For harmonious geothermal development with nearby hot springs

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ABSTRACT

An integrated geothermal reservoir operation system for adequately controlled utilization was developed to avoid interference to nearby hot springs. The system consists of four parts: geothermal system modeling, monitoring technology, estimation of reservoir change by numerical simulation and integration of a reservoir operation system. Hachijojima and Minami-Izu geothermal areas were selected as model fields to apply this system and various field surveys and monitoring were conducted. The final product is an integrated system that enables to evaluate impacts of geothermal development on surrounding hot springs a priori and to design geothermal exploitation without negative impacts on hot springs. The system may contribute to promote geothermal exploitation.

1. INTRODUCTION

For new geothermal developments, understandings and agreements of local residents are essential. However in some cases in Japan, geothermal projects have been delayed or even cancelled due to the concerns of local hot spring owners in fear that their springs would be interfered by geothermal exploitation. Supposing such troubles with hot spring owners are particular to Japan, considerations to the nearby environment would be a common subject in any place because a geothermal project needs cooperation of local stakeholders.

Logically there should not be a problem if; (a) natural heat and fluid recharges and utilization are well balanced, or (b) a caprock exists between a hot spring and a geothermal reservoir. In order to prove this logic, a three-year research project "Development of an advanced geothermal reservoir management system for the harmonious utilization with hot spring resources" had been done (2010-2012). The project aims to develop an integrated geothermal reservoir operation system for adequately controlled utilization and to indicate the way to exploit geothermal energy without negative impacts on nearby hot springs.

The project consists of: 1) geothermal system modeling, 2) monitoring technology, 3) numerical simulation, and 4) system integration as shown in Figure 2. A unique feature of this study is that both numerical modeling and monitoring regions cover surrounding hot spring aquifers over a caprock of a geothermal reservoir to realize interference between them while a conventional study handles only inside a geothermal reservoir under a caprock.

Figure 1 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 two model fields to apply the integrated system. The types of relation between geothermal reservoir and hot spring aquifer in Figure 3 are investigated for these fields.

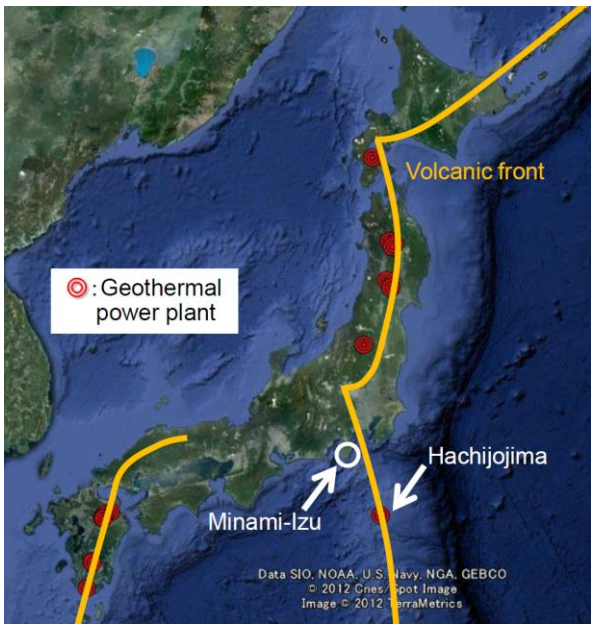


Figure 1: Locations of Hachijojima (island) and Minami-Izu.

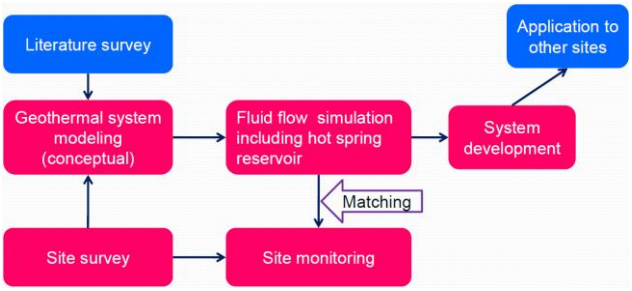


Figure 2: Concept of the integration system

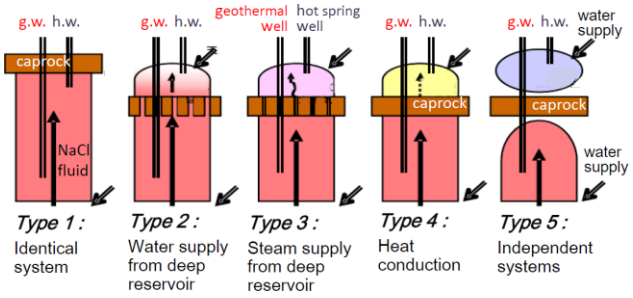


Figure 3: Five types of connection between geothermal reservoir and hot spring aquifer.

