# RESULTS OF THE "HARMONIOUS UTILIZATION WITH HOT SPRING RESOURCES" PROJECT

Kasumi YASUKAWA[1], Keiichi SAKAGUCHI[1], Toshiyuki TOSHA[1], Toshihiro UCHIDA[1], Munetake SASAKI[1], Tsuneo ISHIDO[1], Norio YANAGISAWA[1], Kazunari NAWA[1], Mitsuhiko SUGIHARA[1], Isao MACHIDA[1], Masao KOMAZAWA[1], Osamu MATSUBAYASHI[1],Seiichi IOKA[2], Kazuo MATSUYAMA[3], Yusaku YANO[1] and Tetsuro NODA[1]

[1]Institute of Geo-resources and Environment, AIST, 1-1-1 Higashi, Tsukuba city, Ibaraki 305-8567, Japan
[2]North Japan Research Institute for Sustainable Energy, Hirosaki University, 2-1-3 Matsubara, Aomori city, Aomori, 030-0813, Japan
[3]Tokyo Electric Power Services Co., Ltd., 3-3-3 Higashi-Ueno, Taito-ku, Tokyo 110-0015, Japan
e-mail: kasumi-yasuakawa@aist.go.jp

## ABSTRACT

A three-year research project was conducted in FY2010- 2012 to develop an integrated geothermal reservoir operation system for adequately controlled utilization and to apply the system to model fields. The purpose of this study is to prove that geothermal exploitations can be performed without interference to nearby hot springs. The project consists of three parts: Geothermal system modeling, Development of monitoring techniques, and Estimation of reservoir change by numerical simulation, all including nearby hot spring aquifers. The integrated geothermal reservoir operation system was applied to two model fields, the Hachijojima and the Minami-Izu geothermal fields. As results, the relation between geothermal reservoir and hot spring aquifer(s) in the Minami-Izu field was identified as "identical system" or "water supply from deep reservoir" in which a geothermal development may affect on hot springs, while that in the Hachijojima field was identified as "identical systems" in which a develop may not affect. A proto-type system support software, which helps "type analysis of hot spring and geothermal relation" and "time series analysis of hot spring monitoring data" was also developed. Since the software needs some improvements for practical use, improvement will be done in a separate project.

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

## 1. INTRODUCTION

No geothermal development has been done in Japan for a decade mainly because of legal, economical and social problems in spite of its rich geothermal resources. The three major reasons are; 1) regulations on development in natural parks, 2) resource risk and cost and 3) negative campaign by hot spring owners. The former two problems were mitigated after nuclear accident in 2011 by supports of the federal government which changed several regulations 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. Logically there should not be a problem if the amounts of natural heat and fluid recharges and utilization are well balanced, or, there exist a caprock between hot spring and geothermal reservoirs. In order to prove this, a three-year research project was conducted in FY2010- 2012.

The aims of the project are to develop an integrated geothermal reservoir operation system and to apply the system to model fields. The system consists of three parts, geothermal modeling, numerical simulation and monitoring. All these three technical components are basically identical to those of normal geothermal exploration, but unique point of our system is that all three components include nearby hot springs. We considered five types of relation between hot spring and geothermal reservoirs, which are; Type 1: identical system, Type 2: water supply from deep reservoir, Type 3: gas supply from deep reservoir, Type 4: heat conduction from deep reservoir and Type 5: independent systems (as shown in Figure 1). Possible impacts of geothermal development on nearby hot springs would be identified accordingly to these types. The integrated geothermal reservoir operation system was applied to two model fields, the Hachijojima and the Minami-Izu geothermal fields. A proto-type system support software, which helps "type analysis of relations between hot spring and geothermal reservoirs" and "time series analysis of hot spring monitoring data" was also developed.

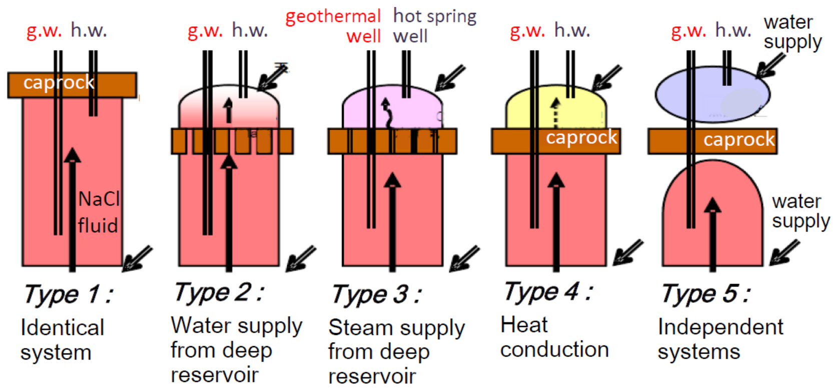


Figure 1: Five types of relations between geothermal reservoir and hot spring aquifer.

