

Review of R. Chikugo-gawa Alluvial Fan (General Remark)

MIYAZAKI Seisuke*

Abstract

The River Chikugo-gawa alluvial fan is the southwestern-most one among the six alluvial fans that has been taken up by RHF for detailed study. It comprises of an area where annual precipitation is less than 1,500 mm in a dry year, and proper water-utilization has been given top priority. Comparing the groundwater level conditions between 1961 and present day, it is clear that present-day groundwater level is 2-3 m lower in the central part of the fan. The decreasing trend of groundwater is evident from the drying up of the spring water and decrease in number of artesian wells. The reasons behind this may include decrease of the amount of groundwater recharges due to progress of urbanization and consequent increase in groundwater pumping rate among others.

This report is the outline of the hydrogeology in the alluvial fan, its hydrologic cycle, and a water budget.

1. Introduction

The R. Chikugo-gawa is the largest river of Kyushu island. It originates in the Kuju volcano (1,787 m) and emerges on the Chikugo Plain through some intermountain basins. It has a total length of 143 km. The catchment area is 2,860 km² (Fig.1). The Chikugo Plain, an agriculturally productive region, covers an area of 620 km². Upstream of Kurume is the Ryouchiku Basin, a triangular tectonic basin of 290 km². Downstream of Kurume is a coastal plain and delta. The Ryouchiku Basin is surrounded by horst mountains (700-900 m) formed during Quaternary upheaval. The R. Chikugo-gawa flows through the center of this basin in a westerly direction. The R. Koishiwara-gawa and R. Sata-gawa, which flow from the Kosyo-Umami mountains to the north, form alluvial fans on the plain. We call these fans "Chikugo-gawa alluvial fan". This alluvial fan has been inhabited since the Yayoi Age. Amagi town on this fan is surrounded by areas rich in spring water. The area was used mainly as a highland field before 1950. However, since 1950 irrigation networks have been developed. As a consequence, farmland has been consolidated with increased rice fields and the population has also been increased. Water supply from surface water sources was inadequate to meet the demands of increasing rice cultivation. Wells were bored, but the fall in groundwater-level from excess pumping was questioned.

KEYWORDS : Alluvial fan, half-graben rift basin, Pyroclastic flow deposit, "Segire", Recharge river, Global warming, Freshwater resources

2. Hydrogeology

2.1 Geomorphology and land use

R. Chikugo-gawa alluvial fan is 12km wide along east to west, with a length varying between 5km (on the eastern side) to 10km (on the western side) and having gross area of 62.8 km². The lower terrace along the river is

* Yachiyo Engineering Co., Ltd.

lower than the alluvial fan by 2-5m. The alluvial fan is divided into three areas bordering on R. Koishiwara-gawa and R. Sata-gawa. On the right bank of the R. Koishiwara-gawa, the distance of the fan toe from R. Chikugo-gawa is nearly 9km and having a gentle slope of 4/1,000. In the area on the east, the fan toe is closer to R. Chikugo-gawa with a distance of 5km and the slope is steep i.e. 6/1,000.



Fig.1 Location map

Till 1970s the alluvial-fan surface was used as rice fields or upland farm. Subsequently, dams were built and maintenance of irrigation network became better. As a result, the rice field area had been increasing every year (Fig.3). During the last 30 years, these rice fields changed to the upland farm and developed as urban area.

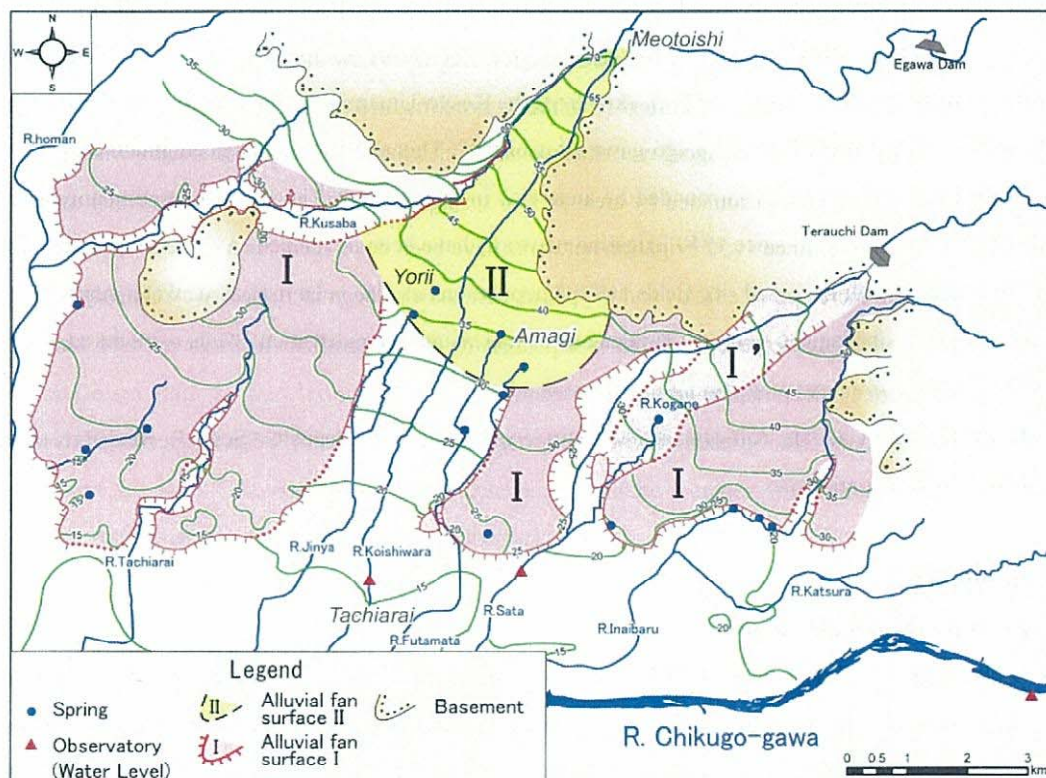


Fig.2 Geo-morphological regionalization

2.2 Geology

The upstream area is made up of Triassic metamorphic rocks, Cretaceous granitoids and Neogene volcanic rocks. In the R. Koishiwara-gawa upstream areas have crystalline schists and granites. While, granites are less abundant in the upstream side of R. Sata-gawa. In this way, the rock species differs in both the catchment areas (Fig.4).

Unconsolidated sediment spreads thickly on such alluvial fan forming on a plain. The alluvial fan is mainly composed of debris flow deposits, while sand layers and pyroclastic flow deposits are intercalated. (Fig.5). On the other hand, on the floodplain along R. Chikugo-gawa, sediment is mainly composed of sand and silt with intercalated gravel beds. There are two tephras i.e. Yufugawa pyroclastic flow deposit

(hereafter Yfg: 500,000 to 600,000 years ago.) and Aso-4 pyroclastic flow deposit (Aso-4: 90,000 years ago). Aso-4 is the regional tephra, which erupted from the Aso caldera before the last glacial stage. It is distributed all.

Table 1 Stratigraphy of the R. Chikugo-gawa fan

Holocene ~ Pleistocene		The present river deposit Debris flow dep.
Cenozoic	Neogene	Aso-4 Pyroclastic dep. (9.0ka) Debris flow dep. fluvial bed~Debris flow dep. Yufugawa Pyroclastic dep. (60ka) fluvial bed~Debris flow dep.
	Miocene~Pliocene	
Mesozoic	Cretaceous	Granitic rocks
	Triassic	Metamorphic rocks

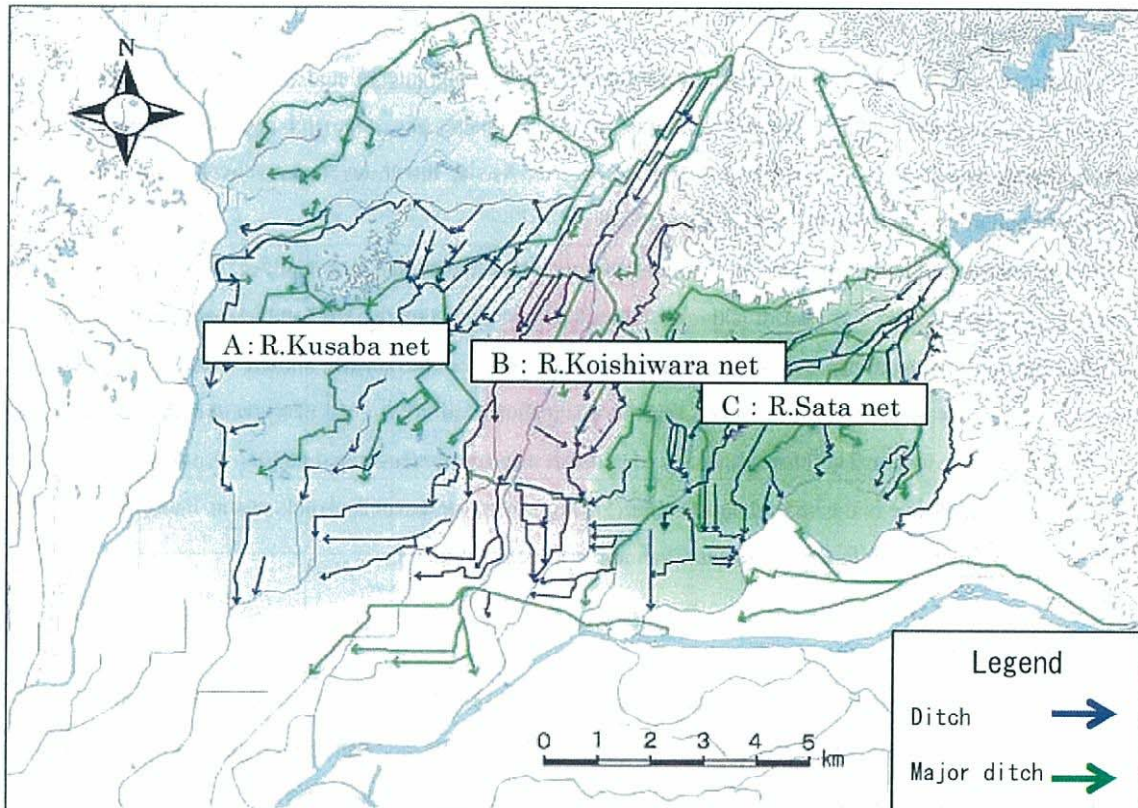


Fig.3 Irrigation-water network in alluvial fan

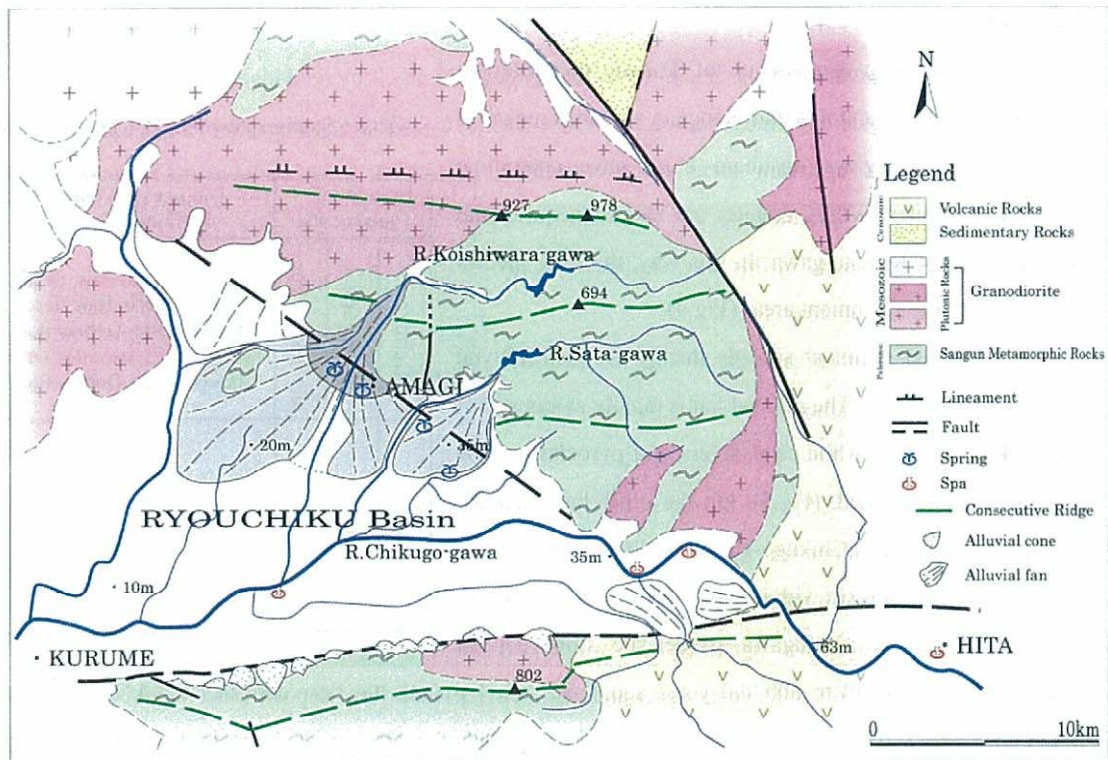


Fig.4 Geological map

2.3 Hydrogeology

As mentioned above, this alluvial fan is having debris flow deposits intercalated with pyroclastic flow deposits. Gravel bed contains subangular gravel of crystalline schists. It consists of matrix-supported debris flow deposit and clast-supported re-deposited materials. With respect to Aso-4, the lower layer is well-compacted debris flow deposit and upper layer is loose re-deposited material.

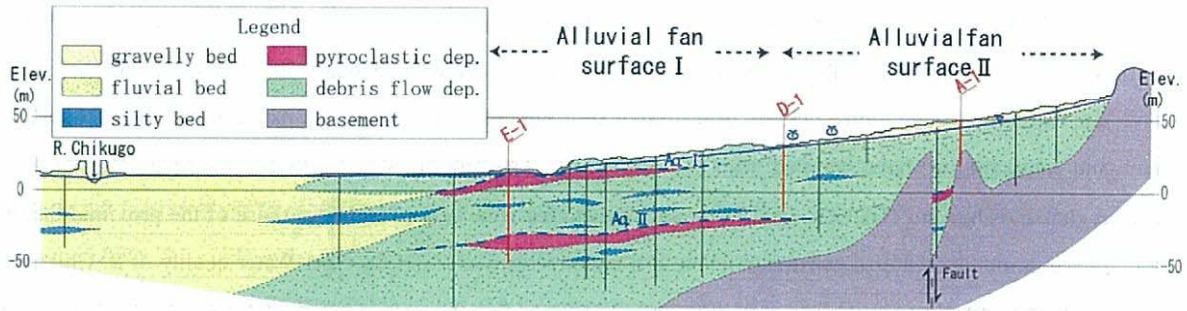
Aso-4 is outcropped at the fan head of R. Sata-gawa. It is distributed at a depth of 5-15m from the surface and having thickness of around 10m. It is thickly present in the successions on the left bank of R. Sata-gawa, while it is often lacking in other areas. Yfg is distributed below 50-70m from the surface and are not laterally consistent.

Even if Aso-4 is not present in some parts there is a significant difference of hydraulic head between the upper layers and the lower layers. Therefore, it is considered that aquifers are separated by Aso-4, upper one is the first aquifer and the lower one is the second aquifer (Fig.5). Moreover, basement rock acts as impermeability basement at the top of the fan, while Yfg forms the basement at the toe of the fan.

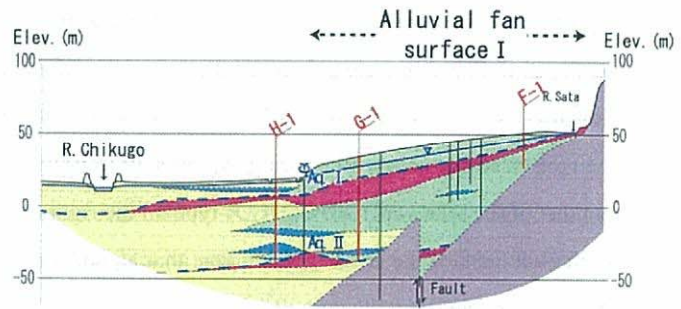
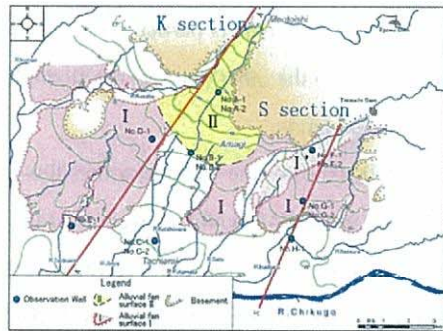
2.4 Permeability

The permeability of each layer is summarized in Table 2. The test value of the first aquifer is 2.41×10^{-5} - 7.17×10^{-4} m/s, average 3.62×10^{-4} m/s, and is taken as $3 - 9 \times 10^{-4}$ m/s according to stratigraphic facies. The test value of the second aquifer is 1.97×10^{-6} - 1.00×10^{-5} m/s with an average of 2.04×10^{-5} m/s, and is taken as $1 - 5 \times 10^{-5}$ m/s. The single digit hydraulic conductivity of each aquifer differs. Nevertheless, this measurement has been interpreted directly from the facies. Although the test value has not been determined in Aso-4, about $1 \times 10^{-6-7}$

m/s is presumed by their characters. The silt deposited on the floodplain of the R. Chikugo-gawa lowland has yielded a test value of 3.80×10^{-5} - 7.45×10^{-5} m/s and an average of 5.63×10^{-5} m/s. The gravel and sand are estimated to be about $1 - 5 \times 10^{-4}$ m/s. The test value of Yfg is 1.40×10^{-6} - 7.65×10^{-6} m/s, average 4.81×10^{-6} m/s and it is considered to be 5×10^{-6} m/s. The metamorphic rocks have few cracks shows lower permeability than Yfg.



(a) K section (R.Koishiwara-gawa)



(b) S section (R.Sata-gawa)

Fig.5 Geological profile

Table 2 Permeability and characteristics of aquifer

Aquifer division	Hydraulic conductivity (m/s)		Facies	Water quality		
	Adoption value	Test value		EC (μS/cm)	type	Ion concentration
Present river deposit	5×10^{-3}	—	Gravel deficient in a matrix	8.5~20.0	Ca-HCO ₃	
First aquifer	$3 \sim 9 \times 10^{-4}$	$2.41 \times 10^{-3} \sim 7.17 \times 10^{-4}$ (Average : 3.62×10^{-4})	Debris flow dep.	12.5~14.5	Ca-HCO ₃	
Aso-1 pyroclastic flow dep.	$1 \times 10^{-6} \sim 1$	—	Fine-grained secondary sediment, surface are clay-ization by a weathering	—	—	
Second aquifer	$1 \sim 5 \times 10^{-3}$	$1.97 \times 10^{-3} \sim 1.00 \times 10^{-4}$ (Average : 2.04×10^{-5})	Debris flow dep., well compacted	12.1~32.6	Ca, Mg-HCO ₃ Ca-HCO ₃	
Flood-plain dep. of R.Chikugo-gawa	$1 \sim 5 \times 10^{-4}$	$3.80 \times 10^{-5} \sim 7.45 \times 10^{-5}$ (Average : 5.63×10^{-5})	Organic silt, River bed gravel	18.0	Na-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-HCO ₃	
Metamorphic rocks	5×10^{-6} 以下	—	Pelitic Schist	—	—	

2.5 Water quality

(I) Hexagonal diagram of main elements

The water quality of the surface water and groundwater that flows through the alluvial fan was analyzed and seasonal changes were evident from hexagonal diagram. The vertical profile of an alluvial fan is shown in Fig. 6.

In R. Koishiwara-gawa, the water quality at the proximal fan is similar to river water, i.e. CaHCO₃-type. Although, in samples of only the second aquifer the ion concentration increases in the downstream direction as Ca and Mg ion concentrations increase near in the toe of the fan. In R. Sata-gawa, as the formation of Aso-4 is thick and consistent, we have sampled from the first aquifer. The water quality is close to the river water of the whole region and showing CaHCO₃-type. In the second aquifer, river water resembles those of the proximal fan, but ion concentration increases downstream where it is characterized as CaHCO₃-type. Water quality of R. Chikugo-gawa lowland is showing NaHCO₃ in type. The author assumed that they are in a different groundwater flow system for each other. The planar distribution of the hexagonal diagram for the first aquifer in a non-irrigating season shows remarkable CaSO₄-type of water at the right-bank of R. Koishiwara-gawa fan. This is particularly so at the toe of the fan as well as in the central part of the fan on the left bank of the fan. On the other hand, in the floodplain of R. Koishiwara-gawa and left bank of R. Sata-gawa, CaHCO₃-type is more common.

In the R. Koishiwara-gawa during irrigation season in August, CaSO₄-types of the water becomes less abundant and the most of the water are CaHCO₃-type on the right bank side near the toe of the fan as well as in the mid-fan on the left bank of the river. It is apparent that an underground infiltration of irrigation water (river water) occurs. On the other hand, the flood plane of R. Koishiwara-gawa and left bank of R. Sata-gawa, both show CaHCO₃-type water and poor in seasonal change. From these observations, we assume that river water recharges to the groundwater every year.

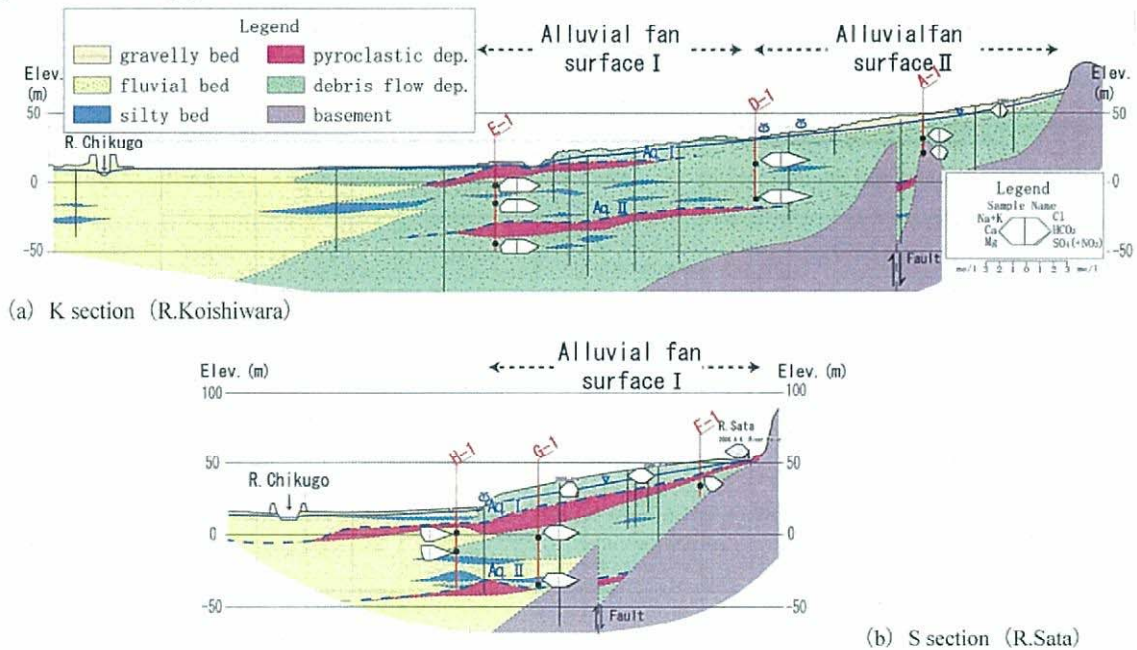
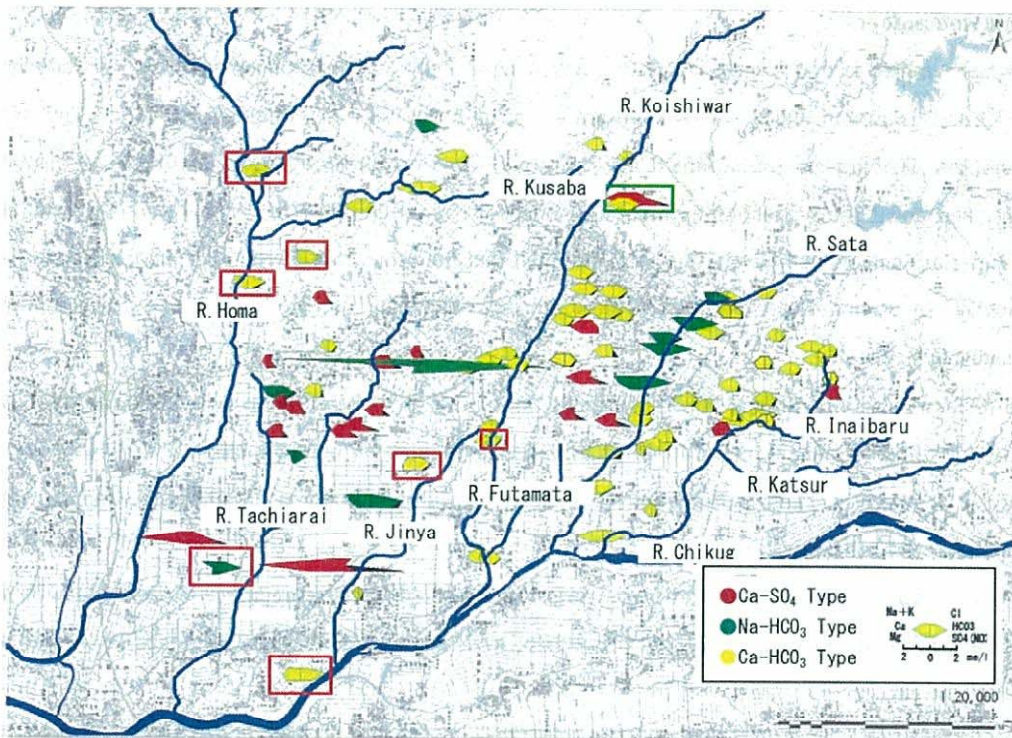
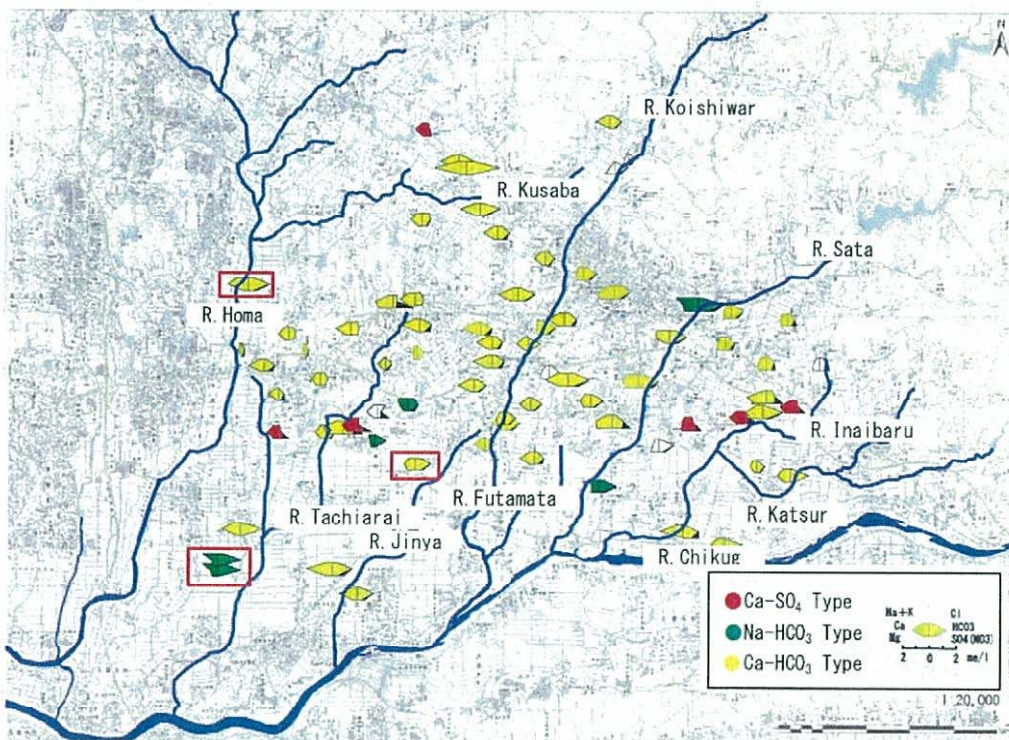


Fig.6 Geological profile and hexadiagram



(a) April, 2006



(b) August, 2006

* Yellowish green indicates a basement rock and red extent is a release about the water quality of the second aquifer

Fig.7 Distribution of hexadiagram

(2) Stable isotopes

Water was sampled in two seasons (April and August 2006) and analysis is carried out for stable isotope ratios of ^{18}O and deuterium. On the R. Koishiwara-gawa, both $\delta^{18}\text{O}$ and δD are comparatively heavy with respect to other areas. The upstream area of the R. Koishiwara-gawa is, on average, 46 m higher in altitude than that of the R. Sata-gawa, and 231m higher at their highest points. However, no difference was observed in isotopic ratio near the present main channels of both rivers. It is assumed that the groundwater recharge after receiving heavy element condenses by evaporation. However, it is clear from the delta diagram (Fig.13a & b) that seasonal influences differ in each catchment area.

In the R. Sata-gawa alluvial fan, no difference was observed for two seasons and the ratios are plotted on the same line of inclination. While in R. Koishiwara-gawa alluvial fan, the inclination of the regression line of both season differ greatly. The trend in August is observed to be such that concentrations of $\delta^{18}\text{O}$ and δD are plotted nearly on the R. Sata-gawa line.

It is shown that isotopic ratio differs significantly in a groundwater-recharge system and groundwater flow system. On the R. Sata-gawa alluvial fan, it is proved that the river waters are recharged to the groundwater throughout the year.

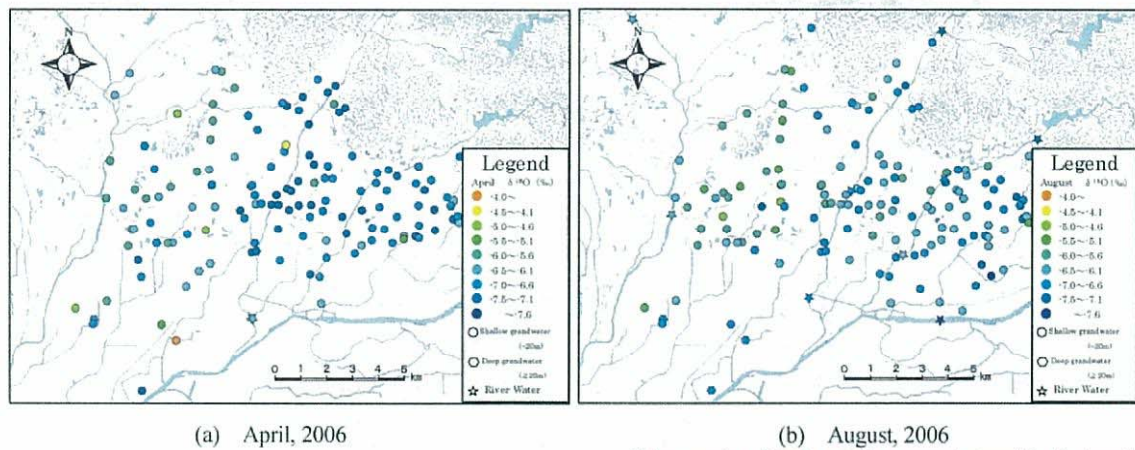


Fig.8 Seasonal difference in oxygen isotope ratio

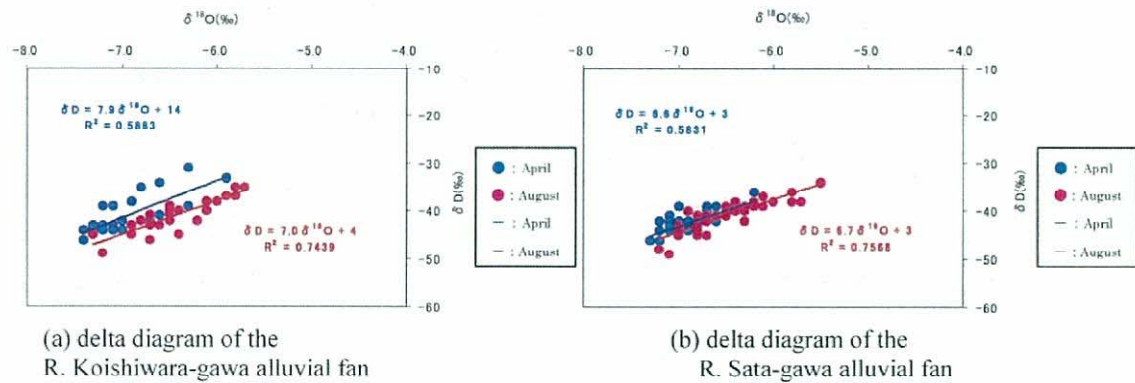


Fig.9 Seasonal change in delta diagram

3. Hydrologic Cycle and Water Budget in Alluvial Fan

3.1 Hydrology and Meteorology Analysis

The annual mean temperature of Asakura (former Amagi city) is 16°C (27°C in August; 5°C in January). However, it is on an increasing trend since 1978. During these 26 years (1978 - 2004), temperature is going up by 1.6°C. The range of fluctuation of annual precipitation is large (980 ~ 2,870mm). Water shortage is produced at a rate of once in 10 ~ 15 years. A potential evapo-transpiration is calculated to be 870mm (by Thornthwaits method).

3.2 Stream flow and Water Budget of the Main Channel

At the R. Chikugo-gawa catchment area, river runoff rises in the rainy-season (June to July) and decreases in the winter (December to January). In certain years, it may rise in typhoon season. The Ryouchiku plain region has little or no snowfall in winter, so, a swell of the yield by snowmelt is not observed (Fig.11).

In the R. Koishiwara-gawa, river runoff decreases toward the mid-fan from proximal fan (Fig.12), and the "Segire" (lost stream) phenomenon occurred temporarily. On the other hand, in R. Sata-gawa, river runoff decreased at the top of the fan and "Segire" could occur characteristically. At those "Segire" sections, surface water is recharged to the groundwater. River runoff increases at the mid fan by the spring water on the right-bank of the fan (left bank of R. Koishiwara-gawa). The change section of such a stream flow is supported also from the profile of groundwater table of Fig.13.

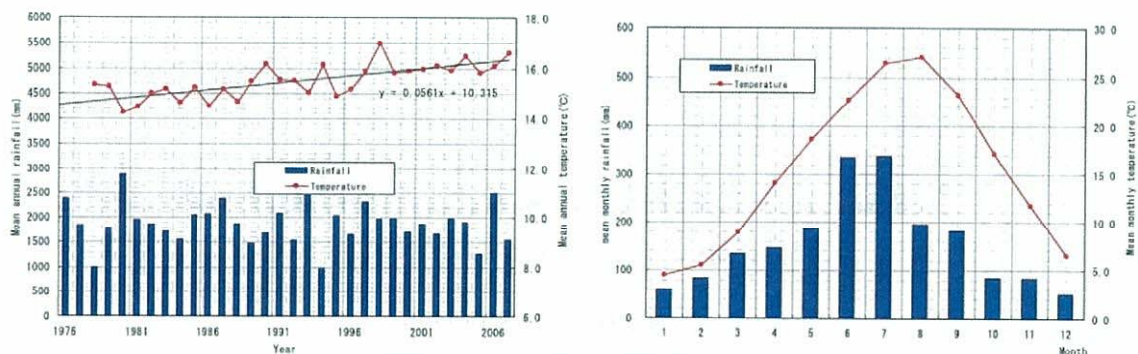


Fig.10 Temperature and precipitation at Asakura

3.3 Shape of groundwater table

The groundwater contour line was plotted by the measurement both surface water level and the water levels of wells (Fig.13). All isobath lines are harmonic to a geomorphic surface. On the surface of alluvial fan, contours are convex towards south (harmonious to the surface of the fan), while, contours are concave at the riverbed.

Strictly, the shape of groundwater table changes bordering the Amagi town. In the same area stream flow also decreases. On the other hand, the axis of the valley has shifted to the left bank of the fan in the upstream of R. Sata-gawa. It considered that this section acts as groundwater recharge section from the river.

In dry season compared to wet season, the range of fluctuation of groundwater level is measured as 3 ~ 5m. In the well, which is the source of Kogane-gawa water level change is notable. Water level increases in summer and falls in winter. In earlier times it used to naturally spring out, but in recent days, water pumped up for the cultivation of laver (Suizenji-nori; species of red alga).

