From the result of the simulation carried out as a preliminary examination of the influence of climate change, we predict that a dramatic fall in groundwater levels will occur at the head of the Shigenobu-gawa alluvial fan and around the *segire* regions.

The groundwater model used in this research is based on limited data and the results f a recent investigation. A more clear understanding of the actual conditions of deep roundwater flow, such as groundwater storage, amount of flow, and water quality, is ecessary to clearly show whether a deep well could provide new water resources. We hink that a more accurate report could be attained by investigating the shape (depth) of the roundwater basin and the hydrogeological features of the deep aquifer and by carrying ut examinations using the groundwater model based on the obtained results.

CKNOWLEDGMENTS

The authors wish to express their sincere thanks to the municipalities of Matsuyama city, Masaki town, Toon city, and others in the Dogo Plain for their primary study of data related o water and groundwater issues in the region. The authors also thank Mr. Koike, Manager of the River Division of the Shikoku branch of MLIT, for his kind advice on this work. The uthors are grateful to the committee members and colleagues of RHF for their continuous ncouragement and helpful advice on this work.

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CHAPTER 16

Hydrogeology and water balance in R. Chikugo-gawa Plain, Fukuoka Prefecture, Japan

Satoshi Hasegawa, Akira Oishi & Seisuke Miyazaki
Yachiyo Engineering Co., Ltd., Nishiochiai, Shinjyuku-ku, Tokyo, Japan

Naoki Kohara
Nippon Koei Co., Ltd, Kojimachi, Chiyoda-ku, Tokyo, Japan

ABSTRACT: It is important to understand river and groundwater interactions. The authors attempted to clarify these interactions by a survey of the hydrogeological structure of the study area. The alluvial fan sediments mainly consist of debris flow deposits. The gravel composition of surface outcrops includes granite on both banks of the R. Koishiwara-gawa, but these were not present on the left bank of R. Sata-gawa. The epiclastic sediments of the Aso-4 is divided into Aquifer I and II. Within the present annual water balance from 2003 to 2007, the recharge to groundwater was larger than the discharge from groundwater. It was estimated that the annual total surface flow was 400,000,000 m^3/day, and that the ratio of abstraction to the whole discharge was quite small. It was observed that groundwater closely interacts with river water, and that the recharge from the irrigation water amounts to about 40% of that from rainfall.

Keywords: Chikugo-gawa alluvial fan, Ryochiku Basin, hydrogeological structure

1 INTRODUCTION

The study area is located on the Ryochiku Basin in the northern Kyusyu district under non-snow coverage region where snowfall melts immediately, and the annual precipitation is about 1,500–1,900 mm. The Chikugo-gawa alluvial fan was formed by the rivers Koishiwara-gawa and Sata-gawa, which are flowing from the Kosyo-Umami Mountains of the north side of Ryochiku Basin (Fig. 1).

It seems that the groundwater environment of this area has been largely unaffected by human activities up to recent times, although reductions in spring discharges and decreases of the flowing wells have been caused by lowered groundwater level due to pumping from deep wells to serve the industrial and large-sized commercial buildings and by progressive urbanisation.

The Chikugo-gawa alluvial fan has been inhabited since the Yayoi Period, and was used for paddy fields which were irrigated from the spring waters and irrigation ponds on the alluvial fan until the 1950's as recorded in the Old Map of the Akizuki Clan created in 1842, shown in Fig. 2.

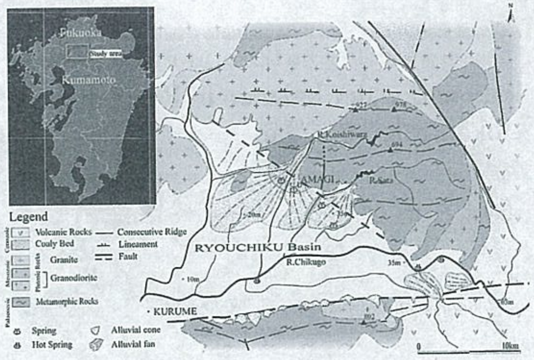


Figure 1. Study area.

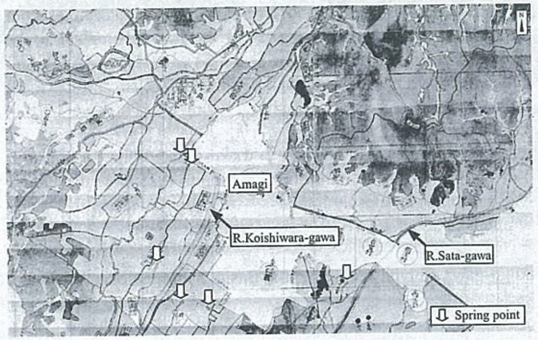


Figure 2. "Akizuki-Funai-zu" published in 1842.

Cropland abandonment and urbanization increased recently, although the arrangement of the irrigation networks and the arable land holdings were upgraded by the construction of Egawa Dam and Terauchi Dam and were made into rice fields in the 1960's.