Figure 2 shows the locations of two model fields of this study, Hachijojima and Minami-Izu geothermal areas, respectively. Various field surveys and monitoring had been done in the two model fields to apply the integrated system and to identify types of relation between geothermal reservoir and hot spring aquifer as shown in Figure 1. In the Hachijojima island, a commercial 3,000 kW geothermal power plant has been in operation since 1999 (see Figure 4) while no geothermal development has been done in Minami-Izu. Therefore the amounts and kinds of available data are quite different for these two fields. Thus our integration system shown in Figure 3 was applied to each field accordingly to the amount of available data so that it may be applied to any other filed. The followings are the summary of this project.

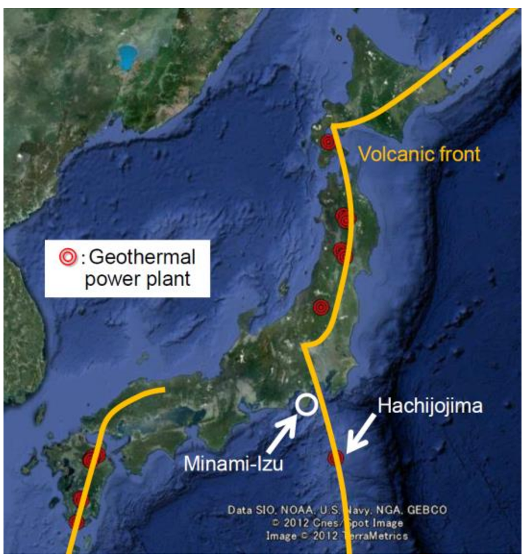


Figure 2: Locations of model fields

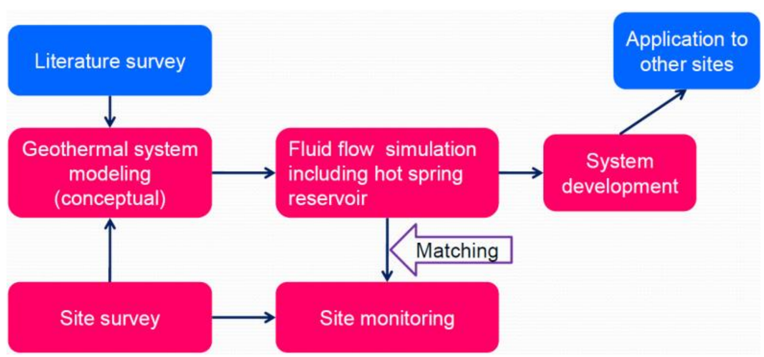


Figure 3: Concept of the integration system

## 2. Geothermal System Modeling

### 2.1 Hachijojima

A conceptual geothermal system model of Hachijojima, which includes groundwater flows and hot springs, has been developed based on pre-existing data and newly conducted geological, geochemical and geophysical (MT and AMT) survey data (see Figures 5 and 6). The model is consistent with a hydrological structure model around the observation well that was drilled in FY2010 in this project. The model was referred to construct a detailed numerical model of the Hachijojima geothermal system including hot springs.

As can be seen in geothermal model in Figure 5, the geothermal reservoir in Hachijojima is isolated from hot spring aquifers by a caprock, which can be also identified as low resistivity zone in Figure 6. Also the locations of hot springs are farther than 1 km in plan-view in Figure 4. Therefore the relation between hot spring aquifers and geothermal reservoir was considered to be Type 5 of Figure 3, independent systems.

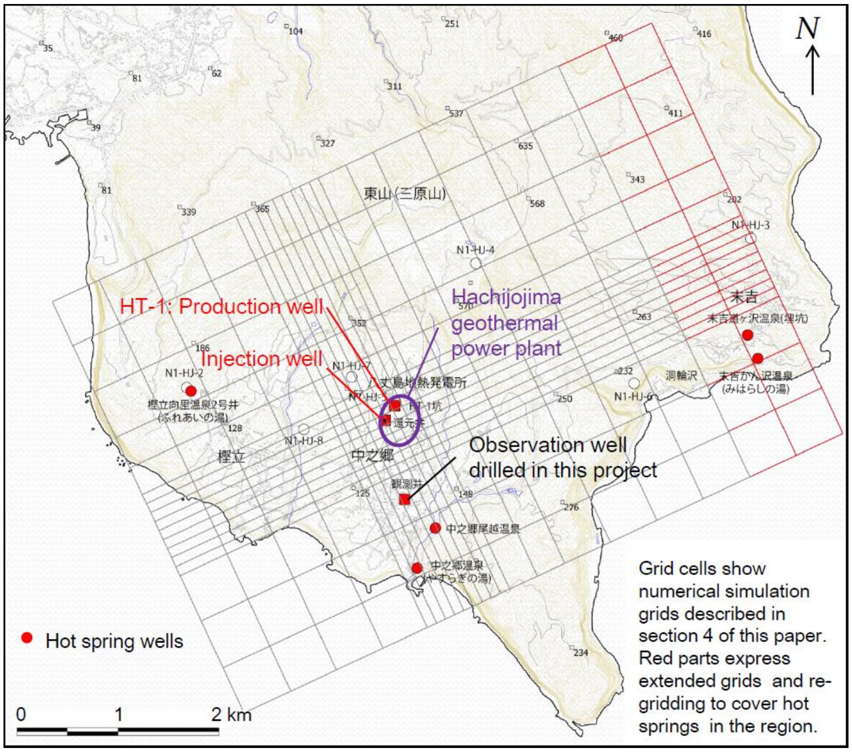


Figure 4: Map of the Hachijojima geothermal field, in the Hachijojima-island.

