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Monitoring and Resources Evaluation of the Geothermal Fields in Tianjin

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ABSTRACT

Geothermal monitoring was started in Tianjin in the 1980s, in order to better develop and utilize the geothermal fields. After more than 20 years of continuous improvement, the geothermal dynamic monitoring system has been set up in Tianjin. Meanwhile, the technical criterion monitoring of low-medium temperature geothermal fields in Tianjin was compiled in 2006. Aiming at the difficulties of measurement, cost recovery and administrative monitoring, research and development of an intelligent management Net PC system for geothermal wells was carried out. This system can make a real-time monitoring for every developer, raising the ability and the level of geothermal administration to a new level. It is very helpful for scientific planning and management of the geothermal development and utilization in Tianjin. Based on the continuous geothermal monitoring for many yeas, a new evaluation of the geothermal resources in the plain area of Tianjin has been carried out from 2005 to 2007. The optimization plans are put forward for future geothermal development．

1. INTRODUCTION

Geothermal monitoring was started in Tianjin in the 1980s, in order to better develop and utilize the geothermal fields. After more than 20 years of continuous improvement, the geothermal dynamic monitoring system has been set up in Tianjin. Meanwhile, the technical criterion monitoring of low-medium temperature geothermal fields in Tianjin was compiled in 2006. The analysis and research of a large amount of data of dynamic pressure, temperatures and flow rates of the geothermal wells, are helpful for scientific planning and management of the geothermal development and utilization in Tianjin.

In 1995, the geothermal resources administrative department began to finance the geothermal monitoring in Tianjin. The geothermal wells were fewer than 50 in 1996, but in 2007 there were 291 wells (Song, Wang, Xu et al., 2007). Additionally, the distribution area of the monitoring system was gradually enlarged from urban area to the whole jurisdiction of Tianjin. Meanwhile, the monitoring methods and equipment have constantly been improved. From the manual works at the beginning, until now, automatic metering of the production and reinjection rates in most of the geothermal wells has been implemented. The long-distance automatic monitoring of water level, pressure, temperatures and flow rates has been carried out in some geothermal wells. The geothermal monitoring has become an important tool for both the geothermal utilization and for research.

2. BASIC MONITORING CONTENTS

The geothermal observation net covers 15 districts and 2 counties in Tianjin.

2.1 Main Contents

The main works of geothermal monitoring include:

(1) The investigation of the production status of every geothermal station, such as its heating area or how many families are using geothermal water; and if the monitoring facilities such as thermometer, pressure gauge, of geothermal well, are in good condition;

(2) Monthly collection of data on water level, temperature, and flow rates of production and reinjection;

(3) Chemical tests, water samples are taken from controlling wells every winter. The samples cover the main geothermal field, ranging from Tertiary to Proterozoic;

(4) Analyzing the technical problems of production and reinjection doublet systems during the space heating period, and taking note of the possible technical faults, such as the decline of reinjection rate, corrosion etc.;

(5) Maintaining and updating the monitoring facilities; and

(6) Predicting the development potential of the geothermal production and reinjection by modelling.

2.2 Technical Criterion

(1) Geological exploration standard of geothermal resources (GB11615-89);

(2) Appraising measures of geothermal resources (DZ40-85); and

(3) Technical standards of dynamic monitoring of low-medium geothermal resources in Tianjin (2005).

3. GEOTHERMAL MONITORING IN TIANJIN

Every year, the geothermal resources administrative department finances the geothermal monitoring, according to the related provisions of the management and the use of mineral resources. Based on the status of geothermal utilization and the monitoring data from the previous year the fieldwork, such as monitoring, investigation, maintenance and the update of the monitoring facilities, geophysical logging and geochemistry of geothermal fluid are chosen. After analyzing the water quality, interpretation of temperature and pressure logging, the annual report of geothermal monitoring is compiled. There were 291 geothermal wells monitored in 2007 (Figure 1)(Zeng, Ruan et al., 2007).