In Hachijojima, 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 for these two fields quite differ both before and after this project. Thus our integration system shown in Figure 2 was applied to each field accordingly to the amount of available data. It may be applied to any other filed. The followings are the summary of this project.

2. GEOTHERMAL SYSTEM MODELING

2.1 Hachijojima

A conceptual geothermal system model of Hachijojima, which includes flows of groundwater 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. Thus the relation between hot spring aquifers and geothermal reservoir must be Type 5 of Figure 3, independent systems.

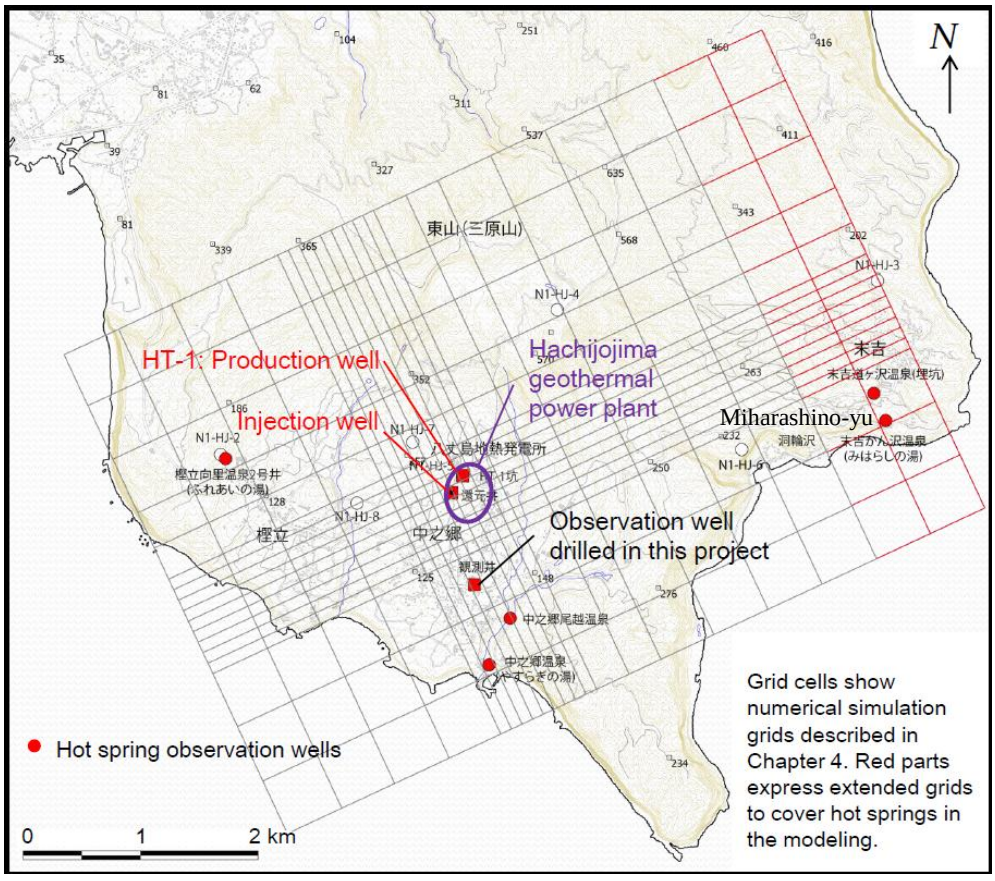


Figure 4: Map of southern part of Hachijojima island.