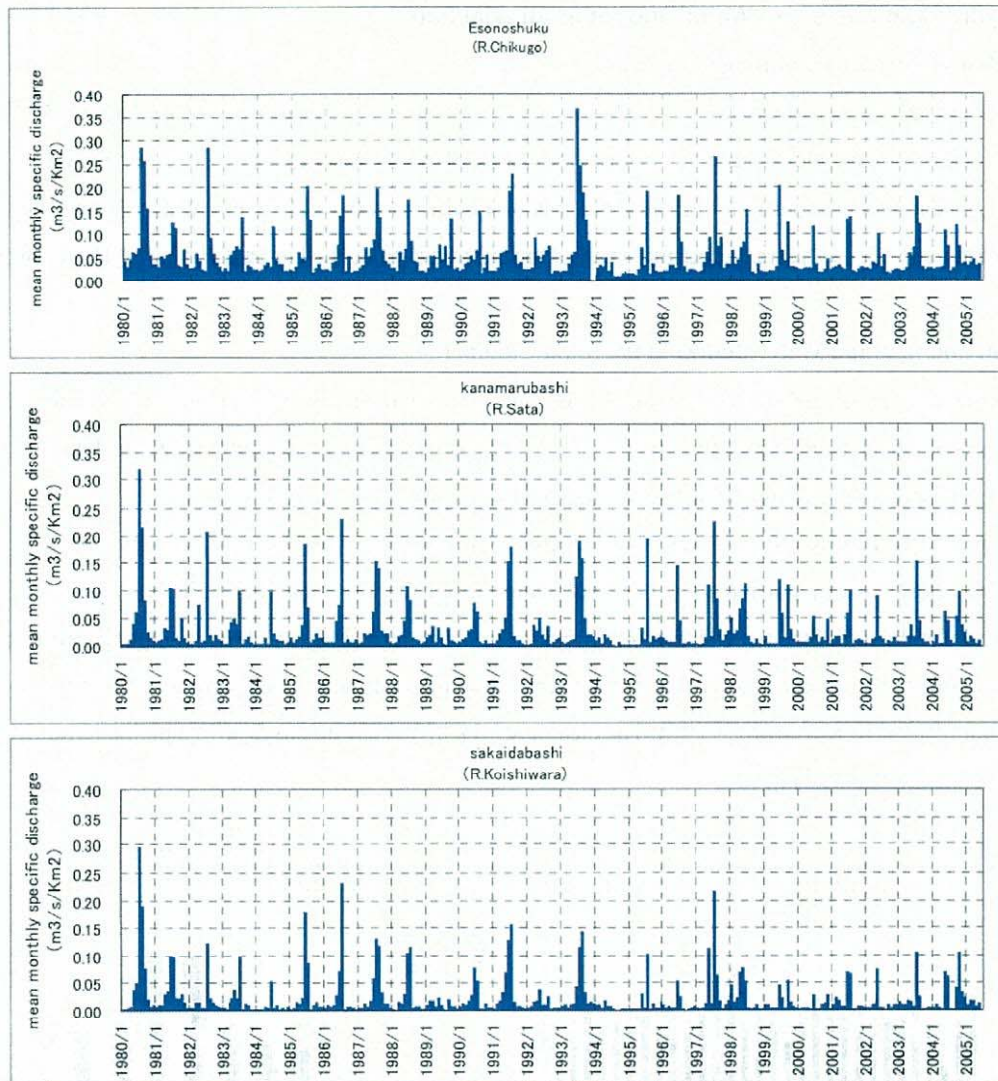


Fig.11 Trend of stream flow

3.4 Potential distribution of the vertical section

The twin observation wells, where groundwater levels of the first aquifer and the second aquifer can be measured separately, are installed at six places (Fig.14). According to the observation results, water level of the first aquifer is always higher than that of the second aquifer in the right bank of R. Koishiwara-gawa, at C site, a clear difference is observed in the water level for both aquifers. The second aquifer falls by 2m during irrigation season (July~October). On the other hand, in the left bank of R. Sata-gawa, both aquifers have clear difference of water level at any well site. In particular, G site has about 3m difference of water level through every year. A difference of water level is set to 5m during irrigation season.

The boundary of both aquifers is made by Aso-4. Therefore, along the R. Koishiwara-gawa with lack of Aso-4, it is considered that the groundwater is carrying out recharge from the first aquifer to the second aquifer. In R. Sata-gawa, except for the fan-head and some river sections Aso-4 is distributed widely and it is shown that both aquifers are separated.

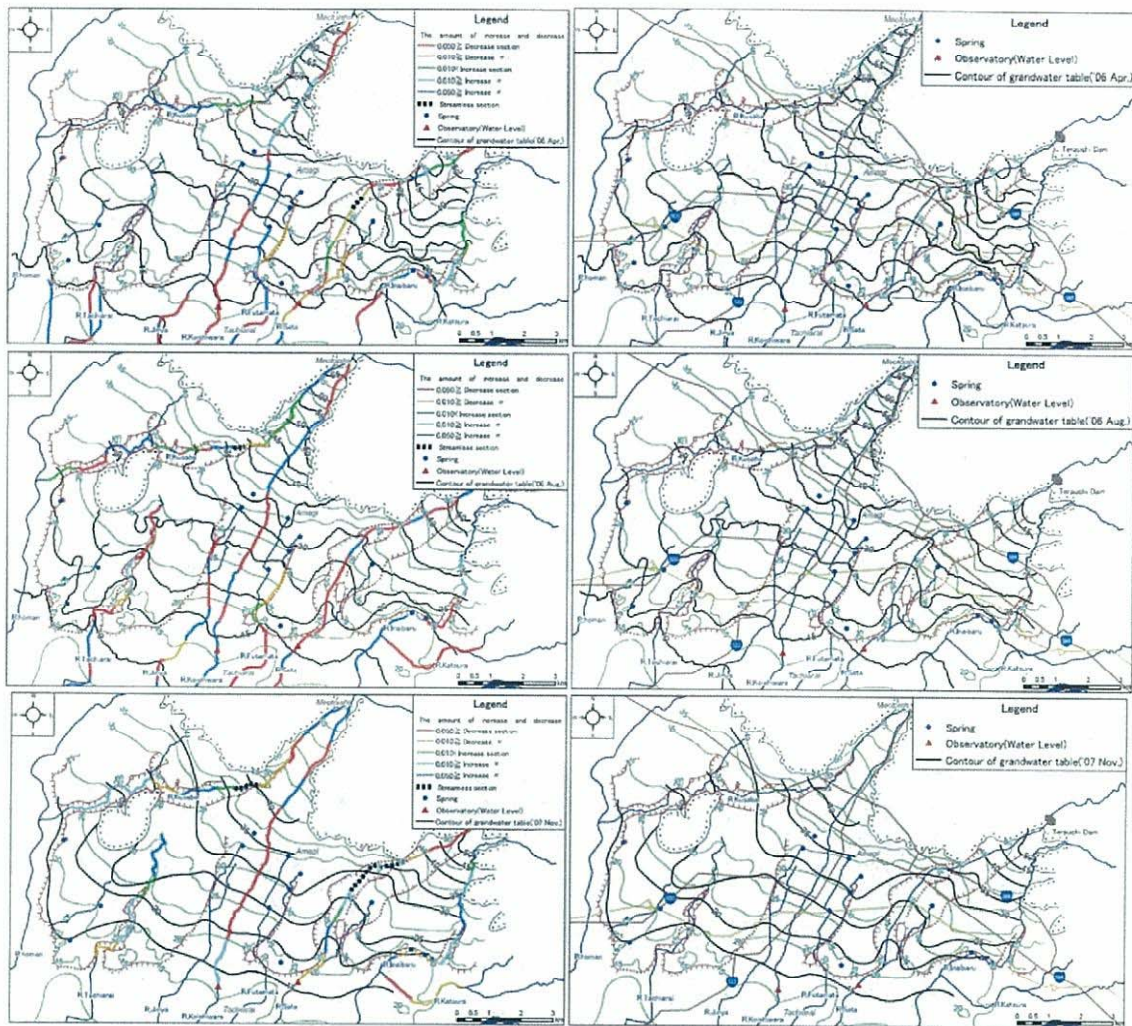


Fig.12 Flow regime of main stream

Fig.13a Profile of groundwater table

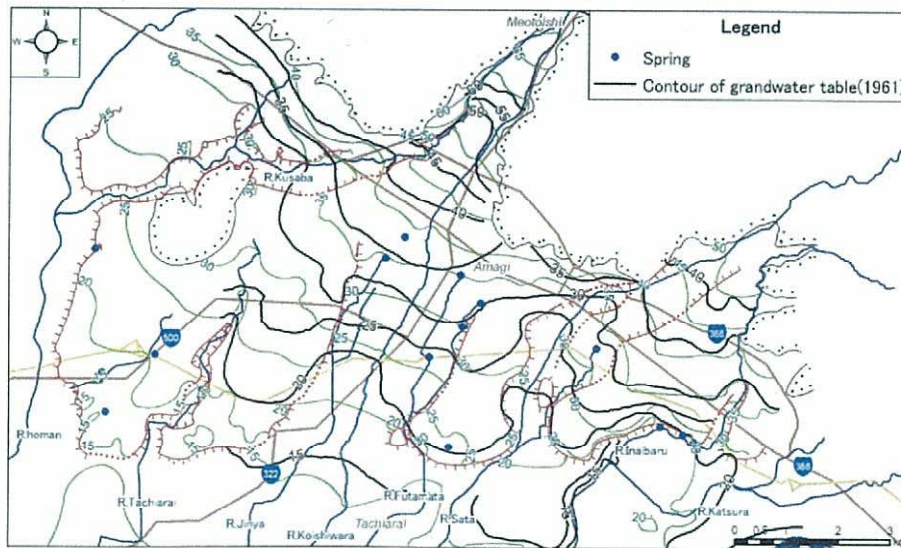


Fig.13b Profile of groundwater table (1961)

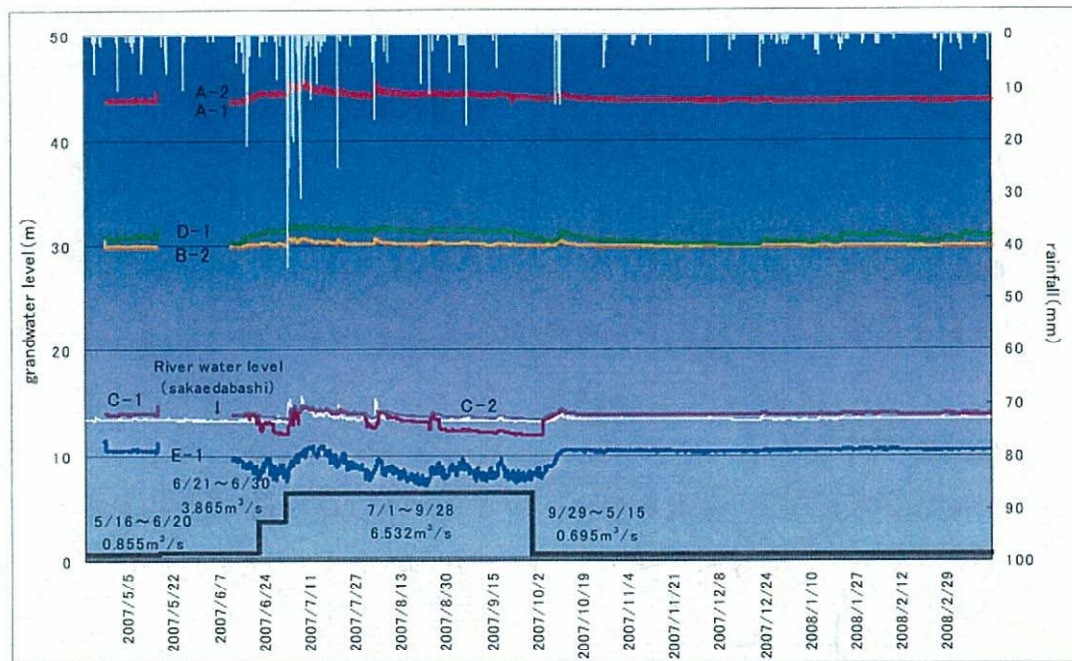


Fig.14a Fluctuation in groundwater level (right bank of R.Koishiwara-gawa)

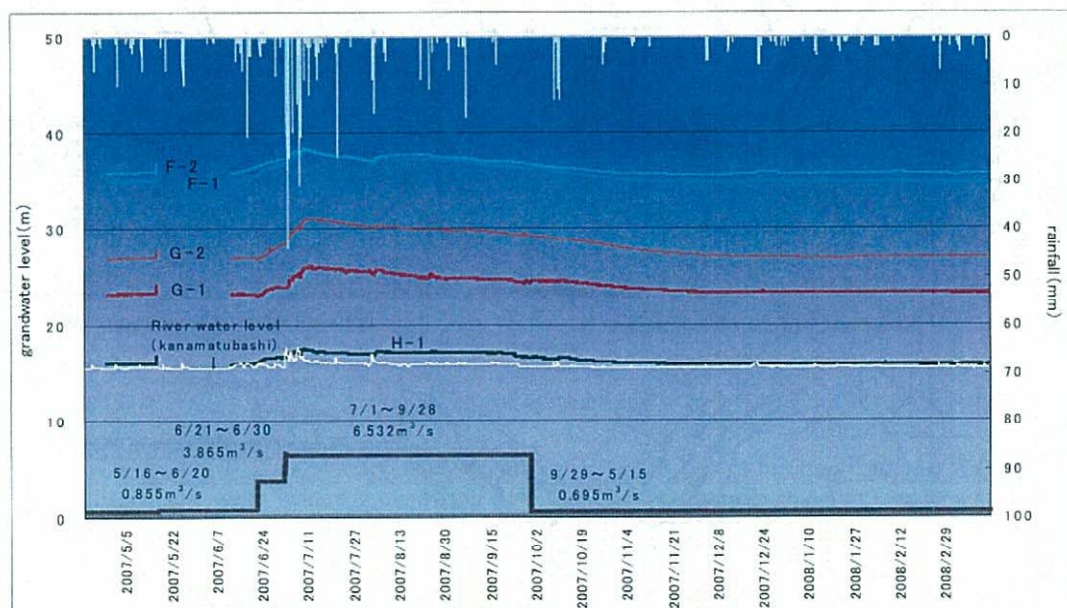


Fig.14b Fluctuation in groundwater level (left bank of R.Sata-gawa)

3.5 Calculation of Amount of Groundwater Recharges

We calculated the amount of recharges from the groundwater level for every land use types (i.e. rice field, upland farm, urban area etc.). The tank model method was used for calculation of the amount of groundwater recharges. Kohara et al., (in this Monograph) has the details of calculation by change of a land use and a review of the amount of groundwater recharges by a tank model.

3.6 Construction of Groundwater Flow System Model and simulation of Present Condition

Visual MODFLOW (The USGS development) was used for the dissection. Moreover, the basic equation that governs former groundwater flow system is based on the following equation.

The aim of simulation study is to find out fluctuation of the groundwater level and condition of groundwater table.

$$\frac{\partial}{\partial x} \left(k_x \frac{\partial h}{\partial x} \right) + \frac{\partial}{\partial y} \left(k_y \frac{\partial h}{\partial y} \right) + \frac{\partial}{\partial z} \left(k_z \frac{\partial h}{\partial z} \right) + R = S \frac{\partial h}{\partial t}$$

h : Total head, t : Time, k : The hydraulic conductivity of the direction x, y, z

R : Pumping/the amount of spring water, S : Storage coefficient

3.7 Water Budget of Alluvial Fan

Fig.15 shows the yield of each constituent by the analysis result. The yield that emerges on the surface from an aquifer was made into the surface runoff. We have estimated about 400 million m³ runoff per year.

3.8 Water Budget of Alluvial Fan by Future Climatic Change

For climatic-change prediction the proposed values of RCM20 (by Meteorological Agency) has been considered and discussed the water budget expected under the conditions. The boundary conditions for the present case are taken as the range used for the simulation of present condition.

Table 3 depicts the assessment of impacts pertaining to the climatic changes between 2031-2050 and 2081-2100.

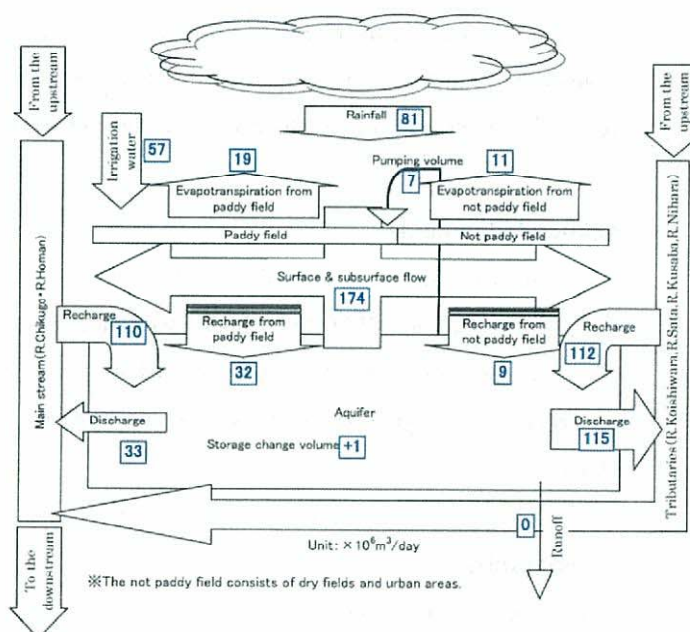


Fig.15 Conceptual diagram of water balance in 2007 (present)

Table 3 Condition of prediction cases II, III and IV

Prediction Case	Land use	Climate condition	Target year
II	1997	1957~1961	1961
III	1997	2046~2050	2049
IV	1997	2096~2100	2097

4. Conclusion

The R. Chikugo-gawa alluvial fan is the southwestern-most among the six alluvial fans studied by RHF group. It comprises of an area where annual precipitation is less than 1,500 mm in a dry year and strict water-utilization policies are given top priority.

Compared to groundwater level in 1961 the present day level is nearly 2-3m lower at the central part of the fan. The trend of the fall of groundwater, as evident from the drying up of spring water and decrease of number of artesian well, is supporting this fact.

Reasons for decrease in the amount of groundwater recharges may lie on the progress of urbanization and increase in groundwater pumping rate.

Generally, with the rise of temperature in future the amount of evapo-transpiration and river runoff will increase due to change in the rainfall pattern, while the amount of recharge to the groundwater is expected to decrease. Additionally, further demand for “fresh water” is expected due to the improvement of the human life and the change in the industrial pattern.

Therefore, it is important to understand that the river and the groundwater are interacting with each other. And, it is advisable to manage the river water and the groundwater in a unified manner in order to utilize effectively the groundwater, which is stable freshwater resource. To do all these, it is of utmost importance to characterize the hydrogeologic structure of the Chikugo-gawa alluvial fan properly with its groundwater-flow conditions.

Acknowledgements

The authors wish to thank all the people concerned with the Chikugogawa River Office, Kyusyu Regional Development Bureau, MLIT, Ryouchiku Basin Water-for synthesis place of business, JWA and Ryouchiku Land use office, Fukuoka Prefecture. They helped by accessing the core samples, analysis of the results of the permeability test and the survey of inspection well for the study of the water environment of the R. Chikugo-gawa alluvial fan.

Bibliography

- Hasegawa, S., Fukami, D., Miyazaki, S., Takada, K., Shimada, J. (2008) : The Groundwater Flow System of R.Chikugo-gawa Alluvial Fan. (In This Monograph)
- Kohara, N., Hasegawa, S., Yanagida, M., Shimoosako, H. (2008): Future Prediction by the Water Balance and Model of R. Chikugo-gawa Alluvial Fan. (In This Monograph)
- Miyazaki, S., Hasegawa, S., Nishihira, H., Hanamura, O., Makino, R., Matsumoto, T. (2008) : The Hydrogeology of R.Chikugo-gawa Alluvial Fan. (In This Monograph)

The Hydrogeology of the Chikugo-gawa Alluvial Fan

MIYAZAKI Seisuke* · HASEGAWA Satoshi* · NISHIHARA Hideaki** · HANAMURA Osamu***

MAKINO Ryugo**** · MATSUMOTO Toshio*

Abstract

The Ryouchiku Basin is a half-graben rift basin formed by faulting in east-west and northwest-southeast directions. Alluvial fans are formed in the gap between the outlets of the R.Koishiwara-gawa and the R.Sata-gawa. Alluvial fans are an important of agricultural production. We studied the hydrogeological setting of the fan to discuss groundwater use accompanying a climatic change. In the alluvial fan there are two geomorphic surfaces. Along the rivers, the lower terrace which dissected the old geomorphic surface is identified. Amagi town was established on the fan toe of new alluvial-fan surface II. Spring water has played an important role in development of the area. The aquifer of the alluvial fan is bisected by Aso-4 pyroclastic flow deposit which exists 10-20 m underground. Along main rivers, Aso-4 is lacking, and it can recharge the river water to aquifer II directly. Such a hydrogeological structure can also explain the stream lost called "Segire"(see Ichimaru et al., in this Monograph).

KEYWORDS: Chikugo-gawa alluvial fan, half-graben rift basin, hydrogeological structure, Aso-4 pyroclastic flow deposit, "Segire"

1. Introduction

The R.Chikugo-gawa alluvial fan is located in the northern Kyushu district, where annual precipitation is about 1,500-1,900 mm. The study area is a non-snowpack region where snowfall melts immediately. A rich forest covers the upstream area of the alluvial fan, and has played a role as a water conservation forest. This alluvial fan has been inhabited since the Yayoi Period. However, it has recently undergone land-use reform. The area was used mainly as an upland field before 1950, but since then irrigation networks have been developed, farmland has been consolidated, and rice fields and the population have increased. Water supply through only surface water was inadequate to meet the demands of increasing rice cultivation. Wells were bored, but the fall in groundwater-level from excess pumping was questioned. This paper reports the results of a study of the hydrogeological structure of the R.Chikugo-gawa alluvial fan, which is regarded as essential to understanding and planning future water use in the area.

2. Geomorphology

The R.Chikugo-gawa is the largest river of Kyushu island. It arises in the Kuju volcano (1,787 m) and has a length of 143 km, reaching the Chikugo Plain through some intermountain basins. The catchment area is 2,860 km² (Fig.1). The Chikugo Plain, a productive grain-producing region, covers an area of 620 km². Upstream of Kurume calls the Ryouchiku Basin is formed to the triangular tectonic basin of 290 km². Downstream of Kurume

* Yachiyo Engineering Co., Ltd., ** Ministry of Land, Infrastructure, Transport and Tourism,
*** Kyushu Chishitsu Consultants Co., Ltd., **** Nittetsu Mining Consultants Co., Ltd.

formed a coastal plain and delta.

The Ryouchiku Basin is surrounded by horst mountains (700-900m) which formed uplifting in Quaternary age. The R. Chikugo-gawa flows through the center of this basin in a westerly direction. The Rivs. Koishiwara-gawa and Sata-gawa, which flow from Kosyo- Umami mountain to the north, form alluvial fans at a gap outlet. Both alluvial fans cover 63 km², and are called the R.Chikugo-gawa alluvial fan (Fig.2). Fan head are 60-65 m high, and the alluvial-fan surface has a gradual slope of 4 to 6/1,000. In an alluvial fan, two geomorphic surfaces (I: old, II: new) are identified, and spring is located on the Yorii-Amagi line (Fig.2) at the fan toe of alluvial-fan surface II. Downstream of the Rivs. Koishiwara-gawa and Sata-gawa, where the lower terrace was 2-5 m lower than the alluvial-fan surface I. A difference in level is as clear as on the toe-of-fan side. On the left bank of the R.Sata-gawa, the former-river-course surface I' is lower than I.

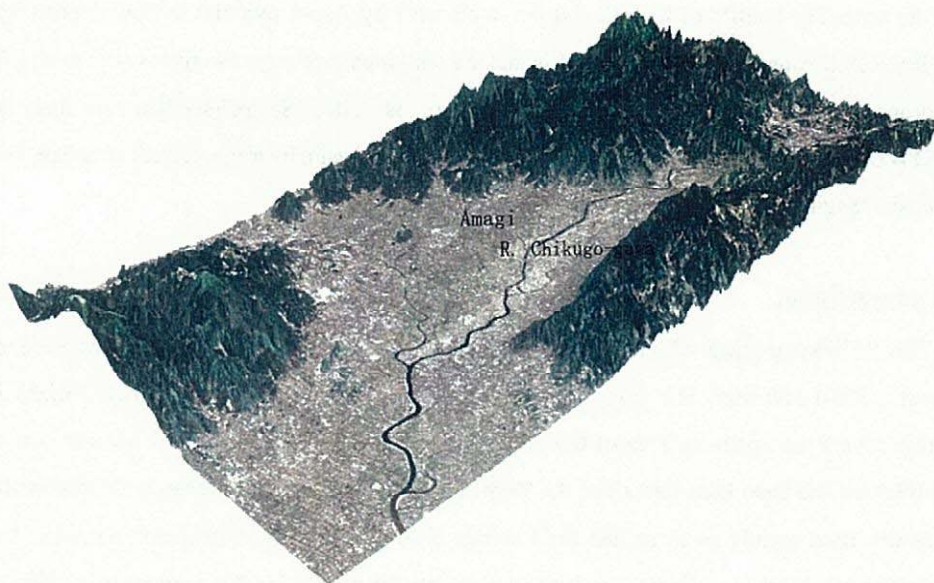


Fig.1 Outline view of the Ryouchiku basin



Photo 1 Erosion scarp of a fan toe. (a lotus paddy field is in foreground)

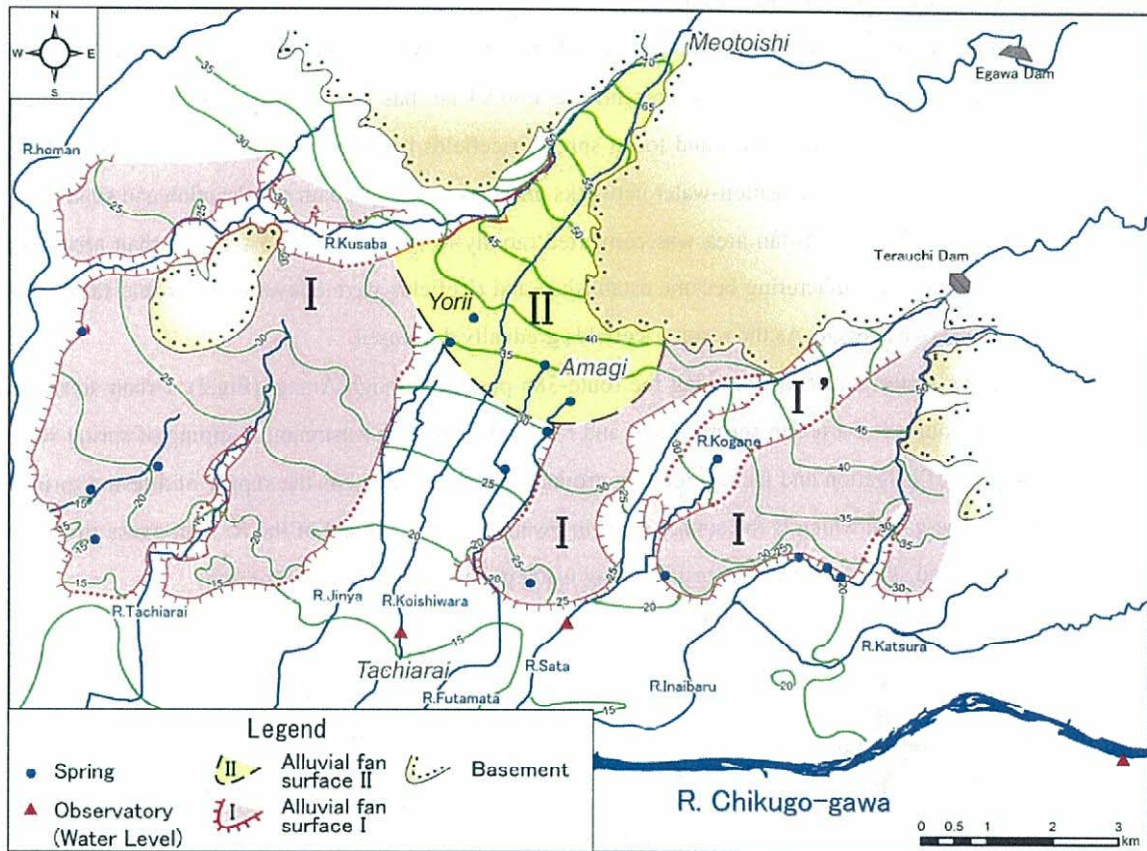


Fig.2 Geomorphological regionalization

The alluvial-fan surface is divided into three by the R.Koishiwara-gawa and R.Sata-gawa. The right-bank of R.Koishiwara-gawa forms a fan head. The distance from the fan head to the fan toe declines by 9km, altitude declines from 55 to 15 m, and average gradient is only 4/1,000. On the left-bank of R.Koishiwara-gawa (right-side of R.Sata-gawa), the distance from the fan head to the fan toe declines by 6 km, altitude from 55 to 20 m, and average gradient is 6/1,000. On the left side of R.Sata-gawa, the distance from the fan head to the fan toe declines 5 km, altitude from 50 to 20 m, and average gradient is 6/1,000. Such a difference is the result the R.Chikugo-gawa eroding the scarp of the fan toe. The height of the long erosion scarp is only 3-5 m above the level of the R.Chikugo-gawa on the west side. However, on the east side near the R.Chikugo-gawa, the fan toe is retreating through erosion. As a result, the eroded scarp is about 10 m height (photo 1).

At the fan head, the lower terrace and alluvial fan surface along the R.Koishiwara-gawa are almost the same height. Downstream of the center of the alluvial fan, the height difference is 2-3 m. In the R.Sata-gawa, the height difference at the fan head is 1-2 m, and at the center of alluvial fan the height is 3-4 m. The scarp height increases large further downstream.

3. Land use and spring water

In R.Chikugo-gawa alluvial fan, the site of Hiratsuka Kawazoe ruins were settled during the Yayoi Period, and has been occupied ever since. At present, the alluvial fan has been used for ricefields or converted to upland farms. When the upland farms and forest spread, ricefields became restricted to the lowland along a main river (Fig.4). In the 1960s, irrigation-water networks progressed, such as dam construction and sinking of wells. At the same time, the alluvial-fan area was converted rapidly to ricefields (Fig.3). Then urban areas expanded, drink and chemical manufacturing became established and ricefields were converted to upland farms through a policy to reduce rice acreage. As the result, ricefields gradually decreased.

Spring water is distributed along the route-386 passing through Amagi (Fig.2). Urban areas have developed around sources of artesian spring water, and ricefields spread downstream. Pumping of spring water to maintain supplies of irrigation and factory reduces groundwater level threatens the supply of artesian spring water. At the R Kogane-gawa, which is the source of spring water on the left bank of the R. Sata-gawa, the laver of red algae is cultivated. The demand for artesian spring water declines after the rainy season.

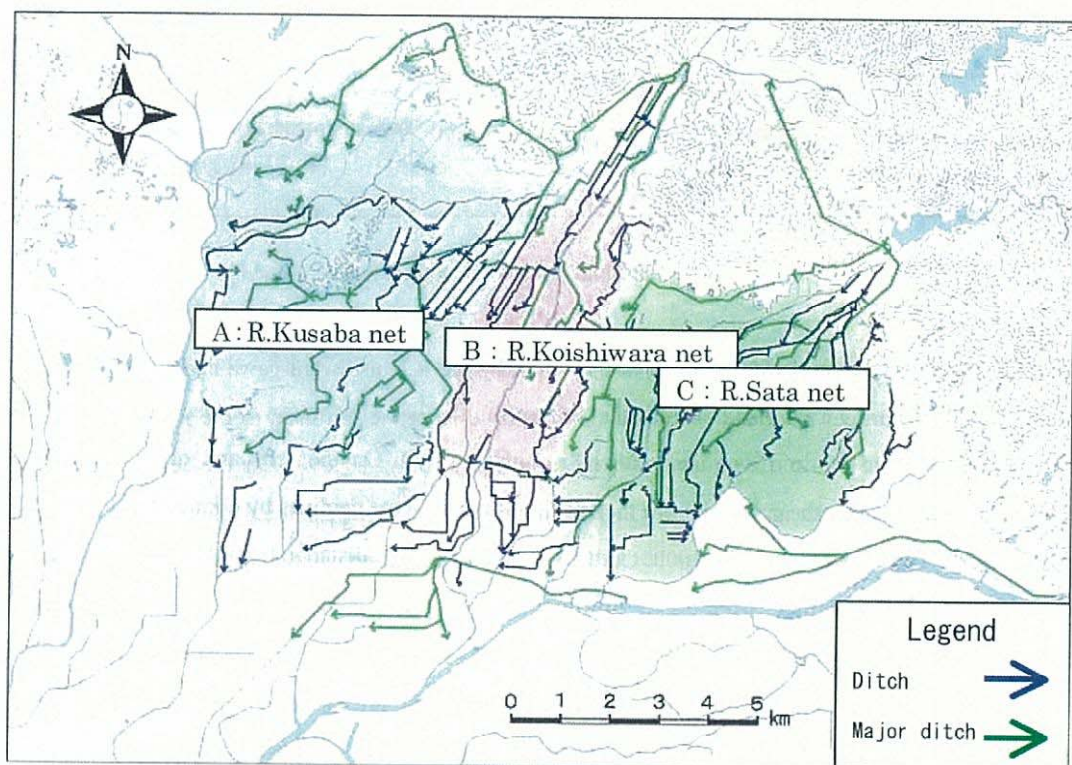


Fig.3 Irrigation-water network in alluvial fan

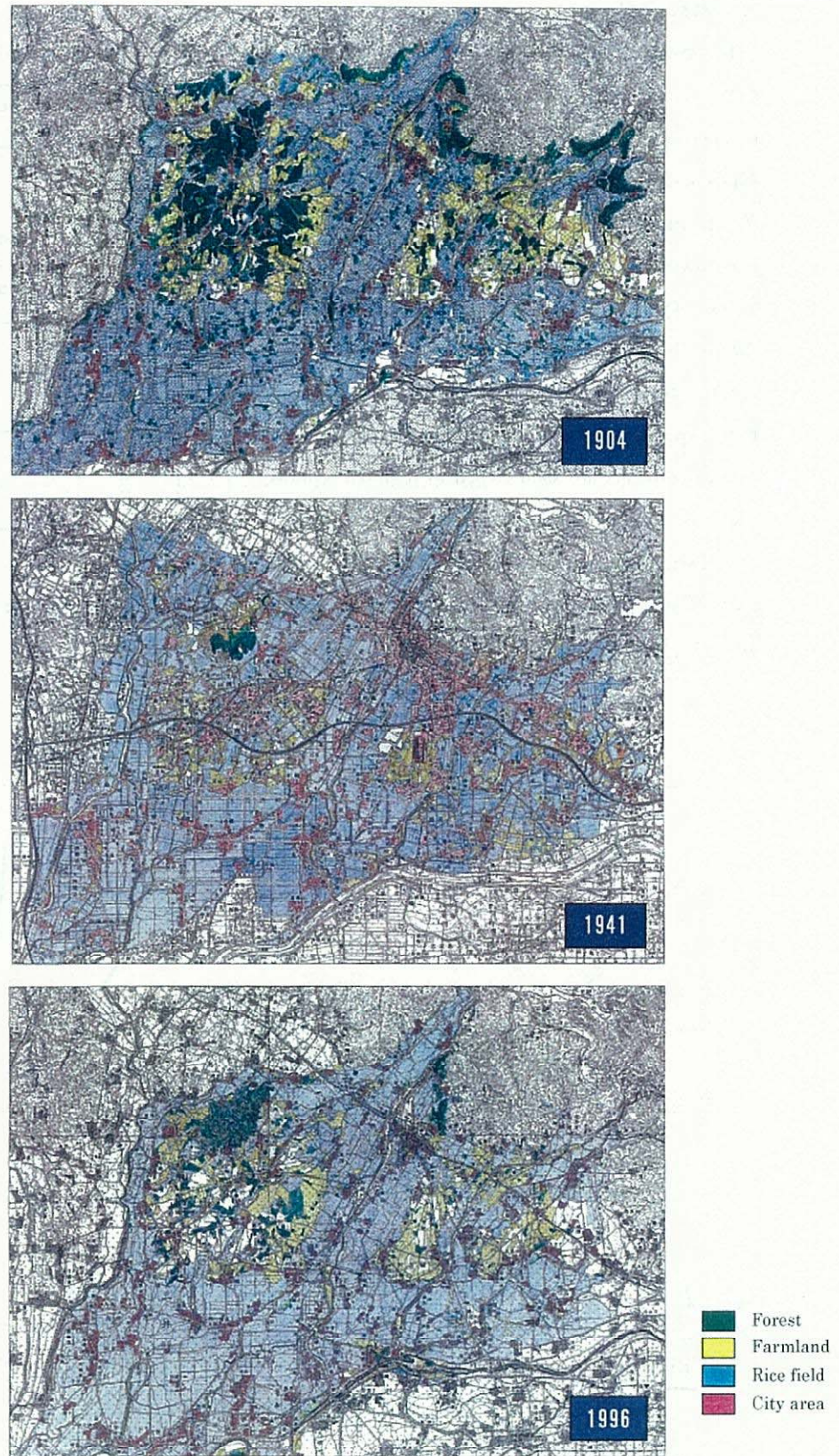


Fig.4 Land-use changes (1904, 1941, 1996)

4. Hydrogeology

In upstream area of fans, Triassic metamorphic rocks and Cretaceous granitoid intruding metamorphic rocks are distributed widely. Pliocene-Pleistocene volcanic rocks are distributed (Fig.5, Fig.6). In the Ryouchiku Basin, these rock masses constitute an impermeable basement.

The Ryouchiku Basin is half-graben rift basin formed by faulting in east-west and northwest-southeast directions. It is filled with debris flow deposits and sediments of flood plain - marsh. These sediments are sandwiched to regional tephras, such as the Yufu-gawa pyroclastic flow deposit (hereafter Yfg) and Aso-4 pyroclastic flow deposit

(Aso-4), and are covered with a river deposits. Debris flow deposits dominate the alluvial fans, and flood plane deposits. The stratigraphy of the R.Chikugo-gawa fan is shown in Table 1.