In the R. Sata-gawa, "Segire" (stream loss) occurs during non-irrigation periods. Therefore the people in the villages are calling R. Sata-gawa the Japanese radish stream "Daikon-gawa". Because they cannot wash Japanese radish "Daikon" which fruited during late autumn to early spring, it is handed down as a "Kobo Daishi" tradition.

On the other hand, R. Kogane-gawa from where the spring water "Suizenji-nori" (a species of a blue algae) is cultivated. At present, spring cultivated. At present, spring water is not drawn except for the wet season, and the river is enriched by pumping from the wells.

Therefore, it is important to understand that the river and groundwater interact. The authors attempted to clarify these interactions by a survey of the hydrogeological structure

Geological techniques, measurement of the water balance and groundwater table, and water quality will be used for clarifying the hydrogeological structure.

The alluvial fan sediments were subdivided by Facies analysis of gravel beds. And the pyroclastic flow deposits were identified in the alluvial fan sediments. Basement rocks are Granitic rocks and Sangun Metamorphic rocks. There are some concealed faults near the pediment.

Based on these facts, the aquifer was classified. This hydrogeological model would account for water balance and water quality without inconsistency.

On the other hand, as mentioned in the IPCC Fourth Assessment Report, global warming has been steadily progressing. It is considered that global warming will causes an increase in evapotranspiration and changes in the hourly to daily rainfall patterns.

The question is how the groundwater environment will change in the study area as affected by similar phenomenon in the future. The past and future changes of the groundwater environment will be estimated and forecasted respectively using a numerical simulation model with simple hydrogeological models. The simulation result based on the hydrogeological model are described later.

2 STUDY AREA

2.1 *General*

The R. Chikugo-gawa is the largest river of Kyusyu Island. It originates in the Kuju volcano (1,787 m) and has a length of 143 km, reaching the Chikugo Plain through some intermountain basins. The catchments area is 2,860 km^2.

The Chikugo Plain, a productive grain producing region, covers an area of 620 km^2 and is divided into two areas near Kurume by relative relief. The upstream side is called the Ryochiku Basin. The Ryochiku Basin is surrounded by horst-mountain (700–900 m) which were formed by uplifting in the Quaternary period. R. Chikugo-gawa flows through the central part of the plain towards the west.

The Chikugo-gawa alluvial fan is formed by the R. Koishiwara-gawa and R. Sata-gawa, which are flowing from the Kosyo-Umami Mountains of the north side of Ryochiku Basin. The alluvial fan covers about 63 km^2. R. Chikugo-gawa is eroding the distal fan area.

2.2 *Rainfall*

Although the Saga meteorological gauging station is slightly beyond the study area, it has acquired relevant long-term annual rainfall data for more than a century as shown in Fig. 3.

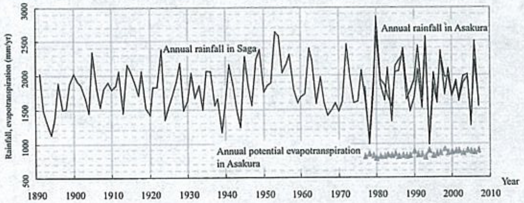
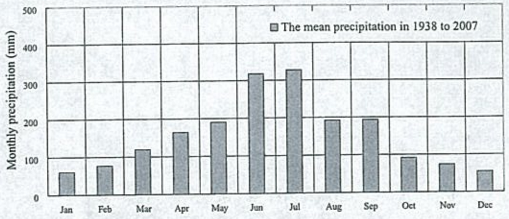


Figure 3. Long-term trend of rainfall.



igure 4. The mean monthly precipitation for 1938 to 2007 (Saga meteorological station).

Over this period, monthly peak precipitation is in the rainy season (June to July); winter s the dry season (Fig. 4).

However, depending on the year, a peak can also occur during the typhoon season in utumn.

According to the Fig. 3, annual rainfall does not clearly show upward and/or downward rends, however, it reveals years of remarkable drought and high rainfall that frequently ccurred especially during the last 30 years. This tendency, as indicated in Fig. 3, is also imilar to the rainfall data from Asakura meteorological gauging station.

.3 *Temperature*

s indicated in Fig. 5, temperature in Saga and Asakura clearly shows an upward trend specially after the 1950s, and the variation is estimated to be about 1.5°C for the last 0 years. However, it is known that land use change (especially due to urbanization) ppears to influence the variability in daily maximum/minimum temperature. From this oint of view, it can be considered that the slightly increasing daily minimum temperature n Saga is due to the fact that the surrounding area was fairly urbanized, especially after he 1980s.

On the contrary, the daily minimum temperature in Asakura does not show such a endency. Hence, it is concluded that the recent warming trend in the study area is not aused by urbanization, but probably due to global warming.

2.4 *Stream flow of the main channel*

In the R. Chikugo-gawa catchment area, stream flow reflects seasonal changes in precipitation. It increases during the rainy season (June to July), then declines until winter (December to January).

Stream flow may increase in the short term during the typhoon season in autumn. Because winter snowfall rarely forms a continuous snow cover, the spring snowmelt does not increase stream flow.

