Proceedings World Geothermal Congress 2015
Melbourne, Australia, 19-25 April 2015

Advanced Software for Harmonious Geothermal Development with Nearby Hot Spring

K. Yasukawa, T. Noda, H. Tokita, N. Uchiyama, O. Matsubayashi and K. Sakaguchi

Renewable Energy Research Center, AIST, 2-2-9 Tameikedai, Koriyama city, Fukushima 963-0215, Japan

e-mail: kasumi-yasuakawa@aist.go.jp

Keywords: geothermal system, hot springs, interference, monitoring, simulation, system integration, software

ABSTRACT

Possible interference of geothermal development on nearby hot-spring is a big issue in Japan. Although problems with hot-spring owners may be peculiar in Japan, interference on surrounding natural hydraulic system may be a common issue around the world. To develop an integrated geothermal reservoir operation system for adequately controlled utilization with nearby hot springs, a three-year research project "Development of geothermal reservoir management system for harmonious utilization with hot spring resources" was conducted from 2010 to 2012. A proto-type software, which helps "1) type analysis of hydrological and thermal relations between a hot spring and a geothermal reservoir" and "2) time series analysis of correlation between hot spring monitoring data and other data such as meteorological data and/or geothermal power generation data", was developed in the project. It may help local hot spring owners to understand the relation between their hot spring and the geothermal reservoir using their own data. Since the software had not reached a level of practical use, some improvement has been done after the described project. This paper introduces the function of the improved software showing the changes from the proto-type software. The major improvements are made for subroutines of both type analysis and time series analysis. For type analysis, the algorithm of basic judgment is simplified to cover regions with fewer kinds of data sets so that a user may obtain a rough judgment, even with limited data. For time series analysis, time lag in correlation of two different data series is introduced although each data series has different sampling interval. The software is thus improved to be used in real cases in which full set of monitoring data is not available but some data is available.

1. INTRODUCTION

In spite of its rich geothermal resources, no geothermal development has been done in Japan for a decade mainly because of legal, economical and social problems. The three major reasons are; 1) regulations on natural parks, 2) development risk and cost and 3) negative campaign by hot spring owners. The former two problems were mitigated after a nuclear accident in 2011 with support of the federal government, which changed several regulations and established new subsidies to promote geothermal development. The remaining problem is the third one. In some cases geothermal developments have been delayed or stopped due to the concerns of local residences that their hot springs may be interfered by geothermal exploitation. Although problems with hot-spring owners may be peculiar in Japan, interference on surrounding natural hydraulic system may be a common issue around the world.

Considering such interference on nearby environment, logically there should not be a problem if the amounts of natural heat and fluid recharge and utilization are well balanced or there exist a solid impermeable zone between a geothermal reservoir and its neighboring hydraulic systems. In order to materialize this idea, we conducted a three-year research project "Development of geothermal reservoir management system for harmonious utilization with hot spring resources" in FY2010-2012 and applied the system to model fields. The purpose of this study was to identify a method to exploit geothermal reservoir without interference on nearby hot springs. If unavoidable interference is suggested by this management system in advance, a development may be stopped.

Figure 1 shows the flow diagram of the geothermal reservoir management system applied in this project (Yasukawa et al., 2013). Beginning with literature survey and site survey of a target field, a geothermal structure model and a fluid flow model are constructed. Based on these models, the influence of geothermal development on hot spring is evaluated. If there is a possibility of influence, a numerical fluid flow simulation should be done to find out development conditions to avoid/minimize the influence. If there is no possibility of interference, the numerical simulation can be skipped. Monitoring data should be used for history matching and to improve geothermal structure and fluid flow models.

The three technical components in Figure 1, geothermal modeling, monitoring and numerical simulation, are basically identical to those of normal geothermal exploration. A unique point of our system is that all those three components include nearby hot springs. In addition to these technologies, a proto-type system support software was developed in this project as shown in Figure 1. This software has two functions: 1) Type analysis of relation between geothermal reservoir and hot spring resources, and 2) Time series analysis of hot spring data to detect the influence of geothermal exploitation. Type analysis may be used to get a rough idea of the geothermal model of the target site and to predict possible influence of geothermal development on hot springs. Time series analysis may be applied to inspect if changes in hot spring characteristics are possibly due to geothermal fluid production or not.