Table 1 Stratigraphy of the R.Chikugo-gawa fan

Holocene ~ Pleistocene		The present river deposit Debris flow dep.
Cenozoic	Neogene	Aso-4 Pyroclastic dep. (9.0ka) Debris flow dep. fluvial bed ~ Debris flow dep. Yufugawa Pyroclastic dep. (60ka) fluvial bed ~ Debris flow dep.
	Miocene ~ Pliocene	
Mesozoic	Cretaceous	Granitic rocks
	Triassic	Metamorphic rocks

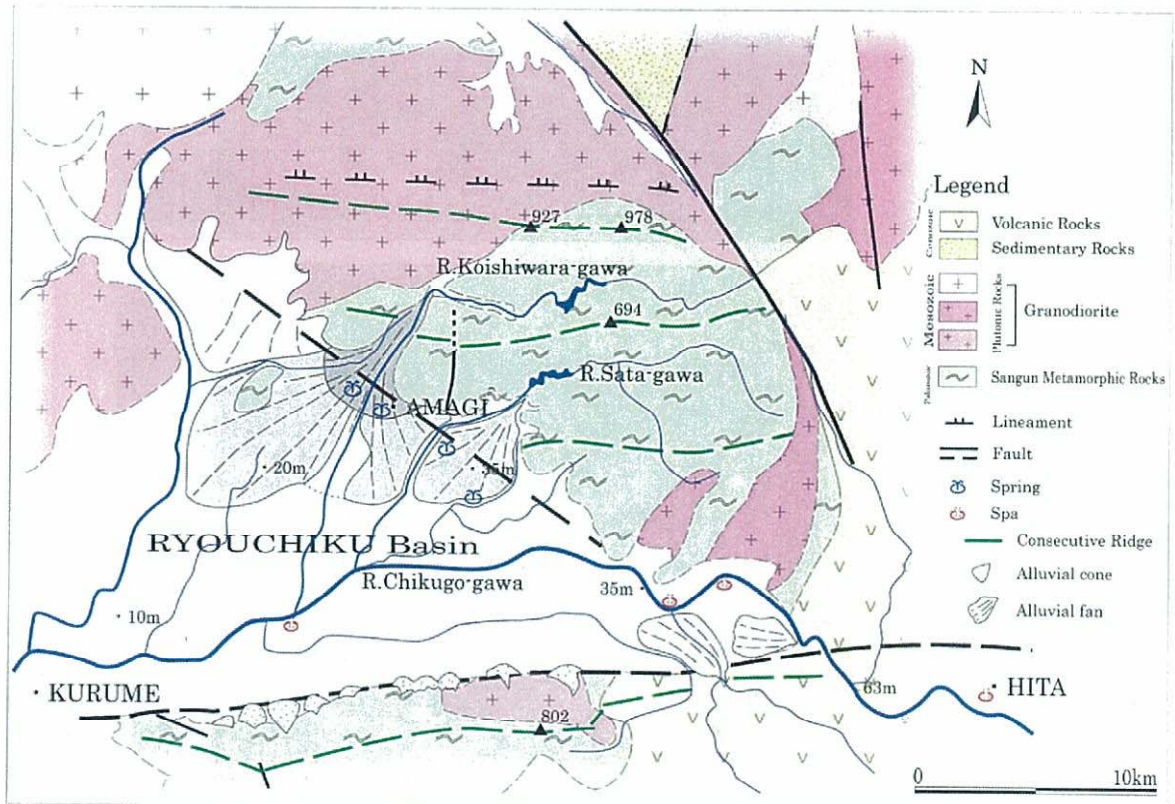
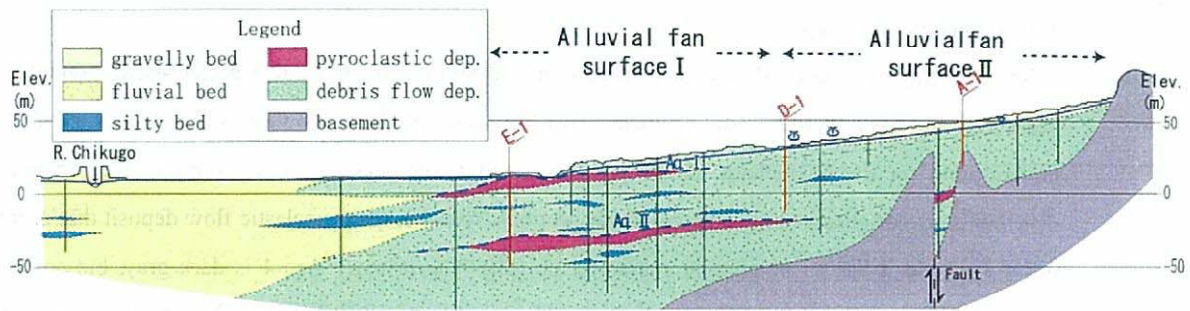
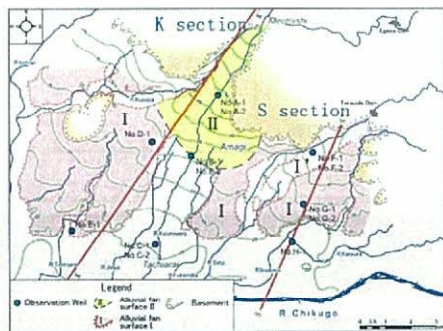


Fig.5 Geological map



(a) K section (R.Koishiwara-gawa)



(b) S section (R.Sata-gawa)

Fig.6 Geological profile

4.1 Fan deposits

The debris flow deposits are matrix supported, thickness is 20-250 cm. Rarely, a sand stratum of several centimeters or less may be inserted into a boundary (Table 2 and 1a). Grains form a subangular - angular gravel, and there is also a horizon in which rounded gravel is mixed. However, in alluvial-fan surface II, the gravel is loose compared with the lower debris flow deposits.

The gravel composition of a surface outcrop includes a granitoid gravel on both banks of the R. Koishiwara-gawa, but not included on the left bank of R. Sata-gawa (Fig.7). In the fan surrounded by the Koishiwara and R. Sata-gawa, this shows that the sediment originated from the R. Koishiwara-gawa. The same result has been obtained also from determination of the matrix composition.

On the downstream side, thin silt and sand that often form flood plane deposits are distributed from the center of the alluvial fan (1b). River-bed gravel rich in pores is distributed in the river channel of the main rivers, (1c).









4.2 Sediment of the R.Chikugo-gawa lowland

In R. Chikugo-gawa lowlands, floodplain deposit is a subject, consisting of an organic silt and a well sorted medium-grained sand (2a, b), intercalated with coarse sand layer contained rounded volcanics (2c) and schist. The former sand layer originated from the R. Chikugo-gawa upstream area on the east, while the latter gravels of schist and volcanics are originated from the upstream area of the alluvial fan.

4.3 Pyroclastic flow deposit

Yfg is a gray pyroclastic flow deposit which erupted 80 km east of the R. Chikugo-gawa 500,000 to 600,000 years ago, and has a biotite crystal characteristic (3a). This pyroclastic flow deposit is distributed about 50-70 m underground on the Ryouchiku Basin. It is assumed to be lacking in the former river channel, because distribution is not observed in some columnar sections. Aso-4 is the pyroclastic flow deposit that erupted 90,000 years ago, and it has an amphibole characteristic (3b). The primary Aso-4 is dark gray, but some Aso-4 are gray-russet because it is a secondary sediment. Although Aso-4 is distributed 10-20m below in the surface on the R. Koishiwara-gawa right side, but it is lack in some places (Fig.8).

Table 2 Characteristics of typical facies

Facies		Characteristics	Picture
Alluvial fan deposits	1a Debris flow deposit	Matrix support, A composition gravel and matrix grains are a subangular - angular gravel, well compacted.	
	1b Silt, Sand thin layer	With a 15 cm or less-thick granule mixture silt. A 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 river bed. The gravel which is deficient in a matrix and is rich in a pore.	
Floodplane deposits	2a Organic silt	Silt contained a plant piece. Gray - dark gray. Sand particle is included.	
	2b Medium-grained sand	Well sorted. It contains feldspar and colored minerals of the volcanic-ash origin.	
	2c Coarse sand contained a rounded gravel	The coarse sand contained a volcanic gravel. A schist gravel is not included.	
Pyroclastic flow deposit	3a Yfg	A pumice and a biotite are included characteristic. Well compacted. and gray color.	
	3b Aso-4	A pumice and an amphibole are included characteristic. It is a secondary sediment, A lamina progresses. Generally it is in gray. At the nature lamina of a silt, it is russet.	

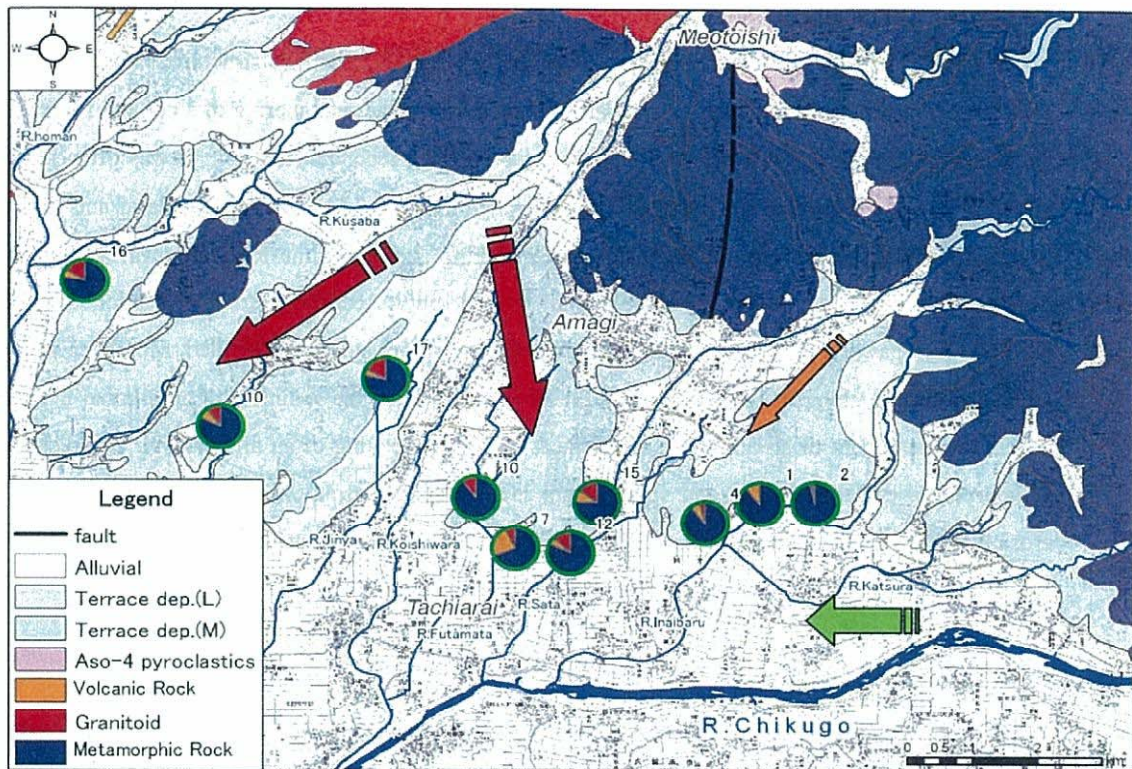


Fig.7 Gravel composition and supply direction of alluvial fan deposits

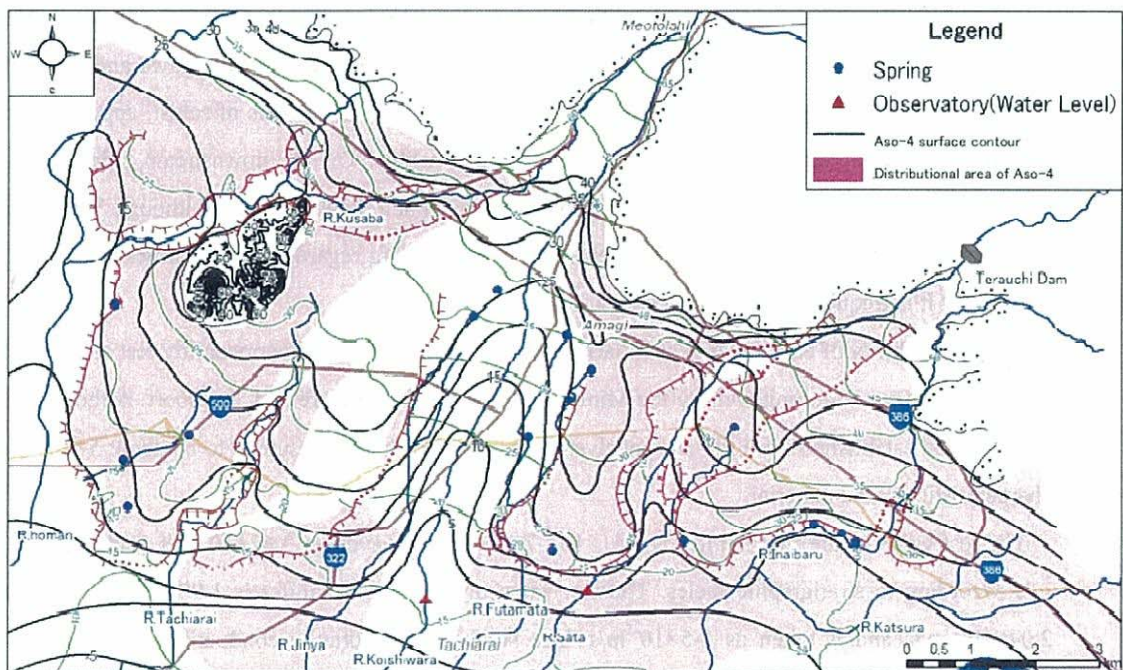


Fig.8 Distributional area of Aso-4

4.4 Structure of an alluvial fan deposit

An alluvial fan deposits which layer of 1 m or less with a stratified structure, intercalated with several centimeters of thin, fine-sand layers. In detail, it is regarded as the retempering of a cut and fill structure. Aso-4 is one of the important key beds, showing the structure of a secondary deposit. It was often removed by the gravel of the upper layer. Main areas of removal range along the Koishiwara, Tachiarai and R. Kusaba-gawa (Fig.8). The range is narrow although it is partly lacking also along the R. Sata-gawa. Yfg are also broadly distributed with a secondary sediment, and eroded out. According to the section that crosses the R.Koishiwara-gawa, a lower stratum was removed and the upper stratum was filled. Moreover, according to the geological profile along the direction of dip, it is considered that the sediment of an alluvial-fan II surface has covered the sediment of an alluvial-fan I surface, at the top heading of an alluvial fan. The distribution of the geomorphologic features slope and spring-water is a possible reason, which is also supported by Fig.2. The erosion scarp of the alluvial-fan I surface, from which it is distributed over both banks of the R. Koishiwara-gawa, cannot be observed from Amagi town upstream.

4.5 Aquifer and permeability

Aso-4 is a tephra from 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 (Fig.9). These traces are secondary deposits of the tephra. The surface weathers in a fine-grained, clay-forming process, and a difference in hydraulic head is observed in the upper and lower aquifer. 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 regards it as impermeable basement from the reason that it is frequently attend with silt particle.

The permeability of each layer is summarized in Table 3, based on the permeability test at the time of drilling the groundwater monitoring well by the Ministry of Land, Infrastructure and Transport. Although the test value has not been established from the present river deposit material, it is presumed to be about 5×10^{-3} m/s from the characteristics of the material.

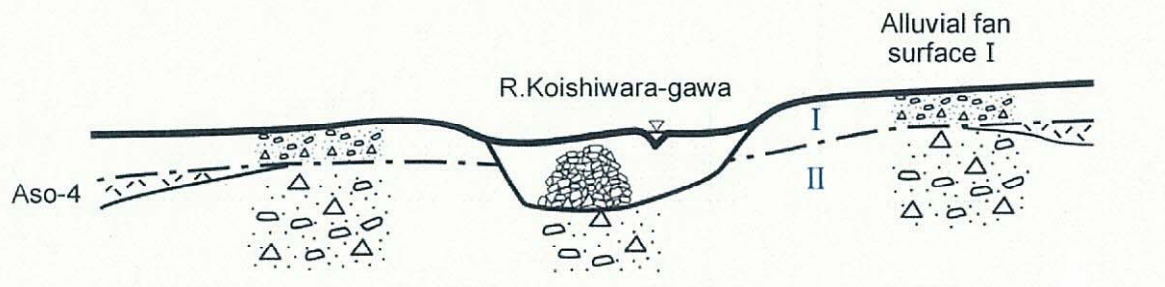
The test value of the first aquifer is 2.41×10^{-5} - 7.17×10^{-4} m/s, average 3.62×10^{-4} m/s, and is taken as $3-9 \times 10^{-4}$ m/s according to stratigraphic facies. The test value of the second aquifer is 1.97×10^{-6} - 1.00×10^{-5} m/s average 2.04×10^{-5} m/s, and is taken as $1-5 \times 10^{-5}$ m/s. The single digit hydraulic conductivity of each aquifer differs. Nevertheless, this measurement has been interpreted directly from the facies. Although the test value has not been determined in Aso-4, about $1 \times 10^{-6-7}$ m/s is presumed from the characteristics

The silt deposited on the flood-plain of the R.Chikugo-gawa lowland has acquired a test value of 3.80×10^{-5} - 7.45×10^{-5} m/s and an average of 5.63×10^{-5} m/s. The gravel and sand are contained, and can be

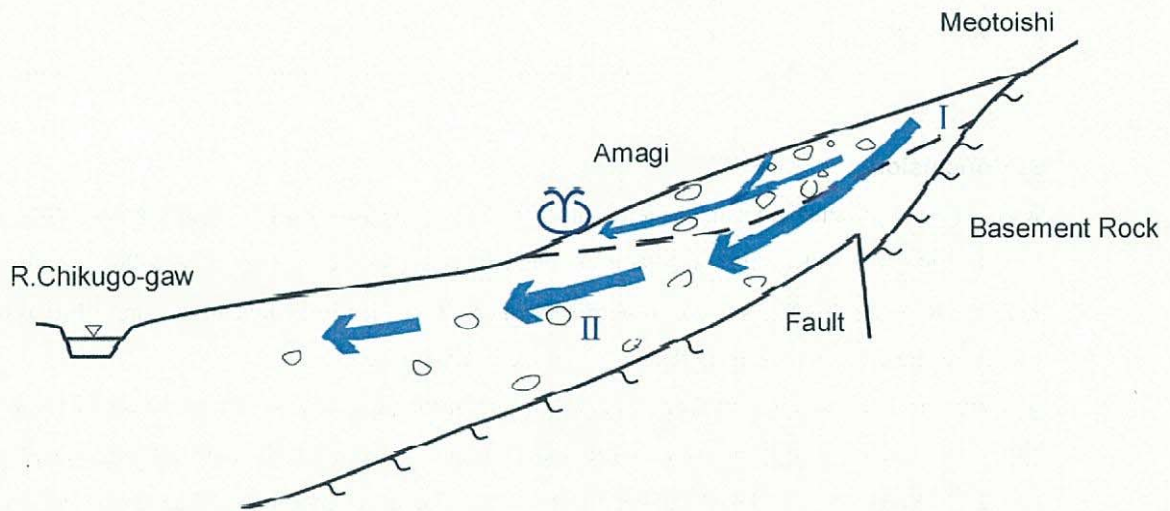
considered to about $1-5 \times 10^{-4}$ m/s.

Because the test value in Yfg is $1.40 \times 10^{-6} - 7.65 \times 10^{-6}$ m/s ,average 4.81×10^{-6} m/s, it is considered to be 5×10^{-6} m/s.

The metamorphic rock has few crack, it is a low permeability from Yfg.



a. The transverse direction of a river bed




b. The vertical section of the R. Koishiwara-gawa

I · II: Aquifer

Fig.9 Schematic profile

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}	—	Gravel deficient in a matrix	8.5~20.0	Ca-HCO ₃	
First aquifer	$3 \sim 9 \times 10^{-4}$	$2.41 \times 10^{-3} \sim 7.17 \times 10^{-1}$ (Average : 3.62×10^{-4})	Debris flow dep.	12.5~14.5	Ca-HCO ₃	
Aso-4 pyroclastic flow dep.	$1 \times 10^{-6 \sim 7}$	—	Fine-grained secondary sediment, surface are clay-ization by a weathering	—	—	
Second aquifer	$1 \sim 5 \times 10^{-5}$	$1.97 \times 10^{-5} \sim 1.00 \times 10^{-4}$ (Average : 2.04×10^{-5})	Debris flow dep., well compacted	12.1~32.6	Ca, Mg-HCO ₃ Ca-HCO ₃	
Flood-plain dep. of R. Chikugo-gawa	$1 \sim 5 \times 10^{-4}$	$3.80 \times 10^{-5} \sim 7.45 \times 10^{-5}$ (Average : 5.63×10^{-5})	Organic silt, River bed gravel	18.0	Na-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-HCO ₃	
Metamorphic rocks	5×10^{-10} 以下	—	Pelitic Schist	—	—	

5. Conclusion

- The slope of the alluvial fan on the left bank of the R. Koishiwara-gawa has a gradient of 4/1,000, and the right bank 6/1,000. The R. Koishiwara-gawa is eroding the surface of the alluvial fan as it flows south. At the same time, the R. Sata-gawa flows to the western edge of an alluvial fan. The slope of the fan surface is 6/1,000. The fan toe has formed into a scarp by the erosion of the R. Chikugo-gawa.
- Springs are located along the Yorii-Amagi line and at the tip of the R. Sata-gawa alluvial fan. The former appears to be toe-of-fan spring water on the alluvial-fan surface II which forms a blanket on the alluvial-fan surface I. Spring water played an important role in the development of urban areas and early ricefield development. At present, artesian flow does not occur and springs serve as wells or reservoirs. Although only small quantities of spring water are derived from erosion scarps, if a lowland frontage turns into a marsh, it is used as a lotus paddy field.
- On the other hand, "Segire" is occurring in rivers, but not to a serious extent in the R. Koishiwara-gawa or R. Kusaba-gawa. According to the history of Amagi, it has occurred since 70 years ago. times and is considered to be a natural phenomenon of the R. Chikugo-gawa alluvial fan. Segire is important when considering the relationship between river water and groundwater.
- Aso-4 is continuously being formed under an alluvial-fan surface. Its formation from a debris flow deposit from means its permeability is low. Therefore, Aso-4 has played an important role in dividing an aquifer into two

layers. On the other hand, along the former river course on the right bank of the R. Koishiwara-gawa and R. Sata-gawas, Aso-4 is lacking. Accordingly, upper and lower aquifer touch and the river water recharges the aquifer II directly.

● On the upstream side, distribution of metamorphic rocks is shallow from the center of the alluvial fan, and the rocks are considered to form an impermeable basement. Yfg has low permeability compared to the upper and lower strata, is distributed on the downstream side. The Yfg is often lacks of its continuity in the ground, but always accompanied with silt beds, therefore it can be regarded as the formation that regulates groundwater flow.

Acknowledgements

The authors wish to thank all the parties concerned associated with the Chikugogawa River Office, Kyusyu Regional Development Bureau, MLIT, Ryouchiku Basin Water-for synthesis place of business, JWA and Ryouchiku Land use office, Fukuoka Prefecture. They helped with observation of the core samples, analysis of the results of the permeability test and the survey of an inspection well for the study of the water environment of the R. Chikugo-gawa alluvial fan.

References

- Ariake Bay Research Group (1969): Quaternary of Kyushu area. Association for the Geological Collaboration in Japan new report, Quaternary of Japan, Vol. 15, 411-427.
- Compilation Commission of the History of Amagi (1982) : The History of Amagi, First Volume.
- Fukuoka Prefectural Sabo Association. (2005) : 1:150,000 Geological Map of Fukuoka Pref.
- Hasegawa, S., Takada, K., Shimada, J., Shimoosako, H., Research Group on Hydro-environment around Alluvial Fans (2006) : Study of Alluvial Fan (Part 8), The Groundwater Flow System in Alluvial Fan, Chikugo Area (Preliminary Report). *Proceedings of Meeting, Japan Society of Engineering Geology*, 157-160.
- Kido, M. (1997) : Fault Development of Minoh Range and the Kitano Plain, Northern Kyushu, Southwest Japan. *Journal of the Geological Society of Japan*, 103, No.5, 447-462.
- Kuroda, K., Kuroki, T. (2004) : Landform Development at the Northern Part of Kitano Plain after Aso 4 Pyroclastic Flow Deposition. *Proceedings of the General Meeting of the Association of Japanese Geographers*, 65, 81.
- Kuroda, K., Kuroki, T., Kagashima, S. (2004): Development of Terrace at the Northern Part of Kitano Plain after Aso 4 Pyroclastic Flow Deposition, Program and Abstracts, *Japan Association for Quaternary Research*, 34, 111-112.
- Kuroki, T., Kuroda, K., Nakamura, Y. (2003) : Relationships between Characteristics of the 1953 Flood Disaster and Microtopography in the Kitano Plain. *Proceedings of Meeting, Japan Society of Engineering Geology*, 267-270.
- Machida, H., Arai, F. (2003) : Atlas of Tephra in around Japan. University of Tokyo Press.
- Matsumoto, T., Miyazaki, S., Oishi, A., Research Group on Hydro-environment around Alluvial Fans (2006) :

Study of Alluvial Fan (part 7), Geomorphology and Geology of Alluvial Fans in the Chikugo Area.
Proceedings of Meeting, Japan Society of Engineering Geology. 153-156.

The Groundwater Flow System of the Chikugo-gawa Alluvial Fan

HASEGAWA Satoshi* · FUKAMI Daisuke** · MIYAZAKI Seisuke*

TAKADA Kaori** · SHIMADA Jun**

Abstract

To understand the state of a groundwater flow system, we discuss the groundwater flow system based on observations of hydrogeological structure, hydrology and meteorology, and from a well survey and a water quality analysis. According to groundwater observation records, groundwater level of the first aquifer is higher than that of the second aquifer. Irrigation increases levels of both aquifers. Precipitation is concentrated in the rainy season (June to July) every year. In the other seasons, the outflow of a dam decreases and river water also decreases and a “Segire” phenomenon is generated. It is clear that differences occur in groundwater recharge, groundwater flow system in the R.Koishiwara-gawa. These observations were by analysis of the results for water quality and stable isotopes.

KEYWORDS : Aquifer, Groundwater table, Recharge river, Hydro-geological structure, Stable isotope

1. Introduction

In the catchment areas of the Koishiwara and R.Sata-gawas, a relatively wet area in northern Kyushu, annual precipitation is 1,870 mm. In order for a catchment area to be sufficiently narrow (50 km² or less), and flow through an alluvial fan, “Segire”(see, Ichimaru et.al., in this Monograph) has occurred except in a wet season. The Egawa Dam and the Terauchi Dam were built in the 1970s to increase water available for domestic and industrial use. During short droughts irrigation water ran short when the area of ricefields expanded. To compensate for this shortage, water was drawn from shallow wells. Factories and large commercial operations also pumped water from wells, with the result that groundwater levels fall.

In this situation, it is important to grasp the relationship between river water and groundwater in an alluvial fan. Therefore, a field study and water quality analysis were conducted and the relationship between a groundwater flow system and river water was analyzed.

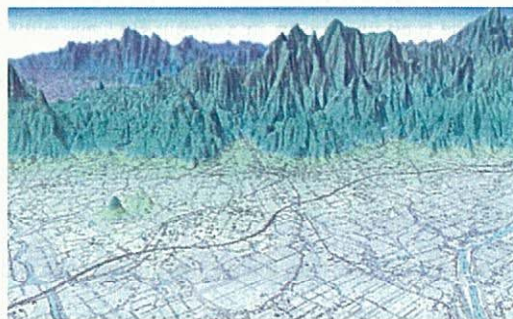


Fig.1 External view of the Chikugo-gawa alluvial fan

* Yachiyo Engineering Co., Ltd., ** Kumamoto University

2. Water budget

2.1 Analysis of hydrological condition and meteorology

The annual mean temperature at Asakura (former Amagi) is 15.5°C. During 1978 to 2007 it has increased by 1.7°C. Annual precipitation ranges widely, from 980 to 2,870 mm.

Over this period, monthly mean air temperature was maximum (27.0°C) in August (summer), and minimum (4.5°C) in January (winter) (Fig.2). Peak precipitation is in the rainy season (June to July); winter is the dry season. However, depending on the year, a peak can also occur during the typhoon season in autumn. Drought occurred three times from 1976 to 2006, in 1978, 1994 and 2005, as a result of extremely low precipitation in the rainy-season. Potential evapotranspiration (estimated by the Thornthwaite method) is 850 mm.

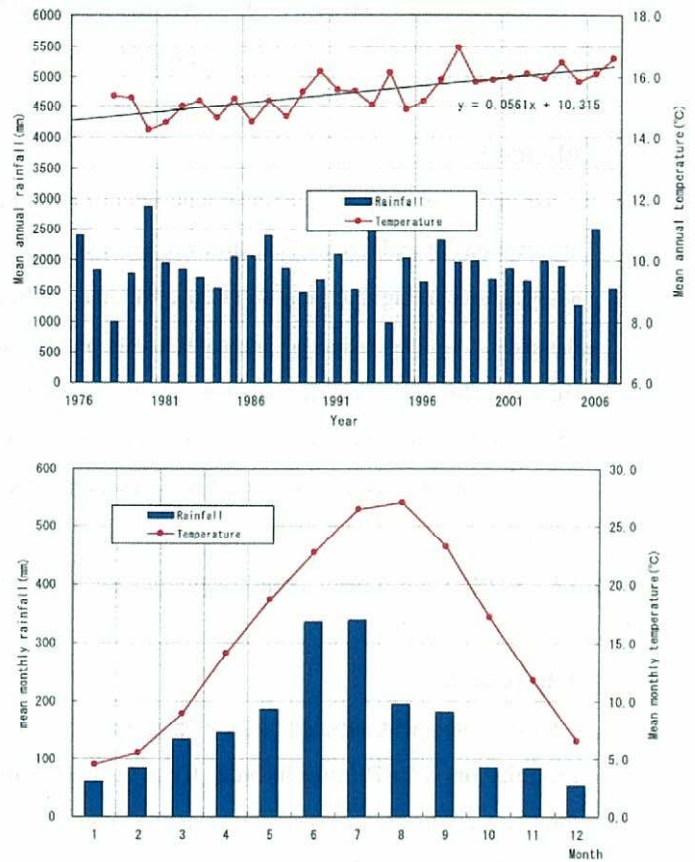


Fig.2 Temperature and precipitation at Asakura

2.2 Stream flow and water budget of a main channel

In the R. Chikugo-gawa catchment area, stream flow reflects seasonal change 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 (Fig.3). Discharge of the R. Chikugo-gawa main stream peaks in the rainy season at 0.13 m³/s/km², then decreases to 0.02 m³/s/km² in the dry season. Discharges of the Rivs. Sata-gawa and Koishiwara-gawa are 30-80% and 20-70%, respectively, of that of the R.Chikugo-gawa.

During a period without irrigation at the R.Koishiwara-gawa, stream flow decreases from the center to the fan head, and increases near the fan toe (Fig.5). At the downstream side of a decline section, stream flow stops temporarily. At the R.Sata-gawa, stream flow decreases except near the fan toe. Therefore, stream flow stops for a long period except for the wet season. The same trends are shown also during irrigation. “Segire” is considered to be a natural phenomenon dating from a historical fact.km²

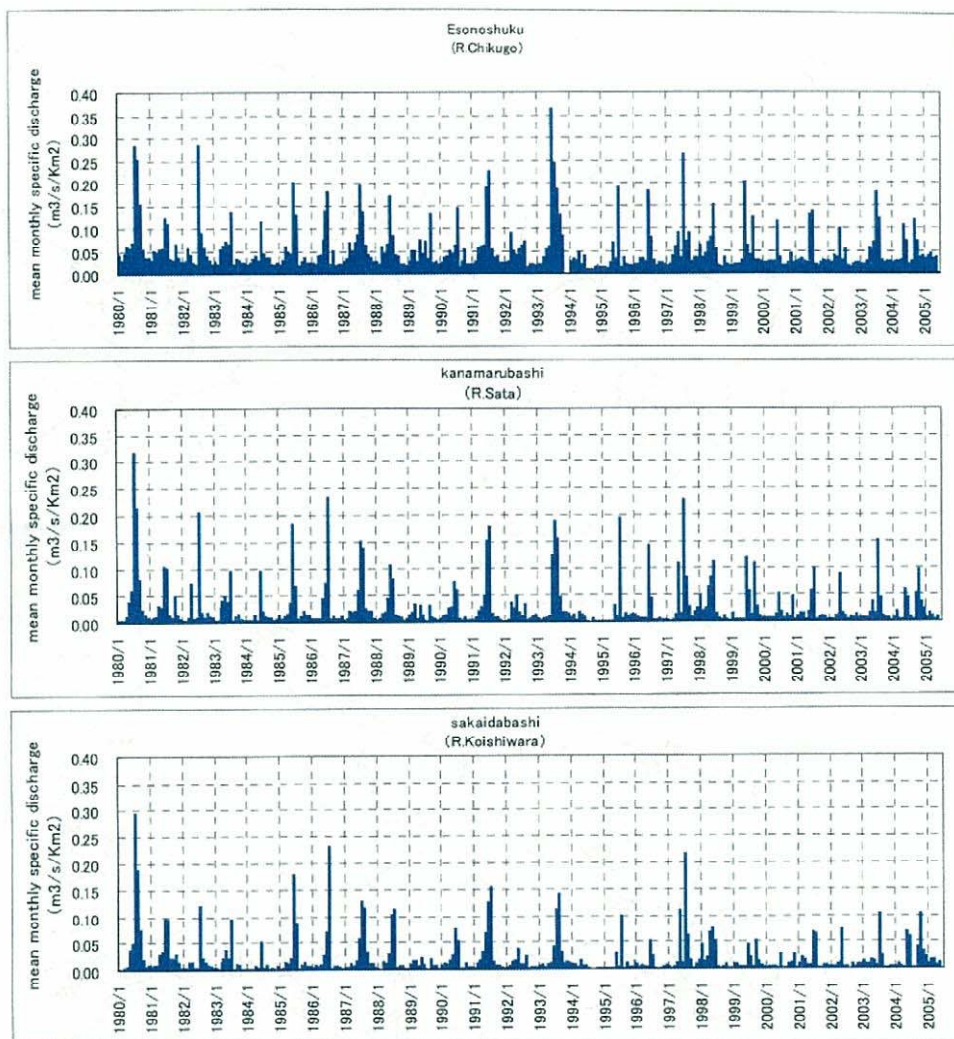


Fig.3 Trend of streamflow

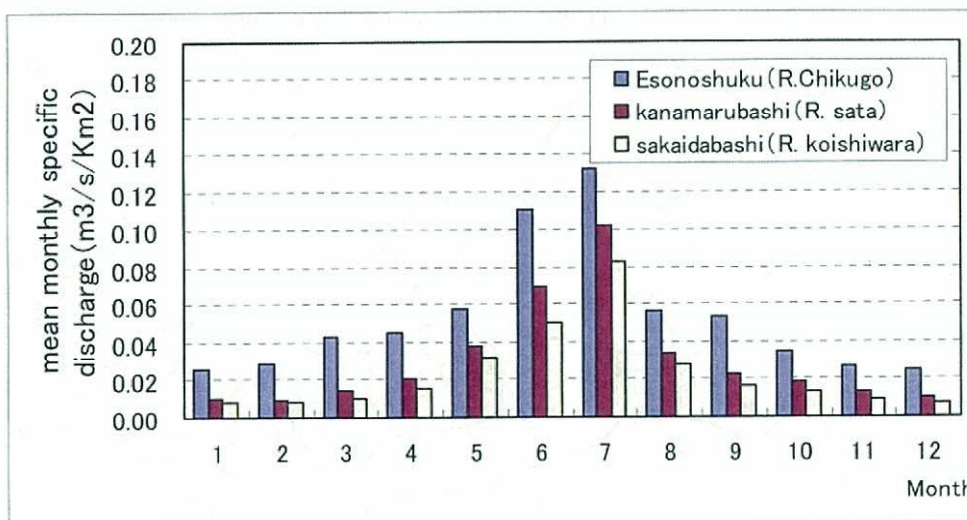


Fig.4 Change in specific discharge

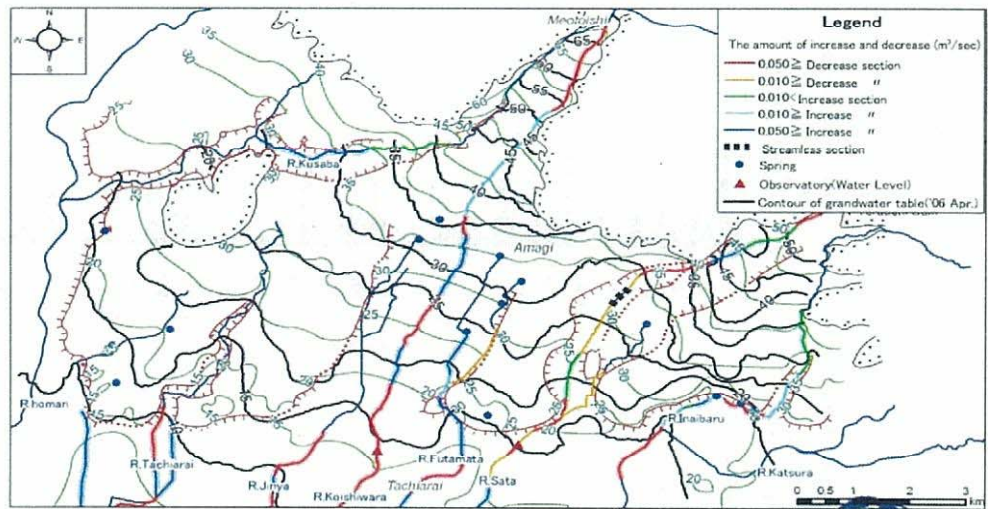


Fig.5a Flow regime of main stream (April, 2006)

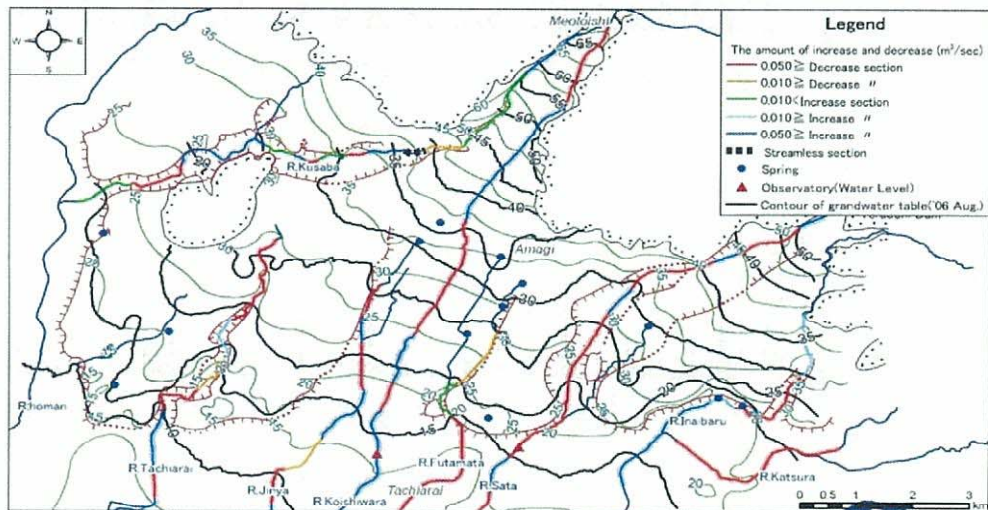


Fig.5b Flow regime of main stream (August, 2006)

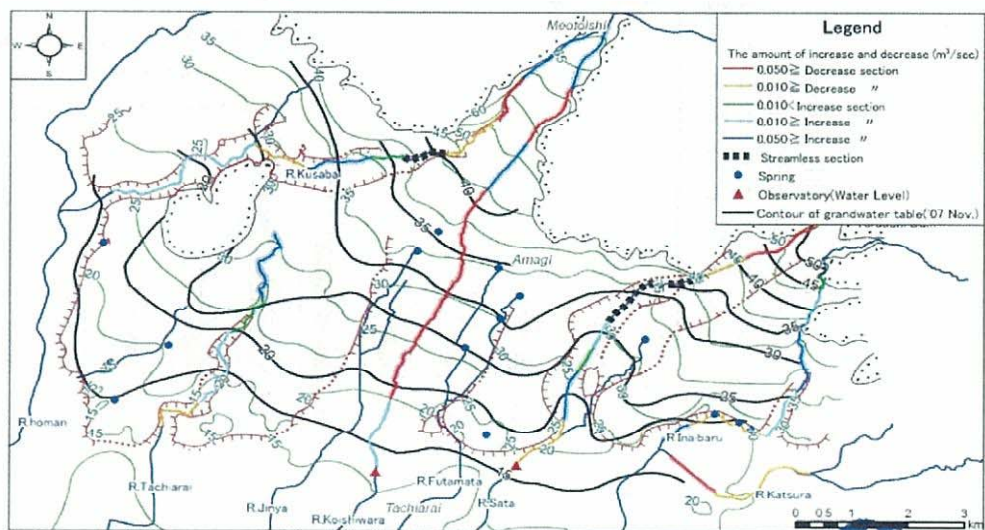


Fig.5c Flow regime of main stream (November, 2007)

2.3 Groundwater table

Chikugo-gawa alluvial fan contains many shallow wells. We investigated in which wells and water sampling were possible (Fig.6). Measurements were carried out in April and November during a period without irrigation, and in August during an irrigation period.

