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Basin artificial recharge of groundwater in the Rokugo alluvial fan, northern Japan

Noboru HIDA* and Yukiko OHIZUMI (OHTA)**

ABSTRACT: 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. The unconfined aquifer of the fan consists mainly of gravel and sand. Four artificial recharge basins were constructed on the central part of the fan. This time, we discuss the effects of artificial recharge on the formation of groundwater mounds under the area of basins No.1 and No.2. Results obtained are based on the recharge operations which have done three times, first: from September 8 to November 10, 1998 (63 days), second: from November 15, 1998 to April 5, 1999 (141 days) and third: from April 19 to April 29, 1999 (10 days). As conclusion, groundwater mounds were formed under the bottom of basins No.1 and No.2. The enhancing of the groundwater cycle in the aquifer has resulted in sustainability for the groundwater environment especially in the distal fan.

Key Words: Artificial Recharge, Aquifer, Groundwater Mound, Environment, Sustainability

1. INTRODUCTION

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. The center of Rokugo town, which is situated on the distal fan, numbers 6,000 inhabitants. They privately bore wells, pump groundwater, and supply the water for their own domestic uses. In addition, there are over 70 water springs including large and small ones in the area of the distal fan. The springs are associated with the regional water environment as well as multipurpose water uses.

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.

An artificial recharge for the aquifer, using four basins was operating during the non-irrigation period in order to enhance unconfined groundwater. The basins, Nos. 1-4, were constructed on the central part of the Rokugo alluvial fan. This idea of recharge basins depends on groundwater cycle in the aquifer of the alluvial fan, i.e. direction of groundwater flow corresponds principally to maximum incline of land surface between proximal and distal fan. Souse water to the basins is withdrawn from irrigation canals in which water flows through the year.

In this paper, we discuss the effects of artificial recharge on the formation of groundwater mounds under the area of basins No.1 and No.2. Results obtained are based on the artificial recharge operations which have done three times, first: from September 8 to November 10, 1998 (63 days), second: from November 15, 1998 to April 5, 1999 (141 days) and third: from April 19 to April 29, 1999 (10 days). We previously pointed out the outcome from the basin No.4 experience (Hida, et al., 1999).

2. HYDROLOGICAL ENVIRONMENT

The unconfined aquifer of the Rorugo alluvial fan consists mainly of gravel, of which hydraulic conductivity is of 10^{0}~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 1,653 mm and annual mean potential evapotranspiration is estimated

*Akita University, Japan, email: noboru@ipc.akita-u.ac.jp
**Akita Higashi High School, Japan

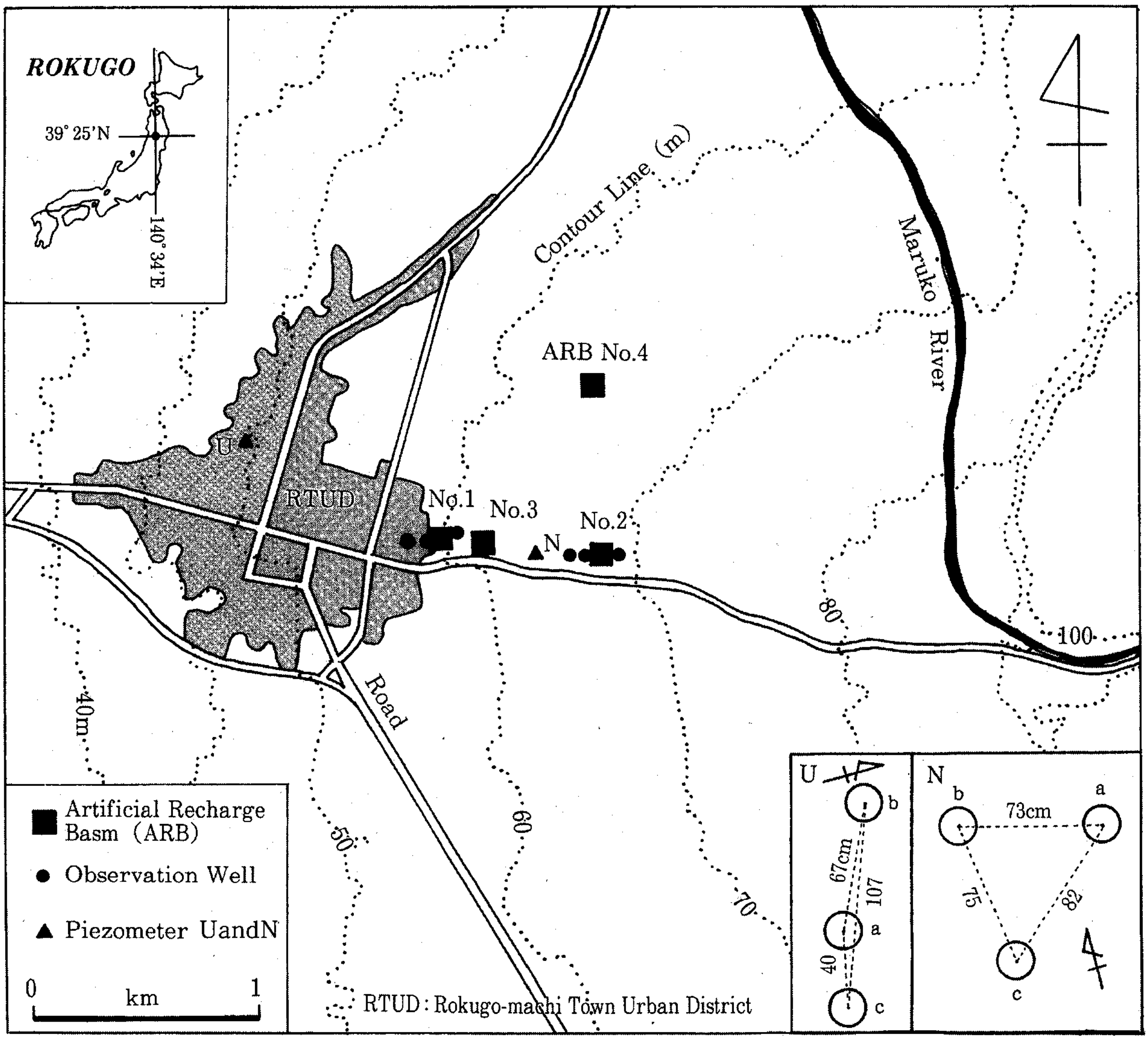

Figure 1. Nos. 1-4 artificial recharge basins for the unconfined aquifer in the Rokugo alluvial fan
Piezometer U and N: letter a is U-20 and N-20, b is U-50 and N-50, and c is U-100 and N-100 in Table 2.