Both geothermal modeling and time series analysis are usually done by highly experienced geothermal experts, normally belonging to the geothermal developer's side. However, local hot spring owners may prefer to know the situation with their own data, rather than with developer's data. Our prototype software was aimed to help such local hot spring owners to understand the situation of their own hot springs and to help decision making by all stakeholders of geothermal development projects. Although a detailed analysis by a neutral expert would be essential at some stage, our software may provide basic information in the early stage of a geothermal development project. Since the prototype software had not reached a level of practical use, some improvement has been done after the three-year-project. This paper describes the functions of the prototype software and its improvement after the project.

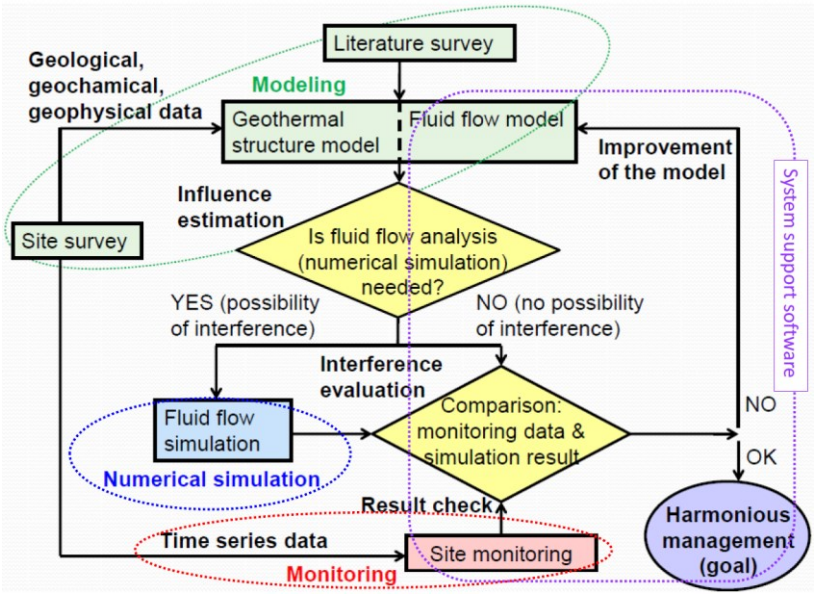
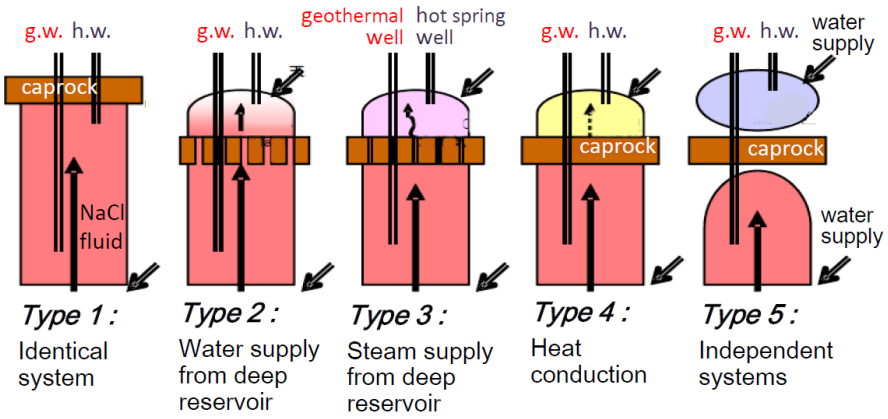


Figure 1: Flow diagram of the geothermal reservoir management system for harmonious utilization with hot spring resources (Yasukawa et al., 2013).