3.1 Routine Monitoring Work of Geothermal Wells

(1) Topographic measurements: Measuring the altitude of the base point of geothermal well is necessary to adjust the effects of ground elevation changes on water level of geothermal wells;

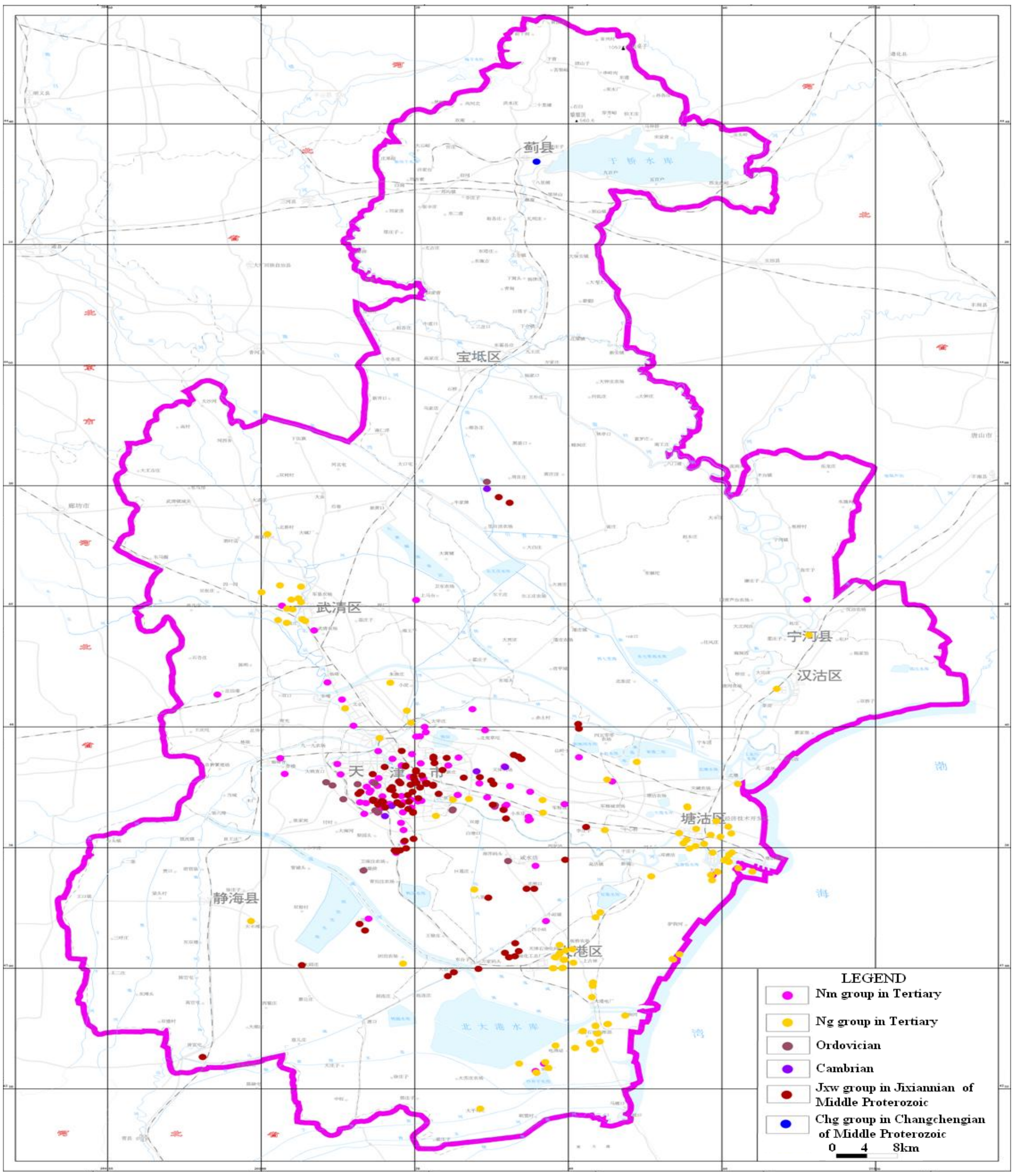


Figure 1: Location of the geothermal wells in Tianjin

(2) Static and dynamic water level and the corresponding temperature in production and reinjection well, instantaneous production and reinjection rate, stable temperature when the well is pumping or during reinjection;

(3) Investigation of the geothermal utilization, such as type and scale of using, temperature of feed water and waste water;

(4) Monthly and annual statistic of production rate and reinjection rate, in order to collect mineral resources compensation;

(5) Maintenance of the monitoring facilities include, if there is the special tube for measuring water level, precision of water meter, flow rates, manometer, and thermometer; and

(6) Synchronous monitoring in the beginning and at the end of the space heating period.

