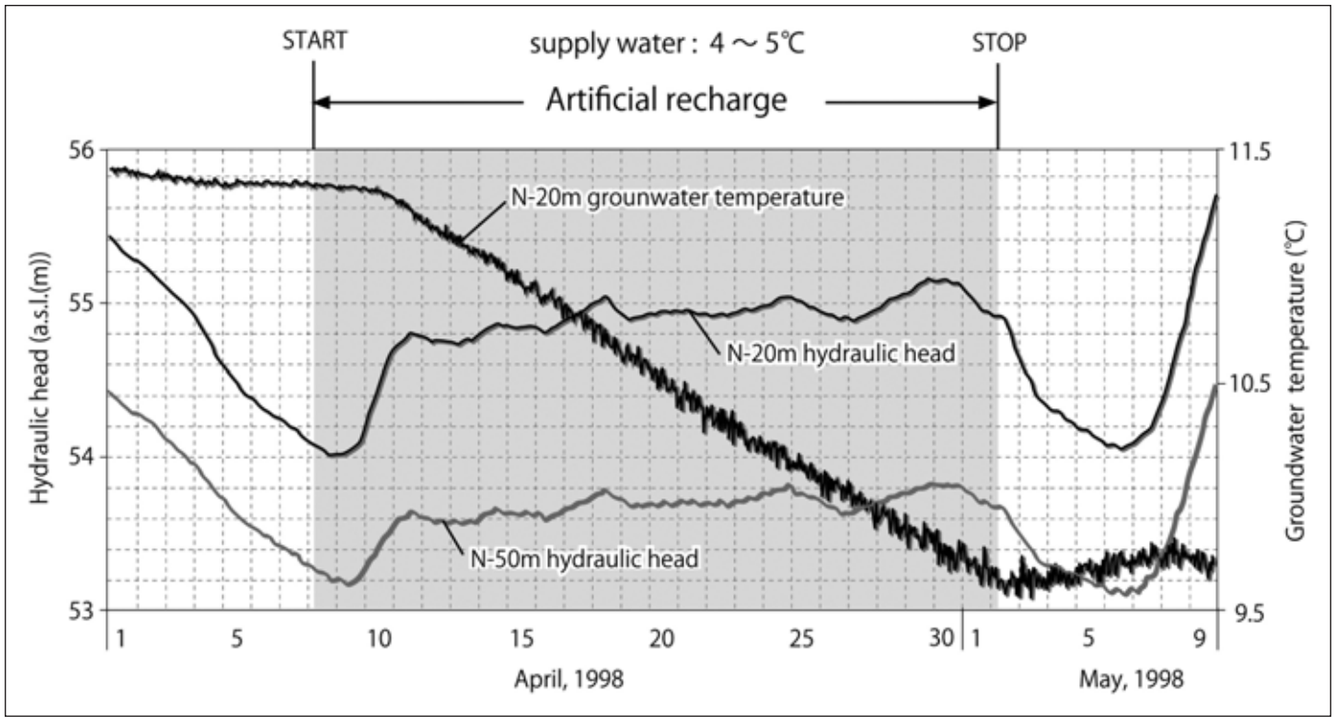

Figure 12. Results of an experiment of April at the Nonaka piezometer
Figura 12. Resultados de un experimento en el piezómetro Nonaka

Second, the effect of basin No. 2 resulted in the water table rising at piezometer U in the distal fan as well. The water supply of approximately 60-70 L/sec raised the water table by 10-30 cm approximately 14 days later at piezometer U at the depth of 20m.

Third, the infiltration rate of the basins Nr. 1, 2 and 4 generally recorded about 20 cm/h at the beginning of the water supply and become about 8 cm/h several months later.

Fourth, when low temperature water, due to snow melt, entered basin No. 2, the characteristic phenomenon of groundwater temperature was recorded by piezometers at a depth of 20 m at both sites of the central (N) and distal fans (U). Consideration of this point is a theme for future studies.