These measurements showed that the profile of the groundwater table of the first aquifer matches the geomorphic surface. In an alluvial-fan surface, the geomorphic surface has a ridge on the downstream side and forms a valley along a river channel (Fig.7). In detail, along the R. Koishi-kawa, the surface forms a ridge on the downstream side near to Amagi town, and spring-water is located around urban areas. Downstream from Amagi, contour lines form a valley. Spring water does not flow into the R.Koishiwara-gawa, but flow into the R.Futamata-gawa or R.Jinya-gawa, and declines. Therefore, the R.Koishiwara-gawa serves as a decline section of the streamflow except for part of the fan toe during a dry season. On the upstream side of route 386, the valley axis has shifted to the left bank side, and matches the decline section of the stream flow. Discharge increases on the downstream side of route 386.

Water level has 3-7 m difference in wet and dry seasons. In the R. Kogane-gawa source on the left bank of the R.Sata-gawa, water level changes greatly. Although spring water flow is high in the wet season, it falls by 5 m or more in the dry season. At recently a groundwater level falls by pumping.

The groundwater table in 1961 (Fig7b) near the center of the alluvial fan was 2-3 m higher than in August, 2006 (1961:the measurement season is not known).

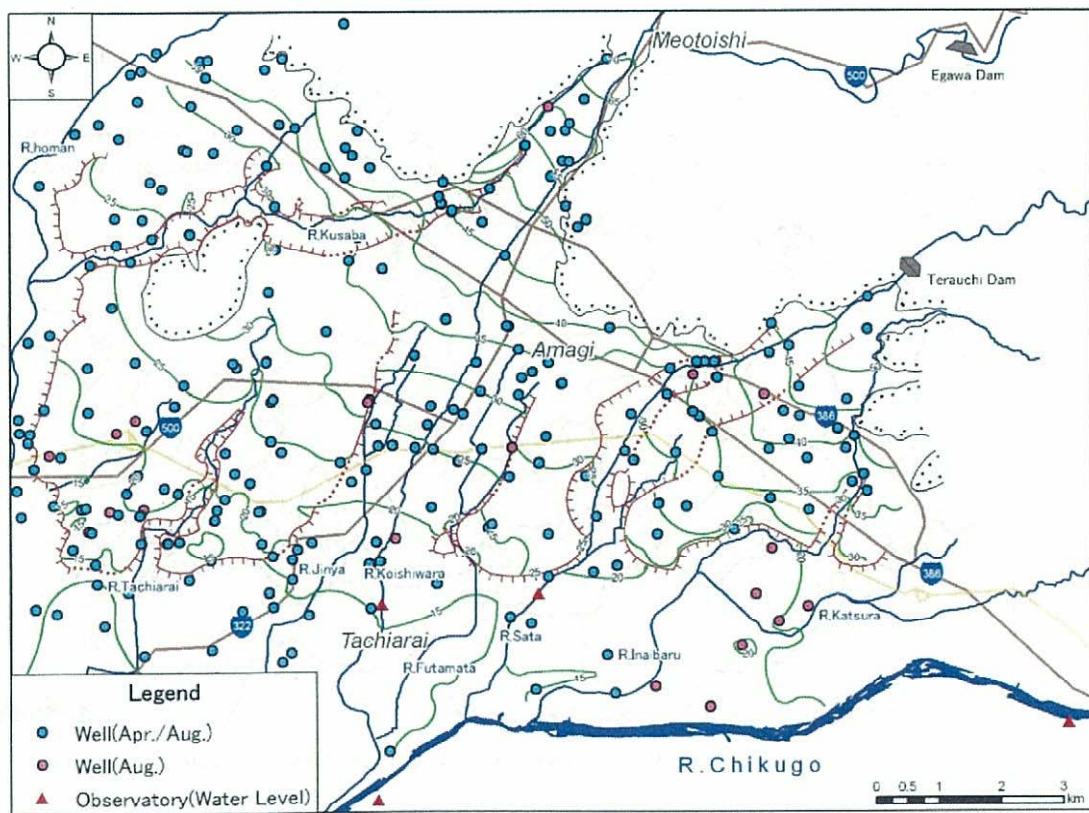


Fig.6 Distribution of research wells

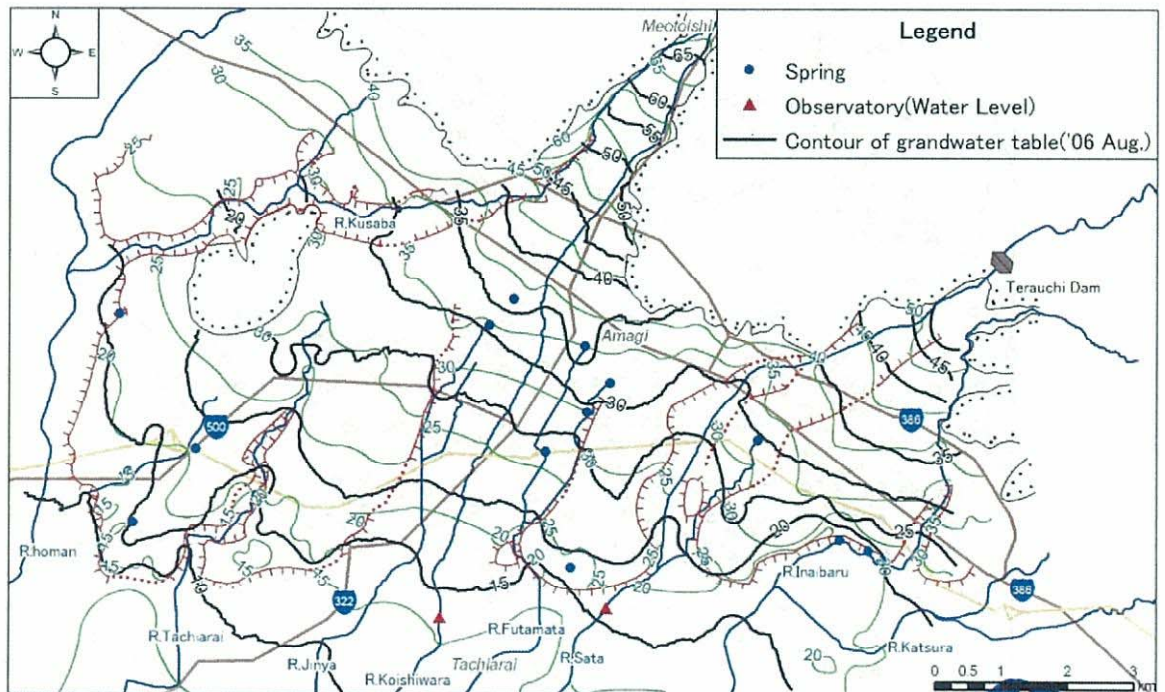
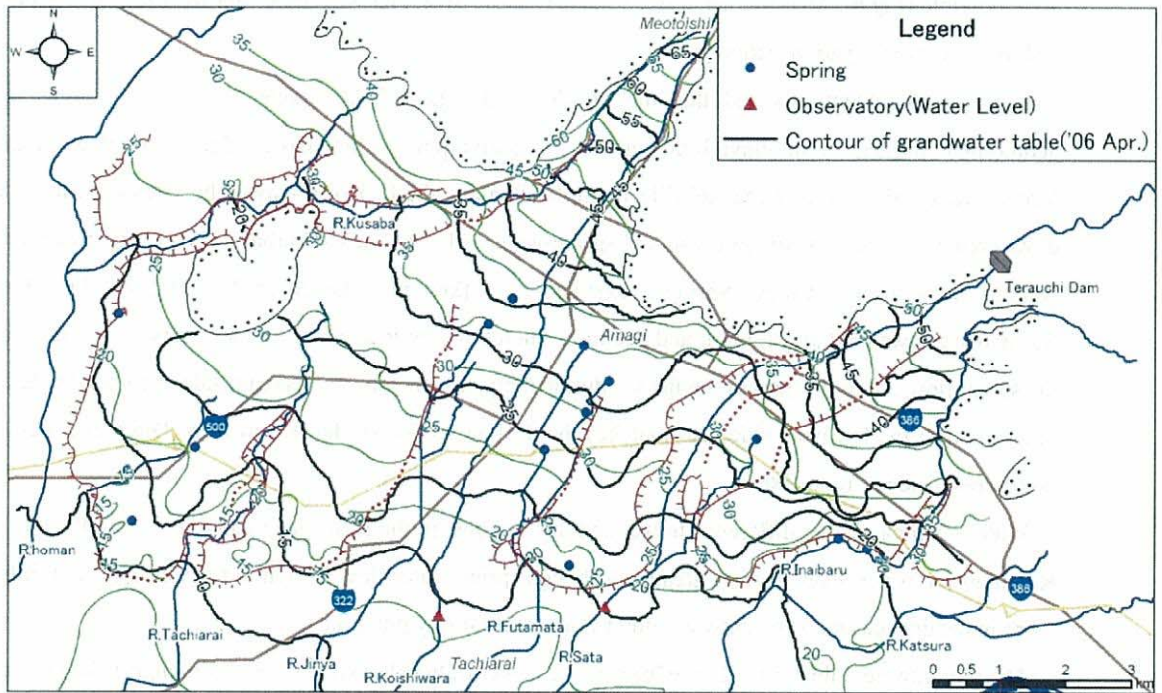


Fig. 7a Profile of groundwater table (April, 2006, August 2006)

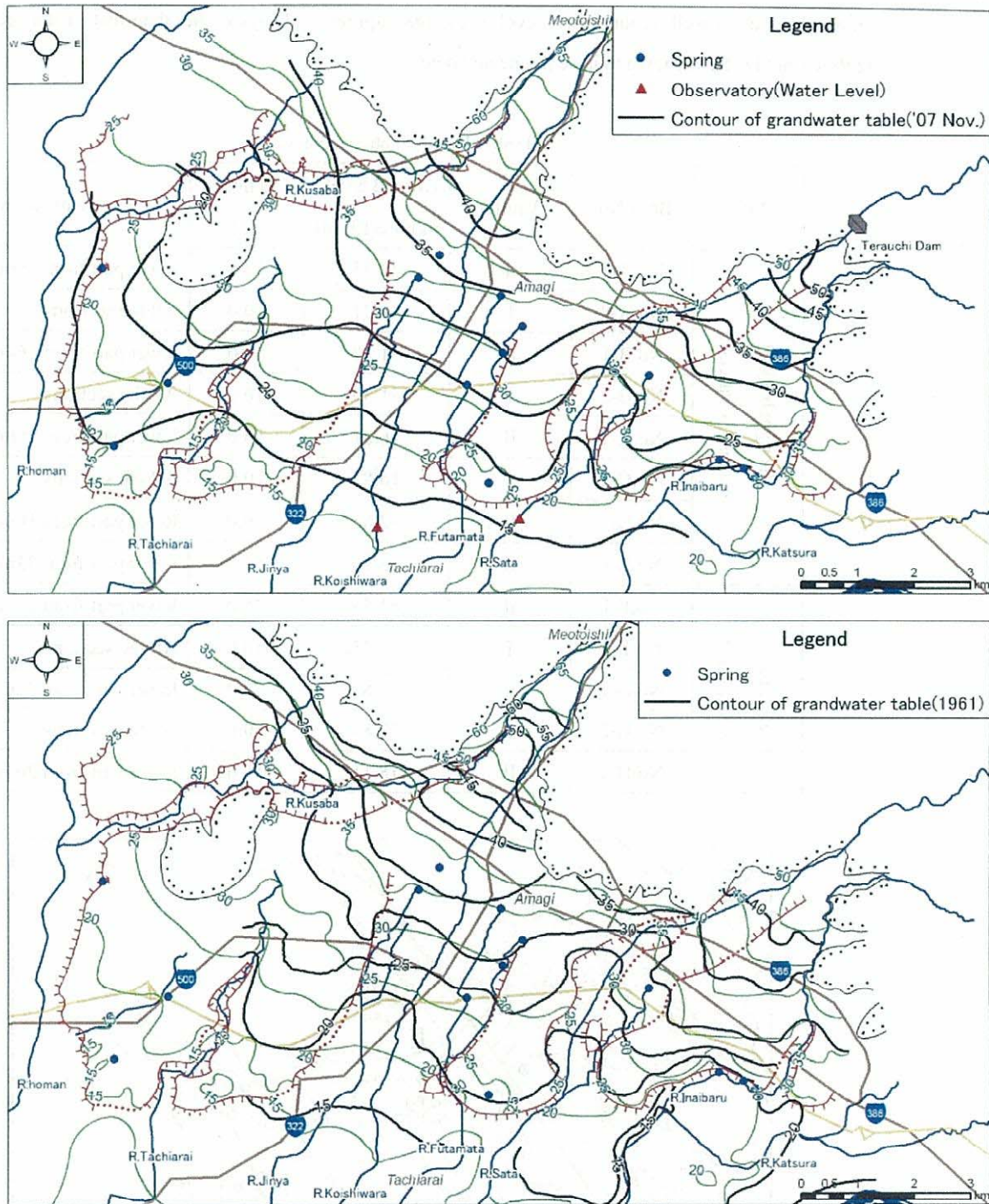


Fig.7b Profile of groundwater table (November, 2007, 1961)

2.4 Fluctuation in groundwater level

In order to grasp the seasonal fluctuation of groundwater level, observation wells were newly installed at eight places (Table 1, Fig.8). Five of these were twin observation wells so that groundwater level of the first and second aquifer could be measured separately.

In an observation well, groundwater level of the first aquifer is always higher than that of the second aquifer (Fig.9). Groundwater is shown to have permeated below.

Table 1 Details of observation wells

Site	Bore No.	Aquifer	Ground level of bore(EL.m)	Length (m)	The position of screen
The right bank of R.Koishiwara-gawa	No.A-1	II	49.45	32.0	lower part from 16m.
	No.A-2	I	49.21	10.0	All the sections
	No.B-1	II	31.38	40.0	lower part from 16m.
	No.B-2	I	31.36	10.0	All the sections
	No.C-1	II	16.81	50.0	lower part from 19m.
	No.C-2	I	16.81	10.0	All the sections
	No.D-1	II	32.85	40.0	lower part from 16m.
The left bank of R.Sata-gawa	No.E-1	II	15.10	65.0	lower part from 33m.
	No.F-1	II	41.53	25.0	lower part from 17m.
	No.F-2	I	41.55	10.0	All the sections
	No.G-1	II	33.83	70.0	lower part from 27m.
	No.G-2	I	33.84	10.0	All the sections
No.H-1	II	18.11	55.0	lower part from 20m.	

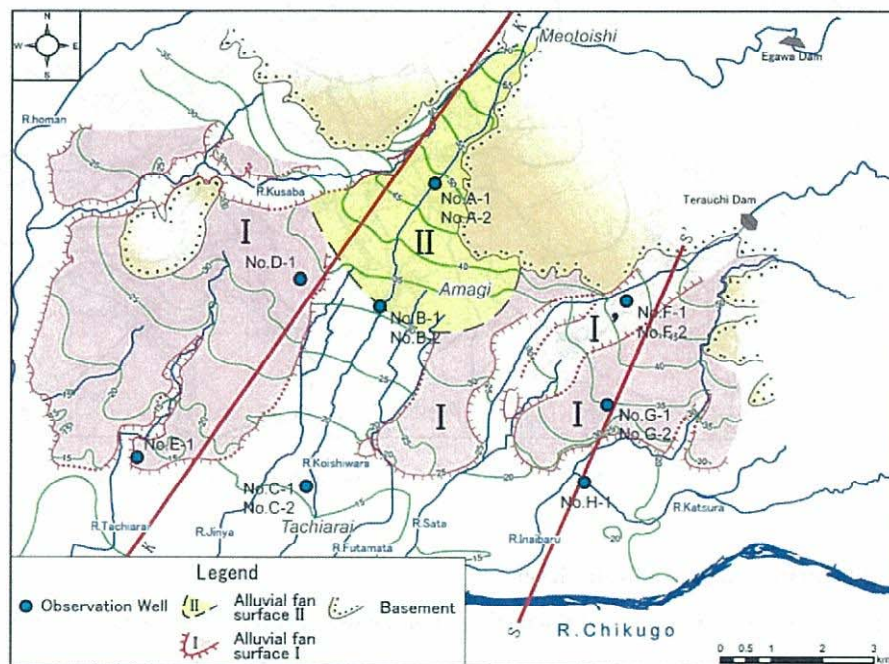


Fig.8 Sites of observation wells

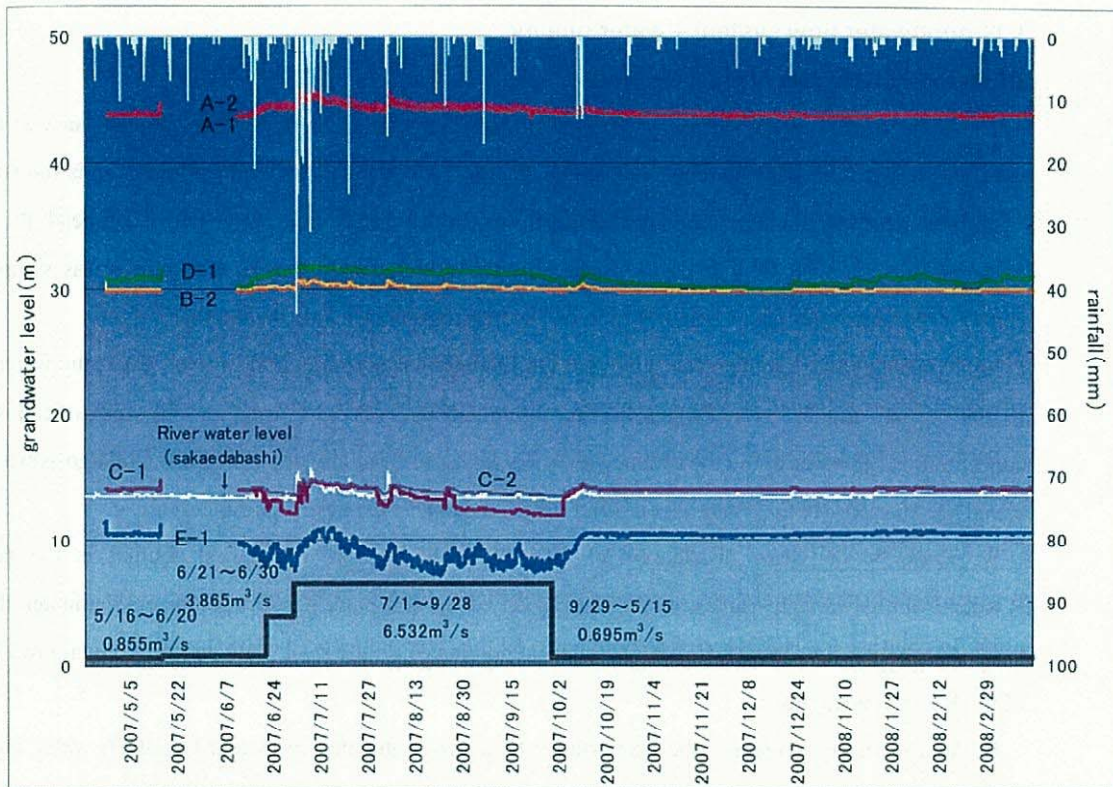


Fig.9a Fluctuation in groundwater level (right bank of R.Koishiwara-gawa)

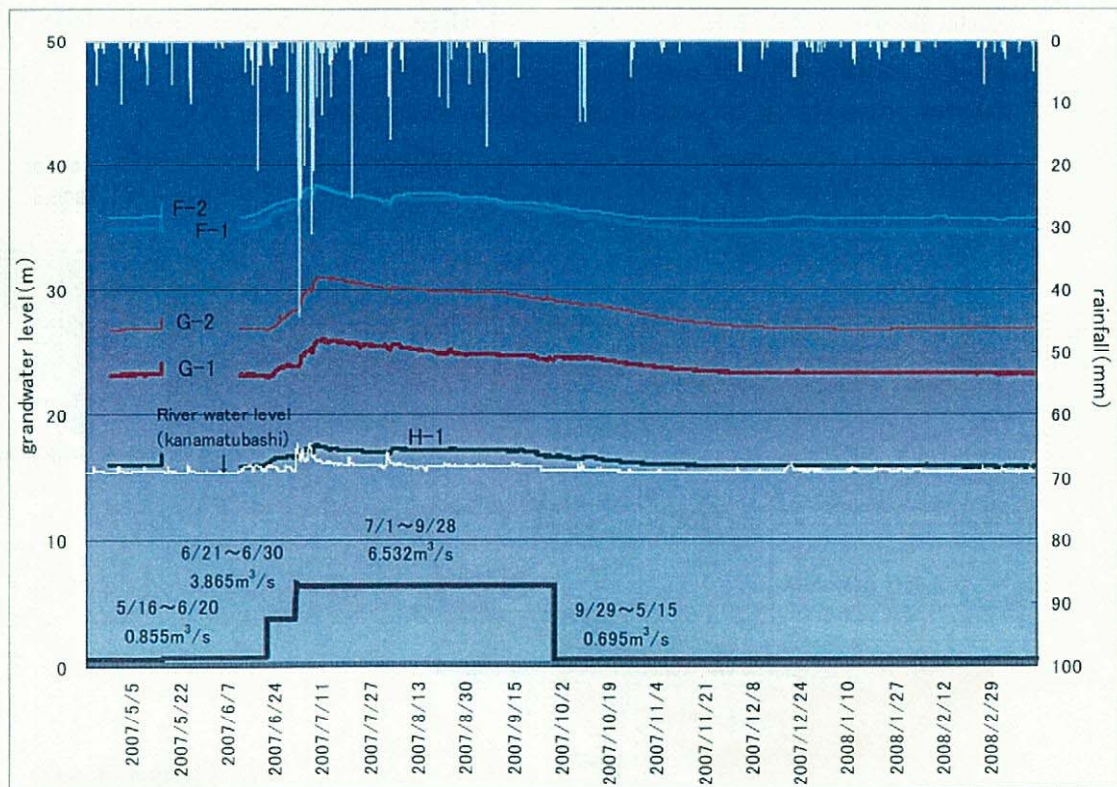


Fig.9b Fluctuation in groundwater level (left bank of R.Sata-gawa)

3. Groundwater flow system – water quality

3.1 Hexagonal diagram of main elements

The water quality of the surface water and groundwater that flows through an alluvial fan was analyzed, and seasonal change was considered by a hexagonal diagram. A vertical profile of an alluvial fan is shown in Fig.10.

In the R.Koishiwara-gawa, groundwater quality resembles that of river water on the fan head; the water type is characterized as Ca-HCO₃. On the downstream side, although only the second aquifer was sampled, total ion concentration increases, and Ca and Mg ion concentrations increase near the fan toe.

In the R.Sata-gawa, groundwater quality of the first aquifer resembles that of river water; the water is Ca-HCO₃. In the second aquifer, groundwater quality resembles that of river water on the apex-of-fan side, and ion concentration increases at the toe of fan. The water is Ca-HCO₃ at any point. In the R.Chikugo-gawa lowlands, the water becomes Na-HCO₃. Therefore, a different groundwater flow system is suggested.

According to the plane distribution of the hexagonal diagram in the first aquifer, in the fan toe of the R.Koishiwara-gawa right-bank area and the center of the left-bank, Ca-SO₄ water predominates during periods without irrigation. In contrast, Ca-HCO₃ water predominates on the river plain and the R.Sata-gawa left-bank area of the R.Koishiwara-gawa.

In August during irrigation, the proportion of Ca-SO₄ water decreases and Ca-HCO₃ water increases at the right-bank fan toe and the left-bank center of the alluvial fan of the R.Koishiwara-gawa. This observation reflects the permeation underground of irrigation water (river water).

On the flood plain of the R.Koishiwara-gawa and left bank of the R.Sata-gawa, seasonal change of water quality is minor, it is the Ca-HCO₃ type every year.

From these observations, we assume that river water recharges groundwater each year.

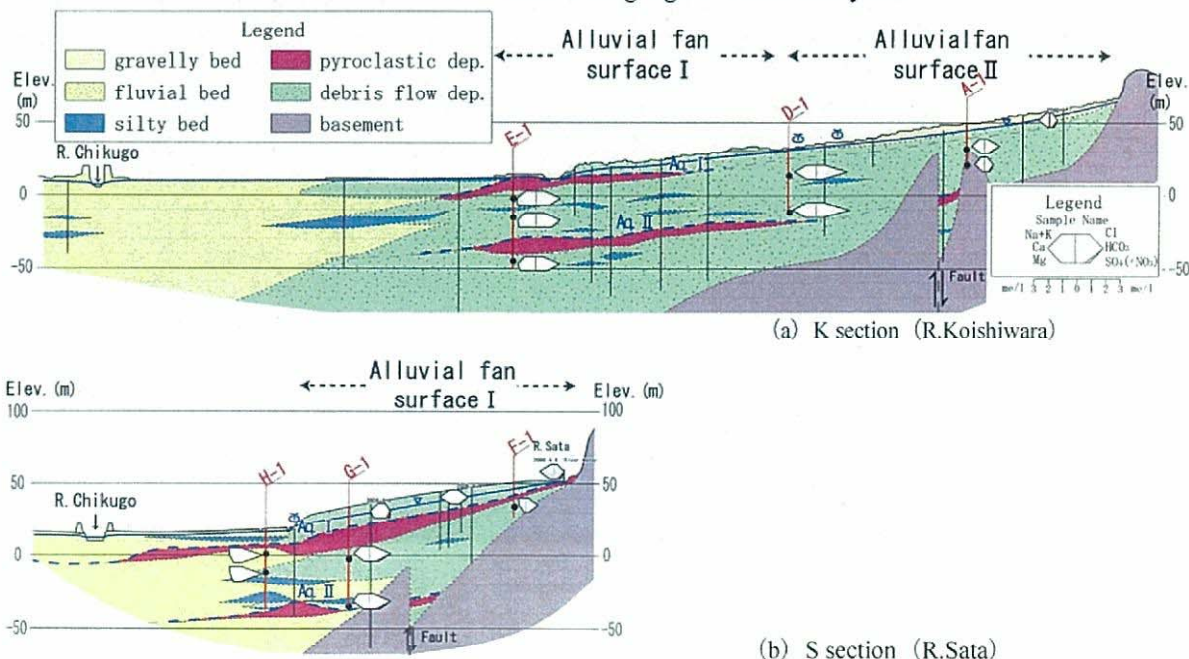
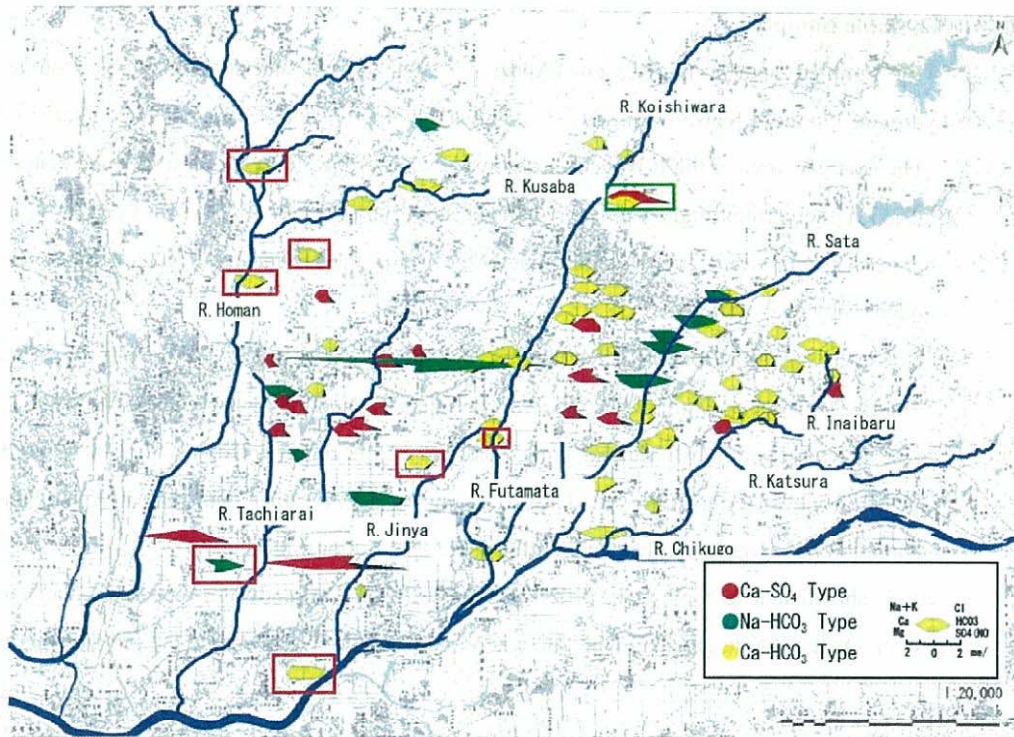
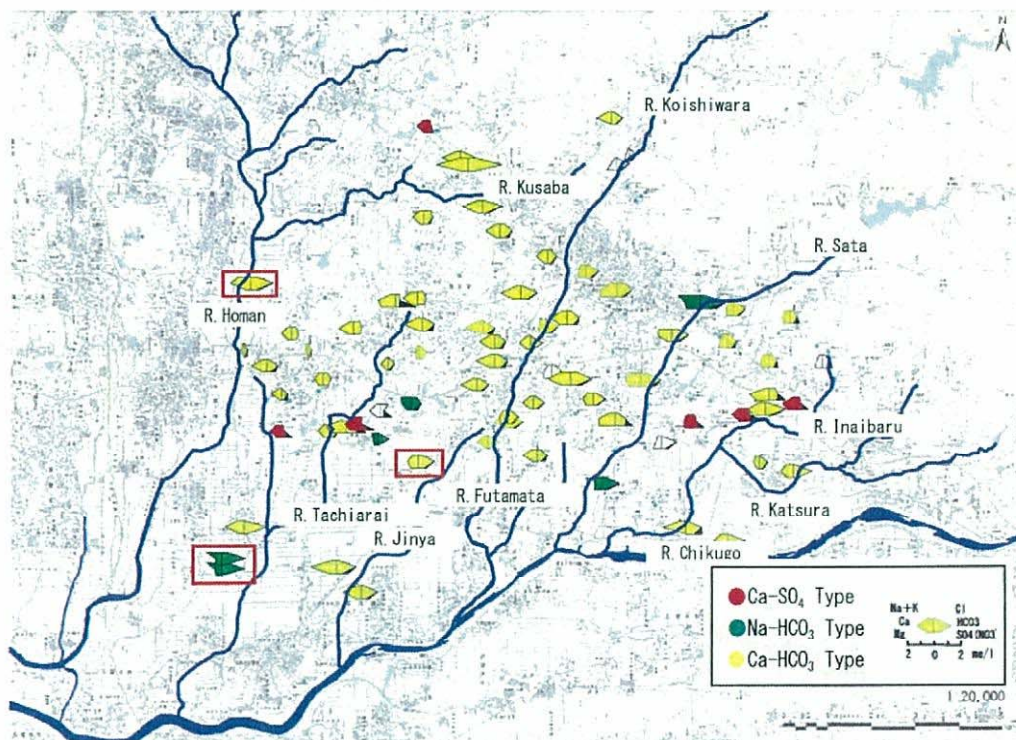


Fig.10 Geological profile and hexagonal diagram



(a) April, 2006



(b) August, 2006

* Yellowish green indicates a basement rock and red extent is a release about the water quality of the second aquifer

Fig.11 Distribution of hexagonal diagram

3.2 Stable isotopes

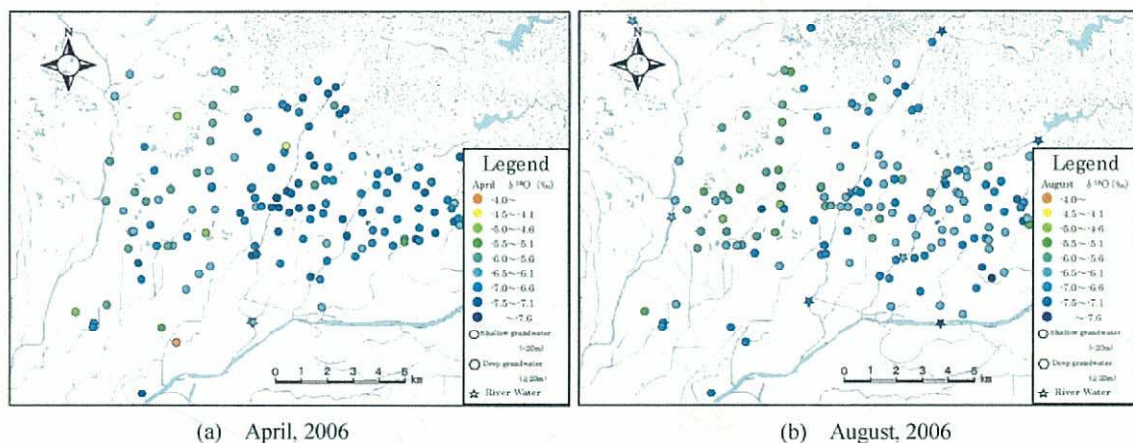
We sampled water in two seasons (April and August 2006), and analyzed stable isotope ratios of oxygen and hydrogen. On the R.Koishiwara-gawa, Oxygen and hydrogen isotopes are heavy compared with other area.

The upstream area of the R.Koishiwara-gawa is, on average, 46 m higher in altitude than that of the R.Sata-gawa, and 231 m higher at their highest points. However, no difference was observed in isotopic ratio near the present main channels of both rivers. It is assumed that as the factor, the groundwater recharge after receiving heavy element condenses by evaporation.

However, it is clear from the delta diagram (Fig.13a, b) seasonal influences differ for each catchment area.

On the R.Sata-gawa alluvial fan, the terms do not differ and the regression lines have the almost same slope. But on the R.Koishiwara-gawa alluvial fan, the slopes of the regression lines of both terms differ greatly, and the regression line for August the trend for a leaning to gentle rather than that in April. This result suggests that evaporation has a marked influence on infiltration of irrigation water.

It is shown that isotopic ratio differs significantly in a groundwater-recharge system and groundwater flow system. On the R.Sata-gawa alluvial fan, it is proved that the river recharge the groundwater through the year.



* A measuring object is mainly a groundwater of the first aquifer.

