EFFECT OF LANDFILL ON LOCAL HYDROGEOLOGICAL PROCESS

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The selection of a reasonable landfill site is very important for “safe” disposal as well as sustainable development of the urban areas. Many negative impacts have been created from the landfill sites such as groundwater pollution, surface water pollution, air pollution and human health. Among of these, groundwater suffers extremely serious problems due to difficulties of prediction and treatment. The change of landuse is considered as the determinate factor to evaluate how groundwater environment is influenced. As such an example, *A.* landfill in *B.* City, Japan was selected as the case study. The authors attempted to evaluate the effects of this landfill on local hydrogeological process. The groundwater flow model was coupled with the recharge model to solve the partial differential equation of groundwater flow. The study demonstrated that the significant change of the groundwater table and spring rates between the present and past conditions was obtained.

Key Words **:** *spring rate, landfill, hydrogeological process, groundwater behavior*

1. INTRODUCTION

During the past several decades, computer simulation models for analyzing flow of groundwater have played an increasingly important role in the evaluation of alternative approaches to groundwater development and management. The underlying philosophy of the simulation approach is that an understanding of the basic laws of physics and an accurate description of the specific system under study will enable an accurate quantitative understanding of cause and effect relationships. This quantitative understanding of these relationships enables forecasts to be made for any defined set of conditions. Even though model results (if developed competently and objectively) are imprecise, they represent the best decision making information at the time the results are made [1).

The partial differential equation of groundwater flow was solved by many researchers. Several numerical models are available for simulating the movement of water in variably saturated porous media[2)]. Among of them, only a few can simulate groundwater flow in unconfined aquifer with complex boundary conditions like seepage face[3)] and even fewer can also consider sloping or irregular boundaries that are quite common at most hydrogeological interface.

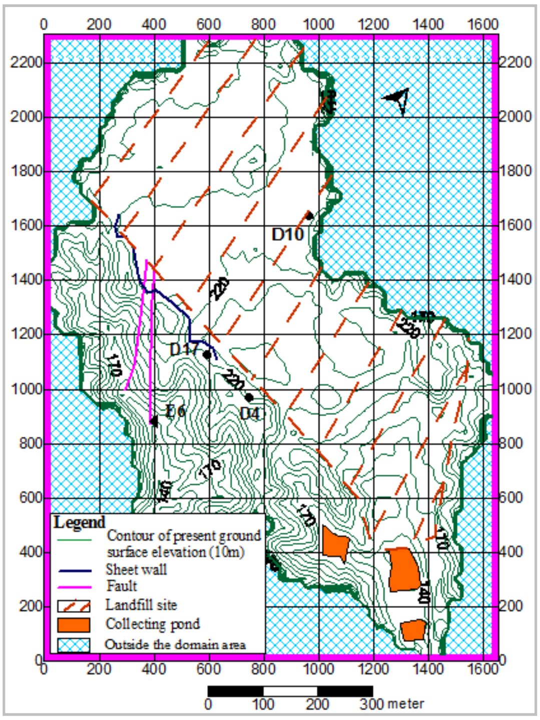

Fig.1 Study location

Besides, many researchers have examined the groundwater quality on the landfill sites[4]. Through the authors' knowledge, rare of the variably saturated models have been applied numerical simulations of groundwater behavior in the unconfined aquifer in response to complex boundaries such as collecting pipe, no flow boundaries, spring, stream, rainfall, and evapotranspiration.

Fig.1 shows *A*. landfill which is located in *B*. City, Japan. This landfill was inaugurated in 1970s. The maximum area of the landfill is 100 hectares. The planned landfill volume is about 20 million cubic meters. The function of this landfill is to dispose the final domestic waste such as domestic garbage, swept refuse from streets. The domain boundaries have been almost assigned as the impermeable boundary conditions. Inside the domain area, there are three waste collecting ponds which are regarded as the impermeable boundaries. A concrete sheet wall system was constructed in order to prevent the leakage of the leachate of the landfill. The topography presents the deep slope of ground surface. Therefore, many springs are found in the study area. Understanding of the behavior of groundwater flow is the most important in order to make the landfill "safety" with the surrounding environment. The authors attempted to evaluate the effects on hydrogeological process outside the landfill site, specifically spring rates and its location.