2. TYPE ANALYSIS

In the "Development of geothermal reservoir management system for harmonious utilization with hot spring resources" project, the relation between geothermal reservoir and hot spring aquifer(s) were categorized into five types as shown schematically in Figure 2. In Type 1, the geothermal reservoir and the hot spring aquifer are identical systems, only well depths are different. In Type 2, the cap-rock between the hot spring aquifer and the geothermal reservoir is rather permeable so that hot spring water is partly supplied from the deep reservoir. In Type 3, water cannot permeate the cap-rock but steam and gas can so that gas content in the hot spring is supplied from the deep reservoir. In Type 4, the cap-rock is so impermeable that only heat conducts from the deep reservoir. In Type 5, the geothermal reservoir and the hot spring aquifer are spatially separated, independent systems.

In cases of Type 1 and Type 2, a geothermal development may interfere with hot springs while in cases of Type 3 and Type 4 a development may not cause serious affect. In case of Type 5, development should not have any affect at all. Lower part of Figure 2 shows possible influence of geothermal development on hot spring aquifer for each type.



Possibility of influence	Large	Medium	Small	Very small	None
Possible major change	Flow rate	Flow rate	Chemistry	-	-
Possible minor change	Temperature	Chemistry	Temperature	Temperature	-
Conditional change	Chemistry	Temperature	Flow rate		
	(If reinjection is conducted)		(If phase change in deep reservoir occurs)		

Figure 2. Relations between geothermal reservoir and hot spring aquifer (explanation added to GRSJ, 2010).

Normally, type analysis may be done through geothermal structure and fluid flow modeling with detailed geological, geochemical and geophysical surveys. However, a simplified type analysis may be done based on geochemical data of the hot spring(s),

supposing that different subsurface structure may cause different chemical characteristics of hot springs. Table 1 shows the relation between geochemical characteristics of hot spring and the above described types in case of volcanic resources (Noda, personal contacts). Possible interference may be predicted in advance of a geothermal development by such type analysis based on hot spring data. Therefore, since type analysis based on geochemical data is rather simple, we developed a proto-type software, which helps "type analysis of hot spring and geothermal relation." The type analysis is based on criteria shown in Table 1.

Table 1. Characteristic of hot springs for Types 1 - 5 shown in Figure 1 in case of volcanic resources.

Type	Hot spring's relation to geothermal reservoir	Interference from deep reservoir (Possibility)	Hot spring's chemical character
Type 1	Identical system	High	Cl^- dominant (>80 % of anion), >90℃
Type 2	Water supply from deep reservoir	Medium	Cl^- type
Type 3	Steam supply from deep reservoir	Low	SO_4^- type
Type 4	Heat conduction	Very low	Total ions < 1000 mg/L, >25℃
Type 5	Independent system	None	No particular type (independent)

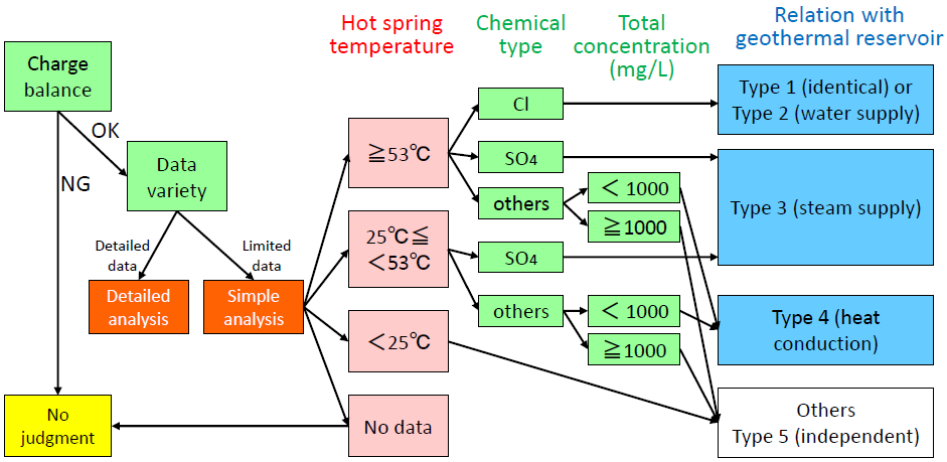


Figure 3: Flow chart of type analysis in a proto-type system support software

Since the proto-type software which was developed in the three-year-project needed some improvements for practical uses, a new version of the software has been done in a separate project. For the type analysis, the algorithm of basic judgment is simplified to cover regions with fewer data kinds so that a user can obtain a rough judgment even with a limited data. For a data set in which charge balance is not appropriate, the proto-type software does not proceed with the analysis while the updated software proceeds with the analysis but shows caution because charge balance is inappropriate. In the updated software, Type 5 is separated from Type 4 by distance between the center of geothermal reservoir and hot spring aquifer as well as total concentration. The software is thus improved to be used in real cases in which whole sets of chemical data are not available but some data is available.