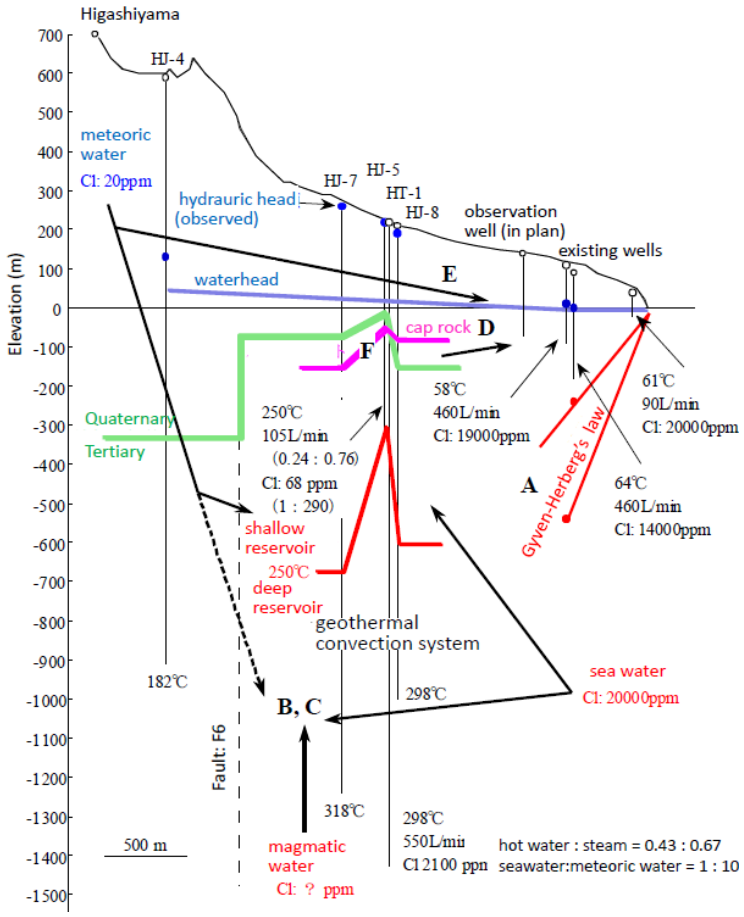


Figure 5 Conceptual model of the Hachijojima geothermal system (AIST, 2011).

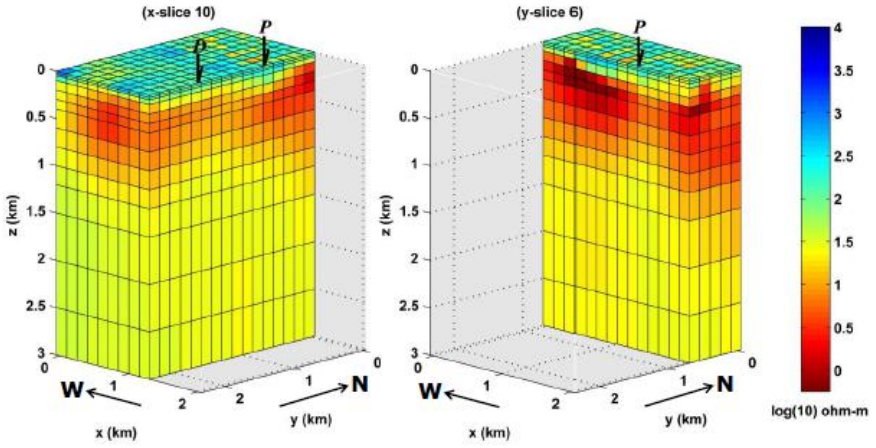


Figure 6: Resistivity model of Hachijojima area as a result of 3D inversion of MT and AMT data (AIST, 2011).

2.2 Minami-Izu

In Minami-Izu area, local people have been drilled quantity of shallow wells of 150-200 m deep for bathing purpose since early 20 century. Automatic discharge of boiling water from these wells can be seen only in early years and recent wells adopt air-lift or pumping system because of the pressure draw-down in the hot aquifer. TEPSCO (2011) suggests existence of a deep 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, various surveys were conducted. 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 aimed at getting information on location of 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 ad 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 some of shallow hot spring wells as shown in Figure 9. It suggests that shallow hot aquifer and deeper part are hydrologically connected.