Discharge of the R. Chikugo-gawa main stream reaches its peak in the rainy season at 0.13 $m^3/s/km^2$, then decreases to 0.02 $m^3/s/km^2$ in the dry season. Discharges of the R. Sata-gawa and R. Koishiwara-gawa are 30–80% and 20–70%, respectively, of that of the R. Chikugo-gawa (Fig. 6).

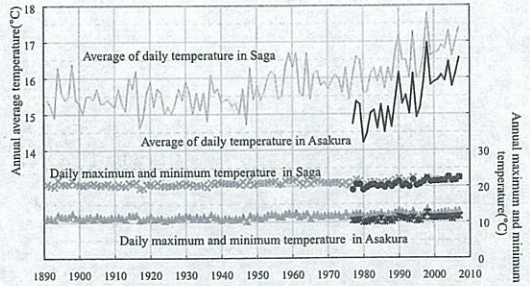


Figure 5. Long-term trend of temperature.

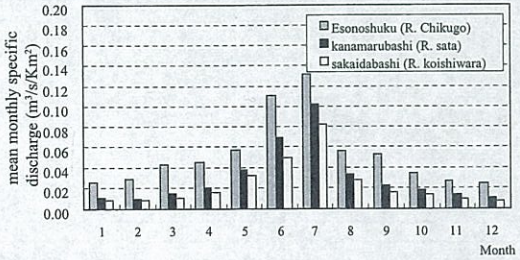


Figure 6. Main river discharge.

3 GEOLOGICAL SETTING

3.1 *Geology*

The Cretaceous granites and the Triassic Sangun Metamorphic Rocks are distributed widely in the surrounding area of the Ryochiku Basin, and the volcanic rocks of Plio-Pleistocene age are distributed in the upstream area (Fig. 1). In the Ryochiku Basin, these rocks constitute an impermeable basement.

In the alluvial fan, two geomorphic surfaces (I: old, II: new) are identified, and springs are located on the Yorii-Amagi line at the distal fan area of alluvial-fan surface II. The lower terrace was 2–5 m below surface I along the downstream of the R. Koishiwara-gawa and R. Sata-gawa. A difference in level is clear at the distal fan area. On the left bank of the R. Sata-gawa, the former river-course surface I′ is lower than I (Fig. 7).

The Ryochiku Basin is a half graben rift basin formed by faulting in E-W and NW-SE directions. This basin is filled with debris flow deposits and flood plain to marsh sediments. These sediments have intercalated regional tephras, such as the Yufu-gawa pyroclastic flow deposit (hereafter Yfg) and Aso-4 pyroclastic flow deposit (Aso-4). The stratigraphy of the Chikugo-gawa alluvial fan is shown in Table 1.

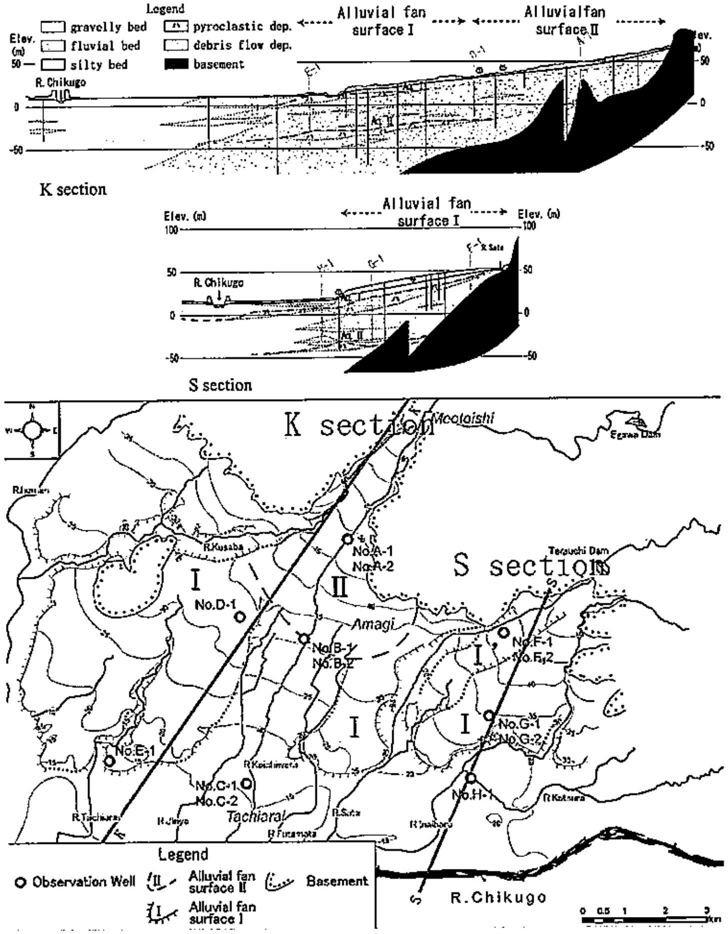


Figure 7. Geological Profile of the Chikugo-gawa Alluvial Fan.