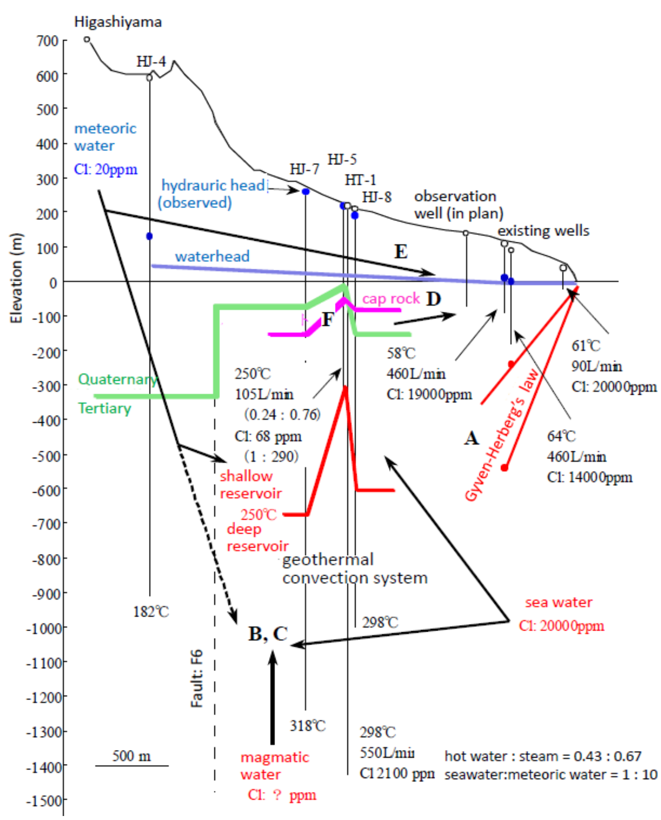


Figure 5 Conceptual model of the Hachijojima geothermal system (AIST, 2011).

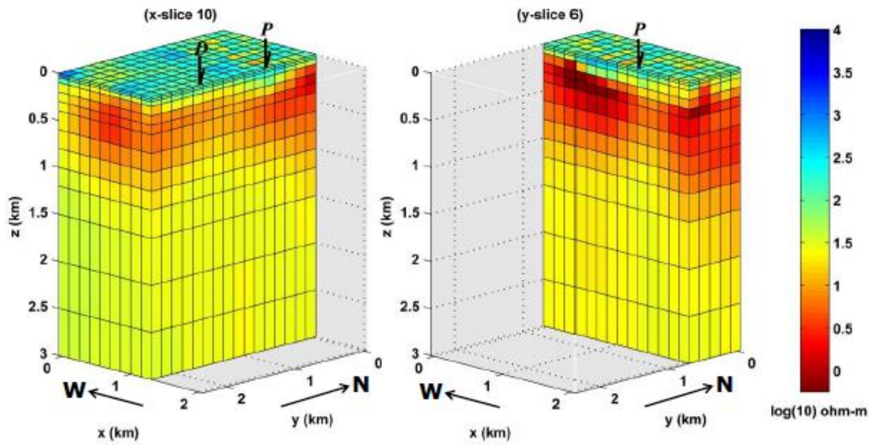


Figure 6: Resistivity model of Hachijojima as a result of 3D inversion of MT and AMT data (AIST, 2011).

**2.2 Minami-Izu**

In Minami-Izu area, local people have been drilled quantities of 150-200 m deep wells for bathing purpose since early 20 century. Self-discharge of boiling water from these wells was observed only in early years and recent wells adopt air-lift or pumping system due to pressure draw-down of the hot aquifer. TEPSCO (2011) suggests existence of a deeper geothermal reservoir in this area.

For this field, pre-existing data were not enough to make a geothermal conceptual model including deeper heat and fluid sources. Therefore in this project, hydrological, geological and geochemical survey has been done for nearly four times larger area than shown in Figure 7. Geophysical surveys including resistivity (MT and AMT), gravity and SP have been done especially aiming for information on up-flow zone in this area. A new production well of 695 m deep and an injection well of 179 m deep were drilled in this project to conduct a production and injection test with a tracer test to confirm the extension and the characteristics of the reservoir (Figure 8).

The result of tracer test from the shallow injection well shows even faster recovery of tracer at the deep production well than at some of shallow hot spring wells as shown in Figure 9. It suggests that shallow hot aquifer and deeper part are hydrologically well connected.