Fig.12 Seasonal difference in oxygen isotope ratio

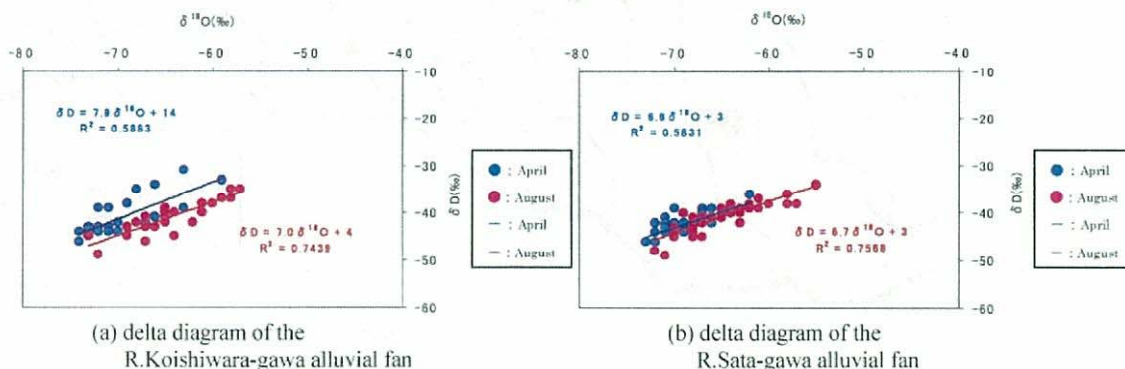


Fig.13 Seasonal change in delta diagram

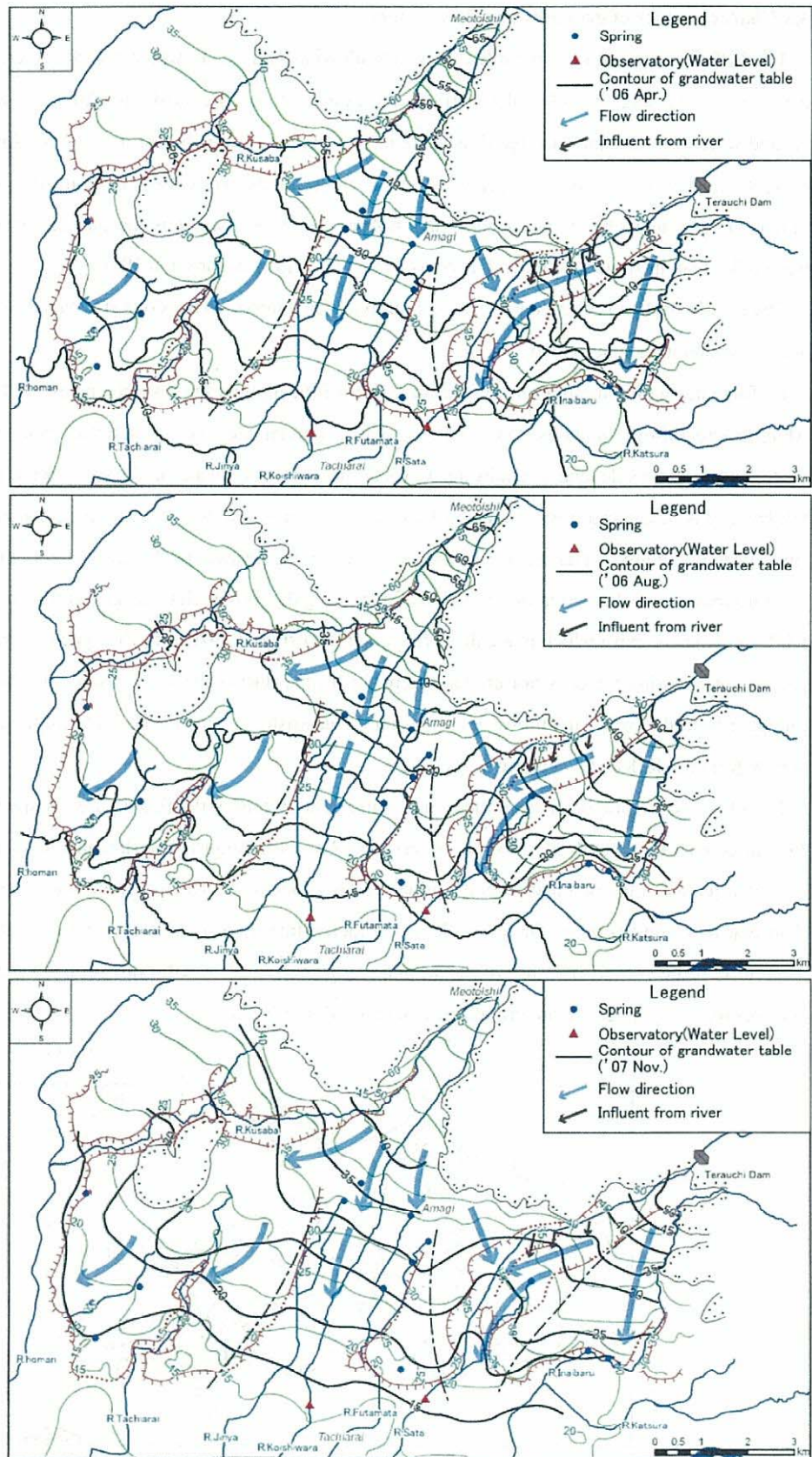


Fig.14b Flow direction of groundwater (April, August, 2006, November, 2007)

4. Conclusion

Mean annual precipitation of the study area is 1,870 mm (range 980-2,870 mm). The precipitation is concentrated in June to July, and water shortage occurs once in every 10-15 year intervals. The dependence on groundwater is high during drought.

Decreases in streamflow in an alluvial fan are caused by a "Segire". This natural phenomenon has important implications for a groundwater recharge. "Segire" occurred before a dam and an irrigation network were construction.

The water level of the first aquifer is always higher than that of the second aquifer. In areas lacking Aso-4, groundwater is always supplied from the first to the second aquifer. As a result of an increase in ricefields after the development of irrigation networks, water recharge from a ricefield is large during the irrigation season. Pumping from wells to compensate for water shortage during drought has strongly influenced groundwater level.

The profile of groundwater table is similar during periods of irrigation or no irrigation, and also little change is observed in the groundwater flow system.

In an alluvial fan, groundwater is recharged from the river or from upstream area. By the time groundwater arrives at the fan toe, some groundwater will have returned to the river. However, most groundwater passes through an alluvial fan and supplies the lowland of the R.Chikugo-gawa.

Acknowledgements

The authors wish to thank all the parties concerned with Chikugogawa River Office, Kyusyu Regional Development Bureau, MLIT, Ryouchiku plain Water-for synthesis place of business, JWA and Ryouchiku Land use office, Fukuoka Prefecture. They helped with observation of core samples, analysis of the results of the permeability tests and a survey of the inspection wells, for the study of the water environment of the R. Chikugo-gawa alluvial fan.

Bibliography

- Amakata, M. et al. (2006) : Investigation and Research for Qualitative Understanding of Ground Water Trend in the Ryoichiku Plain. *Journal of Japan Society of Hydrology and Water Resources*, 19(1), 61-66.
- Amakata, M. et al. (2006) : Dam Engineering, No.234, 43-54.
- Compilation commission of the history of Amagi (1982) : The history of Amagi, First volume.
- Fukuoka Prefectural Sabo Association. (2005) : 1:150,000 Geological map of Fukuoka Prefecture.
- Matsumoto, T., Miyazaki, S., Oishi, A., Research Group on Hydro-environment Around Alluvial Fans (2006) : Study of Alluvial Fan (part 7) Geomorphology and Geology of Alluvial Fans in the Chikugo Area. *Proceedings of Meeting, Japan Society of Engineering Geology*, 153-156.
- Hasegawa, S., Takada, K., Shimada, J., Shimoosako, H., Research Group on Hydro-environment Around Alluvial Fans (2006) : Study of Alluvial Fan (Part 8) The Groundwater Flow System in Alluvial Fan, Chikugo Area (Preliminary Report). *Proceedings of Meeting, Japan Society of Engineering Geology*, 157-160.

- Kuroda, K., Kuroki, T., Kagashima, S. (2004) : Development of Terrace at the Northern Part of Kitano Plain after Aso 4 Pyroclastic Flow Deposition. Program and Abstracts, *Japan Association for Quaternary Research*, **34**, 111-112.
- Kuroda, K., Kuroki, T. (2004) : Landform Development at the Northern Part of Kitano Plain after Aso 4 Pyroclastic Flow Deposition. *Proceedings of the General Meeting of the Association of Japanese Geographers*, **65**, 81-81.
- Kuroki, T., Kuroda, K., Nakamura, Y. (2003) : Relationships between Characteristics of the 1953 Flood Disaster and Microtopography in the Kitano Plain. *Proceedings of Meeting, Japan Society of Engineering Geology*, 267-270.

The Water Balance of Chikugo-gawa Alluvial Fan And Future Forecast Using the Numerical Simulation Model

KOHARA Naoki* · HASEGAWA Satoshi** · YANAGIDA Mitsunori* · SHIMOOSAKO Hiroshi**

Abstract

The past and future changes of the groundwater environment of the R. *Chikugo-gawa* fan in the southern part of Fukuoka Prefecture, was estimated and forecasted respectively using a numerical simulation model. This study is accomplished through three steps. For the first step, the long-term meteorological and hydrological data was collected and analyzed to generally understand the outline of the hydrological environment in the concerned area. When the hydro-geological structure projected from the result of in-situ geological survey was deemed acceptable, the situation of the groundwater flow is analyzed and/or clarified considering the distribution and variation with time of the hydraulic potential.

As a second step, the amounts of groundwater recharges in the paddy field, non-paddy field (such as a dry field or a vacant lot excluding those in the urban area), and urban areas, were estimated using tank models. Finally, as a third step, three-dimensional groundwater flow models were generated based on the hydro-geological structure and amount of groundwater recharges obtained from the first step and second step, respectively. Moreover, using the simulation model, the past to present situations of groundwater environment were analyzed, as well as its projected change in the future.

The simulation model was constructed through validation of information from the last 5 years (until 2007), which includes extensive in-situ data on groundwater. The model was also utilized to simulate the observed groundwater potential head under the land use of 1961, which was the period prior to the consolidation of large farm lands. With due consideration to land use changes such as the decrease in paddy field area and increase in urban area, the past to present transformation of the groundwater environment was estimated. Furthermore, it was also identified how the groundwater environment would be affected by global warming, considering its relationship with temperature increase and change in rainfall patterns. Meanwhile, it was assumed in this paper that the hydrological reference years from 1957-1961 was used to compare the present and future conditions, based on the analysis results of past annual rainfall data, and the hydro-geological condition during said period.

KEYWORDS : fans, global warming, urbanization, water balance, groundwater flow simulation

1. Introduction

The *Chikugo-gawa* fan, the study area covered in this research, lies in the south of Fukuoka Prefecture, and is well-known as an area with abundant groundwater, mainly from river water sources (Riv. *Koishivara-gawa* and *Sata-gawa*). Furthermore, as this area is also a long-standing paddy field, the recharge of irrigation water remains an important groundwater supply origin. Based on the standpoint of hydrological environmental change, it is essential

* Nippon Koei Co., Ltd., ** Yachiyo Engineering Co., Ltd.

to understand the influences brought by land use changes. Land use changes mean (1) the large paddy field improvement as farm land consolidation, along with the high economic growth after the 1960s, and (2) the recent decrease of the paddy fields due to urbanization (e.g. in *Amagi-City* etc.).

On the other hand, as mentioned in the IPCC Fourth Assessment Report, global warming has steadily been progressing at present, and the study area is also subjected to this similar phenomenon. Since it is considered that global warming causes the increase of the amount of evapotranspiration and changes in the hourly to daily rainfall patterns, the authors estimated and forecasted using the numerical simulation model, how the groundwater environment had been affected in the past and would change in the future.

2. The flow of Research

As shown in Fig.1, the study flow based on the in-situ data analysis through the numerical model simulation is divided into three parts as follows, with the third part divided further into three sub-parts :

- 1) Collection, arrangement and analysis of the in-situ data
- 2) Estimation of groundwater recharges using the “tank model” method
- 3) Numerical simulation adopting the three-dimensional groundwater flow model
 - (1) Construction of the numerical model
 - (2) Validation of the model constructed
 - (3) Estimation and prediction of the past, present and/or future hydro-geological environment using the calibrated model

The estimation and prediction were carried out based on the change of the land use pattern and/or the meteorological condition. The land use patterns were obtained from the national numerical information published by the National-Land Information Office, and the meteorological data consisting of the past and/or the predicted future data called RCM20, published by the Japan Meteorological Agency.

3. The meteorological and hydrological data analysis

The meteorological and hydrological data around the *Chikugo-gawa* fan are shown on Fig.2 and Table 1, respectively. In this paper, these data were collected and arranged systematically to construct the groundwater flow model.

3.1 Meteorological data

(1) 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. According to the figure, annual rainfall does not clearly show upward and/or downward trends, however, it revealed years of remarkable drought and rains that frequently occurred especially during the last 30 years. This tendency, as indicated in Fig.3, is also similar to the rainfall data from *Asakura* meteorological gauging station.

The distribution of the non-exceedance probability for the past rainfall data was examined, and the corresponding results are shown on Fig.4. According to this figure, the two-year rainfall (where the non-exceedance probability is 50%) and the ten-drought year rainfall (where the non-exceedance probability is 10%) are 1,820 mm/y and 1,380 mm/y, respectively. The observed annual data of the last five years from 2003 to 2007 depart from the two-year rainfall, which is approximately equal to the average annual rainfall. This fact coincides with the high frequency of extreme drought and rainy years.

In the case of RCM20, the large amount of rainfall will appear after 50 years. On the other hand, the annual amount of rainfall after 100 years appears to be almost the same as the present average rates.

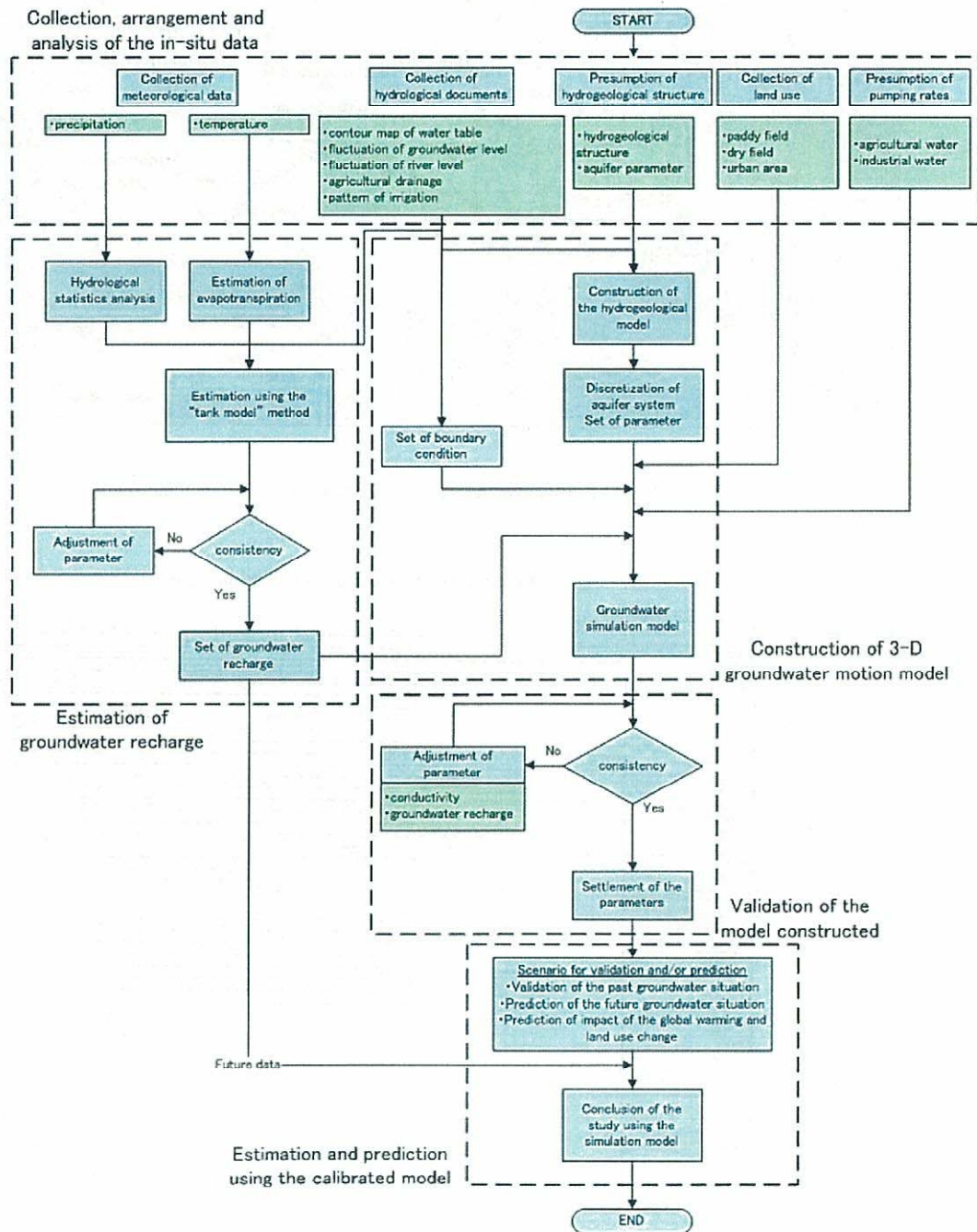


Fig.1 The flow of research

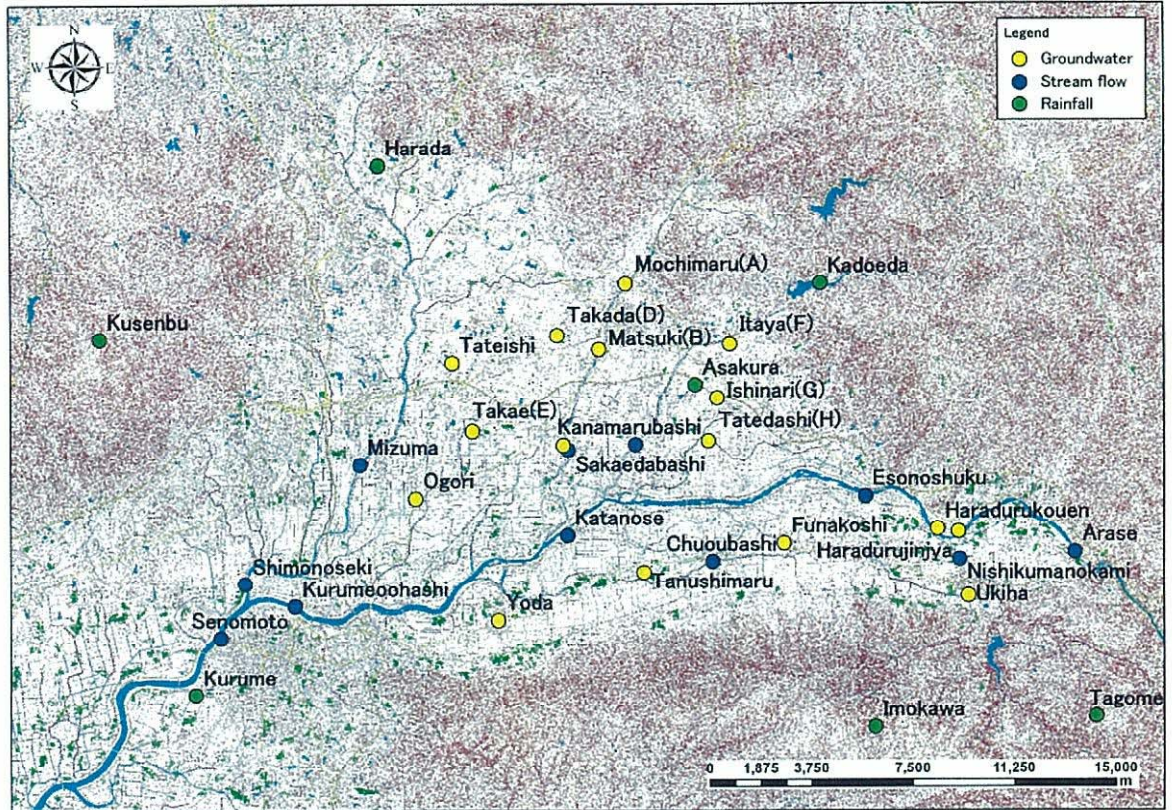


Fig.2 Locations of meteorological and hydrological gauging stations

Table 1 Observed meteorological and hydrological data

Year	Before 1890	1890~1950	1951~1970	1971~1990	1991~1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Rainfall	Kurume	Nov.1890	Jan.1976											
	Asakura													
	Sara													
	Harada	Apr.1952												Apr.2008
	Kadoeda	Feb.1938												
	Kusenbu			Apr.1971	Mar.1934									Jul.2007
	Imokawa													
	Tagome													
Temperature	Asakura			Mar.1977										
	Kurume													
River level and/or River flow	Sara	Aug.1890	Jan.1970											Apr.2008
	Arase	Jan.1955												
	Esonoshuku													
	Katanose													
	Senomoto	Jan.1950												
	Nishikumanokami			Apr.1965										Mar.2007
	Kanamarubashi			Apr.1964										
	Sakaedabashi			Apr.1968										
Simultaneous measuring of river flow	Chuoobashi			Apr.1960										
	Mizuma													
	Shimonoseki													
	Kurumeohashi													
	R Koishinara,R Kuraha,R Sata				Apr.1977									
	R Tachiarai,R Nihara,R Katsura					Apr.2002								
	(Tateishi/shallow)													
	(Ogori/shallow)													
	(Oguri/deep)													
	(Yoda/shallow)													
groundwater level	Tanushimaru(deep)													
	Hunakoshi/shallow)													
	(Ushida/deep)				Apr.1976									
	Harakurubasumi													
	Haradurujinya													
	Mochimaru				Apr.1975									
	Matsuki									Dec.2004				
	Nakabata													
	Tanaka													
	Tsukuba													
water table	Previous investigation result			Mar.1990									Apr.2007	Mar.2008
	Simultaneous measuring of groundwater level			1961							Apr.2005	Aug.2006	Nov.25.2007	
spring water	Survey of spring water												Nov.25.2007	

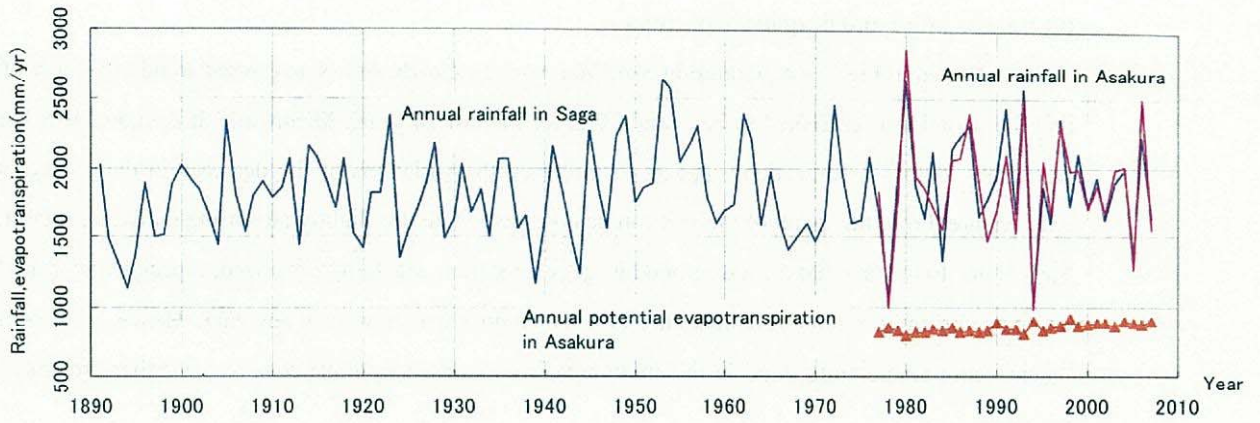


Fig.3 Long-term trend of rain

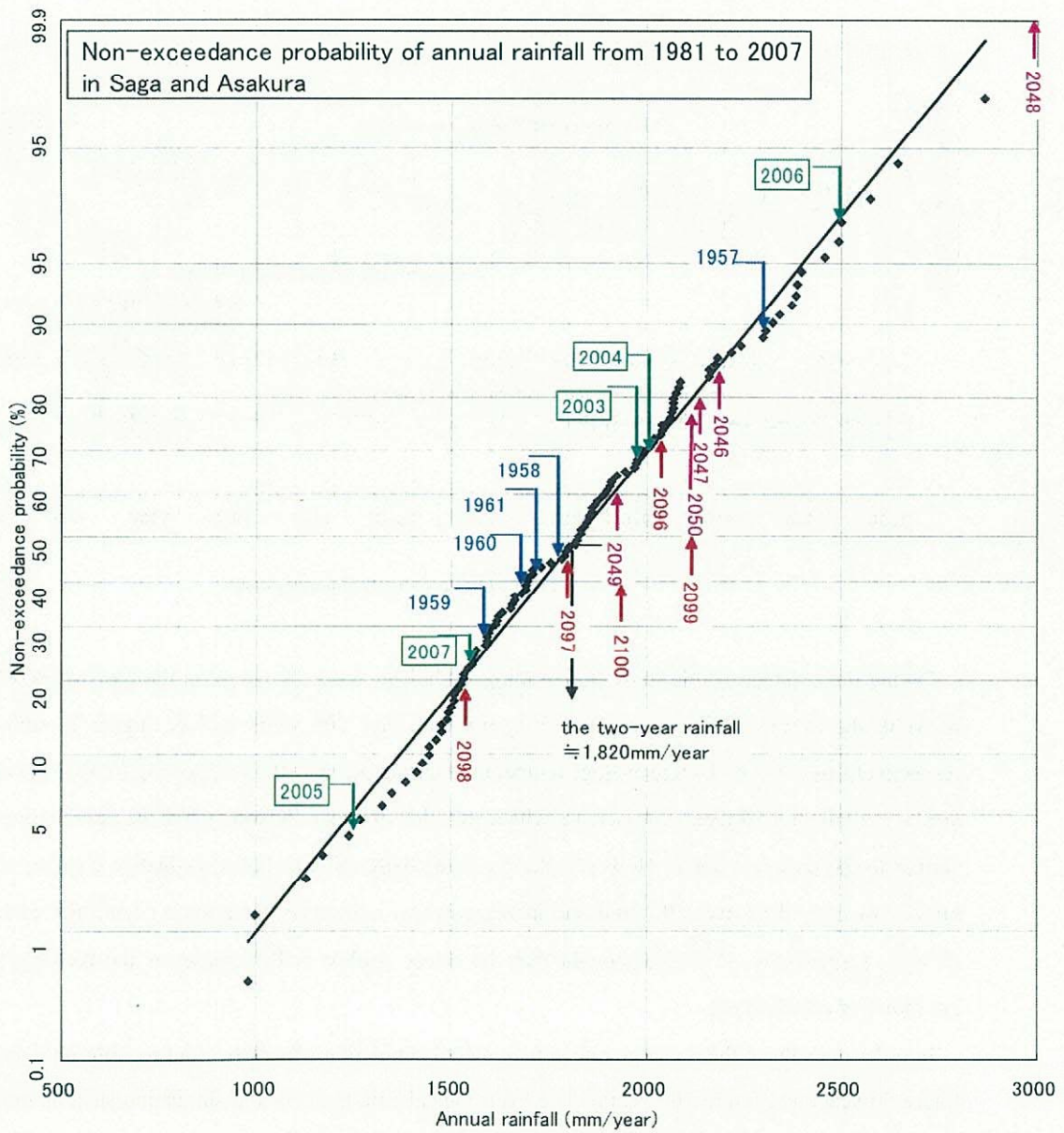


Fig.4 Statistical analysis results based on annual rainfall in Saga and Asakura

(2) Temperature and evapotranspiration

As indicated in Fig.5, temperature in Saga and *Asakura* clearly shows an upward trend especially after the 1950s, and the variation is estimated to be about 1.0°C for the last 20 years. Meanwhile, it is known that land use change (especially due to urbanization) appears to influence the variations of the decrease in daily maximum/minimum temperature. From this point of view, it can be considered that the slightly increasing daily minimum temperature in Saga is due to the fact that the area around its gauging station was fairly urbanized, especially after the 1980s. On the contrary, the daily minimum temperature in *Asakura* does not show such tendency. Hence, it is concluded that the recent warm temperature trend in the study area is not caused by urbanization, but rather probably due to global warming.

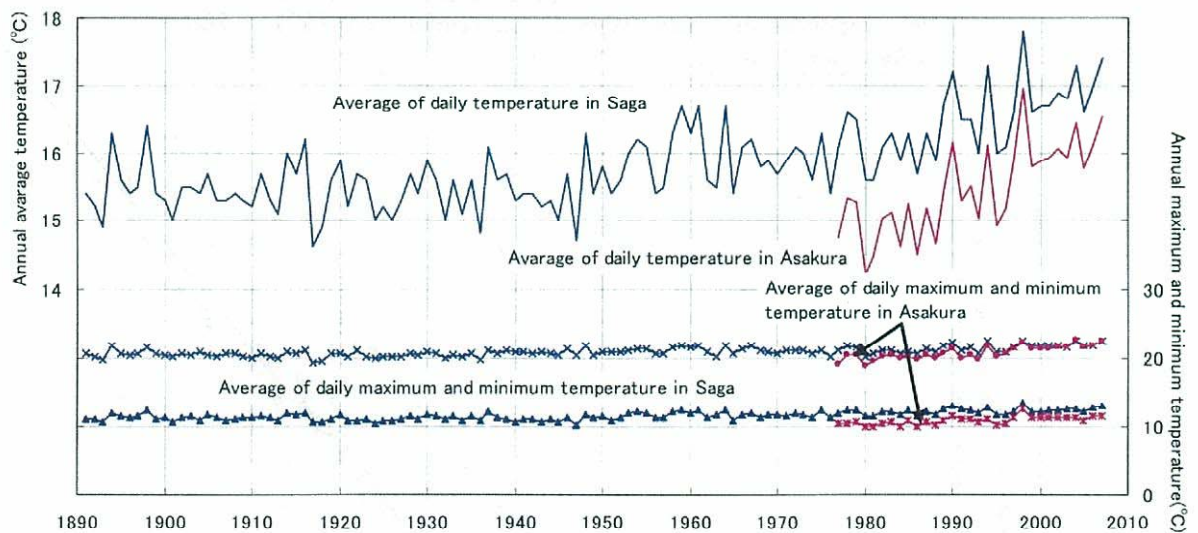


Fig.5 Long-term trend of temperature

During the conduct of this study, future climate changes were discussed on the basis of RCM20. According to RCM20, the average temperature after 50 years and after 100 years will be higher by about 1°C, and 2°C, respectively, as compared to the average temperature during the last 70 years (see Fig.6). RCM20 also shows that the annual rainfall after 50 years will increase with a variation of about 400 mm, while the rainfall after 100 years will be similar to the present amount. However, the predicted daily rainfall shows qualitative changes such as increase in number of rainy days over 50 mm/d and increase in non-rainy days, suggesting occurrence of frequent flood and drought, respectively. It is also thought that the direct outflow will increase, as the recharge decreases for the groundwater environment.

In order to evaluate the recharge rate, a tank model simulation was carried out for four periods (i.e. past, present, future 50-years and future 100-years). The hydrological data used for the simulation such as rainfall and potential evapotranspiration, are shown in Table 2. Potential evapotranspiration, calculated using the empirical equation suggested by *Hamon*, increases yearly, in accordance with the increasing temperature.

Since the annual rainfalls of five years from the "Past" period is close to the two-year rainfall, it was decided that the rainfall pattern from said period, especially that of 1961, will be used for comparison with the "Present" hydrogeological environment. Meanwhile, rainfall patterns of 2049 and 2097 were used to compare the "Present" and "Future" hydrogeological environment.

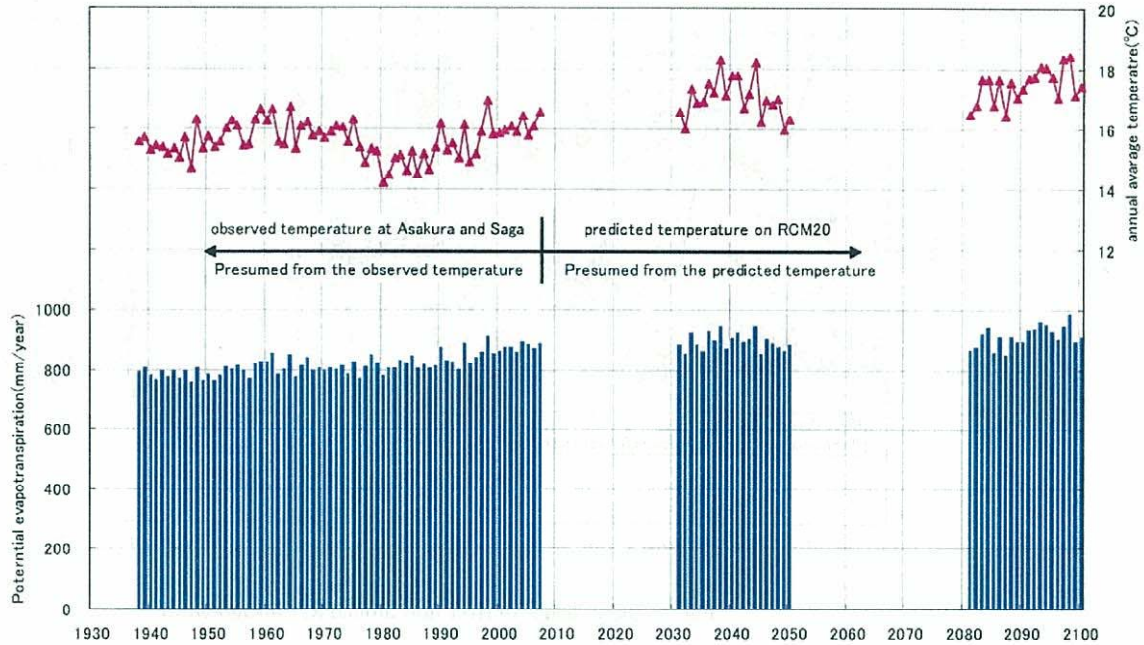


Fig.6 Past and future climate change

3.2 Hydrological data

(1) River level and river flow rate

There are eleven gauging stations measuring the river flow rate and level in the main stream and tributaries of the R. *Cikugo-gawa*, as shown on Fig.7.

It is considered that the base flows of the tributaries are probably affected by the irrigation water during the period from June to September. Meanwhile, the base flow in the main stream can be considered unaffected due to the large river flow rate, in comparison with the irrigation volume.

Fig.8 shows the flow duration curve at the *Senomoto* gauging station, the most downstream observation point in the main stream within the study area, that has acquired long-term observation data. While it is evident that urbanization influences the change of flow duration, such change is not recognizable from Fig.8. Thus, it can be concluded that urbanization hardly progressed in this study area.

Table 2 Rainfall, temperature, available evapotranspiration in each period

Case	Year	Rainfall (mm/year)	Temperature (°C)	evaporation (mm/year)
Past	1957	2,306	15.5	775
	1958	1,788	16.3	822
	1959	1,595	16.7	830
	1960	1,690	16.3	830
	1961	1,730	16.7	857
	Ave.	1,822	16.3	823
Present	2003	1,984	15.9	860
	2004	2,007	16.4	896
	2005	1,265	15.8	885
	2006	2,499	16.1	874
	2007	1,551	16.5	892
	Ave.	1,861	16.2	881
Future 50-years	2046	2,194	17.0	903
	2047	2,133	16.8	890
	2048	2,979	17.0	877
	2049	1,934	16.0	864
	2050	2,115	16.3	886
	Ave.	2,271	16.6	884
Future 100-year	2096	2,055	17.1	906
	2097	1,829	18.3	947
	2098	1,511	18.4	988
	2099	2,156	17.1	896
	2100	1,906	17.4	912
	Ave.	1,891	17.7	930

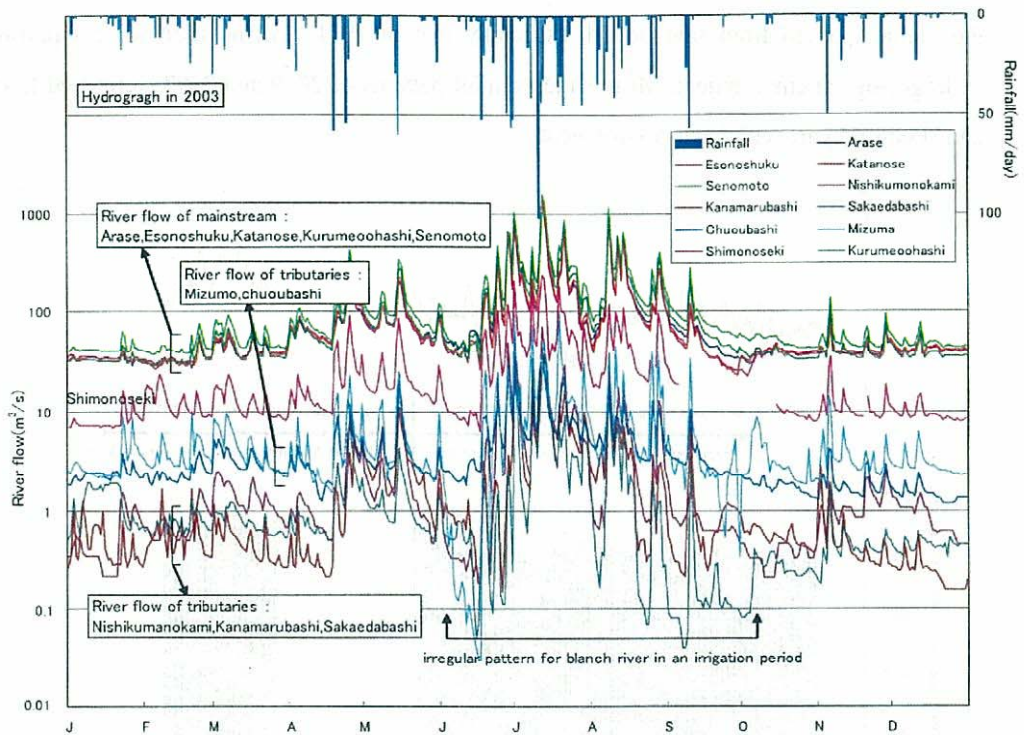


Fig.7 Timely change of river flow around R. Chikugo-gawa

(2) Water balance of river channel

The result of simultaneous runoff measurements carried out in November 25, 2007 shows that each tributary has irregular recharge and discharge sections as indicated in Fig.9. Specifically, *Koishihara-gawa* has a long recharge section in its middle reach.

(3) Groundwater level

Fig.10 shows the result of simultaneous groundwater level measurements carried out in November 25, 2007. Groundwater table contours indicate that the groundwater flows from northeast to southwest. Since concave portion is observed at the R.*Sata-gawa*, it is deemed that adjacent groundwater discharges to this river.