3.2 Terms of Experiment Analysis at the Laboratory

During the space heating period in the winter, geochemistry samples are taken from representative geothermal wells, to analyze the changes of geothermal water quality in the long-term. The analysis includes hydrochemical analysis of sulphur, iron and isotope.

The layout of sampling points is decided by regional hydro-geological conditions, the reservoir, the recharge, the pathway of the geothermal flow, and the type of the utilization. The continuity of the data should also be regarded. The geochemical analysis of the geothermal fluid will be used for identifying the distributive characteristics, analyzing the origin and the recharge of the geothermal fluids.

3.3 Pressure and Temperature Logging in Geothermal Wells

Pressure and temperature logging from wells that are off production or reinjection for several years, can provide, not only information on the exact pressure and temperature conditions of the geothermal reservoir, but also the effects of reinjection fluid upon the geothermal reservoir.

3.4 Layout of Key Monitoring Net

Because there are already more than 300 geothermal wells in 15 districts and 2 counties, and the water levels in most geothermal wells are observed manually, some important geothermal wells are selected to make up a key monitoring net. In order to obtain the overall observation data systematically and to analyze the dynamic nature of the geothermal resources objectively, the layout of a key monitoring net is planned as follows:

3.4.1 District and reservoir: according to the geological conditions of the geothermal field and the development of the reservoir, the observation points are chosen from the productive centre of the geothermal fields. Then the dynamic changes of geothermal development of every district, geothermal field and reservoir can be effectively observed.

3.4.2 Geology tectonics: the key observation points are distributed along the main fracture zones or tectonic elements.

3.4.3 Continuity and integration of data: it is better to make the most of the geothermal wells of long-term off production, to avoid the effects caused by production. Meanwhile the data should be continuously updated and integrated.

Usually the technicians observe the normal points and the key points twice every month. The key observation points were 127 wells in 2007, about 44% of the total number of geothermal wells in the area. There are 43 key points located in urban areas; the rest are in rural areas.

3.5 General Analysis and Annual Reports

<u>3.5.1 Monthly Reports and the Database</u>

All the observation data are collected and added to a geothermal monitoring database. Through the analysis, a monthly report is compiled about the capability or performance of each geothermal well. Geothermal mining enterprises have access to these reports.

<u>3.5.2 Synchronous Monitoring</u>

Since 2004, the synchronous monitoring has been carried out in April and October (at the end and beginning of the space heating period). The observation data of water level and condition of monitoring facilities will simultaneously inform the geothermal mining enterprises, which can examine and repair the equipment and install the submersible pump in suitable depth.

<u>3.5.3 Annual Report</u>

Mathematic modelling is an important tool to study the changes in geothermal reservoirs. Based on field work, analysis in the laboratory and geophysical logging, combining the historical changes of geothermal reservoir, the pressure, temperatures and the chemistry can be simulated and predicted by numeric modelling in an annual report. Every short-term development potential of the geothermal reservoirs has been predicted. Suggestions on geothermal development and management are put forward in the report (Figure 2 and 3).