The main objectives of this study are: (1) to solve the groundwater flow equation by using finite difference method so that it can simulate the groundwater flow in unconfined aquifer, (2) to provide the physical observed data to demonstrate the validation of groundwater flow results, (3) to evaluate effects of landfill on groundwater behavior and spring rates.

2. DEVELOPMENT OF THEORY

(1) Groundwater flow equation

Isotropic and heterogeneous two dimensional groundwater flow equation assuming constant water density can be described by partial differential equation, as Eq.(1):

$$n\frac{\partial h}{\partial t} = \frac{\partial}{\partial x}\left(kb\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(kb\frac{\partial h}{\partial y}\right) + Ra(x,y,t) \qquad (1)$$

where, $h(x,y,t)$[L] is elevation of groundwater table, k [LT^{-1}] is permeability in isotropic media; $Ra(x,y,t)$ [LT^{-1}] is the recharge rate which is calculated from rainfall, rainwater interception and potential evapotranspiration[5].

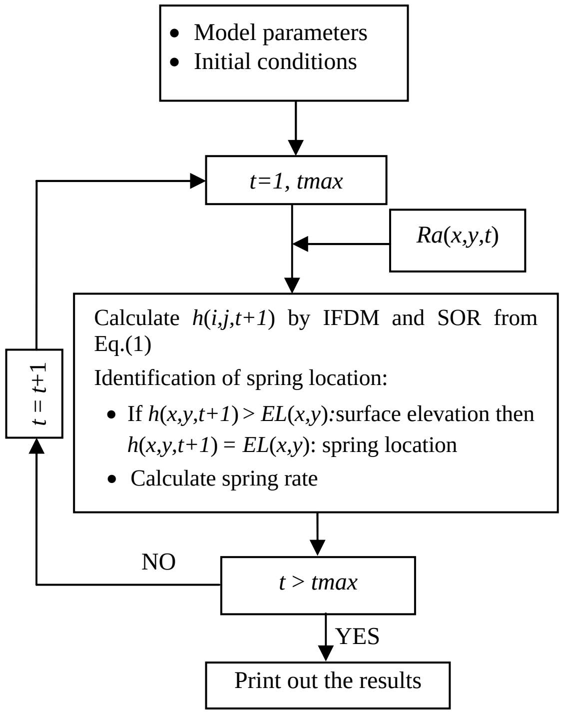

Fig.2 Simulation flow chart

Note that b [L] is b=$h(x,y,t)$-$z(x,y)$, $z(x,y)$ [L] is elevation of bedrock. n is effective porosity.

(2) Model process

The groundwater flow simulation was conducted for the unconfined aquifer. It should be emphasized that a sufficient understanding of natural groundwater flow without disturbances by human activities is indispensable in order to represent the essential changes and the management of the landfill. In the present paper, the mathematical model was employed to make a quantitative analysis.

Fig.2 shows the scheme of the performance of simulation. IFDM and SOR are the abbreviations of an implicit finite difference method and an iterative successive over relaxation, respectively. The most important step is the collection of hydrogeological data used in the applied numerical solution. Another important component is the assumption on the hydrogeological boundaries of the simulation domain. Besides, the modeling of faults and sheet walls constructed to inhibit the groundwater flow toward the outside of the landfill area were crucial. The comparison of observed and calculated values is necessary to make the model more precise.

(3) Conceptual model

Fig.3 shows six boundaries discussed in detail below.

a) Groundwater divide

Groundwater divide is a boundary between two adjacent groundwater basins, which is represented by high point in the water table. In the present paper, groundwater divide was assumed as the impermeable boundary conditions where no groundwater flow takes place.

b) Spring

Springs are present where the groundwater table intersects the ground surface. Springs discharge groundwater to surface water from groundwater flow system.