On the other hand, there are eight observation stations for continuous groundwater level measure-

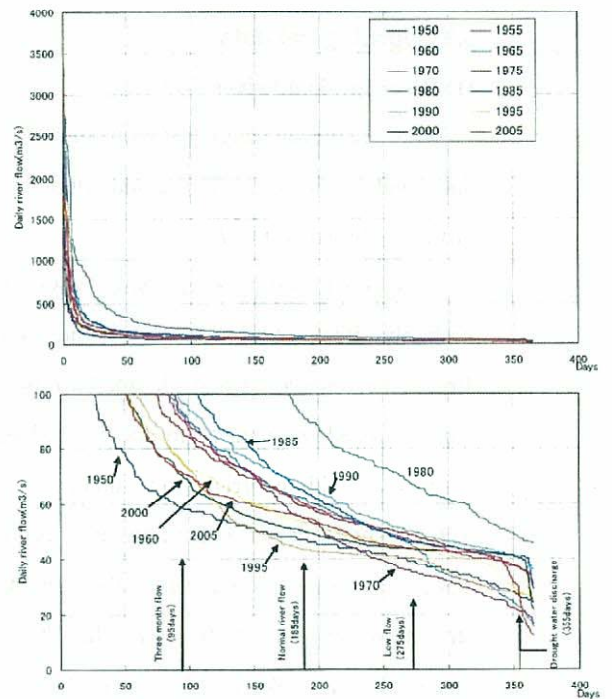


Fig.8 Change of the flow duration in Senomoto

ments, as shown in Fig.11. At *Mochimaru*, *Nakahata*, *Itaya* and *Ishinari* observation stations, two monitoring holes were closely constructed in order to observe both the shallow and deep groundwater levels.

In case of *Nakahata* and *Takahi* observation stations, groundwater level seems largely influenced by the river level change and pumping during the irrigation periods. There are distinct gaps between potential heads of the shallow and deep groundwater at *Itaya* and *Ishinari* observation stations. Potential head of the shallow groundwater is always higher than that of the deep groundwater, thus, it is judged that groundwater flows downwards.

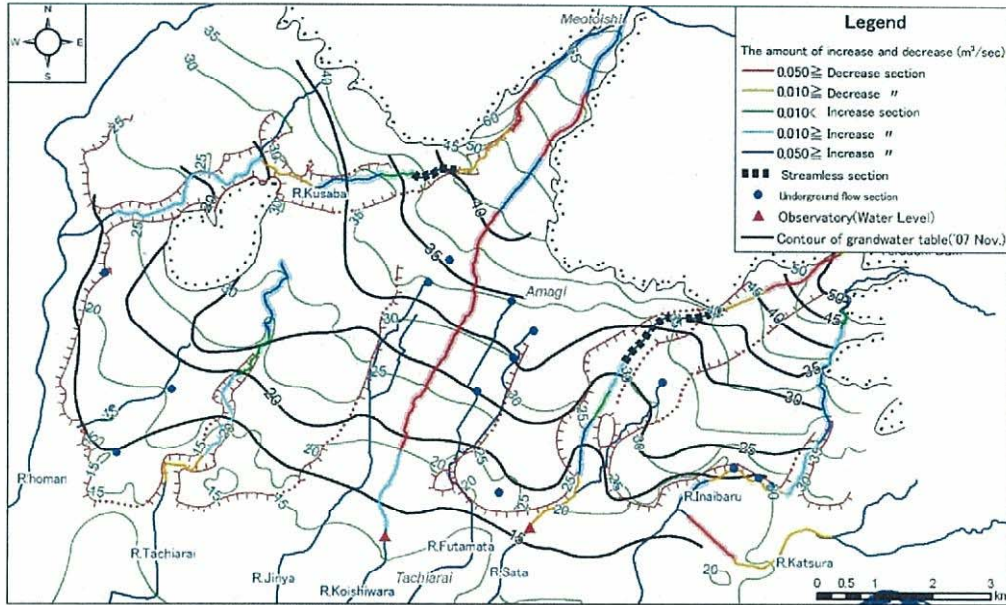


Fig.9 Water balance of river channel

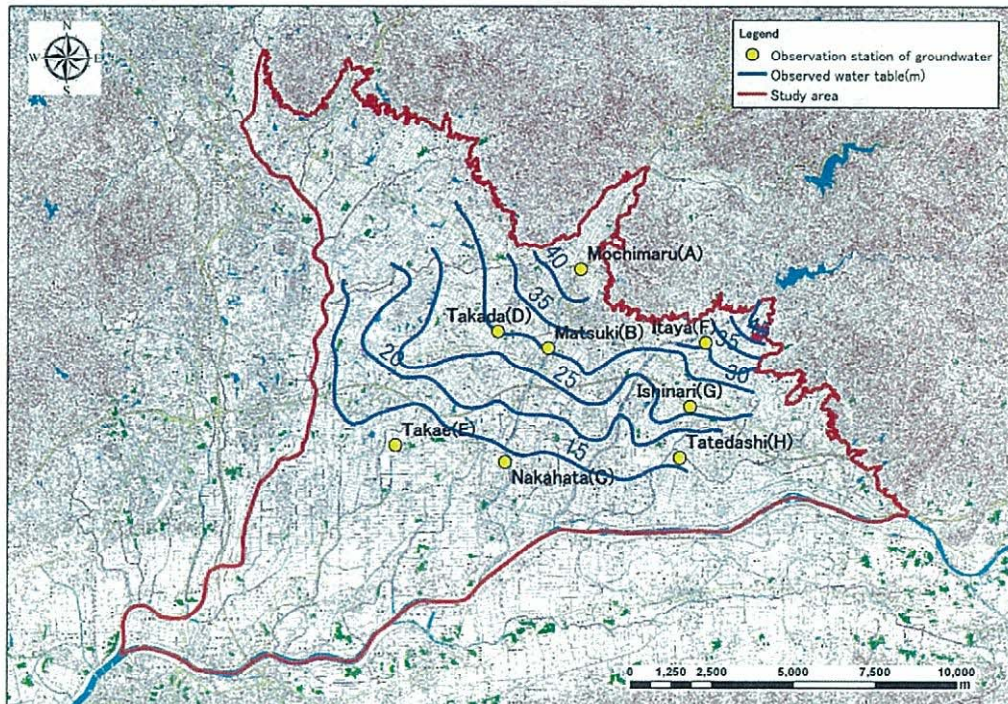


Fig.10 Groundwater table contours

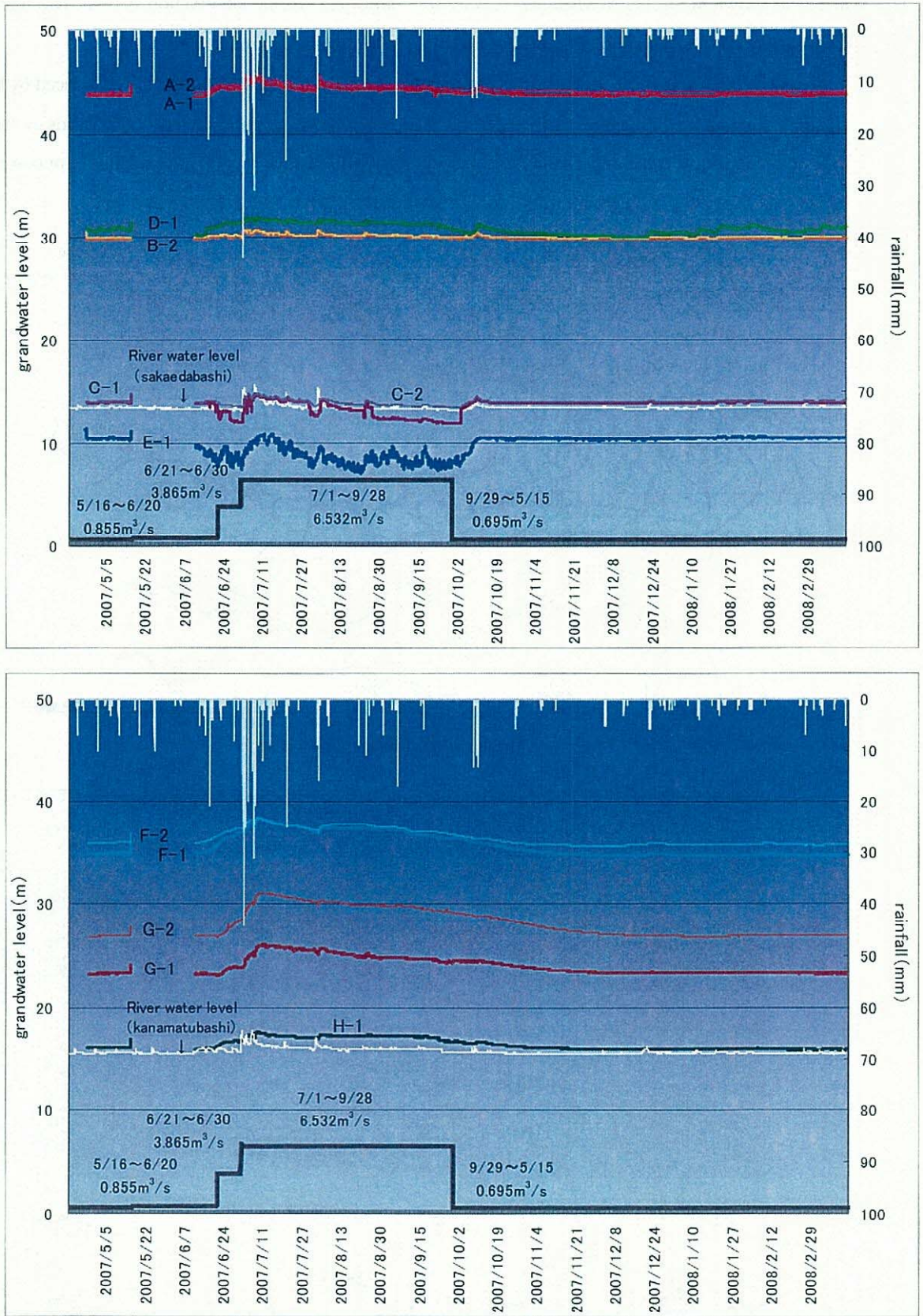


Fig.11 Result of continuous groundwater level measurement (upper: around R. Koishihara-gawa, lower: around R. Sata-gawa)

3.3 Pumping data

The well locations and their pumping rates in the study area had been investigated and reported in the prefectural irrigation pump inventory (2002), as shown on Fig.12. The maximum pumping rates during the irrigation period, amounting to some 470,000 m³/d within the study area (Table 3), were considered for the simulation. According to the inventory, it was found that the ratio in the number of deep wells to the shallow wells is higher in *Tachiarai*-town, where thick aquifer exists.

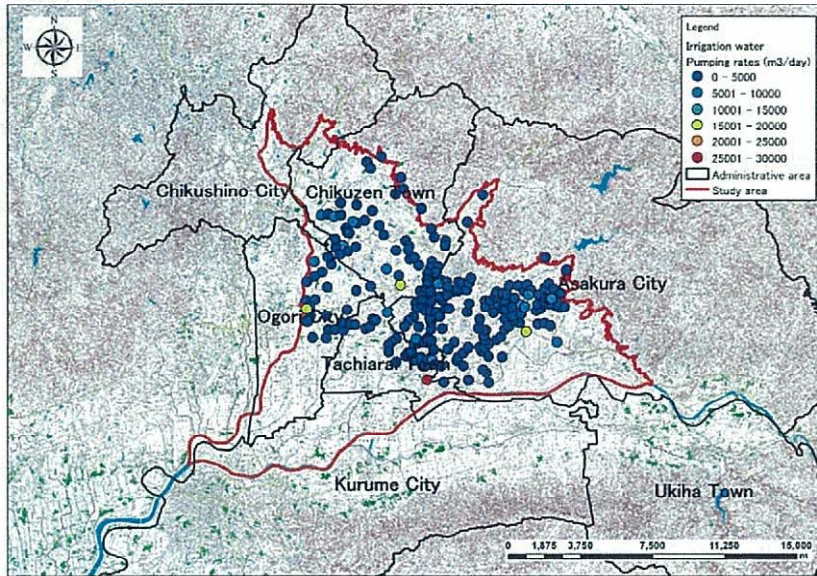


Fig.12 Distribution of irrigation wells

4. Calculation of groundwater recharge

The amount of groundwater recharge was estimated by means of a tank model method for every land use type, namely, paddy field, non-paddy field (including dry fields and vacant lots), and urban area. The procedures can be expressed as follows.

Table 3 Inventory survey result of irrigation wells

Area	The depth type			
	Shallow well		Deep well	
	N	Pumping rates (m ³ /day)	N	Pumping rates (m ³ /day)
T.Chikuzen	30	99,863	8	10,699
C.Asakura	79	227,832	5	6,490
C.Ogori	9	35,880	8	14,943
T.Tachiarai	8	50,511	13	22,747
Summary	126	414,086	34	54,879

4.1 Land use change

Fig.13 illustrates the ratio of land use in 1941, 1976, 1987, 1991 and 1997. Since paddy fields decreased by 5% for 20 years until 1997, while the urban area adversely increased by 5% for the same 20 years, it may be concluded that in the study area, 5% of the paddy fields had been converted to urban areas.

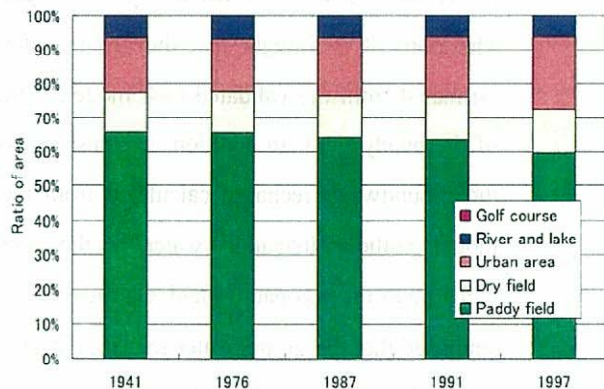


Fig.13 Land use change

The land use data after 1976 were derived from the national numerical information. However, the land use data of 1941 as per Fig.14, published by Geographical Survey Institute, was considered due to the lack of national numerical information data for the land use data on said year.

Table 4 Water depth requirement in a paddy field

Case	Period	Water depth requirement (mm/day)
Pre-irrigation	June 21~June 30	150
Regular irrigation	July 1~September 31	25

4.2 Water depth requirement in a paddy field

Table 4 indicates the water depth requirement in a paddy field proposed by the Japanese Society of Irrigation, Drainage and Rural Engineering, and was used for the tank model simulation for the paddy field.

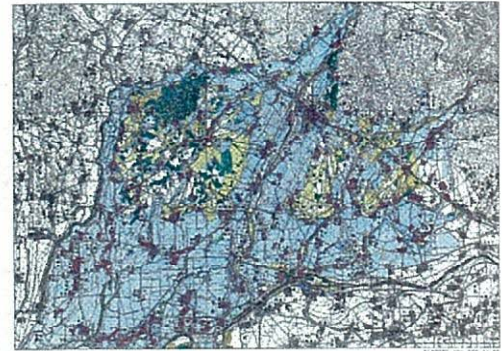


Fig.14 Land use in 1941

4.3 Estimation of groundwater recharges using the Tank Model

The groundwater recharge of each land use type was estimated using the tank model composed of three tanks laid vertically in series, as shown on Fig.15. Each of the tank, namely, the top, second and third tanks, has three outlets on the side and one outlet at the bottom. Outflow from the bottom outlet of the second tank can be assumed as the groundwater recharge in the simulation.

Tank model was validated by determining the R. Chikugo gawa main stream runoff (difference between Katanose and Kurumeoohashi), and the groundwater level fluctuation at the Ogori observation station shown in Fig.16. Ogori observation station is surrounded by a paddy field, and is influenced by the irrigation water. Therefore, it is thought that the groundwater recharge, estimated from the validated tank model, is the recharge of the paddy field. In addition, it is also considered that the groundwater recharge calculated from the validated model without irrigation water is the corresponding recharge of the non-paddy field. On the other hand, it was supposed that the groundwater recharge in the urban area is half the amount of the recharge in the non-paddy field,

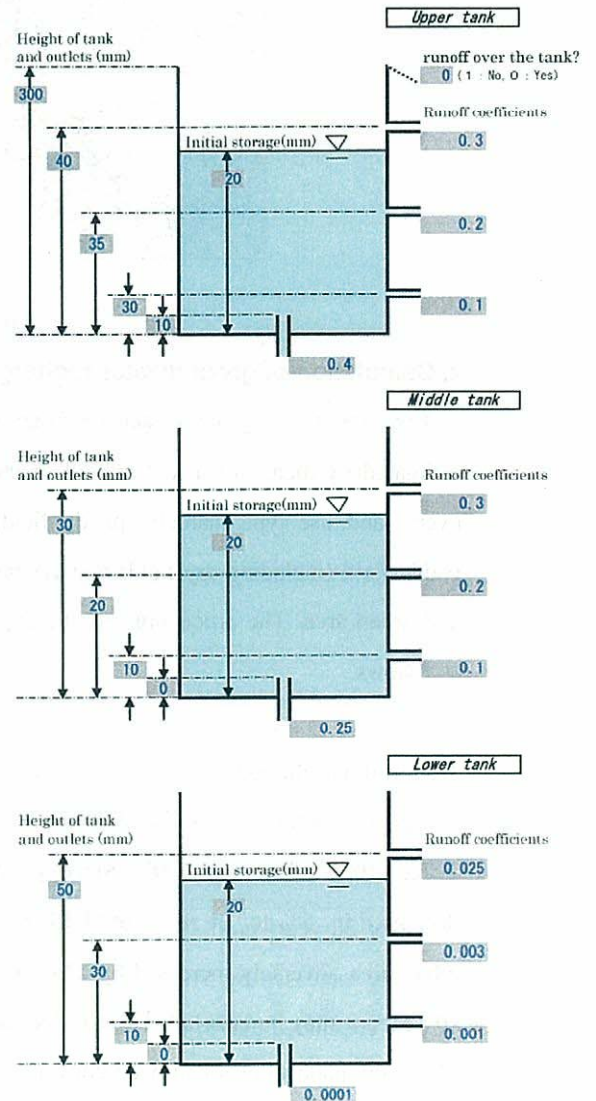


Fig.15 Validated tank model

under the assumption that the infiltration area is half the whole urban area.

Fig.17 shows the calibration result of tank model simulation for the paddy field. The determined groundwater level fluctuation and stream flow approximately coincide with the observed data.

Calculation summary results obtained from all the simulations are shown on the Fig.18 and Table 5.

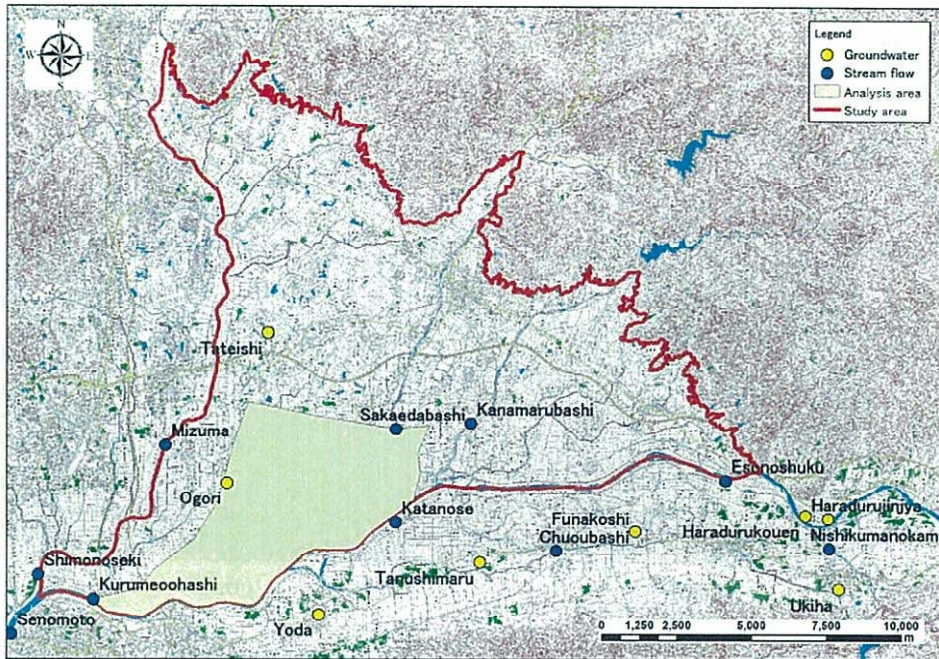


Fig.16 Analysis area and groundwater gauging stations used for the tank model simulation

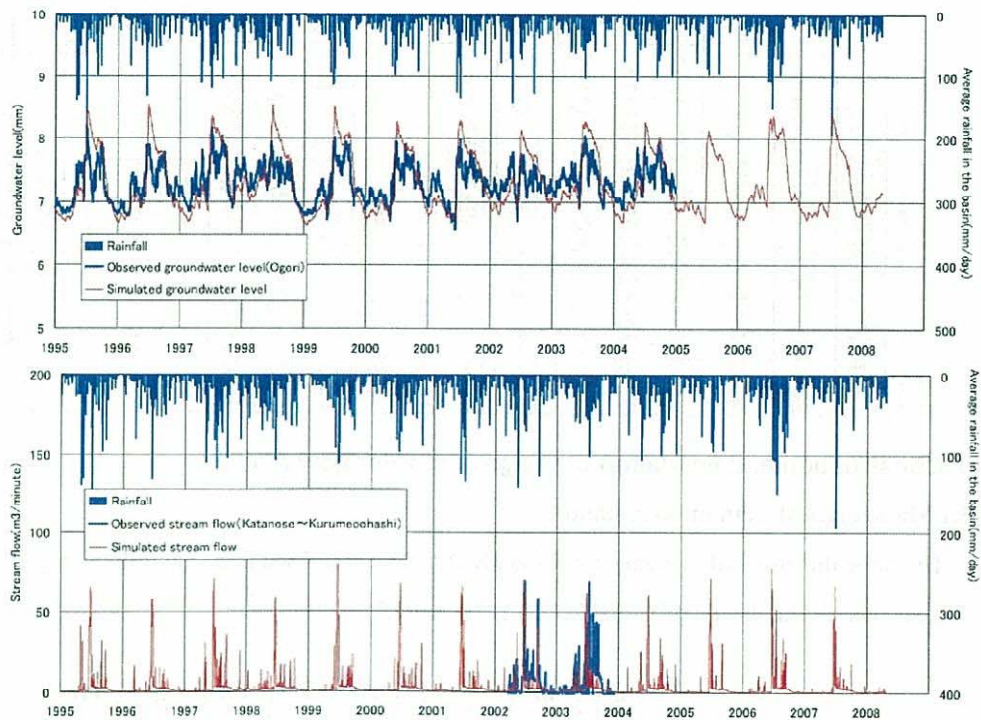


Fig.17 Validation result of the tank model simulation

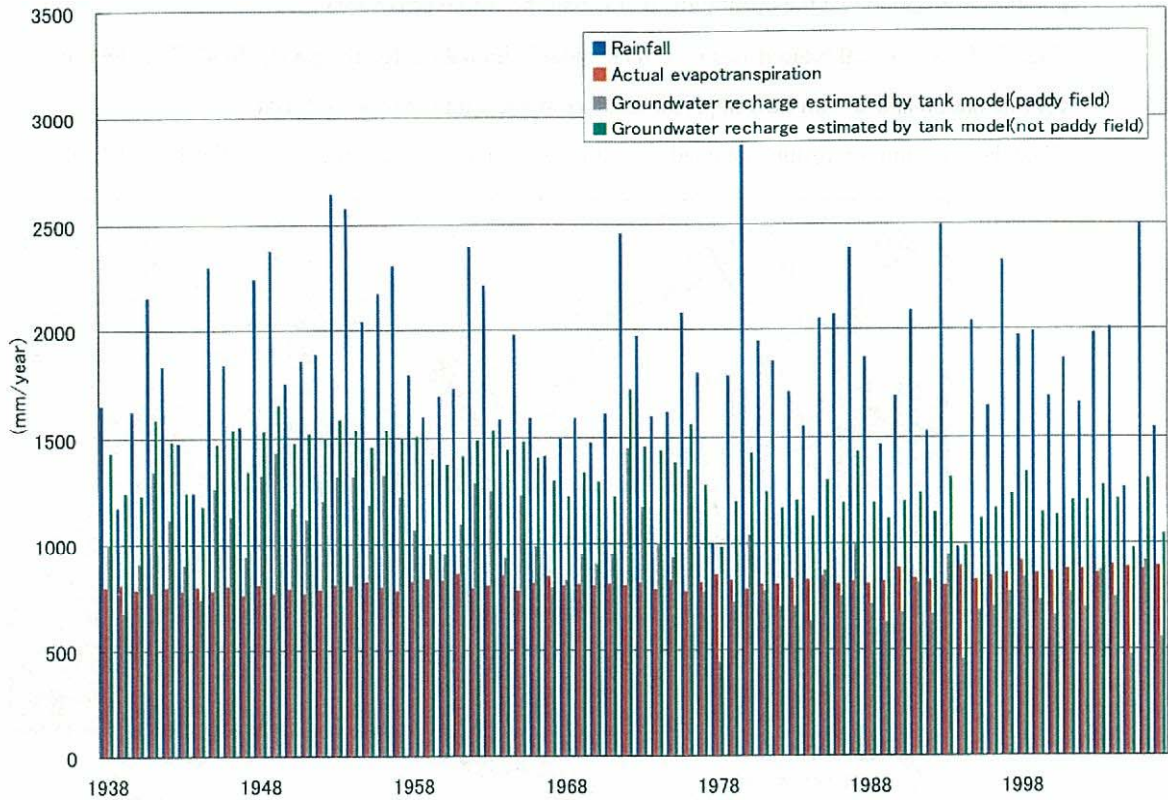


Fig.18 Annual groundwater recharge evaluated by the tank model simulation

Table 5 Summary of the tank model simulation

Case	Year	Rainfall (mm/year)	Potential evapo- transpiration (mm/year)	Actual evapo- transpiration (mm/year)			Irrigation water (mm/year)	Surface,subsurface flow(mm/year)			Base flow(mm/year)			Run-off(mm/year)			Error of Water balance (%)	Groundwater recharge(mm/year)			
				Paddy field	Dry field	Urban area		Paddy field	Dry field	Urban area	Paddy field	Dry field	Urban area	Paddy field	Dry field	Urban area		Paddy field	Dry field	Urban area	From irrigation
Past	1957	2,306	775	555	440	452	1,510	1,753	641	782	1,447	1,168	584	7	5	3	0	1,448	1,125	562	321
	1958	1,788	822	581	424	459	1,636	1,397	302	508	1,489	1,050	525	7	5	3	0	1,458	1,018	509	440
	1959	1,585	830	586	471	485	1,661	1,272	171	404	1,407	954	482	7	5	2	0	1,403	900	450	503
	1960	1,650	830	586	457	478	1,667	1,406	285	485	1,406	975	488	6	5	3	0	1,363	942	471	421
	1961	1,730	857	601	486	500	1,568	1,282	153	422	1,373	1,051	526	6	6	3	0	1,439	1,155	578	283
	Average	1,822	823	582	456	475	1,621	1,422	312	570	1,425	1,041	521	7	5	3	0	1,422	1,028	514	394
Present	2000	1,984	860	571	494	505	1,791	1,935	921	707	1,279	346	173	6	5	2	0	1,272	871	435	400
	2004	2,007	896	658	547	542	1,848	1,978	703	753	1,295	252	146	6	4	2	0	1,207	743	371	464
	2005	1,765	895	619	416	473	1,904	1,585	391	449	983	189	95	5	3	2	0	978	470	235	507
	2006	2,459	874	574	480	502	1,781	2,407	1,112	1,058	1,285	351	175	6	5	2	0	1,306	914	457	392
	2007	1,551	882	622	475	505	1,850	1,720	507	563	1,040	218	109	5	4	2	0	1,042	551	276	491
	Average	1,861	881	609	482	506	1,835	1,924	667	706	1,159	279	140	6	4	2	0	1,161	710	355	451
Future 50-year	2046	2,194	903	662	478	510	1,882	1,987	783	830	1,417	926	463	7	5	2	0	1,426	932	466	494
	2047	2,133	890	605	543	539	1,789	2,090	803	828	1,211	772	366	6	4	2	0	1,225	785	393	439
	2048	2,979	877	548	514	370	1,667	2,653	1,436	1,314	1,478	1,084	547	7	5	3	0	1,420	1,036	516	384
	2049	1,934	864	641	520	519	1,847	1,829	559	666	1,237	799	399	6	4	2	0	1,289	860	430	439
	2050	2,115	866	630	459	486	1,872	1,876	639	742	1,450	1,029	514	7	5	3	0	1,467	1,003	501	464
	Average	2,271	884	617	503	517	1,810	2,095	844	876	1,366	924	462	6	5	2	0	1,267	923	462	444
Future 100-year	2096	2,055	906	633	560	552	1,848	2,012	707	764	1,273	805	403	6	4	2	0	1,250	760	390	470
	2097	1,829	947	692	554	561	1,834	1,824	592	662	1,152	688	344	6	4	2	0	1,140	674	337	465
	2098	1,511	988	745	551	572	1,885	1,525	395	495	1,089	558	279	5	4	2	0	1,117	585	292	532
	2099	2,156	899	565	471	505	1,782	2,061	843	853	1,277	847	423	6	5	2	0	1,253	829	411	430
	2100	1,906	912	616	542	545	1,786	1,824	687	725	1,143	671	335	6	4	2	0	1,163	689	344	475
	Average	1,891	930	650	536	547	1,819	1,873	643	700	1,167	714	357	6	4	2	0	1,184	710	355	474

5. Construction and validation of the groundwater flow model

5.1 Mathematical simulation method

The three-dimensional movement of groundwater flow is defined from the following partial-differential equation, and calculated with the aid of Visual MODFLOW Ver4.1:

$$\frac{\partial}{\partial x} \left(k_x \frac{\partial h}{\partial x} \right) + \frac{\partial}{\partial y} \left(k_y \frac{\partial h}{\partial y} \right) + \frac{\partial}{\partial z} \left(k_z \frac{\partial h}{\partial z} \right) + R = S \frac{\partial h}{\partial t}$$

where, h : potential head, t : time, k : hydraulic conductivity in x, y, z direction

R : recharge and/or pumping discharge, S : storage coefficient

5.2 Construction of three-dimensional (3-D) groundwater flow model

(1) Hydrogeological structure

The hydrogeological structure of the study area is divided into seven layers as shown on Fig.19, Fig. 20 and Fig. 21, in accordance with the investigation results of in-situ boring survey and the previous study report.

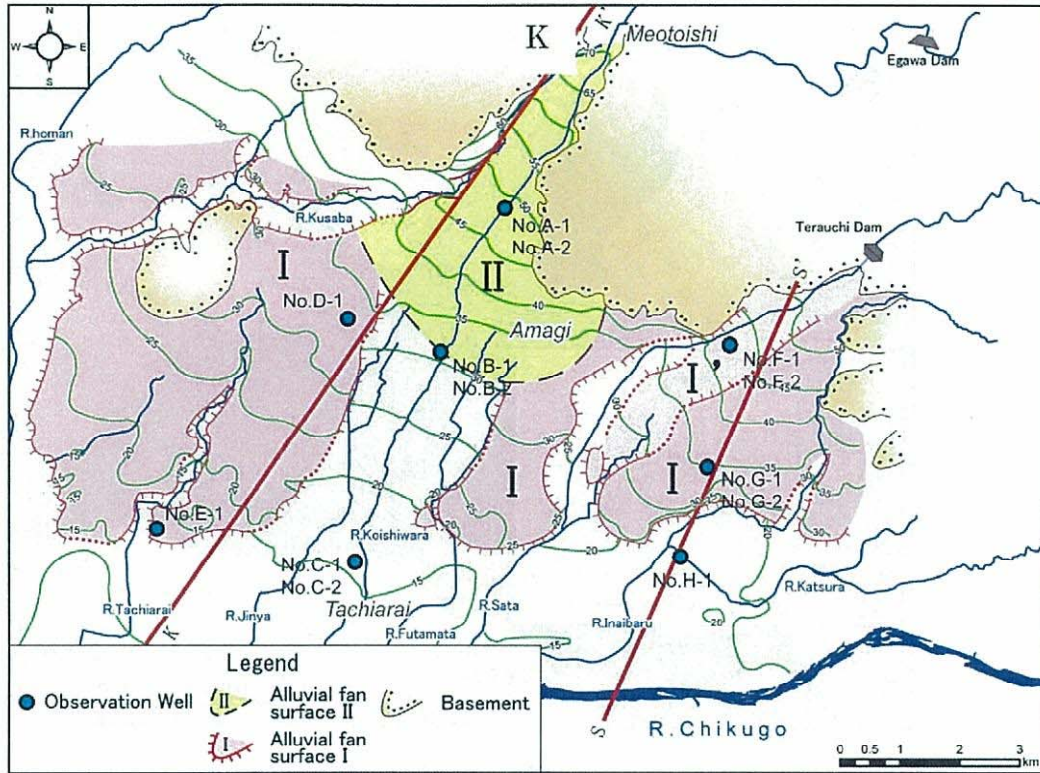


Fig.19 Location of the geological cross section

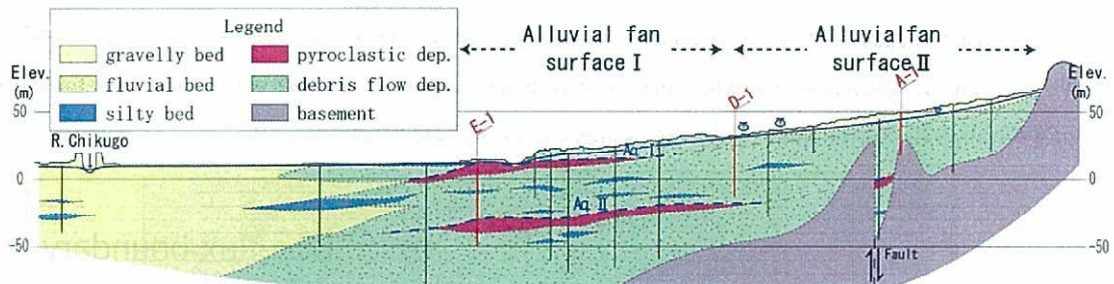


Fig.20 Geological cross section (K) along the Koishiwara-gawa

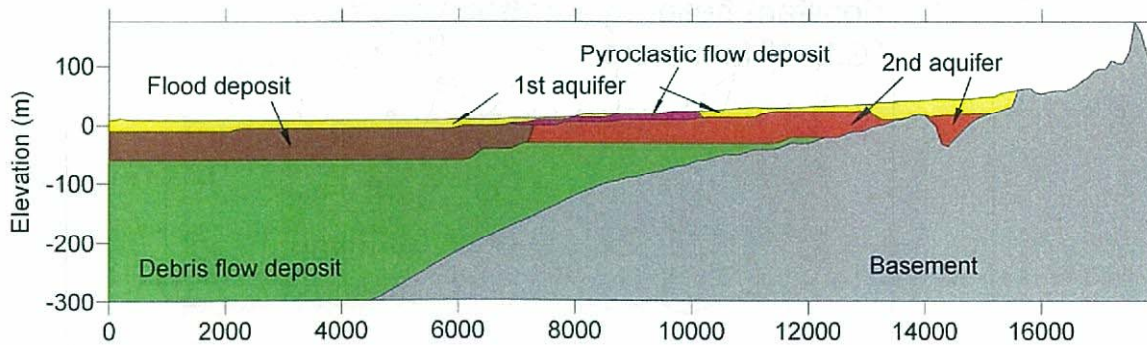


Fig.21 Geological cross section (K) after digitalization

(2) Discretization and cell designations

The study area of 27,000 m × 20,500 m was simulated by generating series of 100 m × 100 m square meshes, on which corresponding national numerical information were reflected. The coordinate system adopted in the simulation is the rectangular plane coordinate system (II).

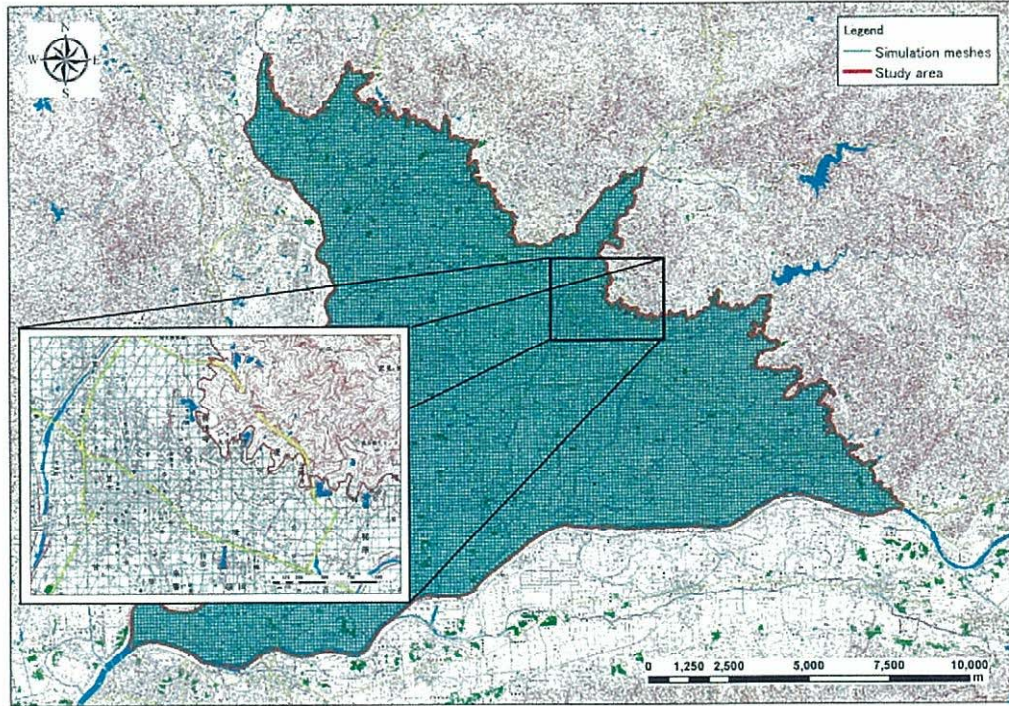


Fig.22 Generated simulation meshes

(3) Boundary conditions

Constant heads of “G.L.-1” in meters were designated for the major rivers such as the main stream of R. *Chikuo-gawa* and R. *Homan-gawa*, while the constant heads measured in 2007 were designated for the tributaries of R. *Chikuo-gawa*. Surrounding mountainous area was designated as non-flux cells.