Table 1 Structure of the basins (See: text)

	Area	Depth	Site	Elv.	Const. yr.
No.1	1,192 ㎡	1.0 m	39° 25′ 05″ N, 140° 33′ 35″ E	58.0 m	1991
No.2	2,120 ㎡	3.4 m	39° 25′ 00″ N, 140° 34′ 05″ E	68.0 m	1992, 1994
No.3	212 ㎡	2.9 m	39° 25′ 01″ N, 140° 33′ 44″ E	61.0 m	1998
No.4	1,045 ㎡	3.0 m	39° 25′ 27″ N, 140° 34′ 05″ E	62.0 m	1998

1994: Expansion

at 660 mm (Saito, et al., 2001). Maximum snow depth appears during a period from mid-January to mid-February. It averages 130 cm in the distal fan and 150 cm in the proximal fan. In recent years, 194 cm was recorded on February 17, 1986 and 86cm on January 26, 1987 in the distal fan.

3 . CHANGE OF ANNUAL GROUNDWATER LEVELS

Groundwater levels annually change in the aquifer of the the Rokugo alluvial fan. It is typically shown as follows at the Nonaka piezometer and observation well station located on the central part of the fan.

(1) Marked high water levels appear two times

through the year.

(2) First, a high water level appears when snow depth becomes zero around the end of March and the beginning of April, because the water of melted snow increases infiltration rate. The groundwater level starts to rise just after thawing begins in the middle of February, and reaches up to the peak just when snow melts away.

(3) Second, water level is high during irrigation activities owing to a large quantity of recharge from the paddy field. In particular, the highest level appears at the beginning of the activities.

(4) The groundwater level temporarily falls between the end of thawing and the beginning of irrigation activities. It takes about ten days for the lowest level changes to rise and reach the highest level. The difference of both water levels is over five meters.

(5) The groundwater level falls after irrigation as the paddy field is finished at the end of

Table 2 The function of observation wells (Ow) and piezometers (Piz)

Observation wells (Ow)

	Ow1	Ow2	Ow3	Ow4	Ow5	Ow6
Site	See: Note and Figures 1-3					
Head/Well, m (1)	59.11	58.65	57.62	68.64	68.56	66.60
Depth, m (2)	10.79	10.50	9.11	17.90	15.05	14.92
Screen, m(3)	1.0	1.0	0.5	4.0	4.0	4.0
Diameter, m/m	50	50	65	45	45	45
Water level gauge	No	NDR	NDR	No	NDR	No
Recorded from	-	1993.11	1993.11	-	2003,12	-
Year of const.(4)	1993.11	1993.11	1984	1995.1	1995.1	1995.1
GCS (5)	See: Figure 5-1					

(1) Elevation of the head of well column, abv. sea level, m
(2) Depth from the head of well column, m
(3) Screen, m : the toe of well column
(4) Year of well construction
(5) Geologic columnar section

Piezometers (Piz)

	U-20	U-50	U-100	N-20	N-50	N-100
Site	See: Note and Figures 1 and 3					
Head/Piz, m (1)	48.88	48.85	48.86	64.56	64.59	64.57
Ground level, m	48.37	48.37	48.37	64.19	64.19	64.19
Depth, m (2)	25.0	55.0	106.0	24.0	55.0	107.0
Screen, m(3)	19-21	47-50	99-102	19-21	46-49	100-103
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 5-2					

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

Note: The Site of observation wells (Ow) and piezometers (Piz)

Ow 1	39° 25′ 05″ N, 140° 33′ 37″ E	Ow 4	39° 25′ 01″ N, 140° 34′ 07″ E
Ow 2	39° 25′ 05″ N, 140° 33′ 35″ E	Ow 5	39° 25′ 01″ N, 140° 34′ 05″ E
Ow 3	39° 25′ 04″ N, 140° 33′ 31″ E	Ow 6	39° 25′ 01″ N, 140° 34′ 03″ E
Piz U	39° 25′ 18″ N, 140° 33′ 03″ E	Piz N	39° 25′ 02″ N, 140° 33′ 55″ E