Being exposed to the atmosphere, the pressure along a seepage face is atmospheric pressure, and; hence, the boundary condition along such surface is assigned equal to the surface elevation[6]. The outlet threshold where groundwater flows out to atmosphere is at fixed elevation. Water emerges from the aquifer into the atmosphere at that fixed elevation, thus, this is a boundary of a fixed piezometric head. Sometimes a groundwater table exists above the threshold which may vary with the rate of flow. However, when the piezometric heads in the aquifer in the vicinity of the spring are lower than this threshold, the spring dries up and ceases to serve as a boundary to the flow domain. It is thus a boundary of fixed potential only as long as the water heads in the vicinity are above the spring outlet: they drop toward the spring (=loss of head in the converging flow in the aquifer)[6].

c) Impermeable walls and collecting ponds

Impermeable walls were constructed to shield the waste water flow from the landfill to the outside of the unconfined aquifer. The length of these walls is more than 900 meters. The depth of walls is 80 meters. Collecting ponds have been built for collection and treatment of leachate. These walls and collecting ponds play a role as impermeable boundaries.

d) Fixed boundaries and streams

These are downstream boundaries in the southern part of the model area. On this boundary, groundwater is continuous with groundwater flow outside the domain area. The streams in the calculated domain area were also treated as a fixed boundary whose groundwater was set equal to the ground surface elevation.

e) Faults and collecting pipes

In the study site, the permeability near by the faults is assumed not significant different from that of surrounding zones because their hydrogeological roles have not been significantly analyzed yet.

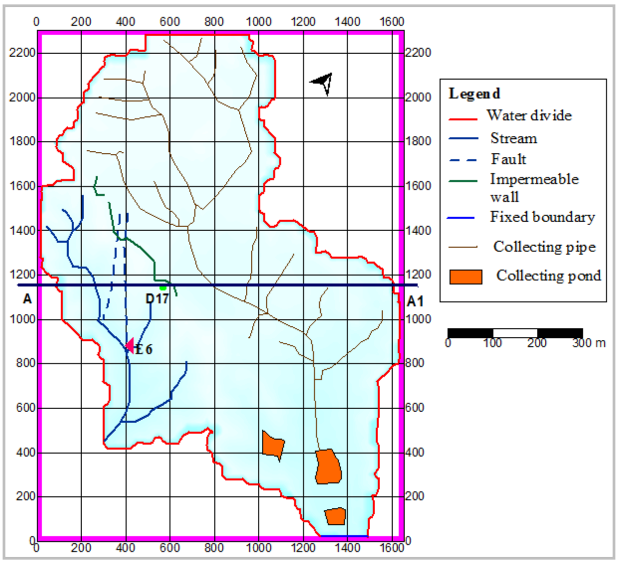

Fig. 3 Conceptual model

The collecting pipes were constructed to collect the leachate from the entire landfill site. The pressure of collecting pipes was assumed equal 0.

f) Recharge rate of rainwater

The time dependent recharge rate is modeled by *Ra*(*x*,*y*,*t*) in Eq. (1). Recharge rate is calculated by the rainwater recharge model[5]. The model includes the calculation of evapotranspiration and recharge of rainfall taking account the landuse factors which are related to the coefficient of surface runoff. In the study area, there are two types of landuse such as forest and landfill site where runoff coefficients are 0.3 and 0.7, respectively. The effect of rainwater interception was also considered by[5]. The daily and hourly rainfall of the past and the present conditions for 5 years were recorded, respectively. The recharge model was applied for two periods: for the past conditions, from 1967 to 1971 and for the present conditions, from 2003 to 2007 with hourly time series. **Fig.4** shows the recharge rate calculated by recharge model.