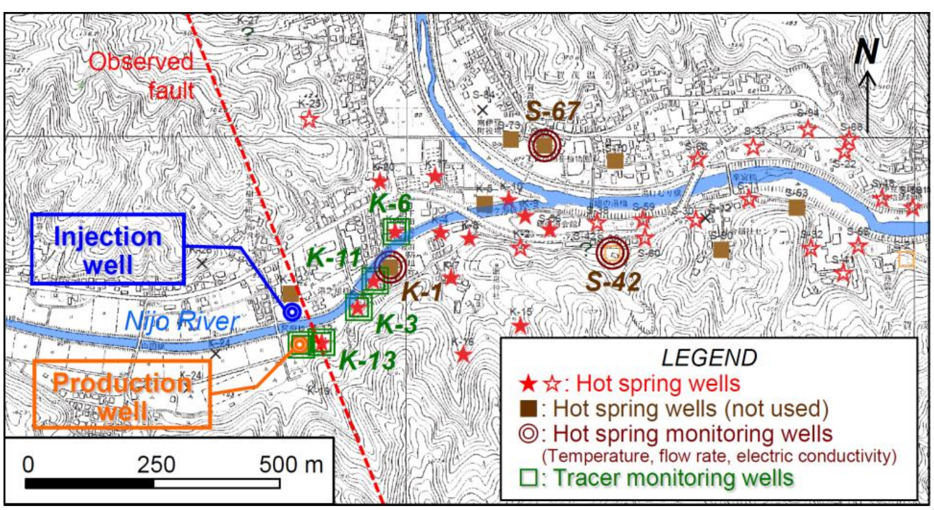


Figure 7: Location of wells in Minami-Izu, including pre-existing hot spring wells.
An injection well and a production well are drilled in this project.

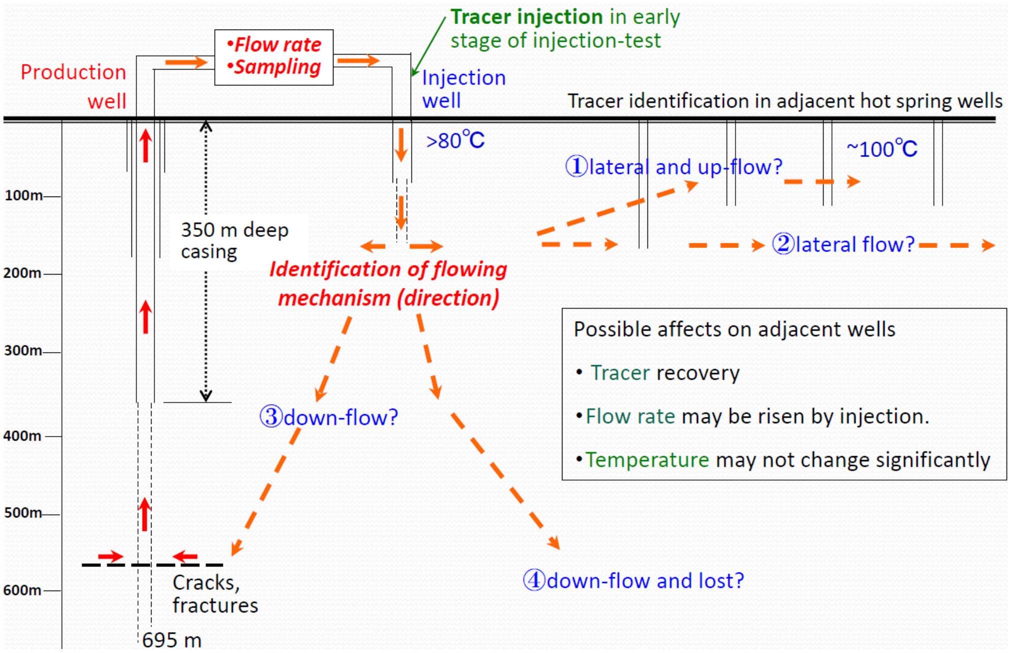


Figure 8: Cross sectional image of production-injection test in Minami-Izu.