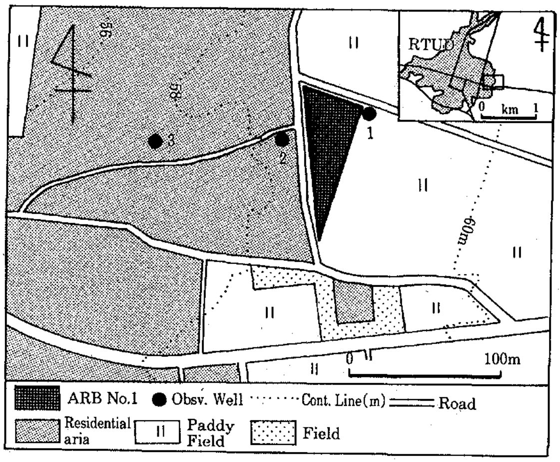

Figure 2. Artificial recharge basin No.1, observation wells 1-3, and surround

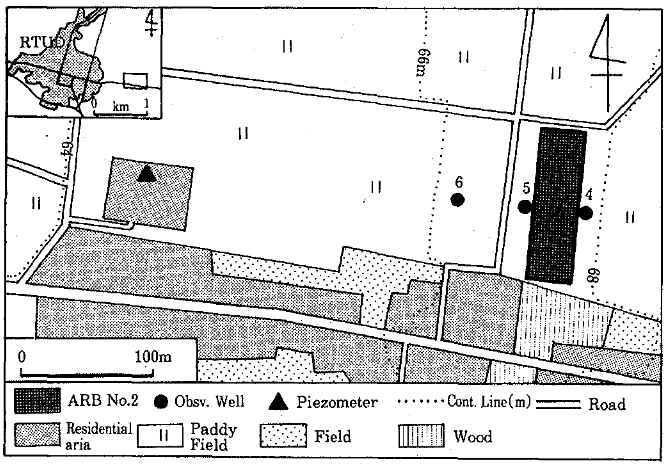

Figure 3. Artificial recharge basin No.2, observation wells 4-6, piezometer, and surround