3. TIME ANALYSIS

For hot spring monitoring, most desirable monitoring parameters are temperature, pressure/flow rate/water level and concentrations of major chemical components. However, for a simplified low-cost monitoring, electric conductivity is recommended to be monitored instead of multiple chemical components. Figure 4 shows an example of hot spring monitoring conducted in the three-year-project. Decline of electric conductivity is due to scaling near the sensor. Since such monitoring of a hot spring has not commonly been done in Japan, it was a trial case and improvement of the measurement system is needed. Nevertheless, slight decrease of water level is observed, suggesting that the pumping (discharge) rate of the hot spring is not sustainable. Note that temperature and water level changes daily due to pumping.

The purpose of time series analysis of hot spring monitoring data is to detect predominant change after beginning geothermal fluid production. The major functions of the time series analysis of the software are a) correlation analysis with other data such as climate data and b) Student's T-test with a particular event. Student T-test can be applied to detect interference of geothermal power generation on a hot spring by detecting a trend change after geothermal fluid production. The concept of T-test analysis is shown in Figure 5.

The software also has a function to show the range of the natural perturbation level of hot spring properties. As shown by Figure 4, it is important to understand the natural perturbation level of hot spring properties.

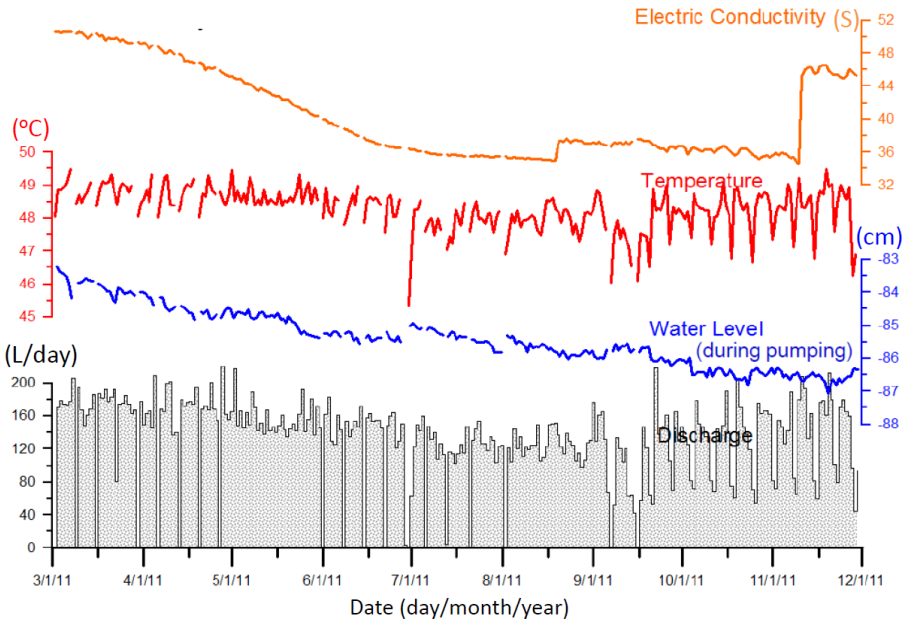


Figure 4: A nine-month-long monitoring of a hot spring in Hachijojima Island, Japan (AIST, 2012).