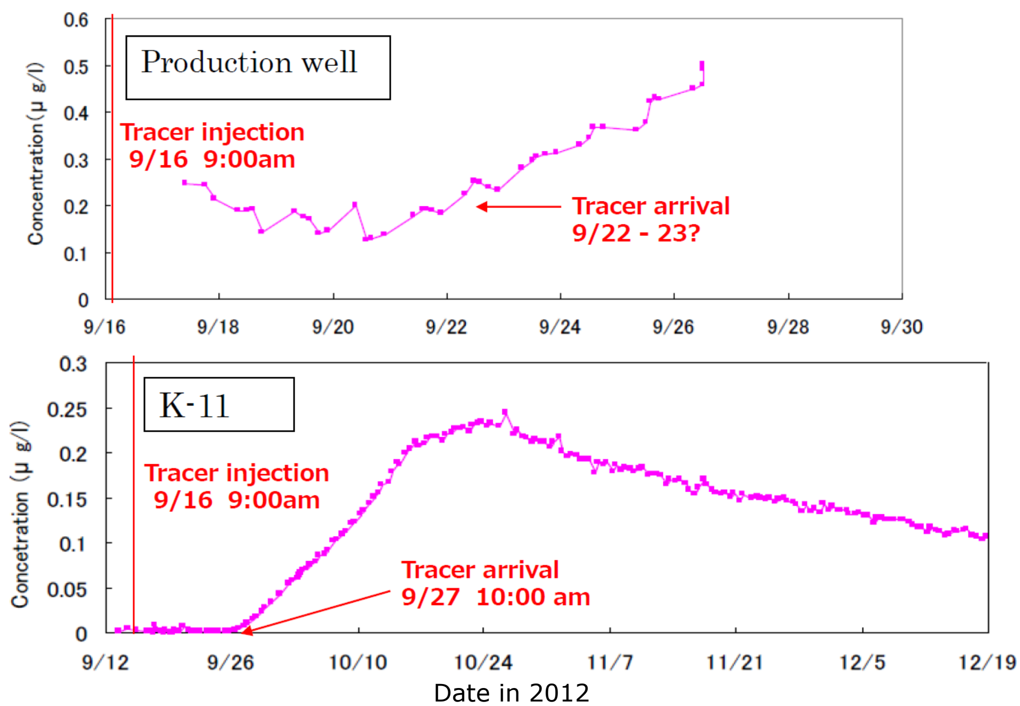


Figure 9: Tracer recoveries at the production well (upper) and hot spring well K-11 (lower). Tracer reaches to deep production well earlier than to K-11, which depth is same level as the injection well (AIST, 2013).

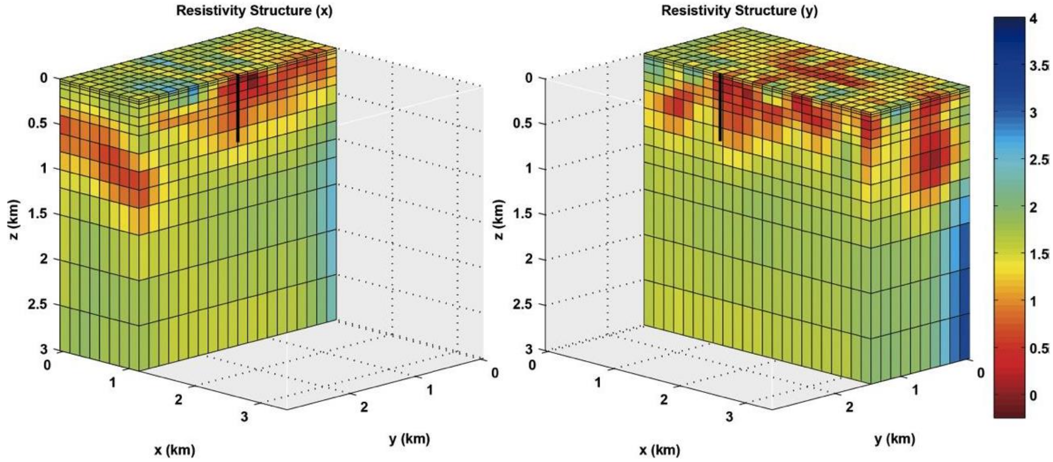


Figure 10: Resistivity model of Minami-Izu area as result of 3D inversion of MT and AMT data (AIST, 2013).

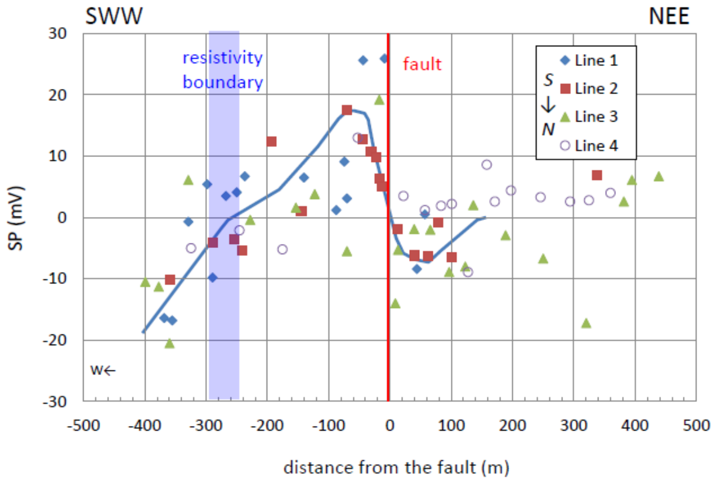


Figure 11: dipolar SP anomaly observed across the fault shown in Figure 7 (Yasukawa et al., 2013).

Resistivity survey results show a continuous low resistivity zone from the shallow hot aquifer level to deeper part as shown in Figure 10, which suggests that the low resistivity zone represents hot aquifer or permeable zone rather than caprock. From these results, shallow hot spring aquifer and suggested deeper geothermal reservoir might be well connected at least to a depth of 800 m, that is corresponding to Type 1 or Type 2 in Figure 3. As for the upflow zone, SP survey result show dipolar anomaly across the fault (Figure 11), which was interpreted as combination of up-flow across a fault and lateral flow at a shallow aquifer (Yasukawa, 2013), but further investigation would be needed.

## 3. MONITORING TECHNOLOGY

### 3.1 Hot spring monitoring

At most natural and drilled hot springs in Japan, no monitoring has conducted and natural perturbation level has not been understood. Thus understanding natural change range is one of the aims of hot spring monitoring in this project to detect influence of deeper geothermal exploitation, if any.