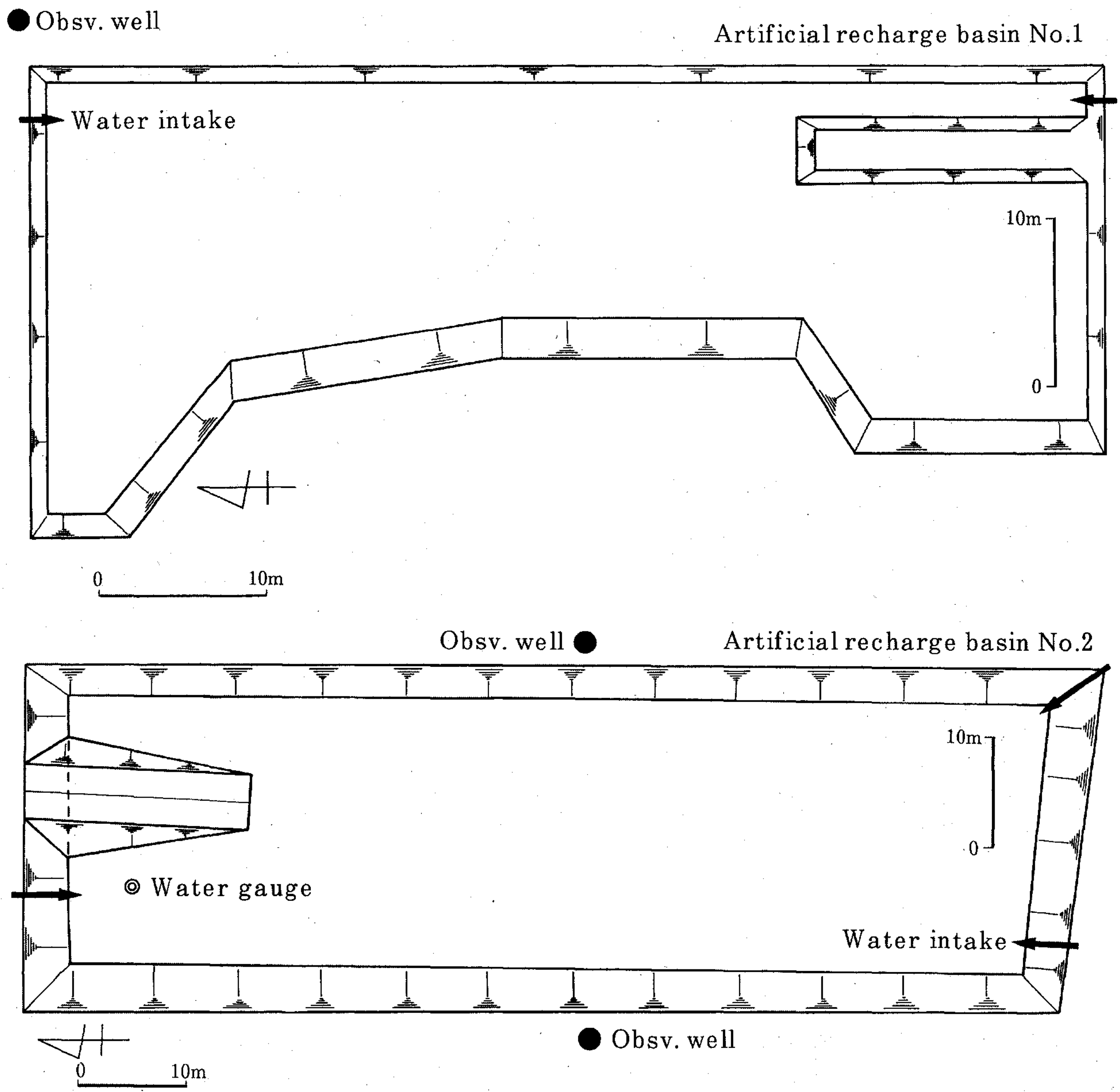

Figure 4. The form of artificial recharge basins No.1 and No.2

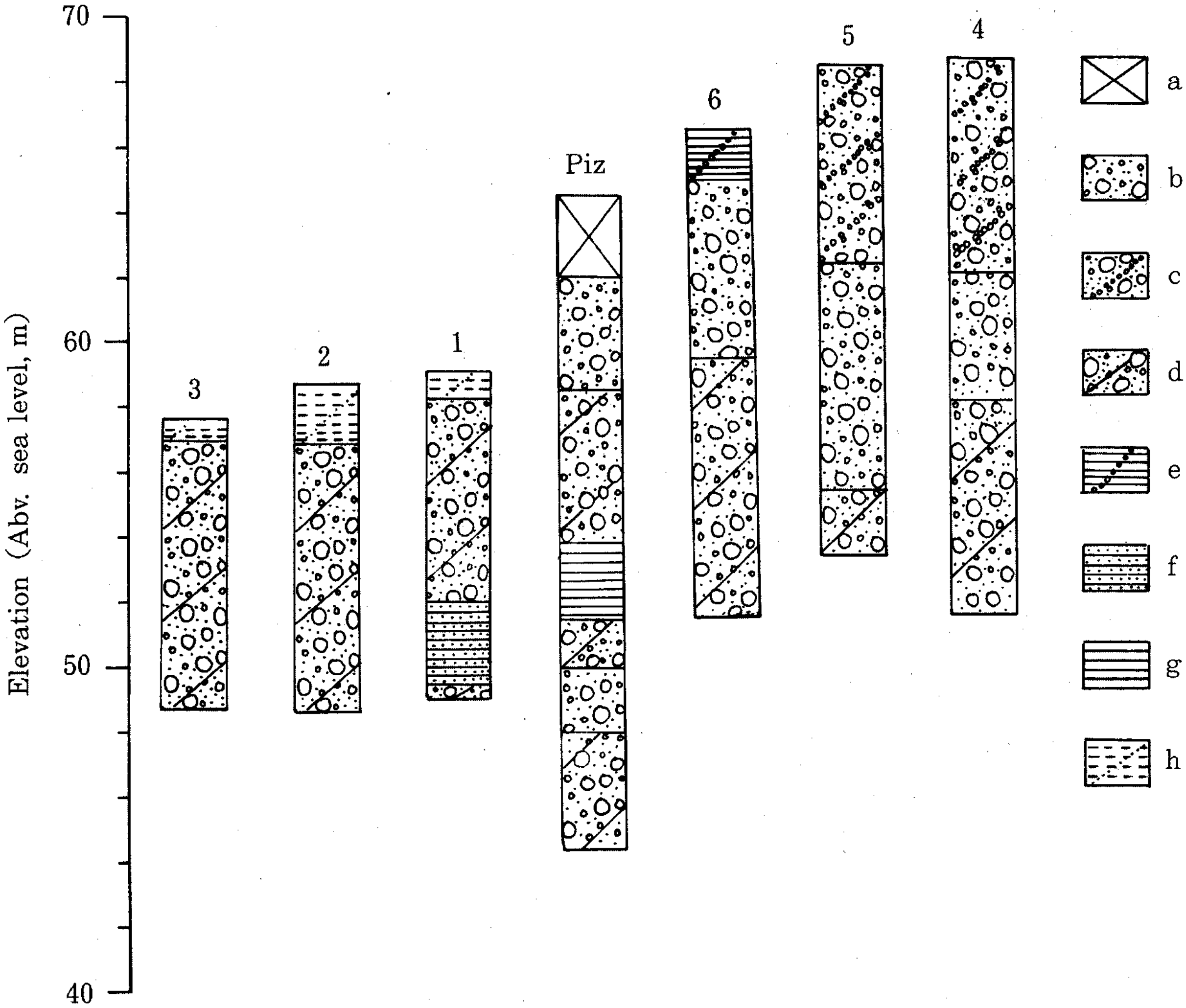

Figure 5-1. Geologic columnar section at the site of observation wells and piezometer

Legend; a: Soil, b: Sand and gravel, c: Sand and gravel with round shingle, d: Sand and gravel with clay, e: Clay with gravel, f: Sand and clay, g: Clay, h: Silt with sand

1~6 : Observation well, See Figs. 2~3 and Table 2
Piezometer: N-20 in Table 2

August, and low water level continues until the next thawing time.

(6) The groundwater level is lowest during the period from mid-January to mid-February, because first, maximum snow depth appears at the same time and the infiltration rate is nearly zero in the range of snow depth over ca. 60-70 cm, and second, inhabitants and industries pump much groundwater in order to melt snow on parking areas.

(7) There are clear responses to rising groundwater level when precipitation records more than 20 mm a day.

4 . ARTIFICIAL RECHARGE BASINS AND OBSERVATION EQUIPMENT

4-1 Site and Structure of the four basins

The site of the four artificial recharge basins is as shown in Fig. 1. Table 1 shows the structure of the basins, Nos. 1-4, such as the Bottom area of the basin, Depth from the ground surface at the basin, Latit., Longt., Elevation, and Construction year.

4-2 Observation equipment

Fig. 2 shows the site of basin No.1 and three observation wells, Nos. 1-3, and Fig. 3 shows the site of basin No.2 and three observation wells, Nos. 4-6 and