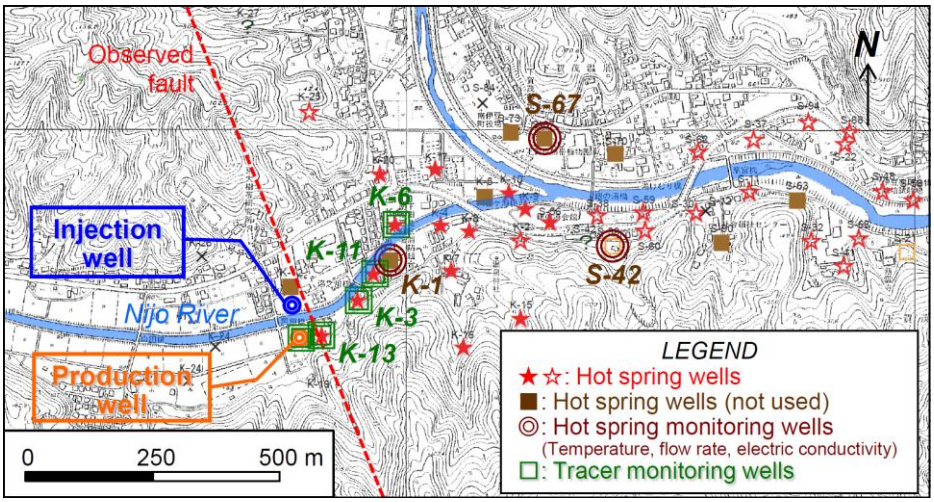


Figure 7: Location of wells in Minami-Izu. Injection well and production wells are drilled in this project.

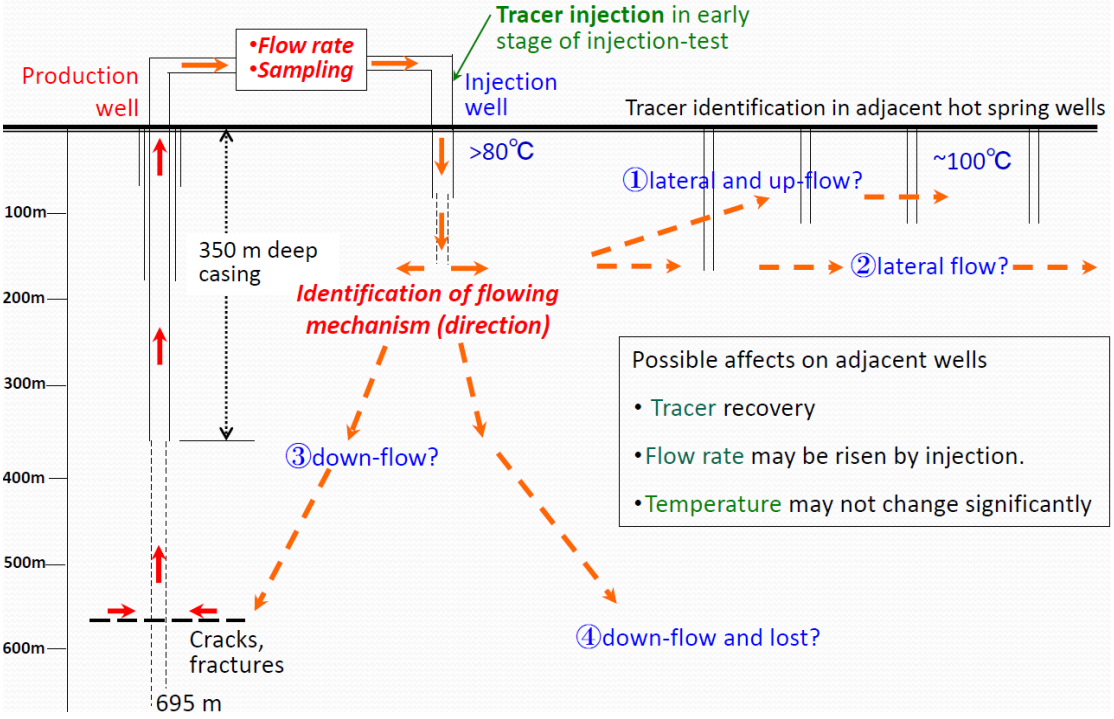


Figure 8: Cross sectional image of production-injection test in Minami-Izu.