3.2 *Alluvial fan sediments*

The alluvial fan sediments mainly consist of debris flow deposits. The consolidated debris flow deposits are matrix-supported with thickness of 20–250 cm. Some sand beds with thickness of several centimetres occur in between along the boundary (Table 2, 1a). Grains are mostly sub-angular to angular gravel, and there is also a horizon in which rounded gravels are mixed. However, in alluvial-fan surface II, the sediments are loose compared to the lower debris flow deposits

Table 1. Stratigraphy of the Chikugo-gawa alluvial fan.

Cenozoic	Quaternary	Holocene	Present River Deposit
			Debris Flow Deposit
		Pleistocene	Aso-4 Pyroclastic Deposit (Aso-4, 90 ka)
			Debris Flow Deposit
			Flood Plane - Debris Flow Deposit
			Yufu-gawa Pyroclastic Deposit (Yfg, 600 ka)
			Flood Plane - Debris Flow Deposit
	Neogene	Pliocene	
Mesozoic	Cretaceous		Granitic rocks
	Triassic		Metamorphic rocks

Table 2. Characteristics of typical facies.

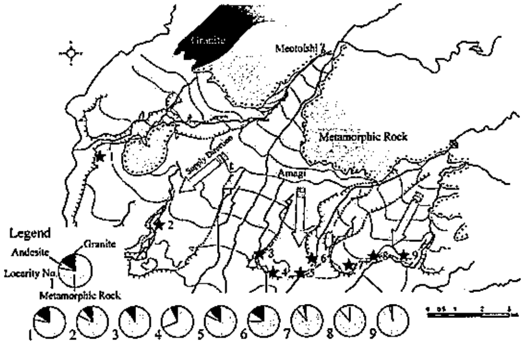
Facies	Characteristics
Alluvial fan deposits	
1a Debris flow deposit	Matrix support, Composed of sub-angular to angular gravel and matrix well compacted.
1b Silt, Sand thin layer	With a 15 cm or less-thick granule mixture silt. Fine sand is at 3 cm or less in thickness. It is frequently inserted into a debris flow deposit.
1c River-bed-gravel	It is distributed along the present riverbed. A high porosity clast-supported gravel bed
Flood plane deposits	
2a Organic silt	Silt containing plant remains. Grey - dark grey. Contains sand particles.
2b Medium-grained sand	Well sorted. It contains feldspar and colored minerals of volcanic-ash origin.
2c Coarse sand Contained a rounded gravel	The coarse sand contains volcanic gravel. Schist gravel are not present.
Pyroclastic flow deposit	
3a Yfg	Pumice and biotite are characteristic components. Well compacted. Grey color.
3b Aso-4	Pumice and hornblende are characteristic components. It is a re-worked sediment Generally it is grey, with lamina of silt showing russet.

The gravel composition of the surface outcrops includes granite on both banks of the . Koishiwara-gawa, that is hardly present on the left bank of the R. Sata-gawa (Fig. 8). the fan surrounded by the R. Koishiwara-gawa and R. Sata-gawa, this figure shows that e sediment originated from the R. Koishiwara-gawa.

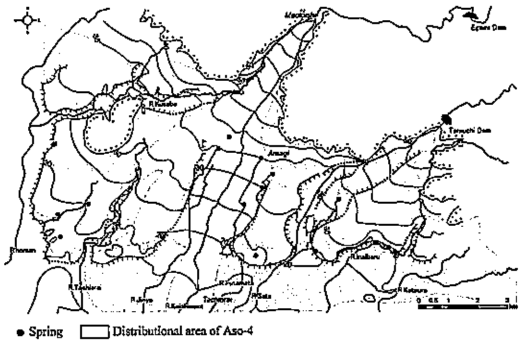
As it goes to the downstream lowland, flood plain silt and sand rate increase (1b). In the ain channel, it is rich in pebbles and has high permeability (1c).

3 *Sediments of the R. Chikugo-gawa lowland*

R. Chikugo-gawa lowlands, floodplain deposits consist of organic silt and well-sorted edium grained sand (2a, b), intercalated with coarse sand layers containing rounded lcanic rock fragments (2c) and schist. The former sand layer originated from the . Chikugo-gawa up-stream area on the east, while the latter gravels of schist and volcanic cks are originated from the upstream area of the alluvial fan.



igure 8. Gravel composition and supply direction of alluvial fan deposits.



igure 9. Spatial distribution of Aso-4

3.4 *Pyroclastic flow deposits*

Yfg is a grey pyroclastic flow deposit which erupted 80 km east of the R. Chikugo-gawa around 500,000 to 600,000 years ago, and has characteristic biotite crystals (3a). This pyroclastic flow deposit is distributed about 50–70 m below the surface of the Ryochiku Basin, although it is missing due to erosion beneath former and current river channels.

Aso-4 erupted 90,000 years ago, and it contains characteristic hornblende crystals (3b). The primary Aso-4 is dark grey with volcanic glass and pumice, and has a limited distribution. The epiclastic sediments from Aso-4 are rich in fine grained fragments with some grey-russet clay. Although Aso-4 is found 10–20 m below the surface on the right side of R. Koishiwara-gawa, it is lacking in some places (Fig. 9).