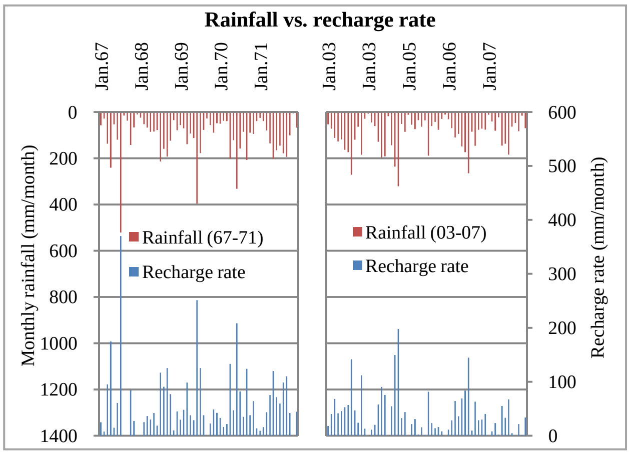

Fig.4 Rainfall and recharge rate

In the groundwater flow model, the extinction depth was set 1.5m to allow the water uptake by trees. Additional evapotranspiration from the groundwater table will not occur on the groundwater table if the groundwater table is deeper than the extinction depth. In the study site, the permeability is different from natural site ($5.2x10^{-4}$m/s) to landfill site ($8.6x10^{-4}$m/s). The permeability was adopted by measured data at the study site.

3. NUMERICAL MODEL

The transient groundwater flow Eq.(1) is solved by an implicit finite difference method using an iterative successive over relaxation technique.

The selection of grid size depends on the computer capacity and the hydrogeological conditions. The maximum of length and width of the selected area is 2,305m and 1,650m, respectively. The model domain is divided into irregular discretized grid system for *x* and *y* direction. The smallest and largest grid sizes are 2m and 10m, respectively in both directions. The grid size gradually changes from 2m to 10m. The densest is closed to the sheet walls and faults to examine their effects on groundwater flow. The bedrock elevation is 80m above sea level. The time interval of model is 1 hour.

4. MODEL RESULT AND DISCUSSION

(1) Calculated and observed data

a) Groundwater table observation

The present paper paid attention mostly on the examination of the changes of spring rates due to the changes of landuse. The model simulated also the hydrogeological process such as groundwater fluctuation in the landfill site.

In order to verify the accuracy of the model quantitatively, the observed and calculated groundwater table were compared for the present case (2003-2007). Then, after the confirmation, the groundwater flow model under the past conditions was simulated by applying the validated model of the present conditions. Three observation wells in the study area were used to verify the accuracy of the groundwater flow model.

Figs.5, 6 and **7** are the comparisons of measured and calculated groundwater tables of wells D4, D10 and D17 in **Fig.1** for time period from October, 2005 to March, 2006. From these figures, the measured and calculated groundwater tables show a good agreement for the period. Moreover, the groundwater table fluctuations corresponded to the changes of rainfall in the study area.