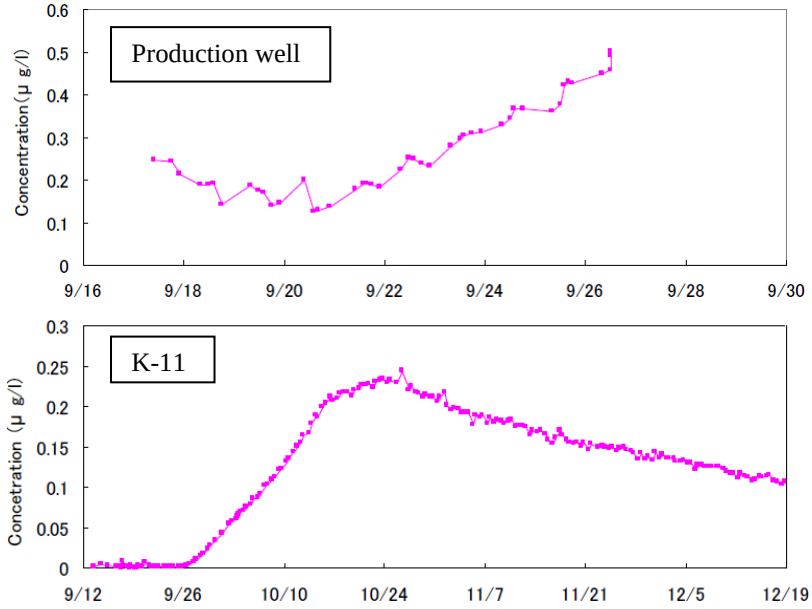


Figure 9: Tracer recoveries at the production well (upper) and hot spring well K-11 (lower). Tracer reaches to deep production well earlier than to K-11 which depth is same level as the injection well (AIST, 2013).

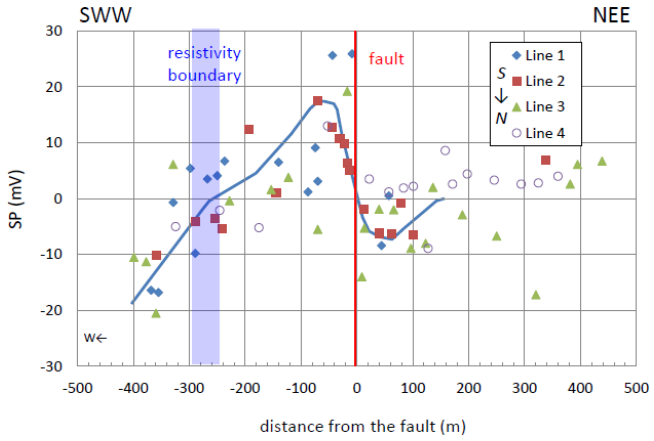


Figure 10: dipolar SP anomaly observed across the fault shown in Figure 7 (Yasukawa et al., 2013).

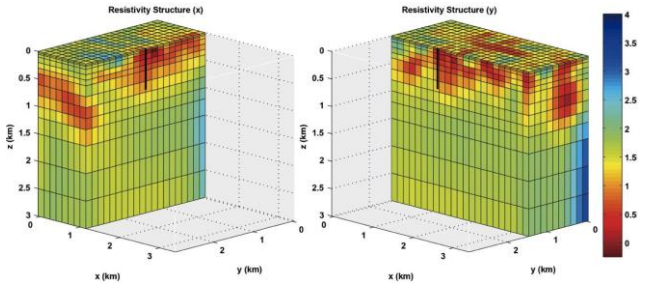


Figure 11: Resistivity model of Minami-Izu area as result of 3D inversion of MT and AMT data (AIST, 2013).

SP survey result show dipolar anomaly across the fault (Figure 10), which was interpreted as combination of up-flow across the fault and lateral flow at a shallow aquifer (Yasukawa, 2013). Resistivity survey results show a continuous low resistivity zone from the shallow hot aquifer level to deeper part as shown in Figure 11, which suggest that the low resistivity zone corresponds to hot aquifer or permeable zone rather than caprock.

From these results, shallow hot spring aquifer and suggested deeper geothermal reservoir are considered to be well connected, that is corresponding to Type 1 or Type 2 in Figure 3.

3. MONITORING TECHNOLOGY

3.1 Hot spring monitoring

Normally no monitoring is conducted for hot spring wells in Japan and natural perturbation levels have not been understood. Thus understanding ranges of natural change 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 Chapter 2.