4 HYDROGEOLOGICAL FEATURES

The fan deposit is regarded as a cut and fill structure. According to the geological profile across the R. Koishiwara-gawa, the channel is filled up with the resedimental deposits. Moreover, according to the profile along the direction of dip, it is considered that the sediment of the fan surface II has covered the sediment of the fan surface I, at the proximal fan. The distribution of the slope of geomorphologic features and spring-water is a possible reason, which is also evident from Fig. 6. The erosion scarp of the fan surface I from which it is distributed over both banks of the R.Koishiwara-gawa, can not be observed at the upstream of Amagi.

Aso-4 was deposited before the last glacial stage and is not preserved in its primary form in the alluvial fan, although traces of it can be seen clearly on the fan surface. These traces are secondary deposits of the tephra. The surface weathers by a fine-grained clay-forming process, and a difference in hydraulic head is observed in the upper and lower aquifers. In this way, the upper aquifer has become Aquifer I, and the lower, bordering on Aso-4, is classified as Aquifer II. However, along the R. Koishiwara-gawa and R. Tachiarai-gawa, Aso-4 has often been reduced by erosion.

The basement rock, which consists of schist, appears in the upstream side of the alluvial fan, and is considered to be impermeable. On the downstream side and along the R. Chikugo-gawa, the basement rock cannot be confirmed even at a depth of 70 m. Although Yfg lacks continuity, it has low permeability compared with a debris flow deposit. Yfg is considered as the impermeable basement because it frequently contains silt particles.

5 PERMEABILITY

The permeability of each layer is summarized in Table 3, based on the permeability tests at the time of drilling the groundwater monitoring well by the MLIT (Ministry of Land, Infrastructure, Transport and Tourism).

The permeability test value of the Aquifer I is $2.41 \times 10^{-5} - 7.17 \times 10^{-4}$ m/s with an average of 3.62×10^{-4} m/s. The test value of the Aquifer II is $1.97 \times 10^{-6} - 1.00 \times 10^{-5}$ m/s with an average of 2.04×10^{-5} m/s, and is taken as $1.0 - 5.0 \times 10^{-5}$ m/s. The two aquifers are similar in their sedimentary facies, but differ in their permeability by one order of magnitude. Aquifer II may be in a compacted weathered debris flow deposit.

Table 3. Permeability and characteristics of aquifer.

Aquifer division	Hydraulic conductivity (m/s)		Facies	Water quality		
	Adoption value	Test value		EC (mS/m)	Type	Ion concentration
Present river deposit	5×10^{-3}	–	Grabel deficient in a matrix	8.5~20.0	$Ca\text{-}HCO_3$	
First aquifer	$3\sim9 \times 10^{-4}$	$2.41 \times 10^{-3} \sim 7.17 \times 10^{-4}$ (Average: 3.62×10^{-4})	Debris flow dep.	12.5~14.5	$Ca\text{-}HCO_3$	Low
Aso-4 pyroclastic flow dep.	$1 \times 10^{-6\sim7}$	–	Fine-grained secondary sediment, surface are clayization by a weathering	–	–	
Second aquifer	$1\sim5 \times 10^{-5}$	$1.97 \times 10^{-6} \sim 1.00 \times 10^{-4}$ (Average: 2.04×10^{-5})	Debris flow dep., well compacted	12.1~32.6	Ca, $Mg\text{-}HCO_3$ $Ca\text{-}HCO_3$	
Flood-plain dep. of R.Chikugo-gava	$1\sim5 \times 10^{-4}$	$3.80 \times 10^{-5} \sim 7.45 \times 10^{-5}$ (Average: 5.63×10^{-5})	Organic silt, River bed gravel	18.0	$Na\text{-}HCO_3$	
Yufugawa pyroclastic flow dep.	5×10^{-6}	$1.40 \times 10^{-6} \sim 7.65 \times 10^{-6}$ (Average: 4.81×10^{-6})	Fine-grained secondary sediment, Organic silt	25.7~30.0	$Ca\text{-}HCO_3$	
Metamorphic rocks	5×10^{-6} under	–	Pelitic Schist	–	–	High

The flood plain deposit of the R. Chikugo-gawa lowland has tested value of $3.80 \times 10^{-5} - 7.45 \times 10^{-5}$ m/s and an average of 5.63×10^{-5} m/s.

Although the test value has not been determined in Aso-4, about $1 \times 10^{-6\sim-7}$ m/s is presumed from the characteristics. Because the test value in Yfg is $1.40 \times 10^{-6} - 7.65 \times 10^{-6}$ m/s with an average of 4.81×10^{-6} m/s, it is considered to be 5×10^{-6} m/s. The metamorphic rock has few cracks, and has a lower permeability than Yfg.

Although the test value has not been recorded from the present river deposit materials, it is presumed to be about 5×10^{-3} m/s from the characteristics of the material.

6 GROUNDWATER FLOW SYSTEM

6.1 *Groundwater table*

There are many shallow wells in the fan. We investigated wells where water sampling was possible. Measurements were carried out in April and November 2007 during the periods without irrigation, and in August during the irrigation period. These measurements showed that the profile of the groundwater table of the Aquifer I matches the geomorphic surface (Fig. 10). On the fan's surface, the geomorphic surface has a ridge on the downstream side and forms a valley along the river channel.