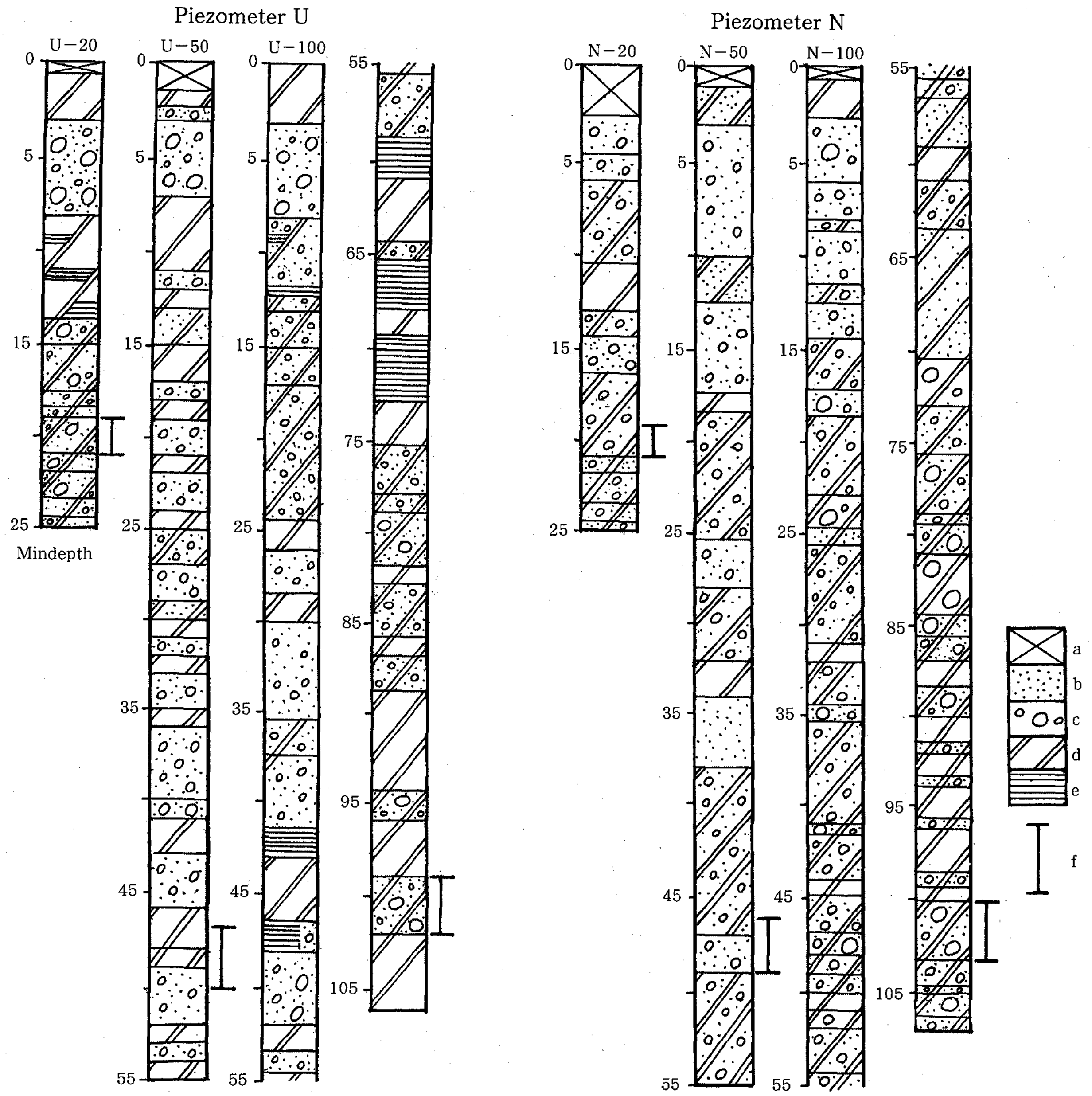

Figure 5-2. Geologic columnar section at the site of piezometers U and N

Legend; a: Soil, b: Sand, c: Gravel, d: Clay, e: Humic soil, f: Screen
GL (Avb. sea level); Piz U: 48.37m, Piz N: 64.19m
See Fig. 1 and Table 2

one piezometer.

Table 2 shows the function of observation wells and piezometers. The form of artificial recharge basins No.1 and No.2 is as shown in Fig. 4. Figs. 5-1 and 5-2 shows the geologic columnar section of the observation wells and the piezometers N and U (in Fig.1 and Table 2).

5. RESULTS AND DISCUSSIONS

5-1 Amount of supply water and infiltration rate: Basins No.1 and No.2

The irrigation canal laid out beside paddy fields supplies water sources to the basins. The canal water is drawn from the Maruko river, whose water quality was analyzed by Shimano, et al.(2001). The water received no pre-treatments. Table 3 shows the

Table 3 Amount of water supplied in ℓ /sec

	First time	Second time	Third time
Basin No.1	(40)	(40)	40
Basin No.2	(96.6)	(96.6)	96.6

Note : 1. The flow rate was only measured during the third time on April 4th, 1999. Others are estimated to be the same.
2. However, the water supplied was slightly changed, because the canal water did not constantly flow.

Table 4 Infiltration rate in cm/h

	First time	Second time	Third time
Basin No.1	(12.0)	(12.0)	12.0
Basin No.2	(16.4)	(16.4)	16.4

Note : The amount was calculated from the measurement of supplied water made on April 4th, 1999. The other infiltration rates are estimated to be equal to or greater than the the third time.

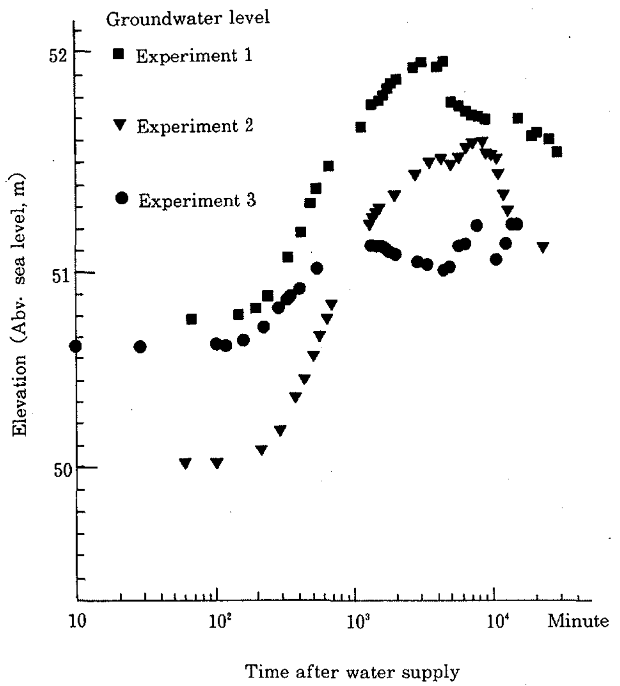

Figure 6. Rise of the groundwater levels after supplying water to artificial recharge bsin (ARB) No.1

Experiment 1: Sept. 8～27, 1998
Experiment 2: Vov. 15～30, 1998
Experiment 3: April 19～28, 1999