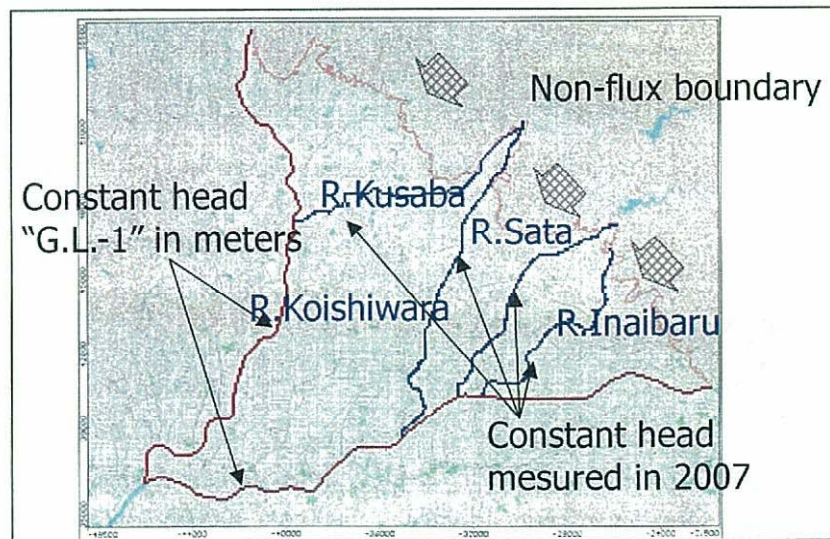


Fig.23 Boundary conditions

(4) Recharge

The groundwater recharge for each cell was distributed in accordance with the land use type composed of paddy field, non-paddy field, and urban area (see Chapter 4), as shown in Fig.24 and Fig. 25.

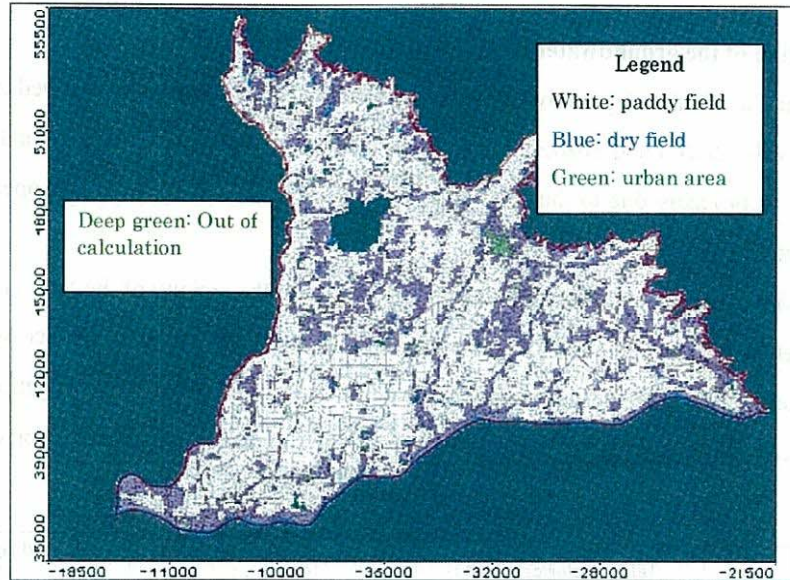


Fig.24 Land use in 1941 after digitalization

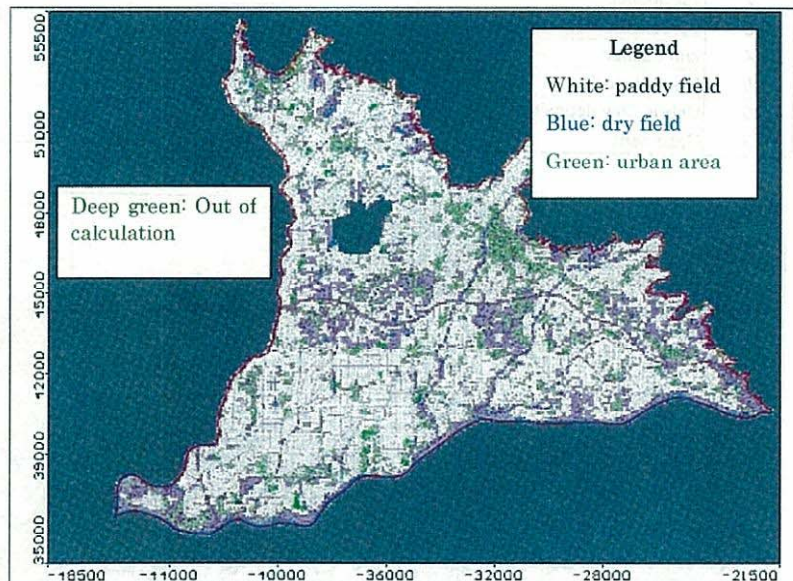


Fig.25 Land use in 1997 after digitalization

5.3 Validation Model

(1) Hydraulic conductivity after validation

The initial hydraulic conductivity presumed from the in-situ data, and after its validation, are shown in Table 6. In order to simulate the in-situ hydrogeological condition, the hydraulic conductivity in the vertical direction of the pyroclastic flow deposit (Aso-4) was set as 1/10 of the hydraulic conductivity in the horizontal direction.

(2) Simulation of the water table

The simulated water table represents the observed well water table, excluding those in the western area where the topography varies widely as shown in Fig.26.

(3) Simulation of the groundwater level fluctuation

In general, the simulated groundwater level fluctuation also represents the observed groundwater level fluctuation, except for *Nakahata(C)* and *Takae(E)* observation stations as illustrated in Fig.27 and Fig.28. The reason for such discrepancy is probably due to the daily river level fluctuation and the pumping operations from the neighboring irrigation wells.

As for *Ishinari(G)* observation station, which is located in the vicinity of the *Sata-gawa* course, there exists about 5-m difference in potential head between the shallow and deep groundwater across an aquiclude (Aso-4). The potential head difference during irrigation period is more than during non-irrigation period. This difference in potential head can be approximately determined from the simulation, with a restriction of up to 2-m disjunction.

Table 6 Hydraulic conductivity after validation

Layer	Hydrogeological name	Initial hydraulic conductivity (cm/sec)	Validated Hydraulic conductivity (cm/sec)
1	River bed deposit	5.0E-02	5.0E-01
2	1st aquifer	3.6E-02	7.2E-02
3	Pyroclastic flow deposit (Aso-4)	1.0E-04	Horizontal: 1.0E-4 Vertical: 1.0E-5
4	2nd aquifer	2.0E-03	1.0E-02
5	Flood deposit	5.6E-03	2.8E-02
6	Debris flow deposit	5.0E-04	1.0E-03
7	Basement	4.8E-06	4.8E-06

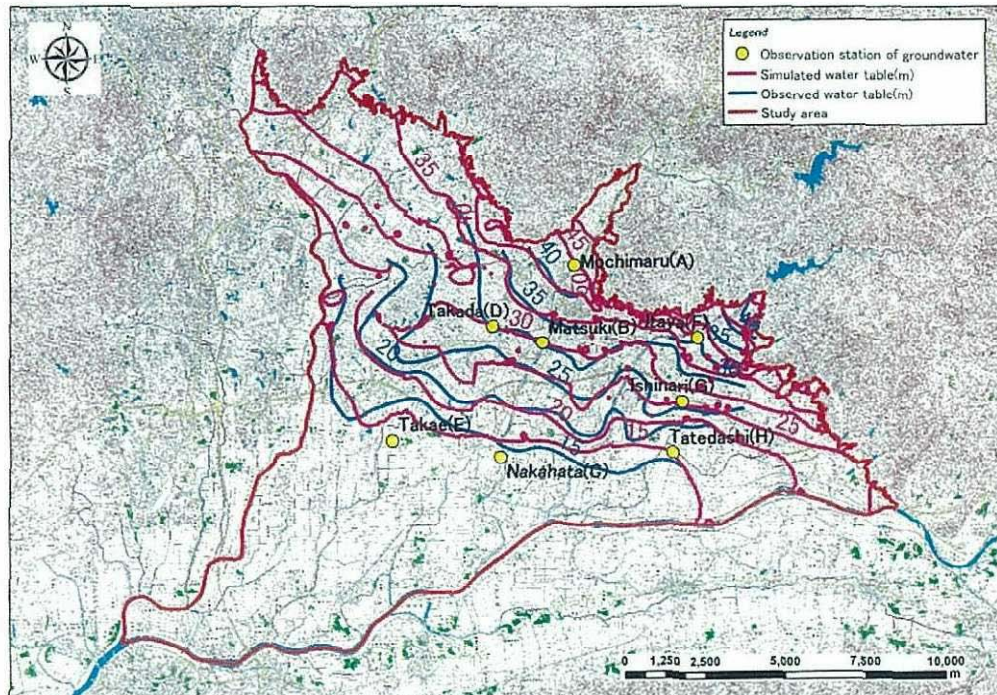


Fig.26 Comparison of water table on 25 November in 2007

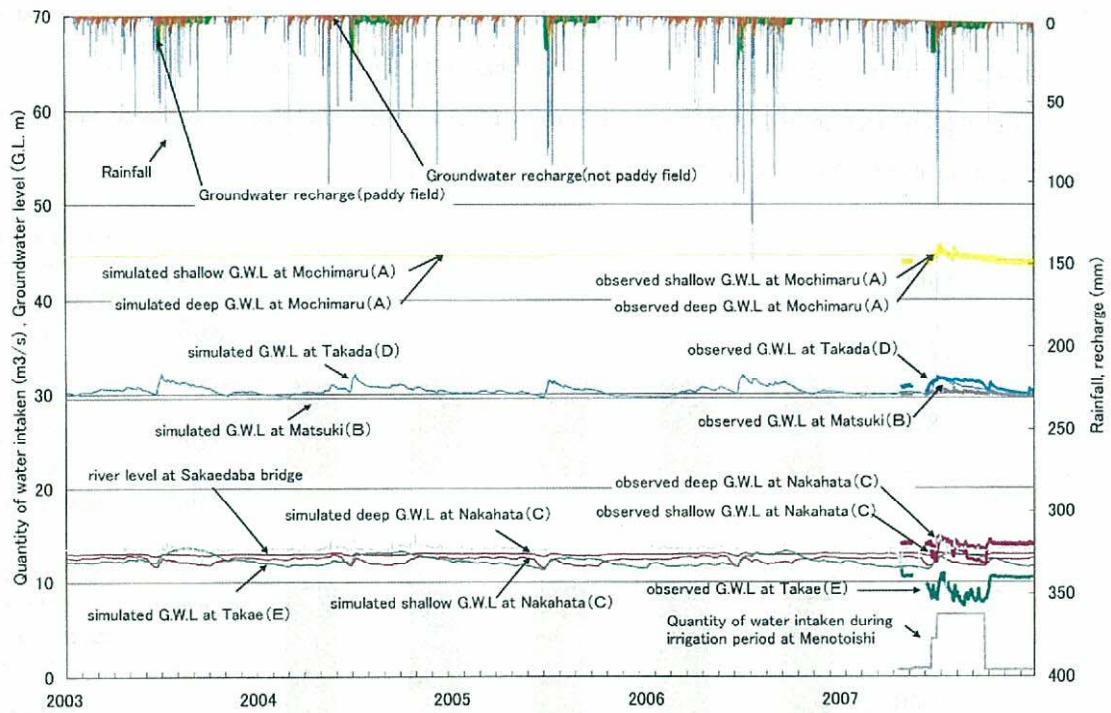


Fig.27 Comparison between the simulation and observations along the *Koishiwara*-river

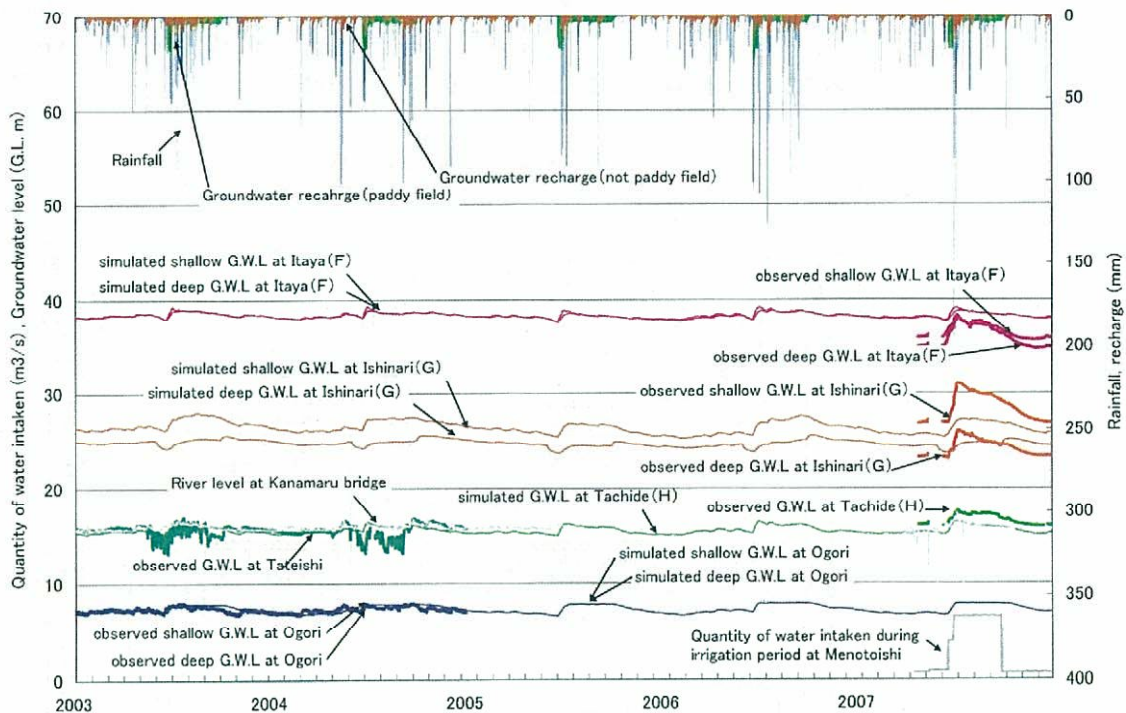


Fig.28 Comparison between the simulation and observations along the *Sata-gawa*

(4) Present water balance

The present annual water balance from 2003 to 2007, simulated using the three-dimensional (3D) groundwater flow model, is shown in Fig.29. During said period, the recharge to groundwater was larger than the discharge from groundwater. It was estimated that the annual total surface flow was 400,000,000 m³, and the ratio of the pumping

water to the whole discharge was quite small. Meanwhile, it can be concluded that the water balance is adequately stable since the error (Σ inflow - Σ outflow) is less than 0.1% for each year.

It was found that groundwater closely interacts with river water, and that the recharge from the irrigation water amounts to about 40% of the rainfall origin as shown in Fig.30.

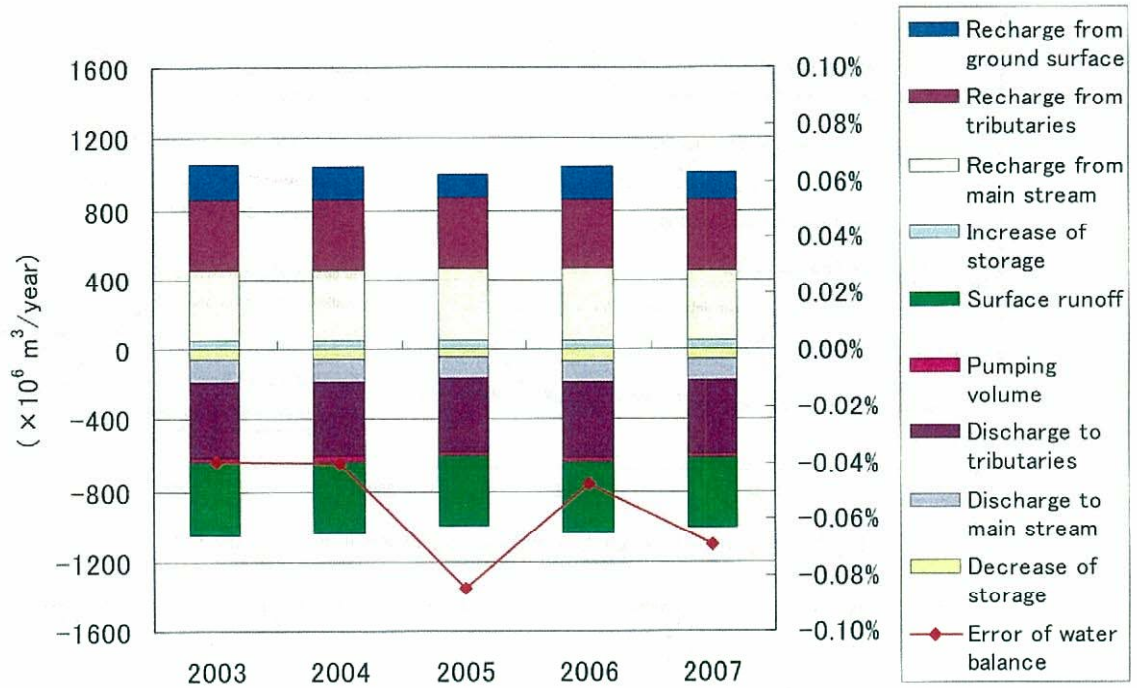


Fig.29 Water balance after validation

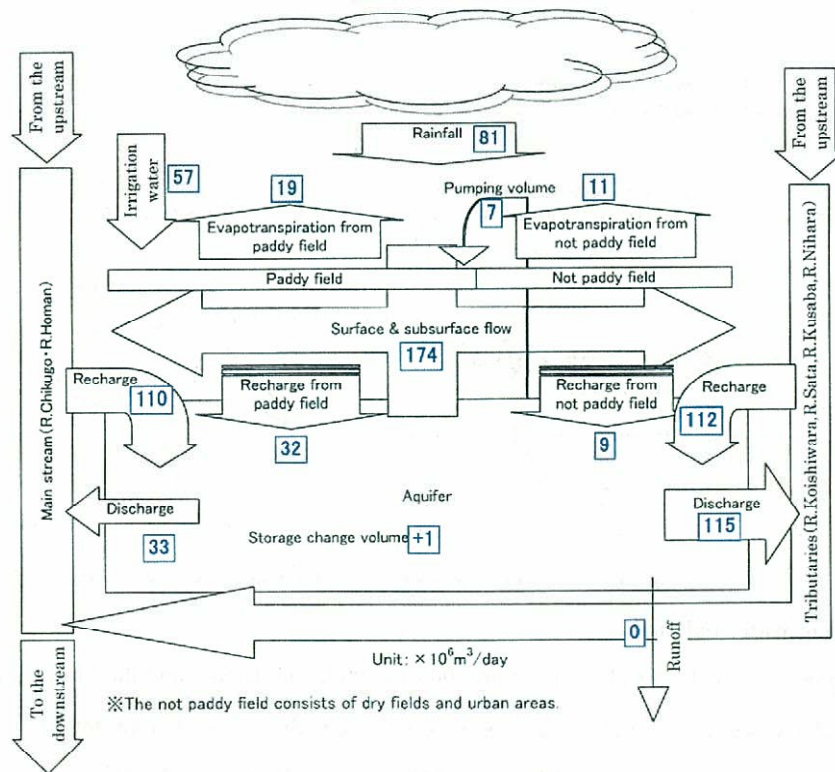


Fig.30 Conceptual diagram of water balance in 2007 (present)

6. Validation of the past situation and prediction of the future condition

6.1 Case of validation and prediction

In the case of the validation of past condition, the calibration target was the groundwater table contours measured in 1961 (see Table 7). On the other hand, for the future prediction, two periods from 2046 to 2050 and from 2096 to 2100 were selected for the simulation. The future predictions for both periods were carried out on the basis of RCM20, which also included one year of approach run to avoid possible influences due to the initial condition.

Table 7 Simulation period and condition in each case

Case	Simulation period	Land use	Remarks
① Past validation	1957~1961	1941	The calibration target is groundwater level in 1961
② Present validation	2003~2007	1997	The calibration target is groundwater level in 2007
③-1 Future 50-years prediction	2046~2050	1997	-
③-2 Future 100-years prediction	2096~2100	1997	-

6.2 Past validation and evaluation of the land use change-derived influence

(1) Past validation

Validation of the past groundwater circumstances was carried out using the calibrated model of the present groundwater conditions. It is known that the simulated water table coincides with the observed well water table as shown in Fig.31. Although the observed water table indicates the existence of a ridge on the right bank of R. *Chikugo-gawa*, this was ignored in the model since the in-situ data was very old to be entirely relied on.

The past groundwater recharge is larger than the present although the annual rainfall of 1961 is smaller than that of 2007, as shown in Fig.32. The reason for this will be discussed in detail in the next section.

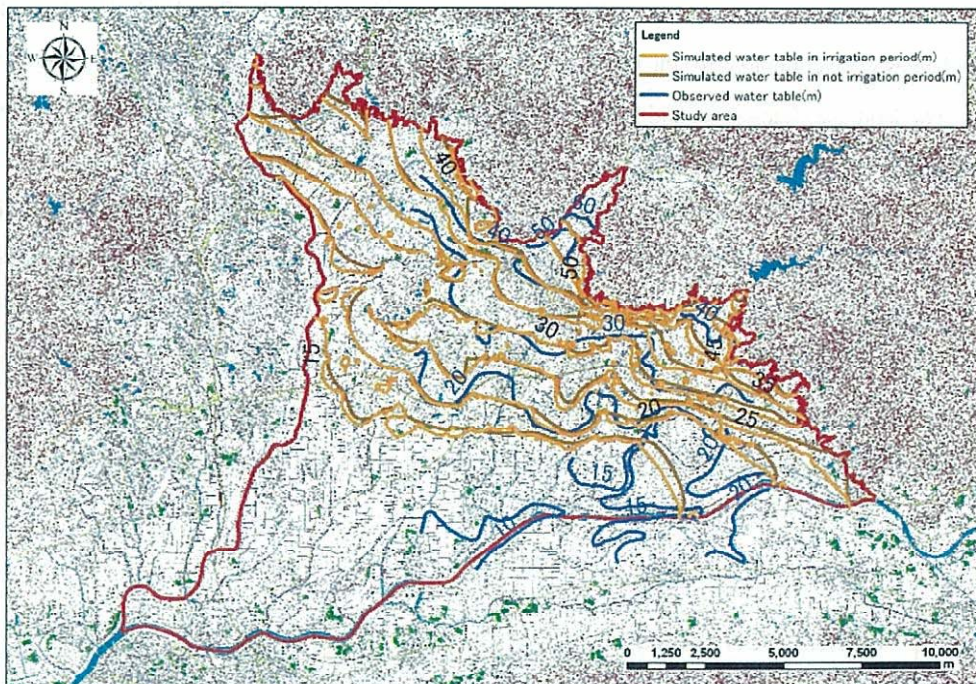


Fig.31 Comparison of water table in 1961

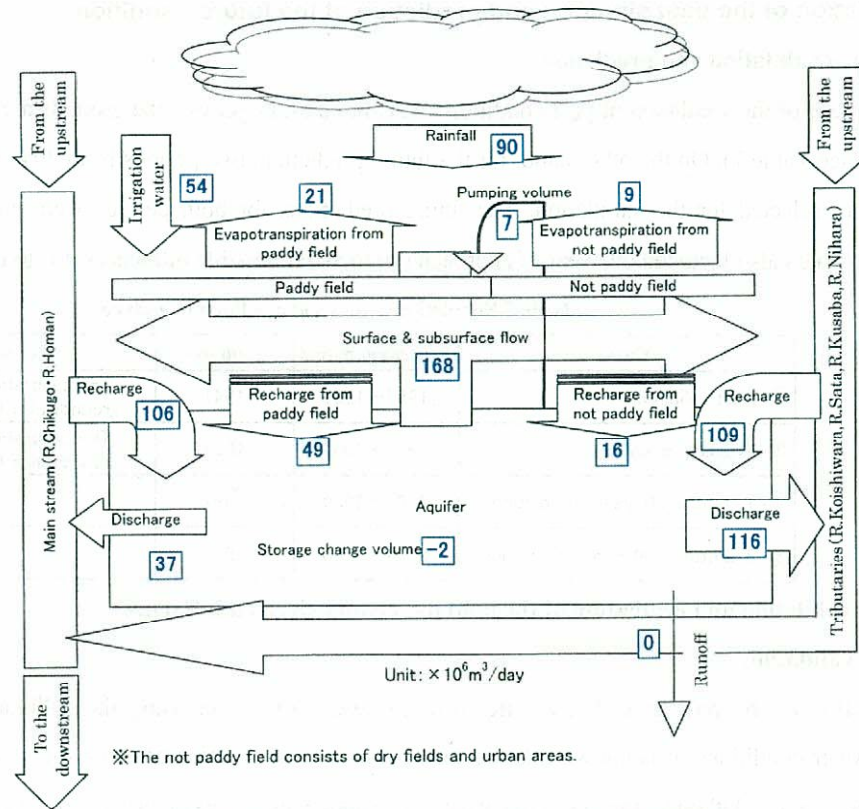


Fig.32 Conceptual diagram of water balance in 1961 (past)

(2) Evaluation of the land use change-derived influence

In order to evaluate influences due to land use changes from past to present, the model was run considering the land use conditions of 1941 and 1997, and climate conditions from 1957 to 1961. The groundwater levels and water balances were compared for the climate condition of 1961, which was identified as the average hydrological year.

The land use changes around the *Amagi-City* in 1976 and 1997 are shown in Fig.33 and Fig 34, respectively. Both figures were described according to the national numerical information.

Fig.35 and Fig. 36 meanwhile are the isolines of the drawdown between two simulations. These figures reveal that urbanization has already progressed in the eastern area of *Amagi-City* during the period from 1976 to 1997. Hence, the groundwater level has consequently decreased at said area. The results indicate that urbanization, which involves decrease of paddy field and increase in impermeable area, influences groundwater environment to a greater degree than what was assumed. In addition, the maximum drawdown during irrigation and non-irrigation periods is 3.2 m and 1.4 m, respectively. Thus, this further indicates that the land use change distinctly influences the groundwater recharge and the distribution of groundwater level.

Table 8 Condition of simulation cases I, II

Simulation Case	Land use	Climate condition	Target year
I	1941	1957~1961	1961
II	1997	1957~1961	1961

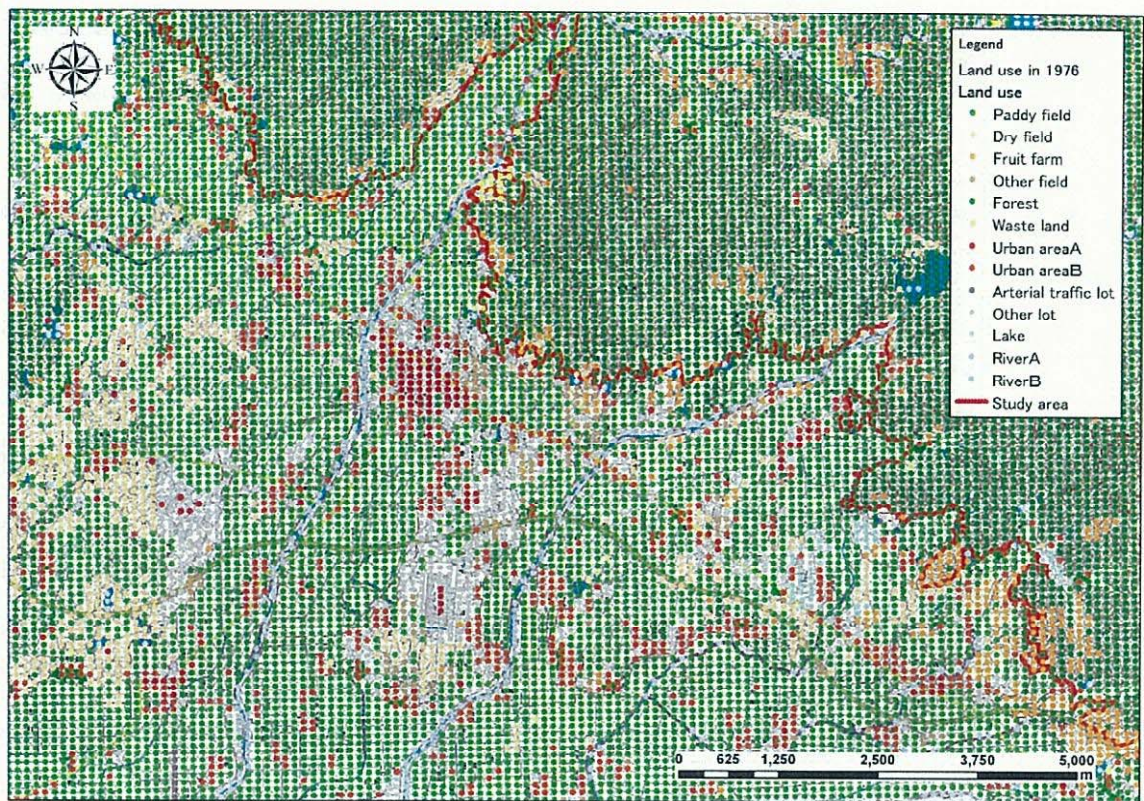


Fig.33 Land use situation in 1976

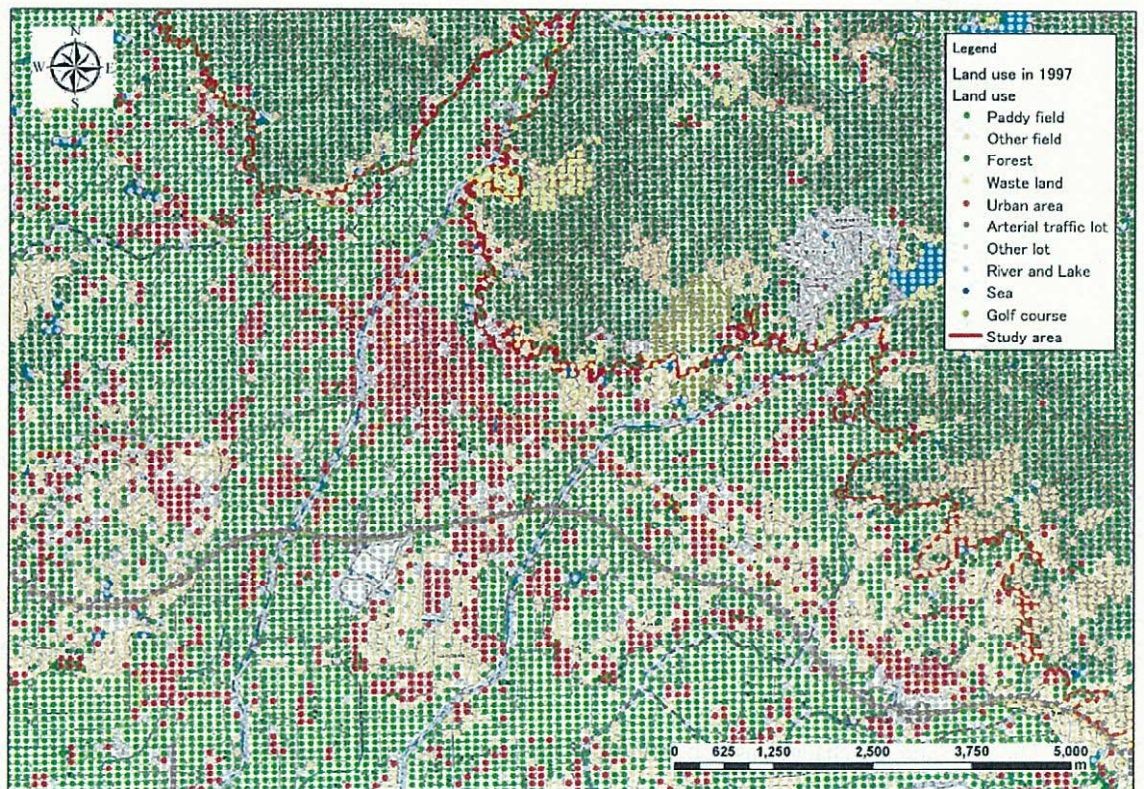


Fig.34 Land use situation in 1997

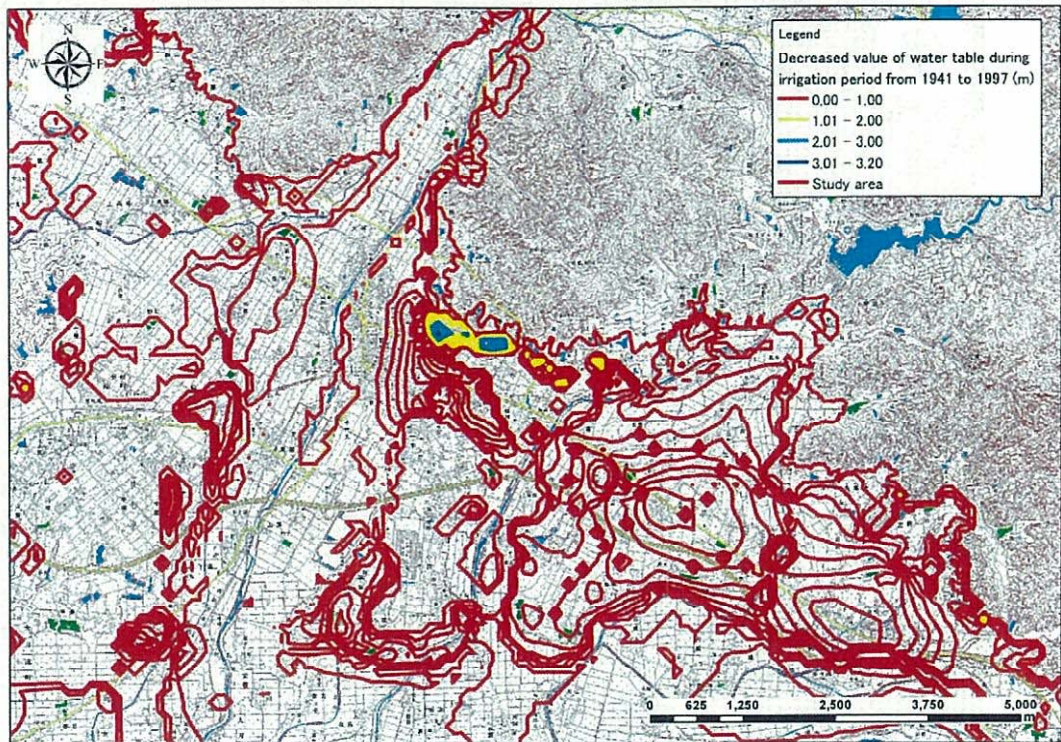


Fig.35 Isolines of the decreased value of water table during irrigation period (Influence of present land use change)

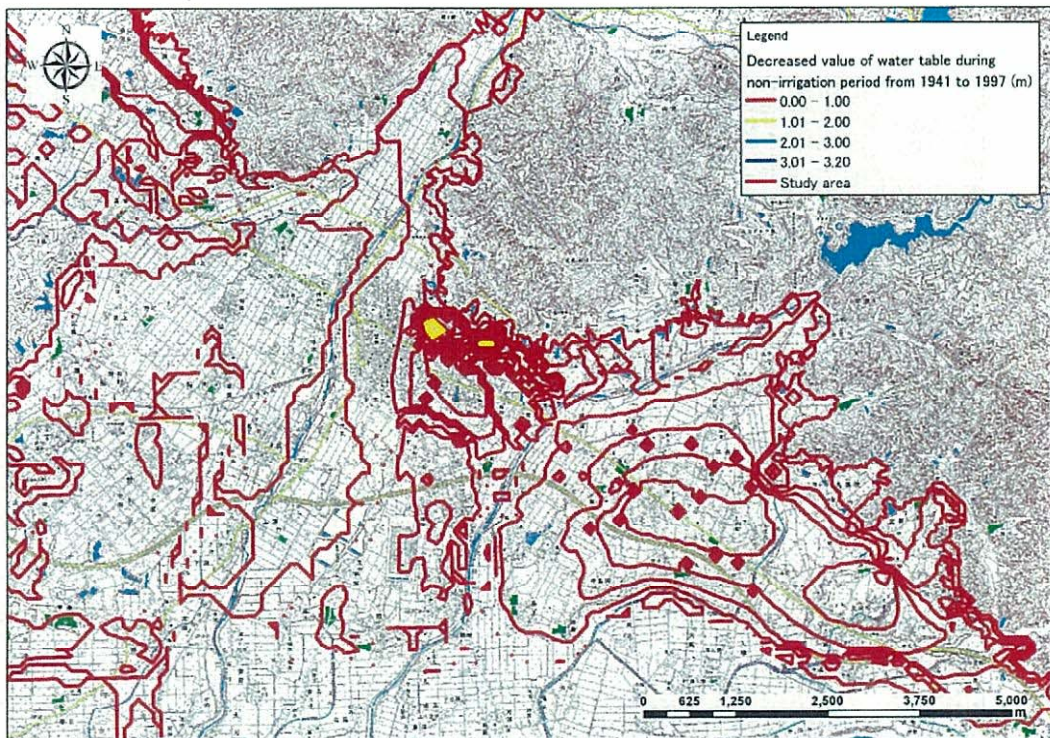


Fig.36 Isolines of the decreased value of water table during non-irrigation period (Influence of present land use change)

The past land use change has also influenced the groundwater level fluctuation. Estimated drawdown is about 10 cm around the *Koishiwara-gawa* and 20 ~ 50 cm around the *Sata-gawa*, as shown in Fig.37 and Fig.38, respectively.