Figure 12 shows long term parameter changes observed in one of the hot spring wells in Hachijojima. A slight lowering of water level is observed in this period. Change of electric conductivity may be because of scaling around the sensor. Perturbation in discharge rate is due to pumping rate. Thus regular changes of characteristics in plural hot spring wells were observed in this study.

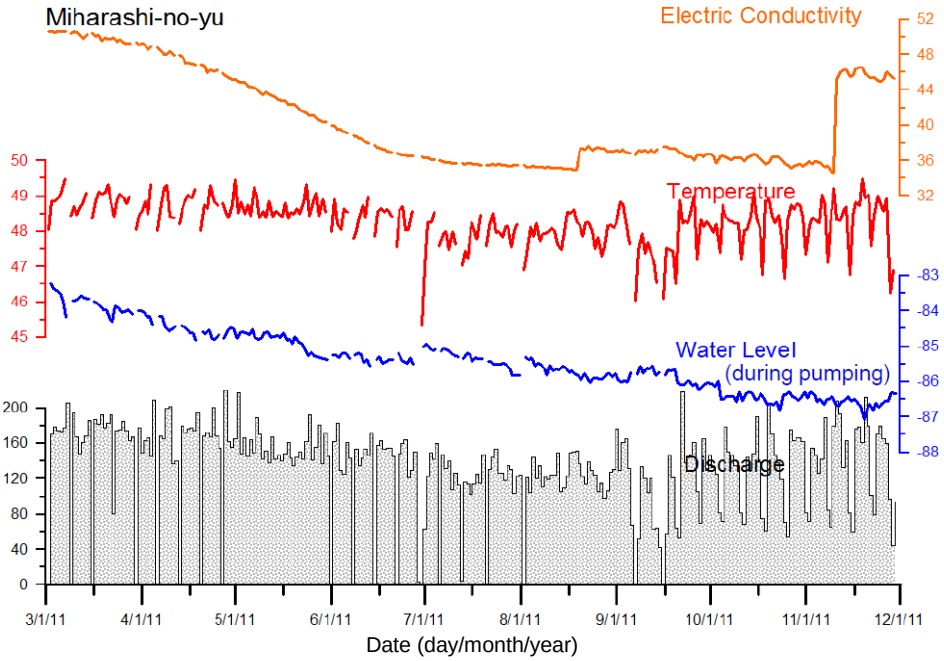


Figure 12: Long term change of characteristics of "Miharashino-yu" hot spring, Hachijojima (AIST, 2012).

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.

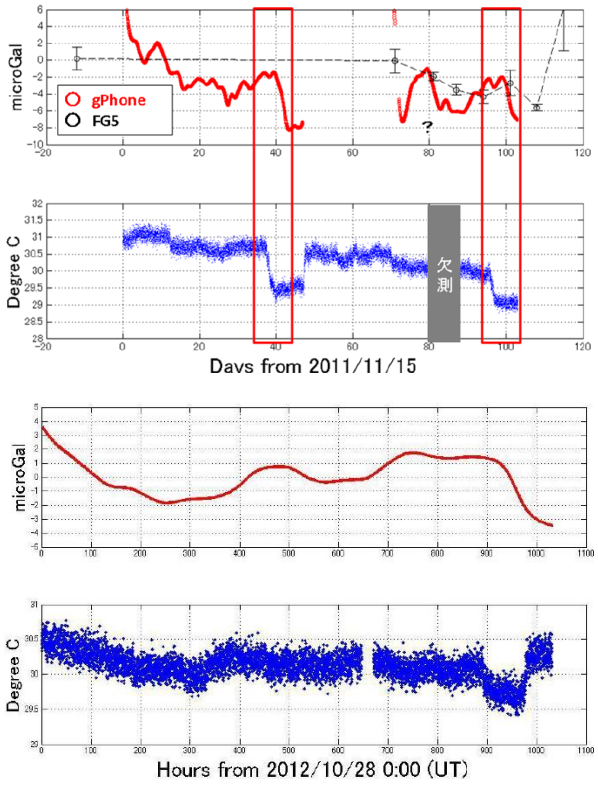


Figure 13: Correlation between micro-gravity and water temperature of a hot spring well (AIST, 2012 and 2013).

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 perturb gravity values so that an improvement is needed for data analysis, gravity drops or rises posterior to water temperature changes were observed and mechanisms were studied (Figure 13).