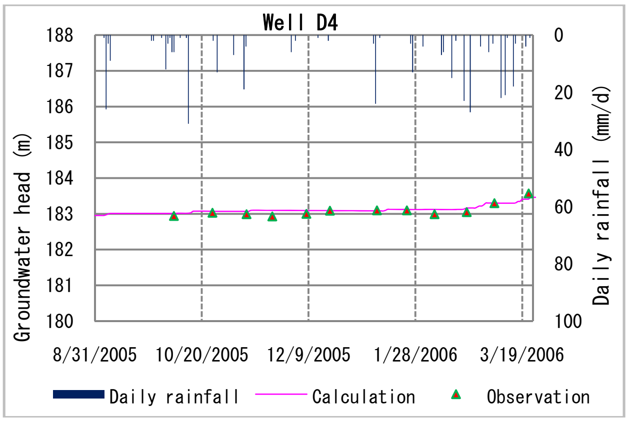

Fig.5 Comparison of observed and calculated groundwater table at well, D4

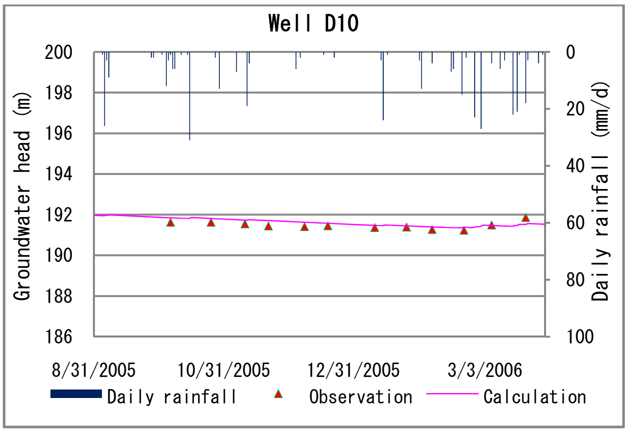

Fig.6 Comparison of observed and calculated groundwater table at well, D10

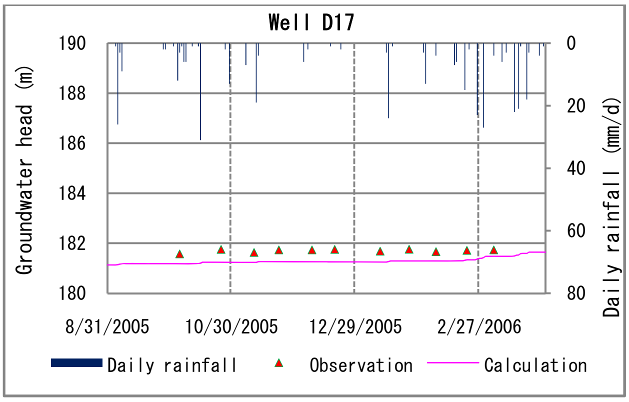

Fig.7 Comparison of observed and calculated groundwater table at well, D17

The fluctuation is not so high because these wells are closed to landfill site where the coefficient runoff is 0.7. Therefore, the rainwater infiltration is small. From these considerations, the model can be used as a proto tool to predict groundwater flow for future water management of the waste site.

b) Spring rate observation

In the study area, only one spring was observed for the period from October, 2005 to October, 2006. The spring location, E6, is nearby the stream in the calculated area shown in **Figs.1** and **3**.

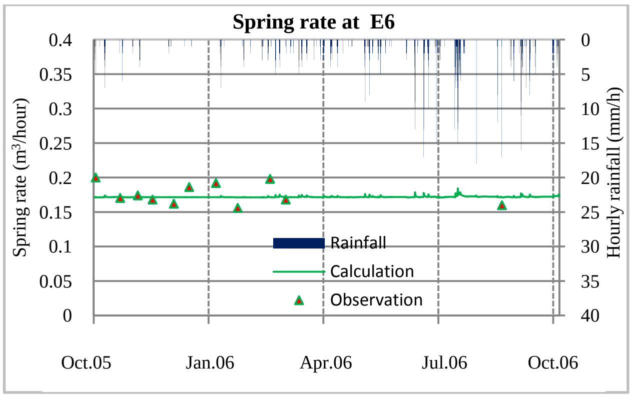

Fig.8 Comparison of observed and calculated spring rate at E6

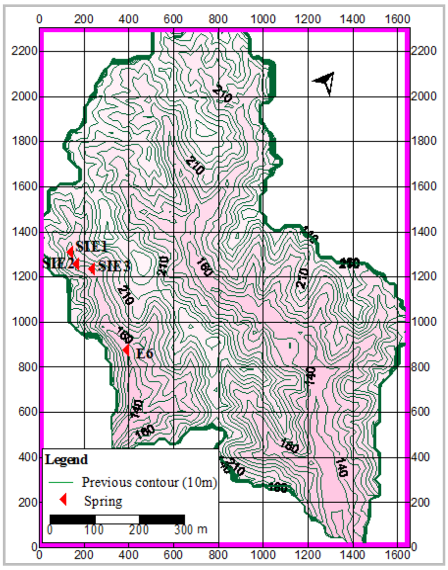

Fig.9 Spring locations in past conditions (before 1971)

The average of observed values is in a good agreement with the calculated values as shown in **Fig.8**. This figure shows hourly fluctuations of the spring rate at E6.