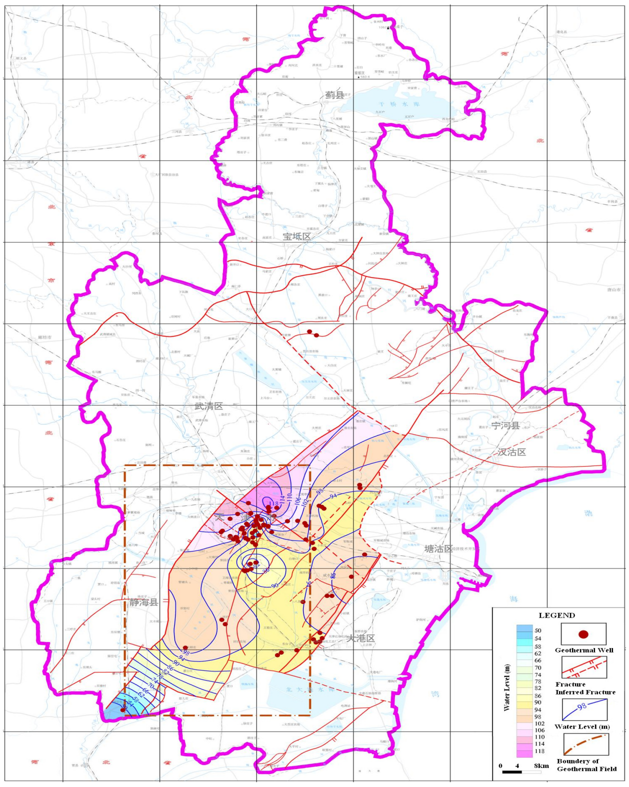


Figure 2: Contour of Water levels of Jxw reservoir in Proterozoic, 2007

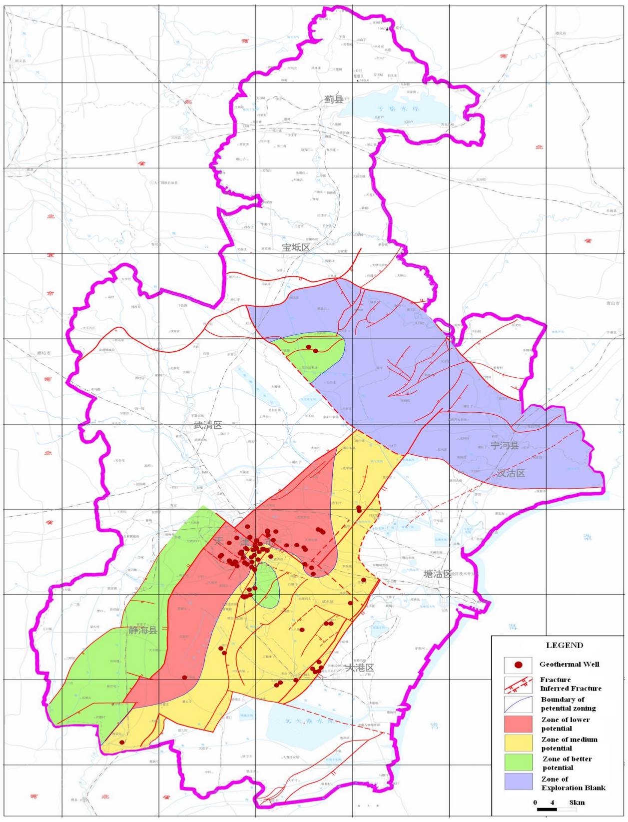


Figure 3: Zoning of development potential of Jxw reservoir in Proterozoic

4. RESOURCES EVALUATION

4.1 The Geological Model of Geothermal Resources in the Plain Area

After the continuous geothermal monitoring for more than 10 years, a new potential evaluation about the geothermal resources in Tianjin plain area has been carried out during the period 2005-2007 (Figure 4).On the basis of the research about the geological conditions, the Earth's temperature field and hydrodynamic field of the geothermal fluid, some geochemical analysis, geophysical exploration and well tests have been supplemented. The new geological model is set up for the resource evaluation.

The Tianjin geothermal fields are typical sedimentary basin low-temperature systems, which are common in eastern and northeastern China. The main heat source is the superposition of convective heat flow from the upper mantle and radiogenic heating from the crust. The heat transfer is mainly by the mode of conduction. But the heat convection mode exists in local part due to the effect of different geological structure and lithology.