The R. Koishiwara-gawa is regarded as a typical alluvial fan river with characteristic continuously decreasing stream flows. On the fan's surface II which extends from Meotoishi to Amagi town, the profile of the groundwater table assumes a ridge downstream. A group of springs is distributed over Amagi town. At present, artesian flow from these springs is rare, even during the wet season. Even in August, groundwater level is tens of centimetres below the surface, and in April it falls to 3–7 m below the surface. Groundwater level in 1961 was higher than in August 2006, and it seems that artesian flow occurred in 1961 (Fig. 11).

The profile of the groundwater table of an alluvial fan extends to the downstream side as a ridge, and along an active channel it becomes valley. R. Tachiarai-gawa emerges from near the centre of the alluvial fan, dissecting the alluvial fan, and it is a river in which stream flow increases.

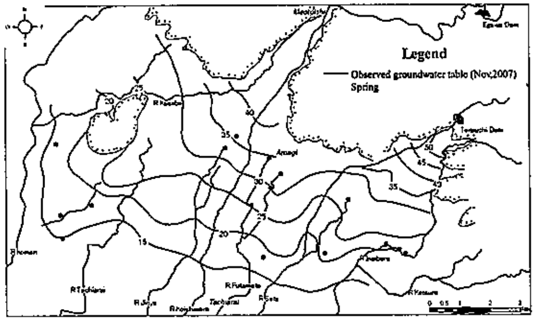


Figure 10. Groundwater table on 25 November 2007.

On the left bank of the R. Sata-gawa, the groundwater table ridge runs through the central art, on the east side, and groundwater flows to the south and gushes in the erosion scarp of e fan toe. The former riverbed and the valley of the groundwater table are in agreement, nd it has become a cause of stream lost "Segire". That is, stream flow decreases on the pstream side rather than in the mid-fan part.

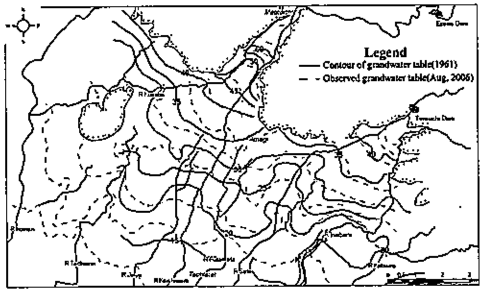
In these sections, groundwater recharged the flows along the former channel and returns o the R. Sata-gawa after a while.

R. Kogane-gawa from where the spring water originates, "Suizenjinori" (a species of lue algae) is cultivated. At present, spring water is not drawn except for the wet season, nd the river is augmented by pumping from the well.

A significant difference in the flow direction of groundwater was not observed in April nd August. The flow in 1961 was also the same.

.2 *Fluctuation in groundwater level*

n order to enumerate the seasonal fluctuation of groundwater levels, observation wells vere newly installed at eight places (Fig. 7). Five of these were twin observation wells so at the groundwater level of Aquifer I and Aquifer II could be measured separately. In n observation well, groundwater level of the Aquifer I is always higher than that of the quifer II (Fig. 12). Groundwater is shown to have permeated below.



igure 11. Comparison of groundwater table on 1961 & August, 2006.

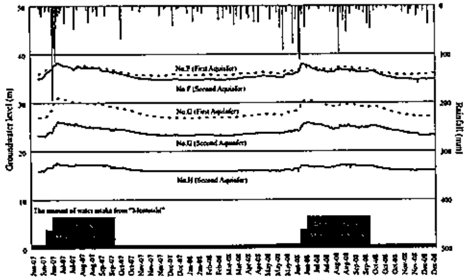


Figure 12. Fluctuation in groundwater level (Left bank of R. Sata-gawa).

7 GROUNDWATER QUALITY

The groundwater, sampled from the observation wells, was analyzed in July and December to take account of seasonal changes. The analysis results are shown in Fig. 13 by hexagonal diagram of the main elements. The water type of Aquifer I is the Ca-HCO_3-type and it is similar to river water. Total ion concentration of groundwater from Aquifer II increases with varied Mg and Na ion concentrations.

On the vertical profile shown in Fig. 14, concentrations of Ca and NO_3 ions in Aquifer I increase from upstream to downstream. NO_3-enrichment may come from cultivated soils. As in Aquifer II, Ca and HCO_3 ions increase.

These tendencies will be stationary in July and December. Therefore, that is the phenomenon throughout the year without irrigation effects.

According to these observations, we assume that river water recharges Aquifer I each year.

8 SIMULATION

8.1 *Simulation of the water table*

The authors discussed the three-dimensional groundwater flow model based on the hydrogeological model. The initial hydraulic permeability was taken from the in-situ data, and after its validation, is shown in Table 4. In order to simulate the in-situ hydrogeological condition, the hydraulic permeability in the vertical direction of the pyroclastic flow deposit (Aso-4) was set as 1/10 of the hydraulic permeability in the horizontal direction.