Therefore, the groundwater flow simulation was also applicable to evaluate the change of spring rates due to the change of ground surface by the landfill. **Fig.9** shows the location of three springs (SIE1, SIE2, and SIE3) which will be discussed on their spring rates in detail in the following section. These springs are nearby the sheet wall and affected significantly by the changes of the elevation of ground surface. **Fig.9** also shows the topographic conditions before constructed the landfill.

(2) Groundwater table comparison

Fig.10 demonstrates the cross section A-A1 of the landfill including the observation well, D17 as shown in **Fig.3**. In the present study, the effects of the collecting pipes and impermeable walls were considered.

As mentioned above, the collecting pipes were assumed to drain the leachate. Even though the collecting pipes are functioning, groundwater table still rises up.

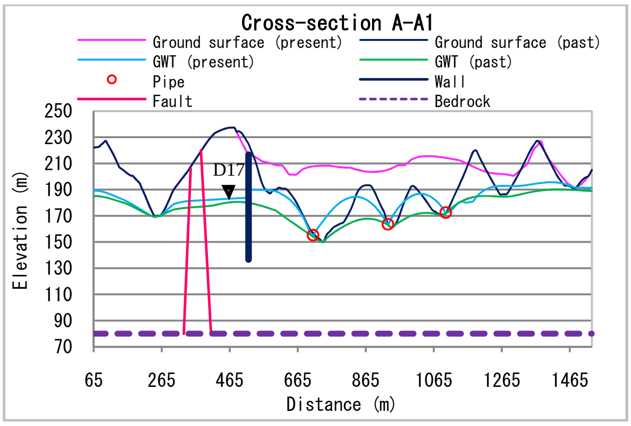

Fig.10 Groundwater tables (present and past conditions)

This is explained that the landfill captures rainfall. Hence, the groundwater table is maintained high at a distant place from the pipes. The groundwater table inside the landfill and close to the sheet wall is higher than that of outside. The faults do not affect significantly on groundwater table under the assumption of the permeability is not significantly different from surrounding zones.

Therefore, it is possible for groundwater to transport the waste water to the outside of the landfill even though the sheet walls were constructed. However, this result has been obtained under the assumption that the sheet walls did not sufficiently reach the base rock. The changes of ground surface elevation should be considered as a key factor before constructing the waste site.

(3) Spring rate calculation

Due to the waste dump process, some springs disappeared in the old valley. At present, this valley is already the landfill site. Outside the landfill, the hydrogeological conditions are not changed. However, the rise of ground surface at the landfill site induced the change of groundwater table consequently, induced the change of spring rate.

Figs.11, 12 and **13** show the spring rates corresponding reasonably to the rainfall in two simulated periods (1967-1971 and 2003-2007). The spring rates are smaller in the dry season and larger in the rainy season. The springs, thus, can be dried up in the dry season (**Figs.11** and **12**). In other words, these springs will disappear seasonally.

Obviously, **Figs.11, 12** and **13** show the spring rates under the past conditions were smaller than those of the present conditions even though the rainfall was higher. As these figures show even though in June, 1970, the rainfall (332.5mm) was greater than that (174mm) in June, 2006, the spring rates, however, were smaller. The explanation is due to ground surface elevation increases by waste dump process, the landfill captures rainfall and raise up groundwater.