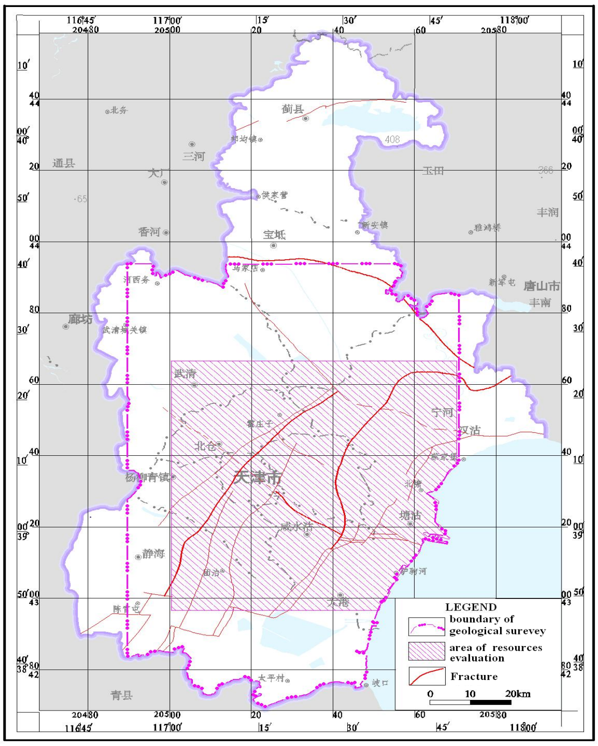


Figure 4: The working area of resources evaluation

Since the Holocene epoch, the regional sea level ascends. Several times transgressions supply the salty materials for the wedge-shaped salty water mass, which is thin in west and thick in east in the Quaternary aquifer. The rising of the regional base level of erosion hindered the horizontal movement of geothermal water. The upward heat flow is obstructed by the huge thick Quaternary stratum and water mass. The sealing state is in favour of the heat-up of geothermal water. Although the sealed water moves slowly, it has quite fast velocity in the decompression zone (Wang, 2005).

The geothermal waters are located mainly in the range of the Cangxian uplift. They are "fractured karst geothermal water in bedrock", accumulated in medium Proterozoic Jixiannian Wumishan (Pt_2W), lower Paleozoic Cambrian (PzH) and Ordovician (PzO) reservoir; and "porous geothermal water in clastic rock" exists in Tertiary and Quaternary. The cold underground water deposits in the fissures of the basement in front of the Yanshan Mountain and the shallow porous/fracture aquifer (500-800m depth) in Tertiary and Quaternary. Based on the isotope analysis, Tianjin geothermal water originates from the ancient precipitation, which is 23～4ka B.P. and sealed up to the present since the Holocene. It is a closed deep circulation system.

The fractured geothermal water in bedrock has the near ^{14}C value (15-4.5 pmc), bigger than the value of pore water (7.6-4.5 pmc). So the bedrock geothermal water is younger than the pore water. After the denudation of long geological period, the bedrock has a huge weathering shell and well-developed fractures and dissolution cavities. Meanwhile there is a large outcrop area in the north and west mountains, so it is semi-closed reservoir. In the other hand, the reservoirs in Tertiary and Quaternary system have a good closed condition. Hereby, the deep circular geothermal system can be divided into (Wang, 2001):

(1) semi-open and semi-closed bedrock subsystem, where the karst geothermal water exists;

(2) closed clastic rock subsystem, where the porous geothermal water exists.

4.2 Potential Evaluation about the Geothermal Resources in Tianjin

4.2.1 Neogene Porous Medium Geothermal Reservoir

The numerical modelling software Modflow was used to calculate the potential of the geothermal resources in the Neogene porous medium reservoir. And its subprogram Interbed was used to calculate the sedimentation rate by coupling the hydrodynamic field of geothermal fluid.

It is assumed that the deepest water level will be shallower than -150m in the next 100 years of geothermal development in the Neogene reservoir, and that the total exploitable reserves in Neogene is $12.11\times10^8 m^3$, which is about 0.29% of the permanent reserve. The quantity of heat in exploitable reserves is 11.12×10^{16}J, amounting to 3.08×10^{10}kWh, which is about 0.27% of the recoverable geothermal resources in the Neogene.

The exploitable reserves of the Minghuazhen Group in the Neogene (Nm) is $6.8\times10^8 m^3$, which is about 0.23% of its permanent reserves. The quantity of heat in exploitable reserves is 4.93×10^{16}J based on the average temperature 41°C, amounting to 1.37×10^{10}kWh, which is about 0.17% of the recoverable geothermal resources in Nm.