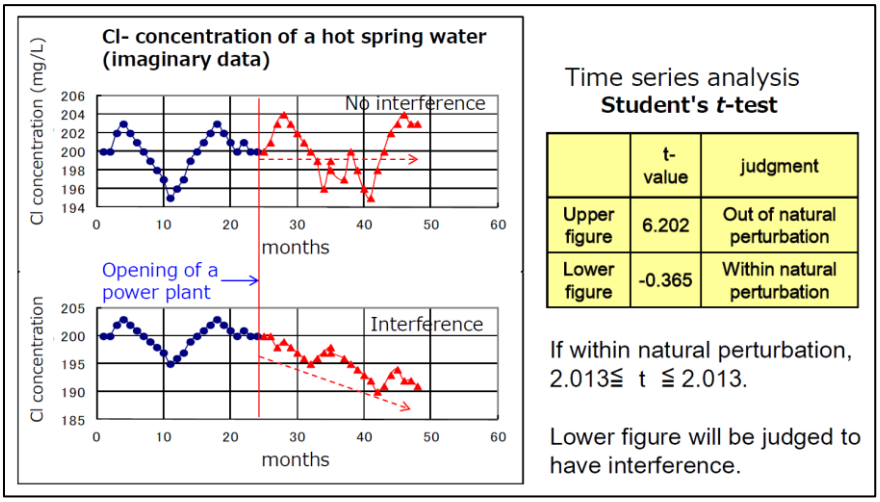


Figure 5: Concept of interference evaluation by time series analysis with Student's T-test.

For the updated version of the software, time lag of two different data series is introduced for correlation analysis although each data series has different sampling interval and serious interpolation is needed. In many cases, data sampling interval changes even for one type of data. The software is thus improved to be used in real cases in which densely taken monitoring data is not available but some data is available.

4. CONCLUSIONS

A proto-type software, which helps "1) type analysis of hydrological and thermal relations between a hot spring and a geothermal reservoir" and "2) time series analysis of correlation between hot spring monitoring data and other data such as meteorological data and/or geothermal power generation data" was developed in the three-year project, "Development of geothermal reservoir management system for harmonious utilization with hot spring resources." It may help local hot spring owners to understand the relation between their hot spring and the geothermal reservoir using their own data. Since the software had not reached a level for practical use, some improvement has been done for both type analysis and time series analysis after the described project. For type analysis, the algorithm of basic judgment is simplified to cover geothermal sites with fewer kinds of data so that a user may obtain a rough judgment even with a limited data. For time series analysis, time lag in correlation of two different data series is introduced although each data series has different sampling interval. The software is thus improved to be used in real cases in which full set of monitoring data is not available but some data is. Applications of the software to real field data will be our next step and such application is necessary for more improvement of the software.

ACKNOWLEDGEMENT

The “Development of geothermal reservoir management system for harmonious utilization with hot spring resources” project is funded by the Ministry of Environment, Japan and conducted in cooperation with AIST, Hirosaki University, Tokyo Electric Power Services Co., Ltd., Nittetsu Mining Consultants Co., Ltd. and Municipal of Hachijo Town, Tokyo, with a support of Municipal of Minamiizu Town, Shizuoka. The modification of the software has been done after the project in collaboration between AIST and West Japan Engineering Co. Ltd., funded by AIST. The authors would like to express appreciation to all those who are involved in or supporting these projects.

REFERENCES

AIST: FY2011 Annual Report on Development of an advanced geothermal reservoir management system for the harmonious utilization with hot spring resources (in Japanese), National Institute of Advanced Industrial Science and Technology, Tsukuba, (2012).

GRSJ: “For harmonious co-existence of hot springs and geothermal developments,” Geothermal Research Society of Japan (in Japanese) (2010).

NEF: “Manual for evaluation of effects of geothermal exploitation on hot spring and groundwater systems,” New Energy Foundation (in Japanese)(1999).

Yasukawa, K., Sakaguchi, K., Tosha, T., Uchida. T., Sasaki, M., Ishido, T., Yanagisawa, N., Nawa, K., Sugihara, M., Machida, I., Komazawa, M., Matsubayashi, O., Ioka, S., Matsuyama, K. and Noda, T.: Results of the “harmonious utilization with hot spring resources” project, Proceedings, AGS2013, Tagaytay, Philippines (2013).