4. NUMERICAL SIMULATION

Generally geothermal simulation models developed for reservoir management purpose do not include shallower hot spring resources overlying cap rocks. Thus, detailed simulation of shallower hot spring resources after geothermal exploitation has not been commonly done. Therefore based on an existing reservoir 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 shallower 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 or shallower, has been simulated. An extreme scenario, such as a few 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 Chapter 2.

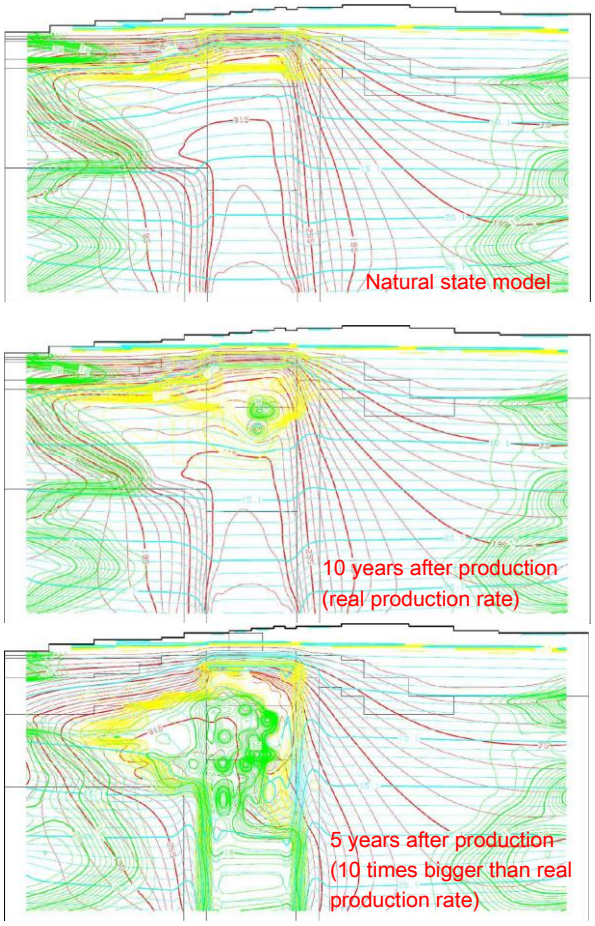


Figure 14: Numerical simulation result for Hachijojima 3D model. Red: temperature contour, blue: pressure, green: salinity, yellow: steam saturation (AIST, 2012 and 2013).

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.

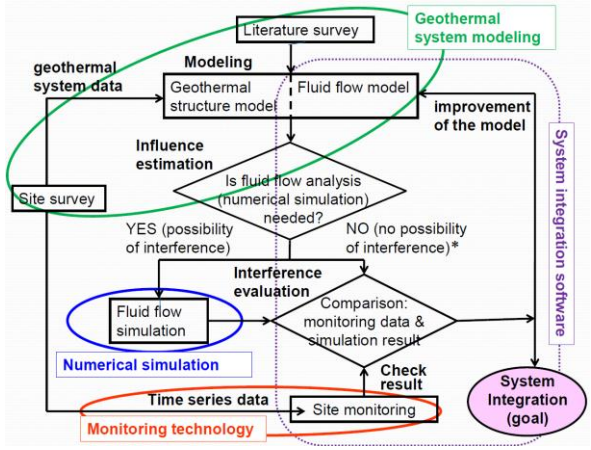


Figure 15: Flow diagram of the system integration.

Table 1 Characteristic of hot spring's relations to deep reservoir for types shown in Figure 3.

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)

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) evaluation of the type of relation between hot spring aquifer and geothermal reservoir (as shown in Figure 3) to indicate 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 in part 1) is based on criteria shown in Table 1. The analysis in time series in part 2) includes correlation analysis with weather data and Student's T test. The software also shows the range of the natural perturbation level of physical properties. This software, which needs some more "tuning" for practical use though, is expected to be used by local hot spring owners as well as geothermal developers.

The integrated system including the software enables evaluation of the effects on hot springs by a geothermal development.

3. CONCLUSIONS

An integrated geothermal reservoir operation system for adequately controlled utilization was developed to conduct geothermal without interference to nearby hot springs. The system consists of four parts: geothermal system modeling, development of monitoring technology, estimation of reservoir change by numerical simulation and integration of a reservoir operation system. 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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