And the exploitable reserves of the Guantao Group in the Neogene (Ng) are $5.31\times10^8 m^3$, which is about 0.43% of its permanent reserves. The quantity of heat in exploitable reserves is 6.19×10^{16}J based on the average temperature 58°C, amounting to 1.71×10^{10}kWh, which is about 0.5% of the recoverable geothermal resources in Nm.

4.2.2 Basement Carbonate Geothermal Reservoir

The numerical modelling software AQUA3D was used to calculate the potential of the geothermal resources in the carbonate reservoir, Ordovician and Wumishan Group of Jixianian in Proterozoic. The analytic modeling Theis Model was used to calculate the potential of the geothermal resources in Cambrian reservoir.

It is assumed that the deepest water level will be shallower than -200m in the next 100 years of geothermal development in the basement reservoir, and that the total exploitable reserves in basement is 15.63×10^{8}m^3, which is about 0.69% of the permanent reserve. The quantity of heat in exploitable reserves is 26.58×10^{16}J, amounting to 7.36×10^{10}kWh, which is about 1.61% of the recoverable geothermal resources in the Neogene.

The exploitable reserves of geothermal fluid in Ordovician is 2.94×10^{8}m^3, which is about 0.63% of its permanent reserves. The quantity of heat in exploitable reserves is 5.13×10^{16}J based on the average temperature 80°C, amounting to 1.37×10^{10}kWh, which is about 0.69% of the recoverable geothermal resources in Ordovician.

And the exploitable reserves of geothermal fluid in the Cambrian are 0.58×10^{8}m^3, which is about 9.3% of its permanent reserves. The quantity of heat in exploitable reserves is 0.93×10^{16}J based on the average temperature 81°C, amounting to 0.26×10^{10}kWh, which is about 9.3% of the recoverable geothermal resources in the Cambrian.

The exploitable reserves of geothermal fluid in the Wumishan Group of Jixianian in Proterozoic are 12.11×10^{8}m^3, which is about 0.75% of its permanent reserves. The quantity of heat in exploitable reserves is 20.52×10^{16}J based on the average temperature 86°C, amounting to 5.68×10^{10}kWh, which is about 2.28% of the recoverable geothermal resources in it.

4.3 Optimizing Plans for Future Geothermal Development

4.3.1 Neogene Porous Medium Geothermal Reservoir

Synthetically taking account of the geothermal utilization status, future plan, and geological condition, four kinds of schemes are designed to predict the water level changes in the next 10 and 30 years of geothermal production of the Nm and Ng group in the Neogene reservoir (Hu, Lin, Lin, et al., 2007). Figure 5 shows that the water level changes of Ng group in different schemes after 30years.

Scheme 1: Assuming that all geothermal wells will keep the same production rate of 722×10^{4}m^3/a in 2004 for future 30 years. Then the deepest water level of Ng group will be -135m in 2034 and the annual drawdown is about 1.0m.

Scheme 2: Assuming that the total production rate of Ng group will reaches 950×10^{4}m^3/a, the amount and lay out of geothermal wells at present will not change in future 30 years. Then the deepest water level of Ng group will be -155m in 2034 and the annual drawdown will be 1.73m.

Scheme 3: On the basis of Scheme 2, the total production rate of Ng group will be 950×10^{4}m^3/a, but 5 new geothermal wells will drilled in selected highly productive area. Then the deepest water level of Ng group will be -138m in 2034 and the annual drawdown will be 1.33m.

Scheme 4: On the basis of Scheme 3, the total production rate of Ng group will be 950×10^{4}m^3/a, but 5 new geothermal wells will drilled in the peripheral regions, outside the high productive area. Then the deepest water level of Ng group will be -130m in 2034 and the annual drawdown will be 1.1m.

Through comparing the water level and its drawdown, Scheme 4 will be the optimizing way for geothermal development in future. The dispersive layout of the production wells will slow down the drawdown of the geothermal productive depression cone.