Continuous monitoring of water level (+pumping rate), temperature and electrical conductivity were conducted at observation wells and pre-existing hot spring wells in Hachijojima and Minami-Izu. These data were analyzed and thus the natural perturbation levels were identified. Tracer monitoring during production and injection test in Minami-Izu was also conducted as described in Section 2.

Figure 12 shows a long term monitoring result of a hot spring well in Hachijojima. Hot water is pumped up regularly from the well resulting in a perturbation of discharge rate accordingly. A slight lowering of water level is observed in this period. Change of electric conductivity may be because of scaling around the sensor. Thus regular changes of characteristics in plural hot spring wells were observed in this study.

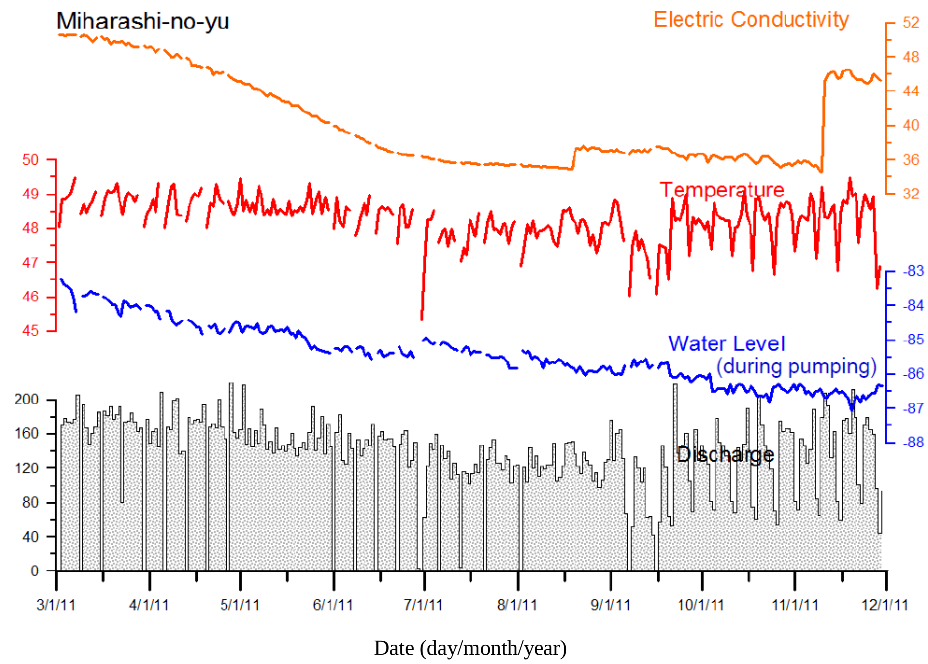


Figure 12: A nine-month-long change of characteristics of "Miharashino-yu" hot spring, Hachijojima (AIST, 2012).

### 3.2 Micro-gravity monitoring technology

Micro-gravity survey at ground surface may be applied to monitor subsurface water level change without direct measurement in wells. Therefore a micro-gravity monitoring system with the latest high-resolution gravimeter for a continuous observation was tested at Hachijojima in this project.

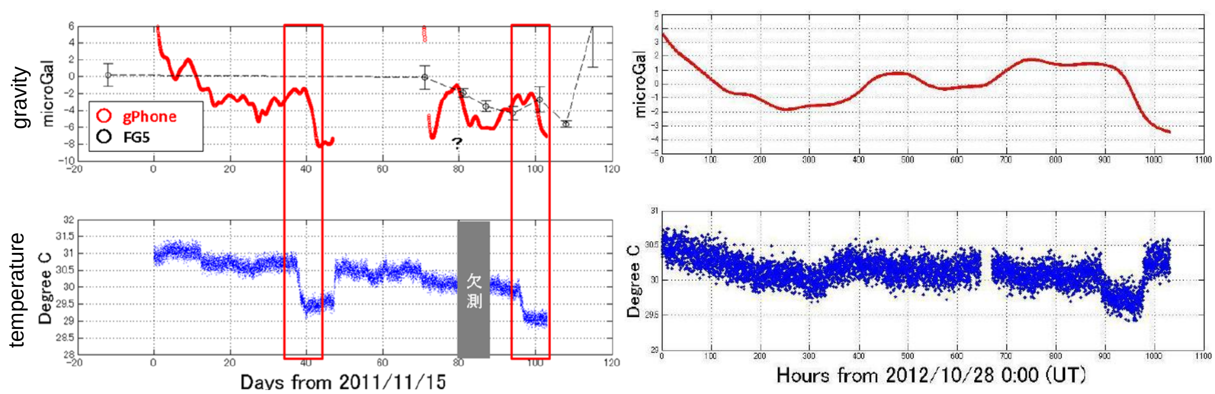


Figure 13: Correlation between micro-gravity and water temperature of a hot spring well (AIST, 2012 and 2013).