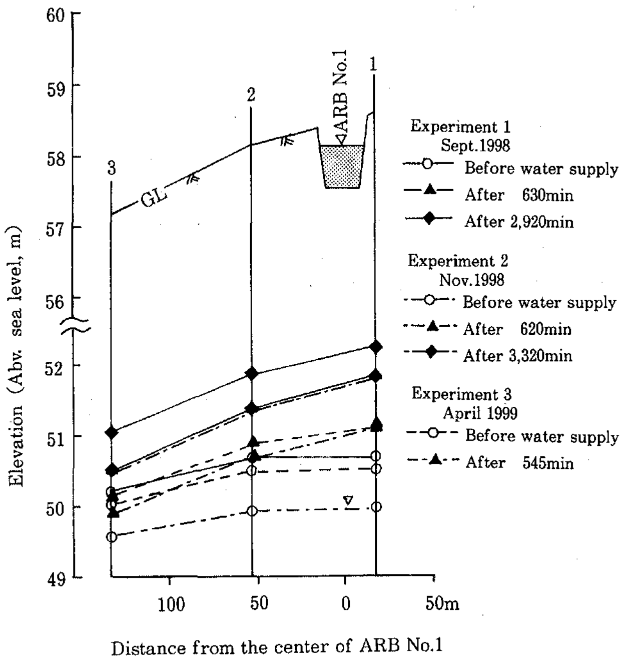

Figure 7. Changes of longitudinal profile of the water table between observation well 1 and observation well 3: after supplying water to artificial recharge basin No.1

1～3: Observation well

amount of water supplied in ℓ/sec and table 4 shows the infiltration rate in cm/h.

5-2 Growth and decay of groundwater mound

Growth and decay of groundwater mound was previously discussed by Hantush (1967) and Marino (1974), etc.

5-2-1 Case of Basin No.1

5-2-1-1 Growth of groundwater mound (Figs. 6 and 7)

In the duration of 10^4 minutes after the beginning of the water supply to basin No.1, we recorded growing water table at observation wells 1 to 3.

The initial water table measurement at observation well 2 was 50.69 meters in the first experiment,

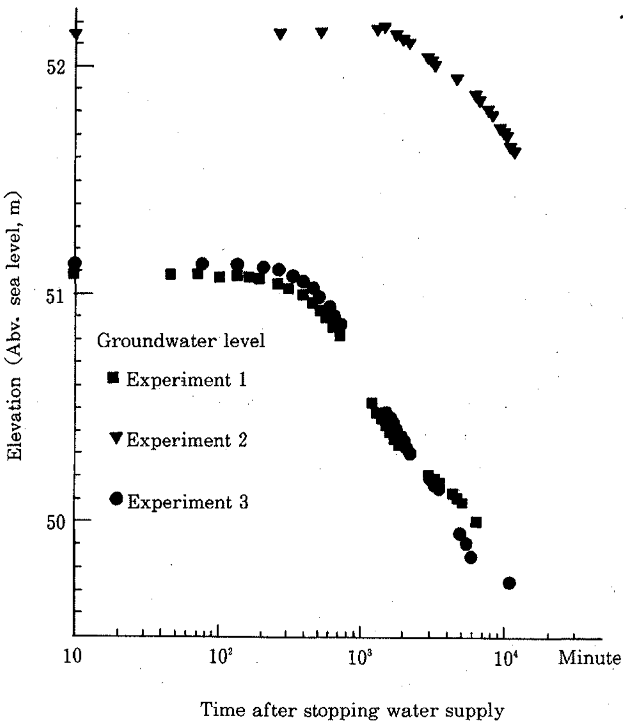

Figure 8. Decline of the groundwater levels after stopping water supply to artificial recharge basin (ARB) No.1

Experiment 1: Nov. 10~14, 1998
Experiment 2: April 5~12, 1999
Experiment 3: April 29~May 6, 1999

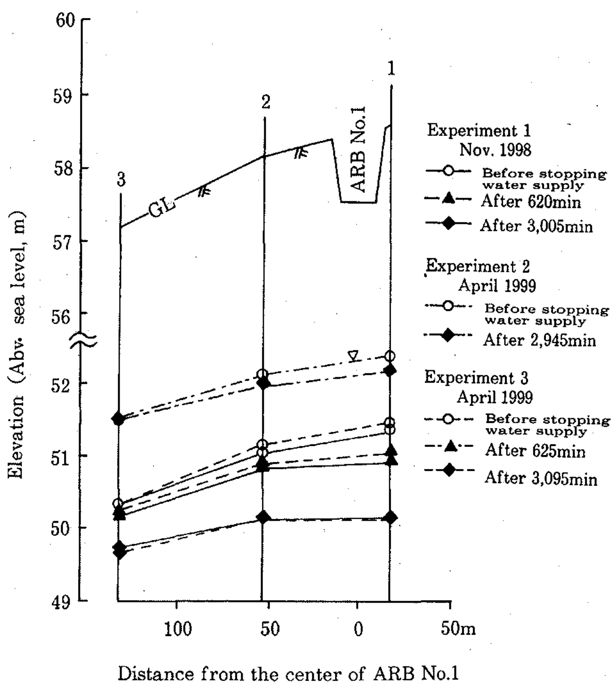

Figure 9. Changes of longitudinal profile of the water table between observation well 1 and observation well 3: after stopping water supply to artificial recharge basin No.1

1~3: Observation well

50.01 meters in the second experiment and 50.55 meters in the third experiment. Below is the record of water table changes observed at well 2 for the three respective experiments (Fig. 6).

In these experiments, water table began to rise after supplying water to basin No.1. In the first experiment, water table reached the highest value, 51.85 meters as of 2,920 minutes (ca. 49hours) in process. The rise in the water table was 1.16 meters during this time. The water table averaged a five centimeter per hour rise until 180 minutes after supplying water, and 10 centimeters rise per hour after that. This high amount is associated with the rise of water level in basin No.1.

In the second experiment, the water table averaged 10 centimeter rise per hour after 95 minutes from the beginning of water supply to basin No.1, and reached the highest value, 51.48 meters as of 6,920 minutes (ca. 115hours) into the process. The water table rose 1.47 meters.

In the third experiment, the water table did not rise as much as in the first and second experiments because the initial water table was high and the quantity of water supplied to basin No.1 was relatively small due to unstable flow of water in the irrigation canal. The water table rose 0.46 meters.