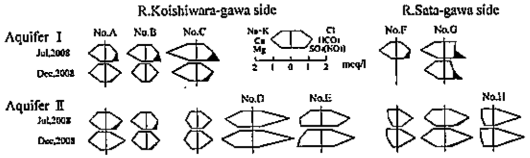


Figure 13. The water quality of a groundwater.

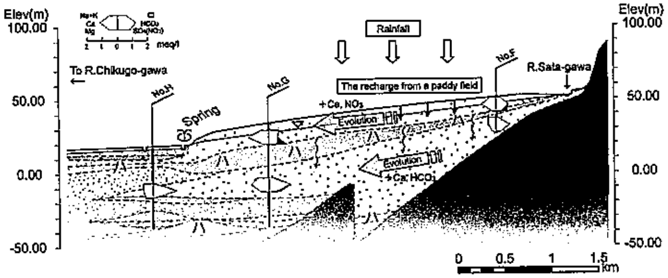
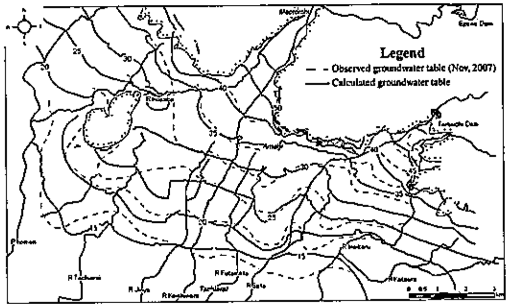


Figure 14. Vertical profile on the R. Sata-gawa side.

Table 4. Hydraulic conductivity after validation.

Layer	Hydrogeological name	Initial hydraulic permeability coefficient (m/sec)	Validated hydraulic permeability coefficient (m/sec)
1	River bed deposit	5.0E^{-03}	5.0E^{-03}
2	Aquifer I	3.6E^{-04}	7.2E^{-04}
3	Pyroclastic flow deposit (Aso-4)	1.0E^{-06}	Horizontal:1.0E^{-6} Vertical:1.0E^{-7}
4	Aquifer II	2.0E^{-05}	1.0E^{-04}
5	Flood deposit	5.6E^{-05}	2.8E^{-04}
6	Debris flow deposit	5.0E^{-06}	1.0E^{-05}
7	Basement	4.8E^{-08}	4.8E^{-08}



igure 15. Comparison of groundwater table on November, 2007.

The simulated water table represents the observed well water table, excluding those in 1e western area where the topography varies widely as shown in Fig. 15.

In general, the simulated groundwater level fluctuation also represents the observed ;roundwater level fluctuation in each observation station as illustrated in Fig. 16.

As for observation station G, which is located in the vicinity of the R. Sata-gawa course, here exists an approximate 5 m difference in potential head between the shallow and leep groundwater across an aquiclude (Aso-4). The potential head difference during the rrigation period is more than during the non-irrigation period. This difference in potential 1ead can be approximately determined from the simulation, with a 2 m difference between he model and observations.

;.2 *Present water balance*

Che present annual water balance from 2003 to 2007, simulated using the three-dimensional ;roundwater flow model, is shown in Fig. 17. During this period, the recharge to roundwater was larger than the discharge from groundwater.

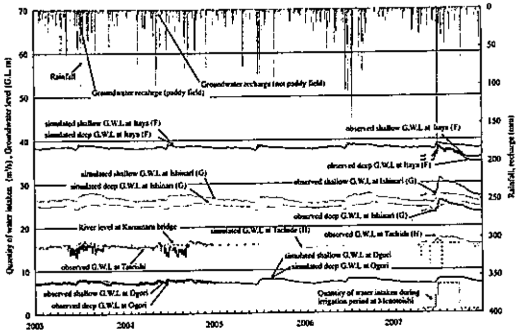


Figure 16. Comparison between the simulations and observations along the R. Sata-gawa.

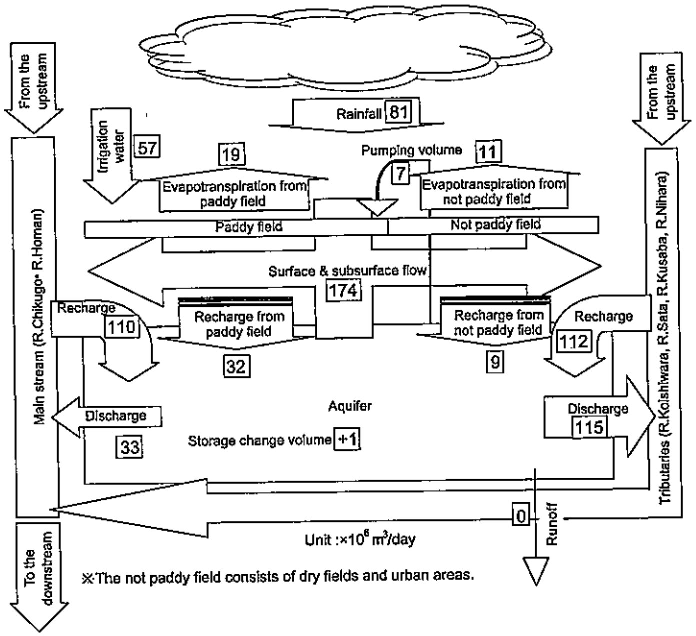


Figure 17. Conceptual diagram of water balance in 2007.