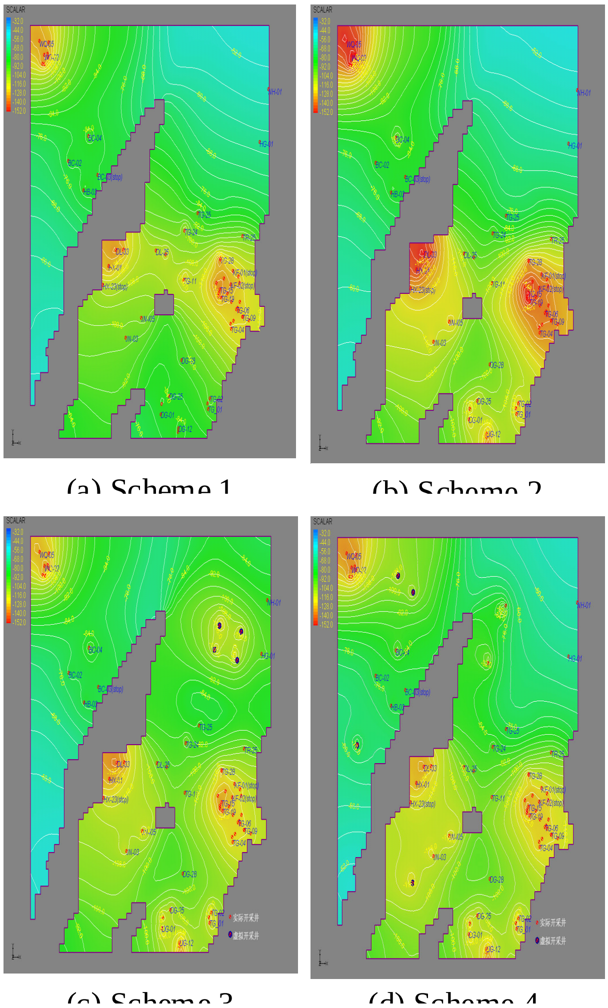


Figure 5: Water level contours of Ng group of different schemes in 2034 (Red dots are actual productive wells. Blue dots are virtual new geothermal wells in scheme 3 and 4)

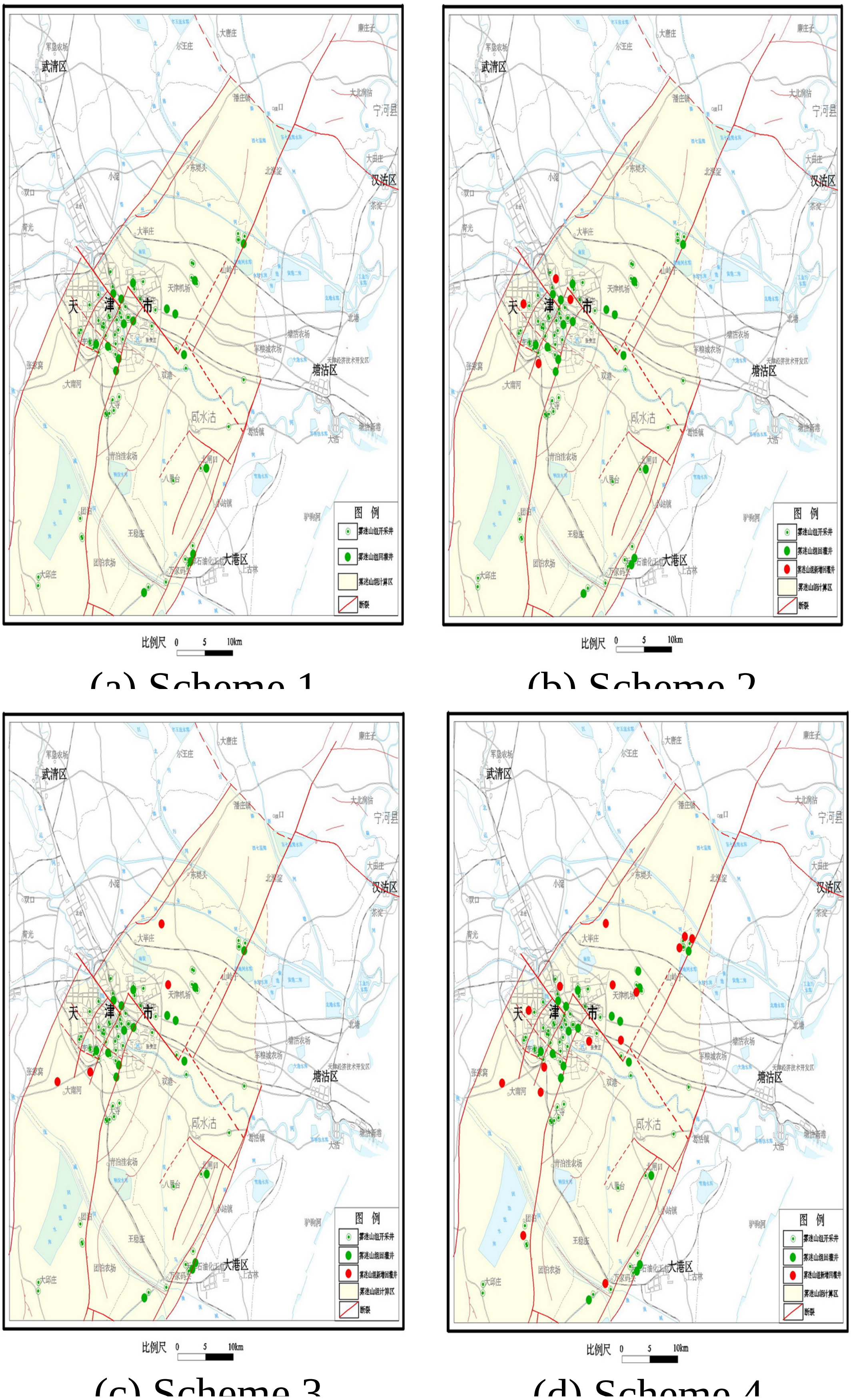
4.3.2 Basement Carbonate Reservoir in Paleozoic and Medium Proterozoic