In each case, groundwater mound was formed under basin No.1 as shown in Fig. 7 which depicts a longitudinal section along observation wells 1, 2 and 3.

5-2-1-2 Decay of groundwater mound (Figs.8 and 9)

In the duration of about 10^4 minutes after the stopping water supply to basin No.1, we recorded a decaying water table at observation wells 1 to 3.

Just before stopping water supply, water table measured at the observation well 2 was 51.09 meters in the first experiment, 52.13 meters in the second experiment and 51.14 meters in the third experiment. Following is the record of water table changes observed at well 2 for the three respective experi-

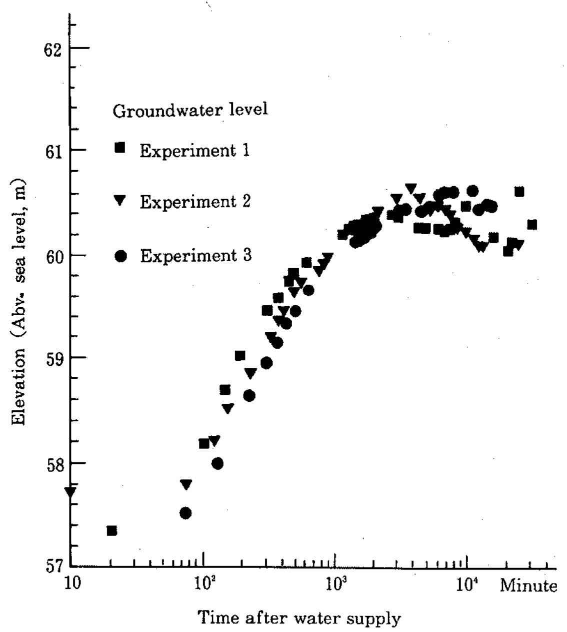

Figure 10. Rise of the groundwater levels after supplying water to artificial recharge basin (ARB) No.2

Experiment 1: Sept. 8~27, 1998
Experiment 2: Vov. 15~30, 1998
Experiment 3: April 19~28, 1999

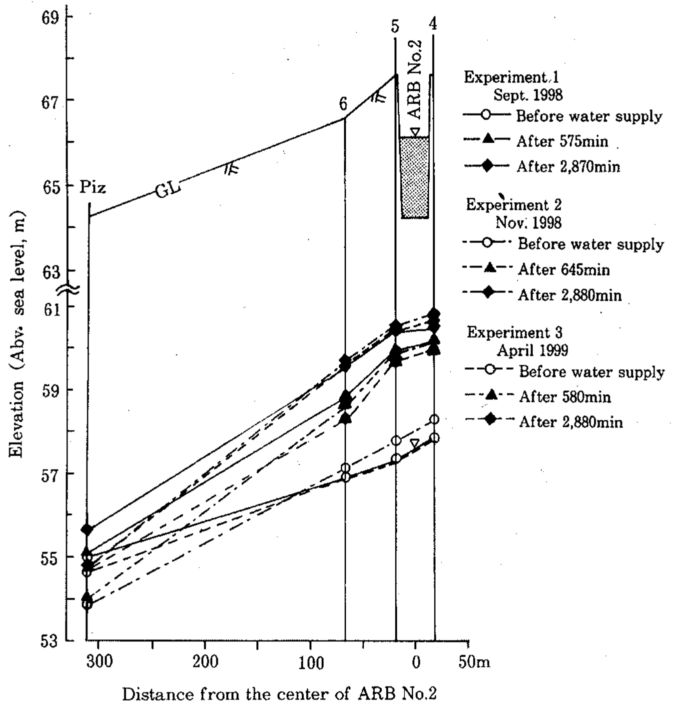

Figure 11. Changes of longitudinal profile of the water table between observation well 4 and piezometer: after supplying water to artificial recharge basin No.2

4~6: Observation well, Piz: Piezometer (N-20)

ments (Fig. 8).

In the first experiment, the water table almost showed no change until 370 minutes (ca. 6 hours) after stopping water supply. After that, it sank at a rate of 2 to 4 centimeters per hour, which was recorded after water level in the basin No.1 reached zero. 5,815 minutes (ca. 4 days) after stopping water supply, water table had sank to 50.02 meters. The decrease in the water table was 1.07 meters over the period of ca. 4 days.

In the second experiment, the water table rose 4 centimeters even after stopping water supply to the basin No.1. It will be seen that water from snow melt was infiltrating basin No.1. As of 1,340 minutes (ca. 22 hours) after stopping water supply, water table sank down to 50.55 meters. The declining amount of water table was 1.58 meters in the ca. 22 hours.

In the third experiment, water depth inside basin 1 was 91 centimeters right before stopping water supply to basin No.1, and reached almost zero centimeters as of 960 minutes. The decrease of the water table was small during the time when the water in basin No.1 was present, and showed 4 centimeters per hour and then 1~2 centimeters per hour after the water in the basin No.1 disappeared. As of 10,155 minutes (ca. 7 days) after stopping water supply, the water table sank to 49.75 meters. The decrease in the water table was 1.39 meters over the ca. 7 days.

In each case, groundwater mound decayed under basin No.1 as shown in Fig. 9, which is drawn in a longitudinal section along observation wells 1, 2 and 3. In the first and third experiments, groundwater mound did not decay immediately after stopping water supply to basin No.1, but it had almost disappeared 2,880 minutes (2 days) after stopping water supply. In the second experiment, the decay began later than in first and third experiments. This is probably why water from snow melt was infiltrated around the basin No.1.