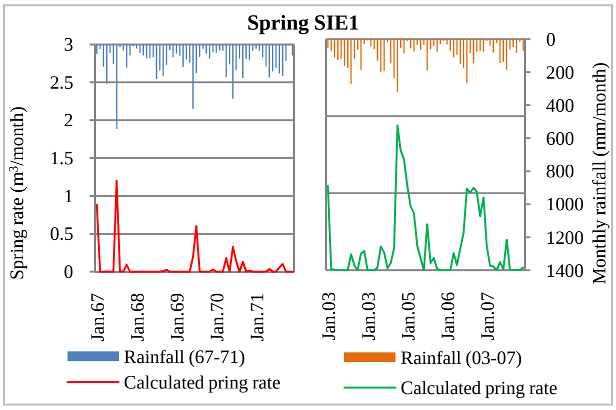

Fig.11 Comparison of spring rate at SIE1

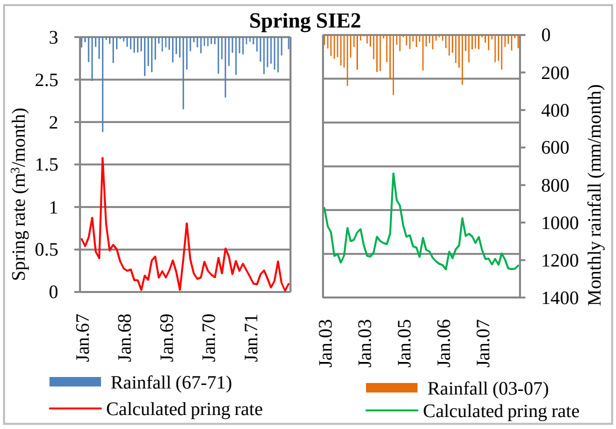

Fig.12 Comparison of spring rate at SIE2

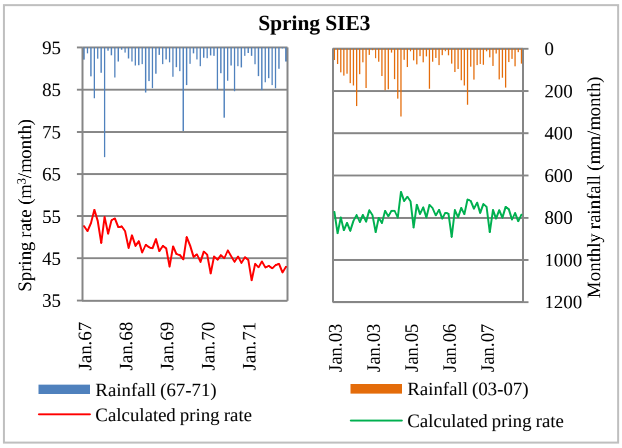

Fig.13 Comparison of spring rate at SIE3

Therefore, the discharge rate closed to landfill site increases. There is a possibility that contaminated groundwater leaks out from the landfill site.

5. CONCLUSION

In order to evaluate the changes of the local hydrogeological processes, the two dimensional horizontal groundwater flow was simulated for the area including the landfill site. To represent the precise groundwater flow, an irregular grid system was adopted. Various hydrogeological parameters and appropriate boundary conditions were assigned. The detailed comparison of measured data and numerical solution showed the good agreement of groundwater table fluctuation.

It was demonstrated that the change of landuse changed not only the groundwater table but also the spring rates. The landfill captures rainfall to perhaps raise groundwater table and increase spring rate. The results also show that the faults do not affect significantly on groundwater table when the permeability along the faults is not high.

The leachate from the inside of the landfill may take place under the sheet wall due to the rise of groundwater table in the landfill. From the observation data, the quality of stream water seeped out from groundwater at outside the landfill remains within the standard of water quality. These calculated results were obtained under the assumption that the collecting pipes function to drain the leachate. It is significant to check the function of collecting pipes.

Although the spring rates are significantly affected by the rainfall, the spring rates under the present conditions were greater than those under the past conditions. Therefore, the changes of landuse are very important factors for the spring rates nearby the landfill.

In this study area, a development of three dimensional groundwater flow model seems to be indispensable to get better understanding of the effects of the landfill on the local scale hydrogeological process. Besides, mass transport model is recommended to simulate the behavior of pollutants as a next step.

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