It was estimated that the annual total surface flow was 400,000,000 m^3/day, and the ratio of abstraction to the whole discharge was quite small. Meanwhile, it can be concluded that the water balance is adequately stable since the error (Σinflow–Σoutflow) is less than 0.1% for each year.

It was observed that groundwater closely interacts with river water, and that the recharge m the irrigation water amounts to about 40% of the recharge from rainfall as shown in g. 17.

SUMMARY

e summary of the findings of our survey on the groundwater flow system in the Chikugo-wa alluvial fan is as follows.

. The Chikugo-gawa alluvial fan is a compound alluvial fan formed by the R. Koishiwara-gawa and the R. Sata-gawa. Two old and new alluvial fans exist and spring water and ill-drained paddy fields are scattered at the edge of the fan on alluvial fan I of the old stage. There are many lotus paddy fields at the lowlands under the cliff in the distal fan part as well. Moreover, the Amagi city area is located in the vicinity of the spring water belt at the edge of the fan on alluvial fan II of the new stage.

. The alluvial fan sediments mainly consist of debris flow deposits. The gravel composition of surface outcrops includes granite on both banks of the R. Koishiwara-gawa, but not on the left bank of R. Sata-gawa. In the fan surrounded by the R. Koishiwara-gawa and R. Sata-gawa, this shows that the sediment originated from the R. Koishiwara-gawa. On the downstream side, thin silt and sand that often form flood plain deposits are distributed at the mid-fan area.

. The alluvial fan deposit is regarded as a cut and fill structure. Aso-4 is not preserved in its primary form in the alluvial fan, although traces of it can be seen clearly on the fan surface. The surface weathers by a fine-grained clay-forming process, and a difference in hydraulic head is observed in the upper and lower aquifers. In this way, the upper aquifer has become Aquifer I, and the lower, bordering on Aso-4, is classified as Aquifer II. However, along the R. Koishiwara-gawa and R. Tachiarai-gawa, Aso-4 has often been reduced by erosion.

. The basement rock, which consists of schist, appears in the upstream side of the alluvial fan, and it is considered to be impermeable. Although Yfg lacks continuity, it has a low permeability compared with a debris flow deposit. Yfg is considered as impermeable basement because it frequently contains silt particles.

. Groundwater table measurements showed that the profile of the groundwater table of the Aquifer I matches the geomorphic surface. The R. Koishiwara-gawa is regarded as a typical alluvial fan river with characteristic continuously decreasing streams flow. On the fan's surface II, which extends from Meotoishi to Amagi town, the profile of the groundwater table assumes a ridge downstream. A group of springs is distributed over Amagi town. At present, artesian flow from these springs is rare, even during the wet season. Even in August, groundwater level is tens of centimetres below the surface, and in April it falls to 3–7 m below the surface.

. On left bank of R. Sata-gawa, the groundwater table ridge runs through the central part, on the east side, and groundwater flows to the south and discharges from the erosion scarp of the fan toe. The former riverbed and the valley of the groundwater table are in agreement, and it has become a cause of stream lost "Segire". That is, stream flow decreases on the upstream side rather than in the mid-fan part. Groundwater recharged in these sections flows along the former channel and returns to the R. Sata-gawa after

7. In an observation well, the groundwater level in the Aquifer I is always higher than that of the Aquifer II. Groundwater is shown to have permeated below. The results of groundwater analysis suggest that river water recharges Aquifer I each year.
8. As compared to the groundwater contour map in 1961, the present groundwater table is lowered by about 2–3 m near the mid-fan. This explains the recent drying-up of the groundwater, and is also evident from the decrease of spring water and flowing wells. A decrease in the amount of groundwater recharge by the advancement of urbanization and an increase in the amount of groundwater abstraction are thought to be the reason.
9. The authors discussed the three-dimensional groundwater flow model based on the hydrogeological model. The simulated water table represents the observed water table, excluding those in the western area where the topography varies widely. In general, the simulated groundwater level fluctuations also represents the observed groundwater level fluctuations in each observation station.
10. In the present annual water balance from 2003 to 2007, the recharge to groundwater was larger than the discharge from groundwater. It was estimated that the annual total surface flow was 400,000,000 m^3/day, and the ratio of abstraction to the whole discharge was quite small. It was observed that groundwater closely interacts with river water, and that the recharge from the irrigation water amounts to about 40% of the recharge from rainfall.

Generally, due to the rise in temperature in the future, the amount of evapotranspiration and river outflow will increase due to the change in the rainfall patterns and the amount of recharge to groundwater is expected to decrease. Additionally, further demand for 'fresh water' is expected due to improvements in human quality of life and the resultant changes in the industrial structure.

Therefore, it is important to understand that the river and the groundwater have interacted with one another. And, it is advisable to manage the river water and the groundwater in a unified concerted manner in order to utilize effectively the groundwater, which is a stable freshwater resource, after taking into consideration the hydrogeological structure of the Chikugo-gawa alluvial fan and the groundwater flow characteristics in this region.

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Author index