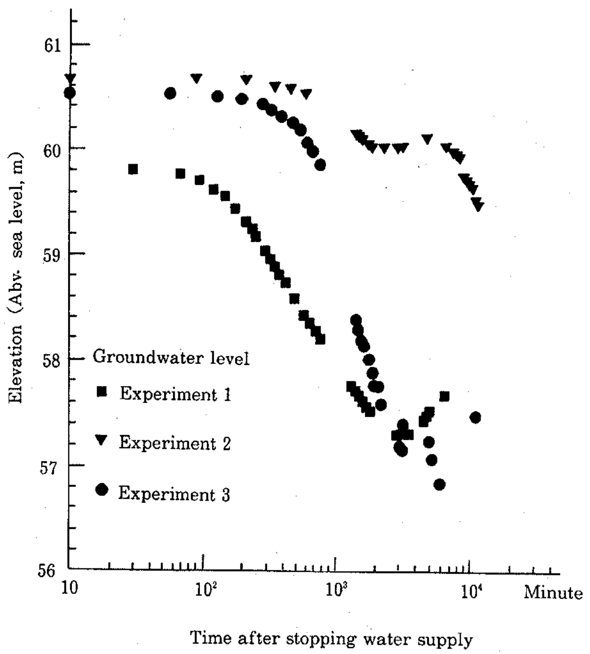

Figure 12. Decline of the groundwater levels after stopping water supply to artificial recharge basin (ARB) No.2

Experiment 1: Nov. 10~14, 1998
Experiment 2: April 5~12, 1999
Experiment 3: April 29~May 6, 1999

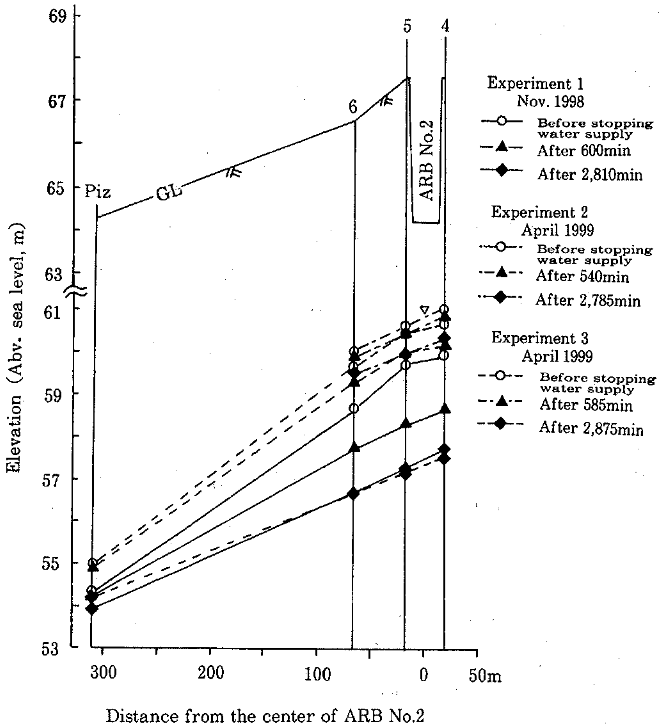

Figure 13. Changes of longitudinal profile of the water table between observation well 4 and piezometer: after stopping water supply to artificial recharge basin No.2

4~6: Observation well, Piz: Piezometer (N-20)

5-2-2 Case of Basin No.2

5-2-2-1 Growth of groundwater mound (Figs.10 and 11)

About 10^4 minutes after beginning water supply to basin No.2, we recorded a growing water table at observation wells 4 to 6 and the piezometer.

Initial water table under basin No.2, measured at observation well 5, was about 57.5 meters in each of the three experiment. The water table began to rise after supplying water to the basin, and reached the highest value, 60.39 meters as of 43 hours in the first experiment, 60.66 meters as of 56 hours in the second case test and 60.66 meters as of 172 hours in the third experiment, in respective order (Fig.10). The increase in the water table was 3.03 meters for the first, 2.87 meters for the second and 3.23 meters for the third. In each experiment, mound was formed under basin No.2 as shown in Fig. 11 which is drawn in a longitudinal section along observation wells 4, 5, 6 and the piezometer.

5-2-2-2 Decay of groundwater mound (Figs.12 and 13)

About 10^4 minutes after the end of water supply to basin No.2, we recorded decaying water table at observation wells 4 to 6 and the piezometer.

Just before stopping water supply, water table measured at observation well 5 was 59.77 meters for the first experiment, 60.63 meters for the second experiment and 60.51 meters for the third experiment. Below is the record of water table changes observed at observation well 5 for the three respective experiments (Fig. 12). In the first experiment, the decrease in water table was 2.49 meters as of 2,820 minutes (47 hours) and 3.71 meters as of 5,460 minutes (91 hours) in the third experiment, after stopping water supply. On the other hand, the decrease in the second case, 0.65 meters as of 2,785 minutes (ca. 46 hours) after stopping water supply, was not as much as in the first and second cases. This would be due to melting snow, whose period coincides with the end of March and beginning of April, and result in a bigger infiltration rate from the surface.

In each case, groundwater mound decayed under basin No.2 as shown in Fig. 13 , which is drawn in a longitudinal section along observation wells 4, 5, 6 and partly including the piezometer.

6. CONCLUSION

The Rokugo alluvial fan, whose aquifer mainly consists of gravel and sand whose groundwater flows in response to the maximum inclination of land surface, suits the practice of artificial recharge. Groundwater mounds were formed under the bottom of the artificial recharge basins that were constructed on the center aria of the fan. The enhancing of the groundwater cycle in the aquifer has resulted in sustainability for the groundwater environment especially in the distal fan.

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REFERRENCES: Hantush, M.S.(1967): Water Resources Research, 3, 227-234. Hida, N. *et al.* (1999): Journal of Groundwater Hydrology, Vol.41, No.1, 23-33. Hida, N. (2002): Journal of Japanese Association of Hydrological Sciences, Vol.32, No.3, 63-70. Marino, M.A.(1974): Journal of Hydrology, 23, 289-298. Saito, M. *et al.* (2001): Proceedings of the Japanese Association of Groundwater Hydrology: 2001 Autumn Conference, 146-151. Shimano, Y. *et al.* (2001): Proceedings of the Japanese Association of Groundwater Hydrology: 2001 Autumn Conference, 138-143.