Fifth, the enhancing groundwater resources in the *Rokugo* alluvial aquifer has resulted in sustainability for the groundwater environment, especially in the distal fan.

Concluding remarks

This paper reviewed the situation regarding the MAR basin which operated as of 2009 in some alluvial fans situated in Prefectures of Yamagata, Toyama and Akita, Japan, making a detailed study of the Rokugo alluvial fan.

Generally, MAR basin contributes to sustainable aquifer management in the alluvial fan. From the viewpoint of our research group, MAR basin performed in alluvium will be utilized more in Japan for the future.

Acknowledgments

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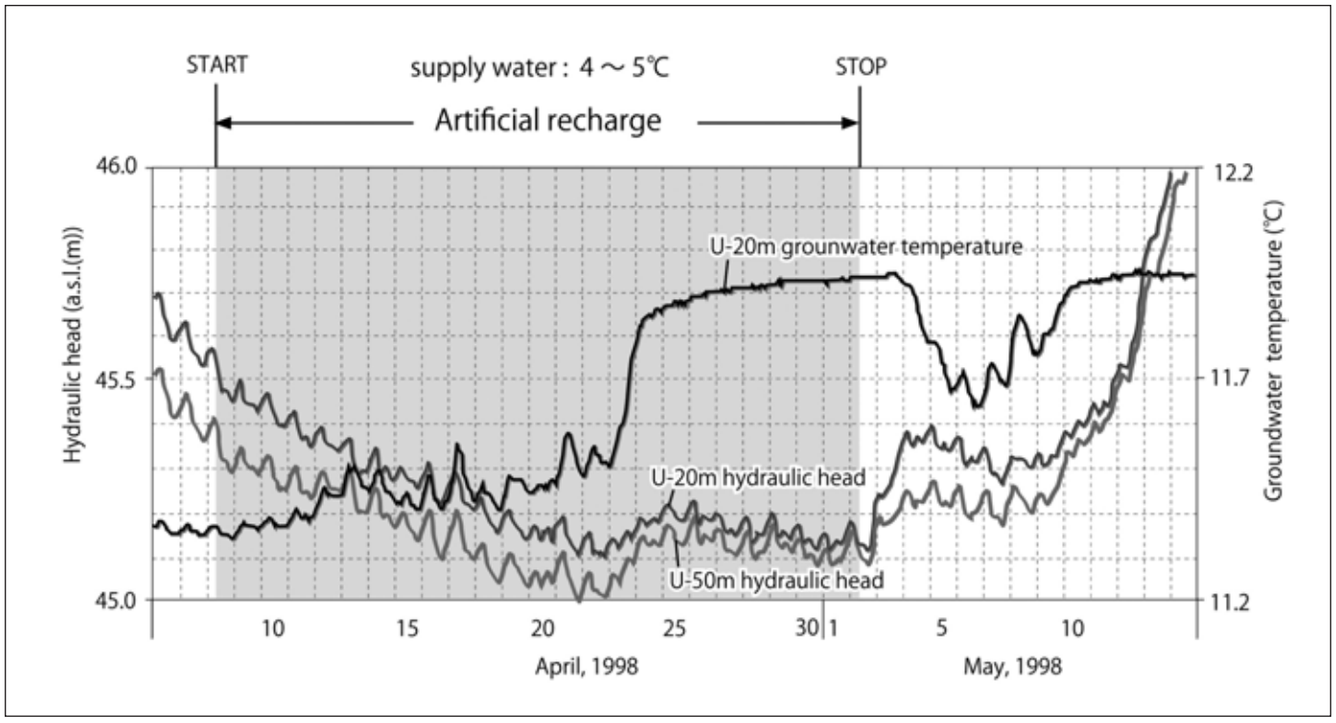

Figure 13. Results of an experiment of April at the Umamachi piezometer
Figure 13. Resultados de un experimento en el piezómetro Umamachi

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Note: Figures in this paper were taken by the author (Hida) excepting Figure 1.

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