The past 20 years production history has been simulated. Until now, there are 58 production wells and 18 reinjection wells in the Jixianian system. The optimization scheme is presented for the Wumishan Group of Jixianian in Proterozoic after the calculation about four reinjection and production schemes (Hu, Lin, Lin, et al, 2007).

Scheme 2: Based on the present layout of geothermal production wells, four new reinjection wells are drilled in the urban area. Thus, the annual production rate will keep 1270×10^{4}m^3/a, but the reinjection rate increases to 362.53×10^{4}m^3/a. Until 2014, the deepest water level will be -164.1m.

Scheme 3: Keeping up the same production rate of Scheme 2, but four virtual reinjection wells are moved outside the urban area. Then 10 years later, the deepest water level will be -166.1m.

Scheme 4: In the basis of Scheme 1, about 11 reinjection wells are added, five of them are located in the south and north of urban area respectively, and one is in the urban area. Thus, the annual production rate will keep 1270×10^{4}m^3/a, but the reinjection rate increases to 542.53×10^{4}m^3/a. Until 2014, the deepest water level will be -108.8m.



(a) Scheme 1 (b) Scheme 2

(c) Scheme 3 (d) Scheme 4

Figure 6: The layout of reinjection wells in four schemes

Figure 6 shows the layout of reinjection wells in the four schemes. Compared with the others, Scheme 4 is the most optimal. The reinjection from the peripheral area of the high productive center will be a more effective way to maintain the reservoir pressure. But the possible distinct cooling resulting from the injection has not been observed in the above four schemes. However, the result is highly uncertain because the flow channel dimensions are unknown. The further research will continue in the future jobs.

CONCLUSION

Through the monitoring of geothermal fields over more than 20 years, it has become an important and necessary part to evaluate the geothermal potentials and to plan the geothermal development by utilizing successful technology. It is also helpful in supplying guidance for mining enterprises on how to reasonably develop geothermal resources.

However, the water levels of most of the geothermal wells are observed manually due to a very heavy corrosion of the monitoring equipment. The automatic observation equipment for water level still waits for improvement for more efficient data collection (Wang, Han, 2007).

More monitoring points should be chosen with the increased geothermal development and utilization in Tianjin. So the nature and properties of the geothermal fields, as well as the response to long-term production and reinjection, can be obtained.

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