Continuous high-resolution gravity monitoring at the observation well and hybrid gravity survey was conducted. The hybrid gravity survey consists of repeating measurements at a base point with an absolute gravimeter and those at thirty survey points with a mobile gravimeter. The monitoring system has a high enough resolution to detect a change in water level of 10 cm. Although many other causes (climate, sea-levels, etc.) perturb gravity values, gravity drops or rises posterior to water temperature changes were observed and mechanisms were studied (Figure 13). More studies are needed for practical use.

## 4. NUMERICAL SIMULATION

Generally geothermal simulation models developed for reservoir management purpose do not include nearby hot spring resources. Thus detailed simulation of shallower hot spring resources after geothermal exploitation has not been commonly done. Therefore based on an existing reservoir simulation model developed for the Hachijojima geothermal power plant, a new numerical model was constructed by re-gridding of the original model to achieve detailed simulation of nearby hot spring resources during production from a deeper geothermal reservoir.

The influence of geothermal fluid production on shallow resources above the cap rock, which is approximately 100 m deep, has been simulated. An extreme scenario, such as ten-times-bigger production than the real case, has also been simulated as shown in Figure 14. Even in this extreme case, shallow hot spring is not affected by production. This result is consistent with that Hachijojima is determined as Type 5 in Section 2.

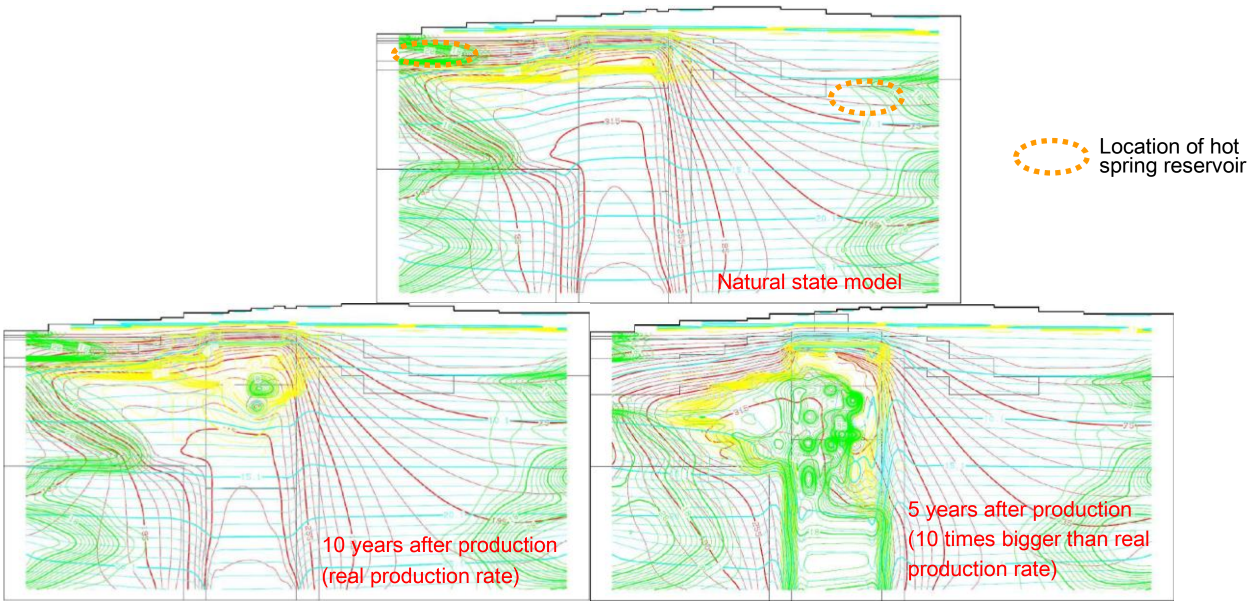


Figure 14: Numerical simulation result for Hachijojima 3D model. Red: temperature contour, blue: pressure, green: salinity, yellow: steam saturation (AIST, 2012 and 2013).

## 5. SYSTEM INTEGRATION

New Energy Foundation (NEF, 1999) compiled a manual showing procedures to evaluate the effects of geothermal development on hot springs. However, the manual had not been used effectively in real geothermal developments. Therefore a more practical new system (scenario) with a support software was developed with applications at model fields.

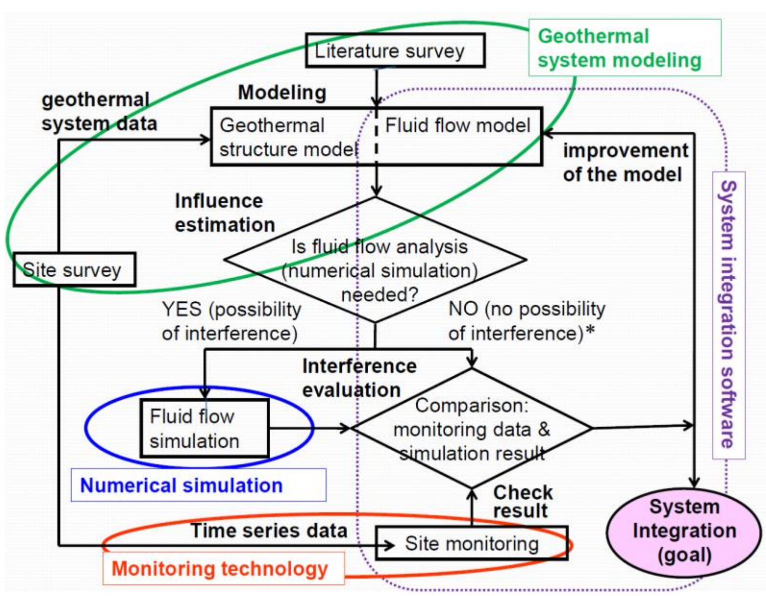


Figure 15: Flow diagram of the system integration.