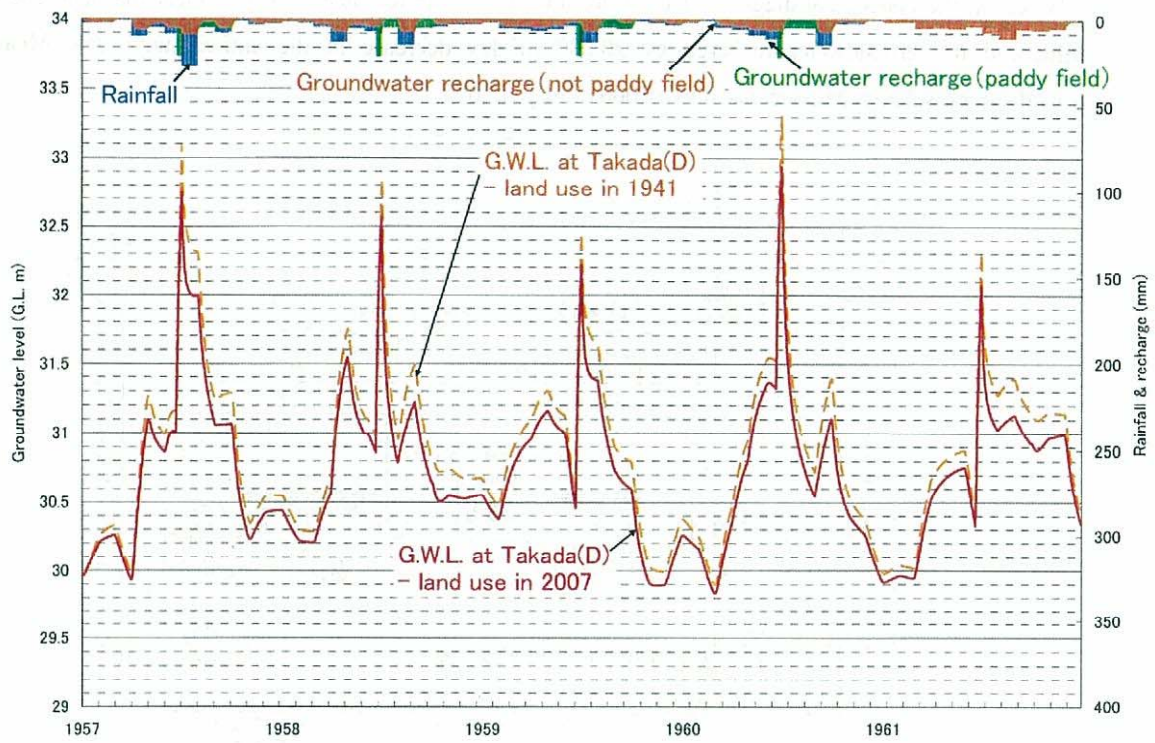


Fig.37 Comparison between simulation and observations at *Takada(D)*

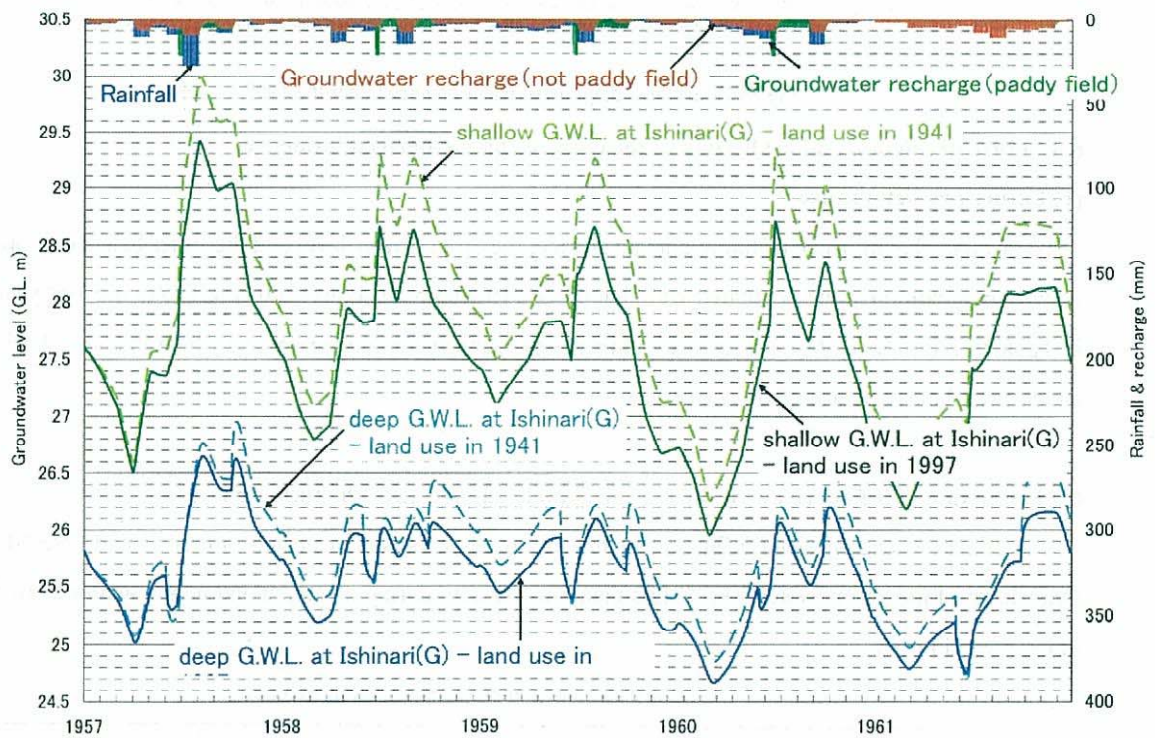


Fig.38 Comparison between simulation and observations at *Ishinari(G)*

Based on the conceptual diagram of the water balance illustrated in Fig.39, it is clear that land use change had influenced the groundwater recharge by 20,000 m³/day decrease in the entire study area. Meanwhile, the groundwater discharge had decreased to 55,000 m³/day in total.

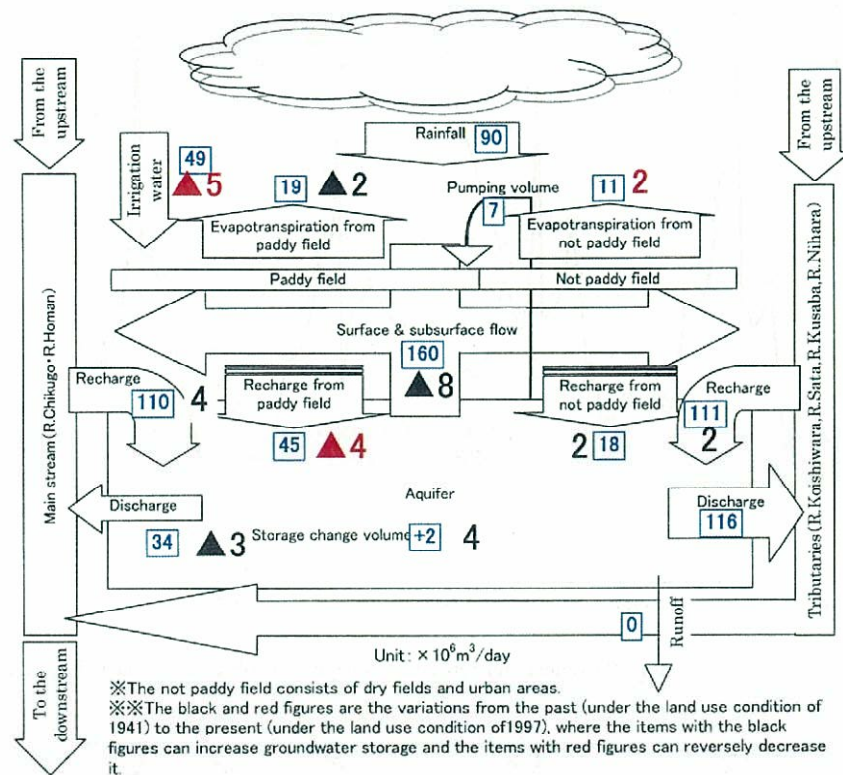


Fig.39 Conceptual diagram of water balance under the 1997 land use

6.3 Future prediction and evaluation of the climate change-derived influence

(1) Future prediction case

To evaluate the influence of future climate change, the groundwater level and the water balance of prediction case II (present condition) were compared with that of case III (future 50-years) and case IV (future 100-years) as shown in Table 9. From the table, “Target year” indicates the subject for comparison, of which the annual rainfall amount are close to the two-year rainfall.

(2) Evaluation of influence derived from the climate change after the future 50-years

The climate change-derived influence for the future 50-years was evaluated in case II and case III simulations. Drawdown of the groundwater level is less than 1 m for both during irrigation and non-irrigation periods, as shown in Fig.40 and Fig.41.

Table 9 Condition of prediction cases II, III and IV

Prediction Case	Land use	Climate condition	Target year
II	1997	1957~1961	1961
III	1997	2046~2050	2049
IV	1997	2096~2100	2097

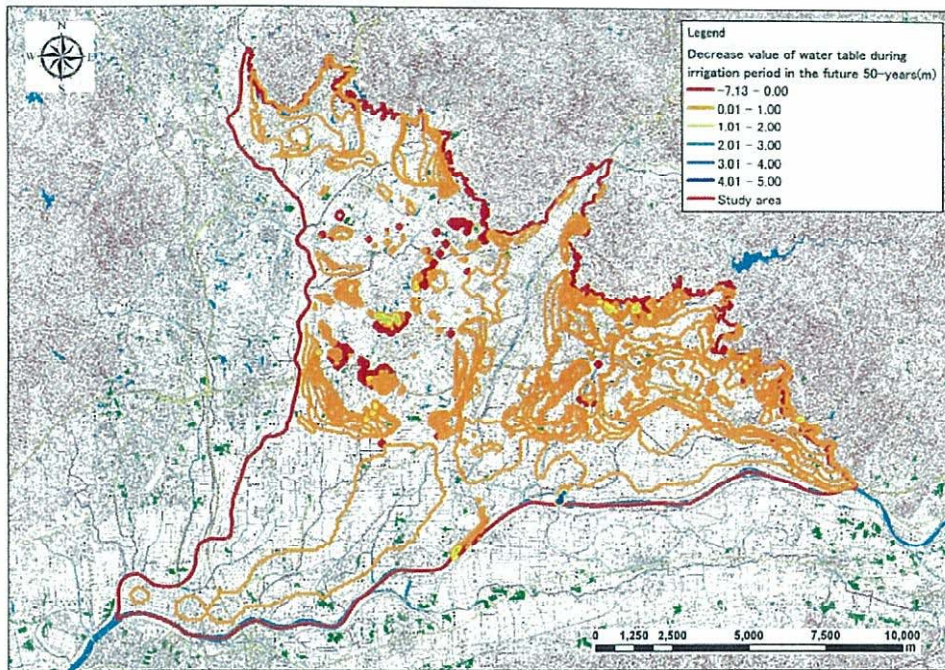


Fig.40 Isoline of the decreased value of water table during irrigation period (Influence of climate change in the future 50-years)

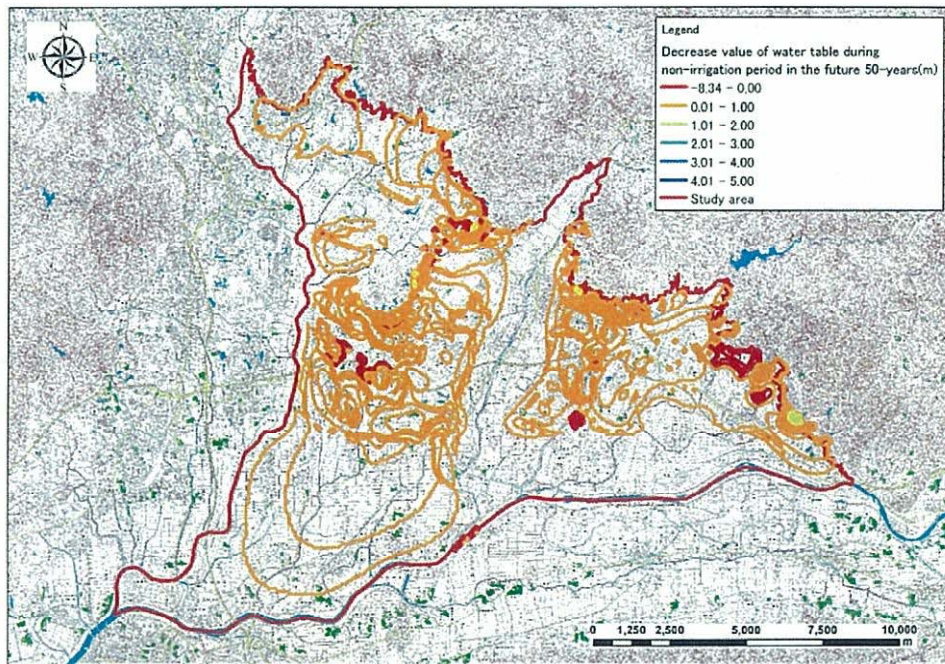


Fig.41 Isoline of the decreased value of water table during non-irrigation period (Influence of climate change in the future 50-years)

Fig.42 illustrates the conceptual diagram of water balance in 2049, which is included in the “future 50-years” case. As shown in the figure, the groundwater recharge decreases in spite of the increase in rainfall. This fact probably indicates that the direct surface runoff increased because of the frequent occurrence of torrential rainfalls, due to global warming.

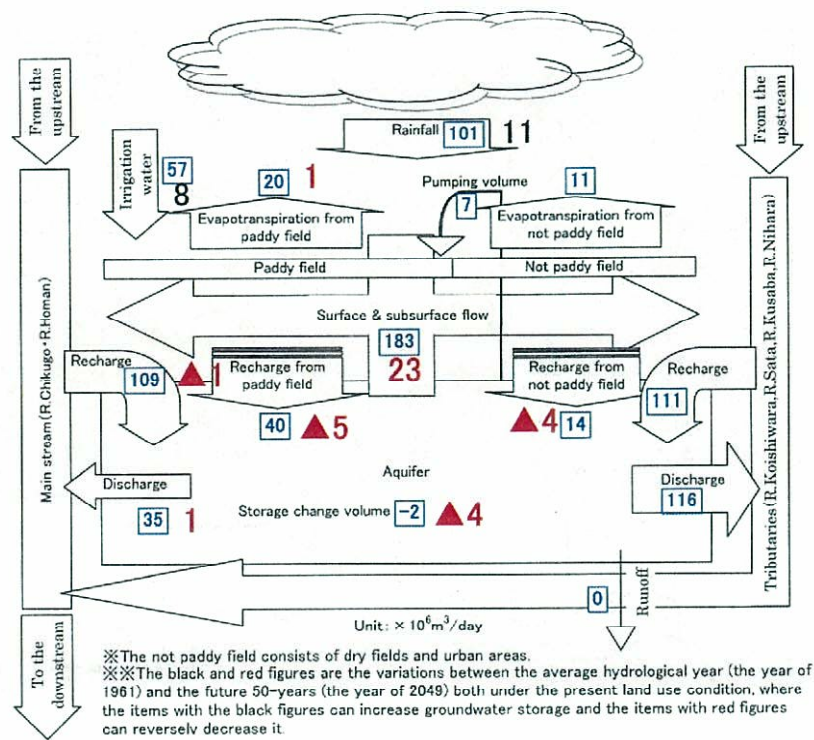


Fig.42 Conceptual diagram of water balance in 2049

(3) Evaluation of influence derived from the climate change after the future 100-years

The climate change-derived influence for the future 100-years was evaluated in case II and case IV simulations. Drawdown of the groundwater level is less than 1 m during the irrigation period, as shown in Fig.43. However in some locations, groundwater level increased conversely during the non-irrigation period (see Fig.44). For this reason, it is considered that the average monthly rainfall during the non-irrigation period in 2097 is greater than that of the present.

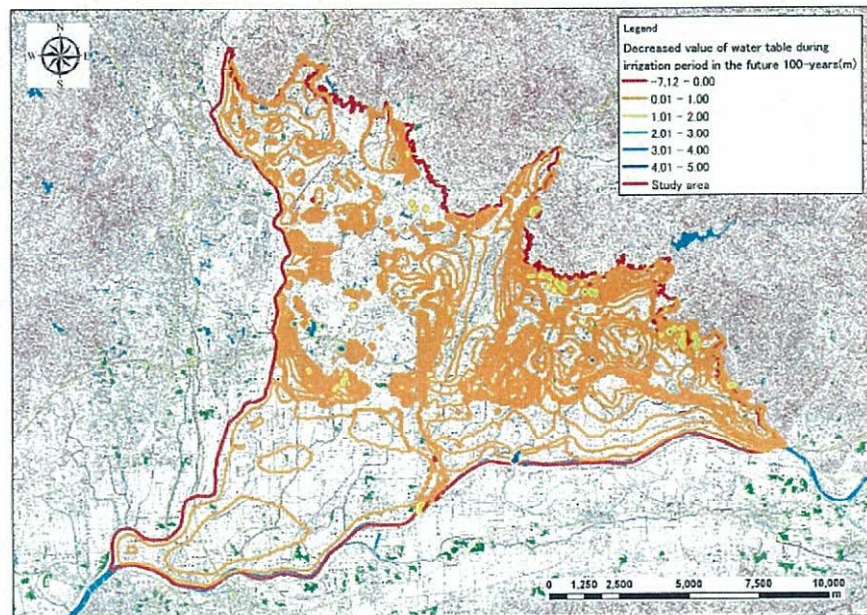


Fig.43 Isoline of the decreased value of water table during irrigation period (Influence of climate change in the future 100-years)

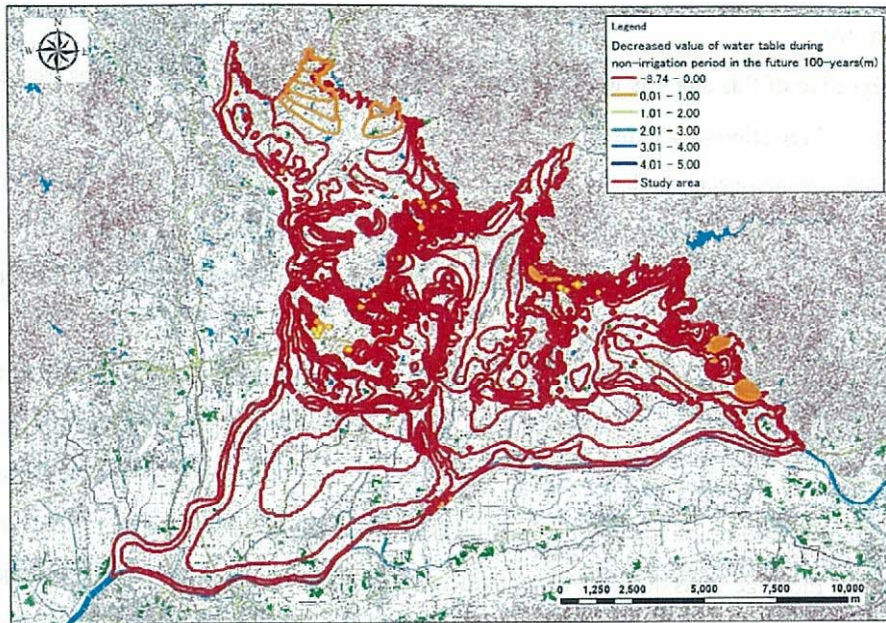


Fig.44 Isolines of the decrease value of Water table in not irrigation period (Influence of climate change in the future 100-years)

Similar to the future 50-years case, the groundwater recharge decreases in spite of the increase in rainfall, due to the frequent occurrence of torrential rainfalls and the increase of the direct surface runoff (see Fig.45).

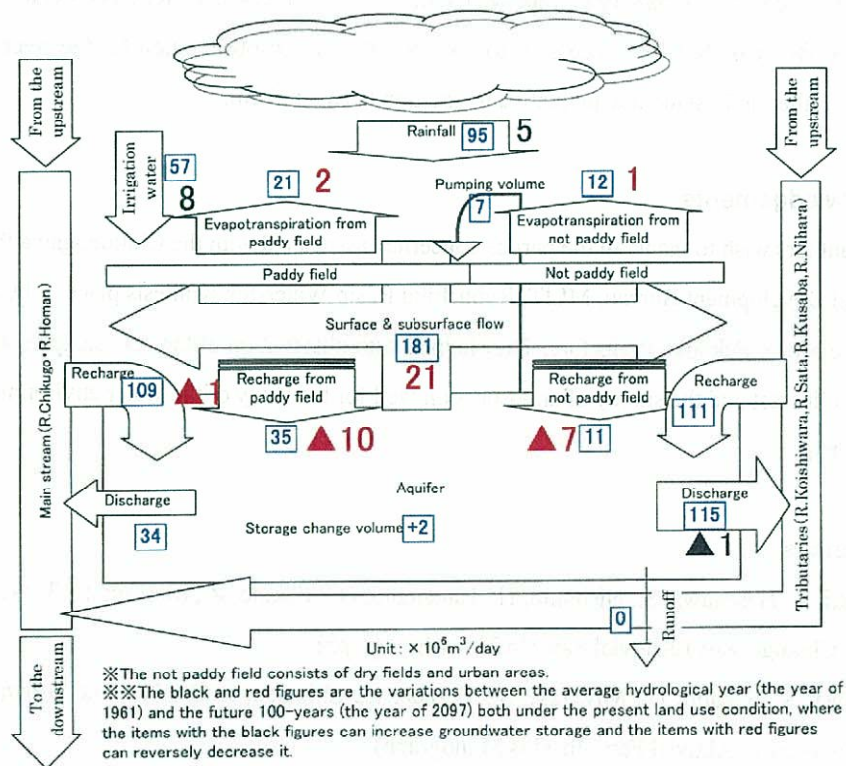


Fig.45 Conceptual diagram of water balance in 2097

7. Summary

The objective of this study is to estimate and forecast the past and future changes, respectively, of groundwater environment, in relation to land use development and climate change caused by global warming.

Land use change during the last 50 years mainly involves the decrease of paddy fields with an increase in urban area. Its influence was estimated to be a maximum of 3.2 m drawdown of groundwater level in the eastern area of *Amagi-City*, where urbanization seemingly progressed rapidly. In addition, the groundwater discharge decreased to 55,000 m³/day in the entire study area.

Future climate change mainly involves temperature increases and the changes in rainfall patterns. The warming temperature induces an increase in evapotranspiration. However it was found that said increase in evapotranspiration hardly influenced the groundwater recharge. On the other hand, it was realized that the changes in rainfall patterns, i.e. the frequent occurrence of torrential rainfalls, significantly increased the direct surface runoff and decreased the groundwater recharge. This decrease of groundwater recharge was predicted to be about 200,000~300,000 m³/day. Based on these circumstances, the changes in rainfall patterns, rather than the variation of the total rainfall volume, induce more severe influence to the groundwater environment.

From the water balance study, it was reconfirmed that the relationship between river water and groundwater was quite significant. It was realized that the groundwater recharge derived from the river water was vital to the entire water balance. Considering this result and the condition of the present simulation where the river level was set to be constantly stable, it is necessary to improve the model to be able to accommodate the transient data of the river level. Consequently, it is therefore necessary to continue the in-situ observation on the river and groundwater levels in order to further understand the qualitative interaction between them.

Acknowledgements

The authors wish to thank all the parties concerned associated with the Chikugogawa River Office, Kyusyu Regional Development Bureau, MLIT, Ryouchiku Basin Water-for synthesis place of business, JWA and Ryouchiku Land use office, Fukuoka Prefecture. They helped with observation of the core samples, analysis of the results of the permeability test and the survey of an inspection well for the study of the water environment of the R.Chikugo-gawa alluvial fan.

References

- Miyazaki, S., Hasegawa, S., Nishihira, H., Hanamura, O., Makino, R., Matsumoto, T. (2008) : The Hydrogeology of R. Chikugo-gawa Alluvial Fan. (In This Monograph)
- Hasegawa, S., Fukami, D., Miyazaki, S., Takada, K., Shimada, J. (2008) : The Groundwater Flow System of R. Chikugo-gawa Alluvial Fan. (In This Monograph)

The Changes of Water Environments and the Future Groundwater Management on the Chikugo-gawa Alluvial Fan, North Kyusyu, Japan

OISHI Akira* · MIYAZAKI Seisuke* · HASEGAWA Satoshi*

Abstract

The Cikugo-gawa alluvial fan area possesses abundant freshwater resources, and has offered the place to live for many people from Yayoi period to today. The meteorological disasters represented by the localized torrential rain increased when global warming changes as it is, and changing in river flow by this had the anxiety that influenced the groundwater environment with close relations to river water. However, in the Chikugo-gawa alluvial fan, Egawa dam is in the upstream in the R.Koishihara-gawa, and Terauchi dam is in the R.Sata-gawa. And, the surface runoff by the rainfall in the upstream mountains area is controlled once by both dams. Therefore, it seems that "the meteorology risk" of the change in the future rainfall pattern and the water environment of an alluvial fan are not related immediately. On the other hand, the groundwater environment has been getting worse because of a decrease in the amount of groundwater recharges and an increase in the groundwater pumping rate, etc, by the advancement of urbanization even now.

After taking into consideration the hydrogeologic structure of the alluvial fan, and the groundwater-flow characteristic controlled by it, it is preferable to perform unified management of the river water and the groundwater.

KEYWORDS : Chikugo-gawa alluvial fan, global warming, freshwater resources, unified management

1. Introduction

IPCC2007 report pointed out that the meteorological disasters represented by the localized torrential rain when global warming changed as it is. Moreover, in the middle-latitude zone in which Japan is situated, the river flow changes under the rainfall change to suddenly and locally pattern that may recognize at these days and it is also pointed out to cause a serious influence in the social life.

The Cikugo-gawa alluvial fan area possesses abundant freshwater resources, and has offered the place to live for many people from Yayoi period to today. In this paper, the change in the water environment of Chikugo-gawa alluvial fan is considered along with global warming, and the way for the water utilization in the alluvial fan that is an important place of agricultural production is described.

2. Present and Future Conditions of Weather and Stream Flow

As shown in Fig.1, the tendency to the temperature rise of about 1 degree is observed in these 20 years from the past weather-survey data in this area (Amagi). Moreover, according to the future prediction by RCM20, in 100 years, the rise of 2 degree further will be forecasted as shown in Fig.2. And, as a result, an increase in the amount

* Yachiyo Engineering Co., Ltd.

of evapotranspiration will be expected.

Though the amount of the annual rainfall is assumed no change too much, it is expected that the localized torrential rain shown in a recent rainfall pattern increases. This shows that the risk of flashflood or water shortage becomes high, and that the amount of river runoff increases and the amount of groundwater recharges decreases in the groundwater environment.

However, in the Chikugo-gawa alluvial fan, Egawa dam is in the upstream in the R.Koishihara-gawa, and Terauchi dam is in the R.Sata-gawa. And, the surface runoff by the rainfall in the upstream mountains area is controlled once by both dams. Therefore, a more appropriate management is requested from “the meteorology risk” of the change in the rainfall pattern, and also from the water environment change of the alluvial fan.

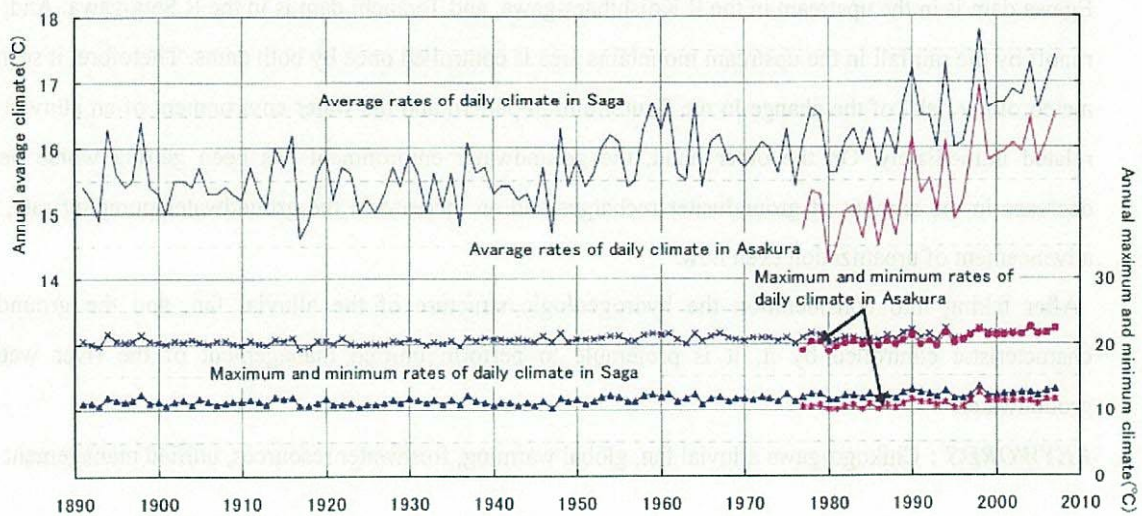


Fig.1 Long-term trend of temperature

3. Relation between Humans and Hydrogeologic Environment of Alluvial Fan

The Chikugo-gawa alluvial fan is a compound alluvial fan formed with the R. Koishihara-gawa and the R. Sata-gawa. Two of 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, and there are many lotus paddy fields at the lowlands under the cliff in the alluvial-fan end part. And the Amagi city area is located in the vicinity of the spring water belt of the edge of the fan on alluvial-fan II of the new stage.

Many of these spring waters have been used for irrigation for many years, and there records the spring-water place of 1842 (Tenpou 13 years) as shown in Fig.3. These old spring water and the recent spring part (Fig.4) are almost in the same point. The alluvial-fan has been widely used as a forest and a field until the 1950's since prewar periods. Cropland abandonment and urbanization progressed recently, though the irrigations network arrangement and the adjustment of arable land holdings advanced and were made a rice field in the 1960's. It seems that the underground water environment has been comparatively kept excellent up to recent date though dryness of spring water and a decrease of the flowing well due to the lowered underground water level are caused by the influence of the well pumping to aim at irrigation and industrial water, considering the transition of the land use.

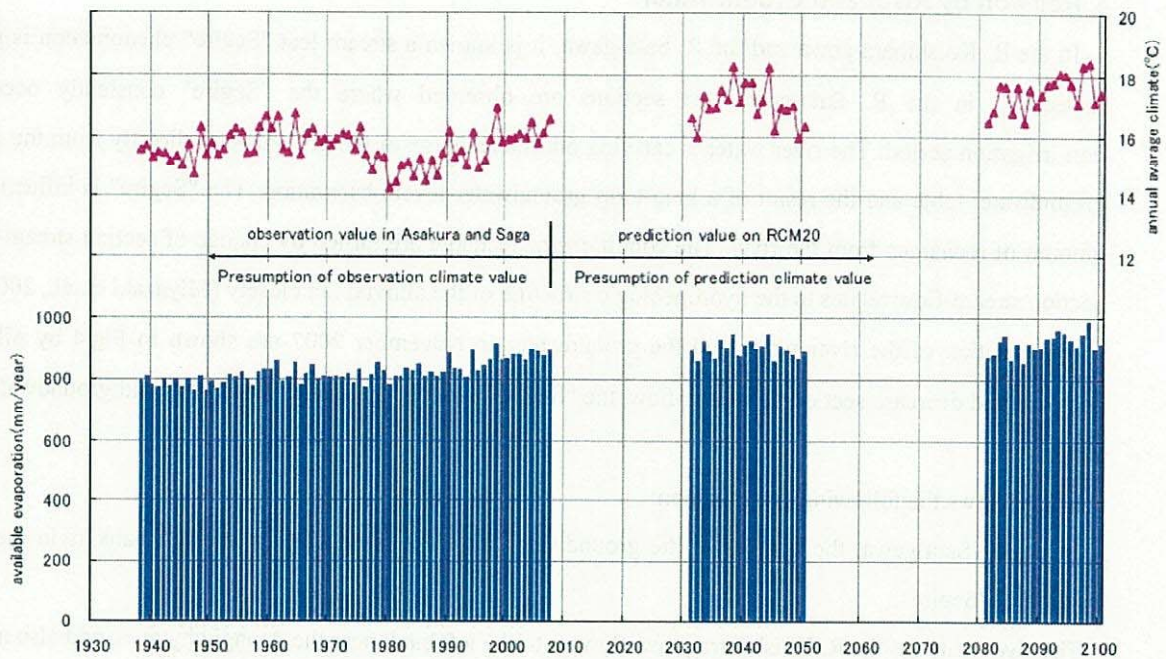


Fig.2 Future prediction of average temperature by RCM20.

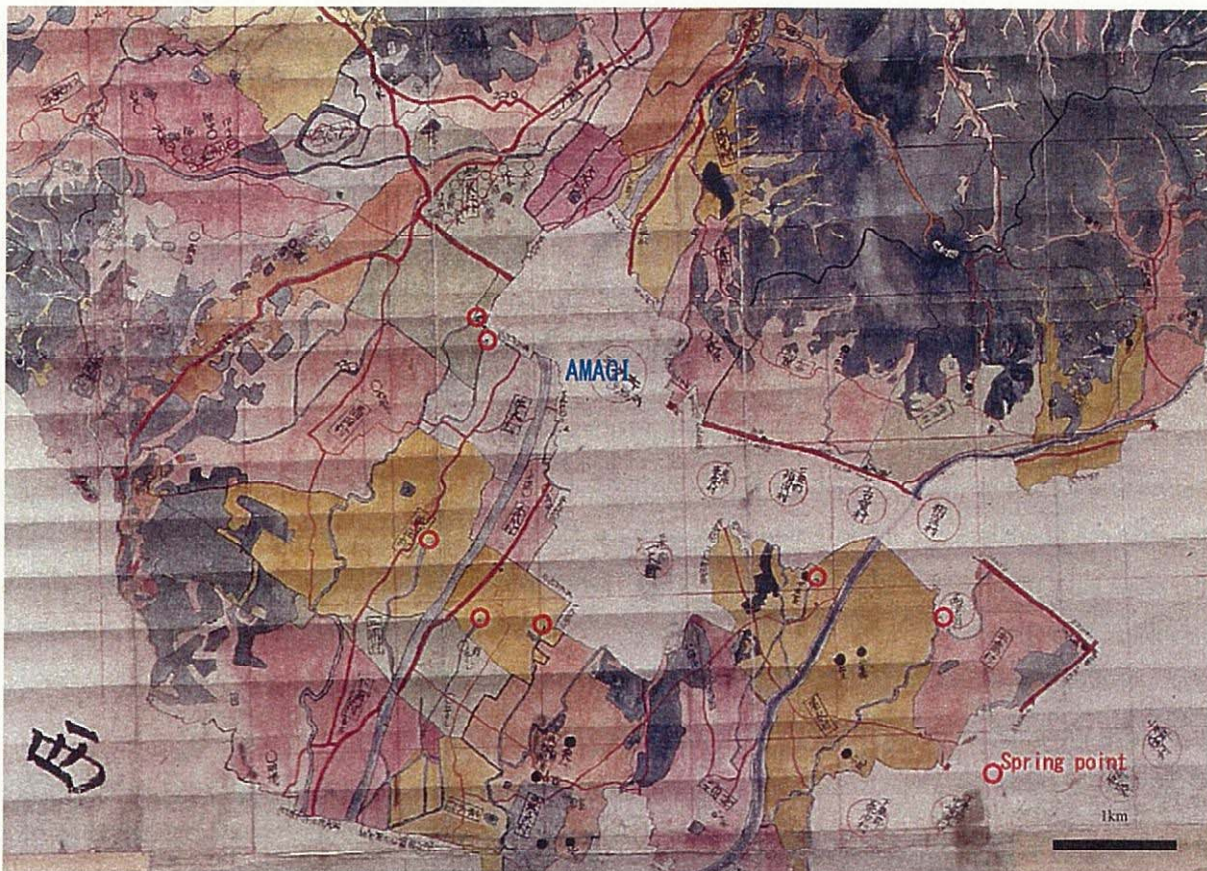


Fig.3 Old Map of Akizuki Clan and Place of Spring Water in 1842 (Tenpou 13 years).

4. Relation by River and Groundwater

In the R. Koishihara-gawa and the R. Sata-gawa, it is known a stream lost "Segire" phenomenon is generated. Especially, in the R. Sata-gawa, the sections are observed where the "Segire" constantly occur during non-irrigation period. The river water is carrying out the recharge of the groundwater directly from the shape of a groundwater table and the result of a long-term groundwater-level observation. The "Segire" is influenced to the amount of recharges from the river. The conditions of recharge are turned by change of section stream-flow. The section stream-flow relates to the hydrogeologic structure of the alluvial fan closely (Miyazaki et. al., 2008).

The relation of the river water and the groundwater in November 2007 are shown in Fig.4 by piling up an increase and decrease section of stream-flow, the "Segire" section, the spring water part, and groundwater contour map.

Fig.4 shows the following phenomenon:

- In the R. Sata-gawa, the transfer to the groundwater from the river water at the left bank is in the upstream section of "Segire".
- The river water of the R. Koishihara-gawa flows into the left bank near the Amagi city area, and also are gushing to the R. Sata-gawa.
- On the right bank, the river water of the R. Koishihara-gawa is gushing to the water source of the R. Jinya-gawa, etc.

These phenomena indicate strongly the relationships of the river water and groundwater in the Chikugo-gawa alluvial fan.

Regarding the "Segire", it is described as follows in the first volume of the *Regional Geography of Amagi*.

- In the R. Sata-gawa near Itaya of alluvial-fan middle-reach region, an anhydrous state continues at the late autumn and the early spring when the precipitation decreases. The people in the village are calling its stream the Japanese radish stream "Daikon-gawa" because they cannot wash Japanese radish "Daikon".

And, this tradition of the "Daikon-gawa" is handed down as "Kobo Daishi" tradition. And considering its age, the "Segire" might be a natural phenomenon occurred for a long time.

Egawa Dam and Terauchi Dam have achieved the buffer function to the surface runoff through the supply of the maintenance flow discharge and irrigation water since the dams are constructed. Accordingly, it is considered that the dams have played the role to shorten the "Segire" period and to keep making the water environment in the downstream to be healthy.

5. Future Water Environment and Water Management

As compare with the groundwater contour map in 1961 and in present, the groundwater table is lowering by about 2-3m near a center of alluvial fan in present. This explains the drying-up of the groundwater of these days, such as decrease of spring water and flowing wells. A decrease in the amount of groundwater recharges by the advancement of urbanization and an increase in the amount of the pump discharge from groundwater, etc. are

Model of Chikugo-gawa Alluvial Fan. (In This Monograph)

Miyazaki, S., Hasegawa, S., Nishihira, H., Hanamura, O., Makino, R., Matsumoto, T. (2008): The Hydrogeological Structure of the Chikugo-gawa Alluvial Fan. (In This Monograph)