Table 1 Characteristics of hot springs in relation with deep reservoir (types 1 - 5) shown in Figure 1.

| 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, >53℃ |
| 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) |

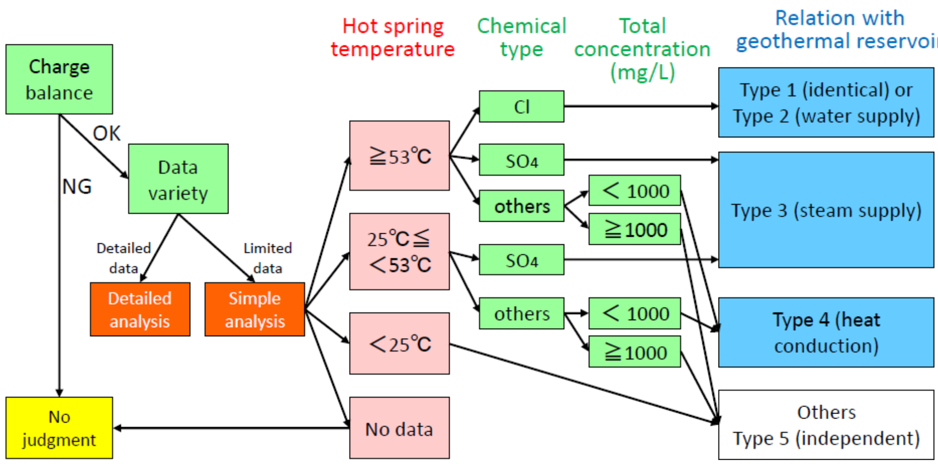


Figure 16: Flow chart of type analysis in a proto-type system support software

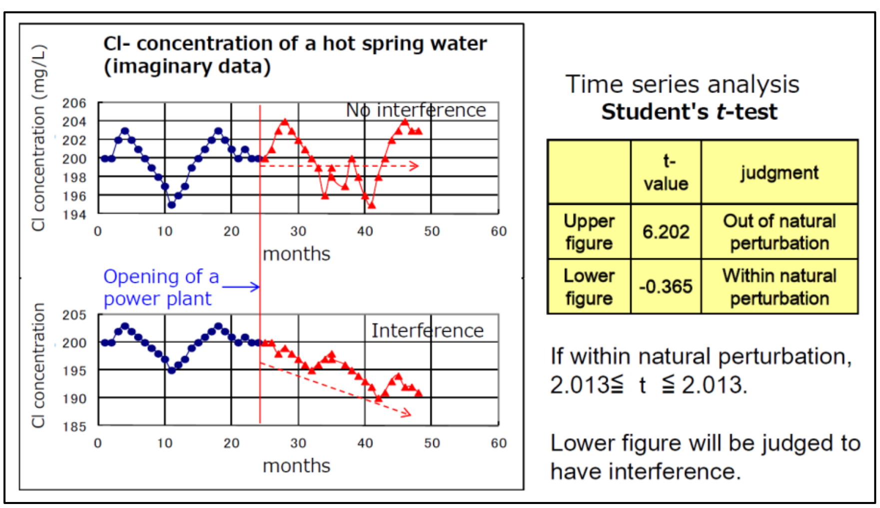


Figure 17: Concept of interference evaluation by time series analysis with Student's t-test

A proto-type software to support detection of an influence of geothermal exploitation on hot springs was developed as part of system integration. It consists of two parts as; 1) type analysis of relation between hot spring aquifer and geothermal reservoir (as shown in Figure 3) to evaluate types of possible influence of geothermal development on hot springs and 2) data analysis of time series in hot spring monitoring data to detect predominant change after beginning of geothermal fluid production. The type analysis is based on criteria shown in Table 1. The analysis in time series includes correlation analysis with climate data and Student's T test. The software also shows the range of the natural perturbation level of physical properties. Although the software needs some more "tuning" for practical use though, it is expected to be used by local hot spring owners as well as geothermal developers.

**3. Conclusions**

An integrated geothermal reservoir operation system for adequately controlled utilization was developed to conduct geothermal exploitation without interference to nearby hot springs. The system consists of three parts: geothermal system modeling, development of monitoring technology and estimation of reservoir change by numerical simulation. Hachijojima and Minami-Izu geothermal areas were selected as model fields and various field surveys and monitoring were conducted. As results of this study, the Minami-Izu field was identified as Type 1 or 2 (identical system or water supply from deep reservoir) while the Hachijojima field was Type 5 (independent type).

The final product of the project, an integrated system that enables to evaluate impacts on hot springs by a geothermal development, may be widely used to promote geothermal exploitation.

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