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MONITORING AND AUTOMATIC METERING OF THE GEOTHERMAL FIELDS IN TIANJIN

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ABSTRACT

Geothermal monitoring was started in the 1980s, in order to better develop and utilize the geothermal fields. After more than 20 years of continuous improving, the geothermal dynamic monitoring system has been set up in Tianjin. Meanwhile, the Technical criterion monitoring of low-medium geothermal field in Tianjin was compiled in 2006. Aiming at the difficulties with measuring, collecting of cost and monitoring the administration, research and development for intelligent management Net PC system of geothermal wells are 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.

1. INTRODUCTION

Geothermal monitoring was started in the 1980s, in order to better develop and utilize the geothermal fields. After more than 20 years of continuous improving, the geothermal dynamic monitoring system has been set up in Tianjin. Meanwhile, the Technical criterion monitoring of low-medium geothermal field in Tianjin was compiled in 2006. The analysis and research of a large amount of dynamic pressure, temperatures and flow rates of the geothermal wells, is 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. Additionally, the distributing area of 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, till now, automatic metering of the production and reinjection rate 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 part for both the geothermal utilization and the 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 problem of production and reinjection doublet system during the space heating period, and take 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. GENERAL STATUS OF 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). Table 1 shows the detailed information about the monitoring of geothermal fields in 2007.

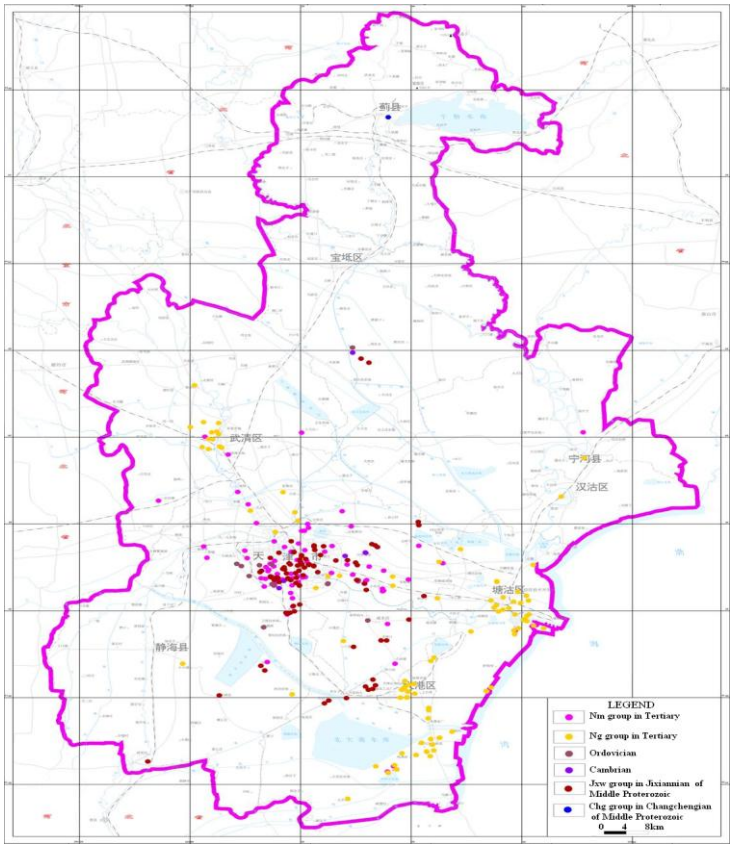

FIGURE 1: Location of the geothermal wells in Tianjin

TABLE 1: Schedule of Geothermal Monitoring in 2007

Item	Contents			Unit	Workload
Fieldwork	Dynamic monitoring	Key wells	Water level, pressure, temperature, flow rate	wells × times	127×24
		Normal wells	Water level, pressure, temperature, flow rate	wells × times	164×12
	Investigation	Production / reinjection rate		wells	291
		Status of geothermal utilization		wells	291
		Monitoring facilities of geothermal wells		wells	291
		synchronous monitoring		wells × times	291×2
	Maintenance of monitoring facilities			wells	12
	Geochemistry	Amount of wells		wells	99
		Amount of wells		wells	11
	Geophysics logging	Temperature		wells	1
		Pressure		wells	1
Research work	Chemical analysis of geothermal fluid's quality			wells	99
	Logging Interpretation of geothermal wells			wells	1
	Monthly report and database			month	12
	Summarize of the synchronous monitoring			times	2
	Figures			figure	85
	Tables and graphs			sheet	45
	Annual report and information system			report	1

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;
(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 lab

During the space heating period in the winter, geochemistry samples are taken from representative geothermal wells, for analyzing the changes of geothermal water quality in the long-term. The analysis includes hydro-chemical 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 geochemistry analysis of 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 the geothermal wells, which 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 (Figure 2 and 3).

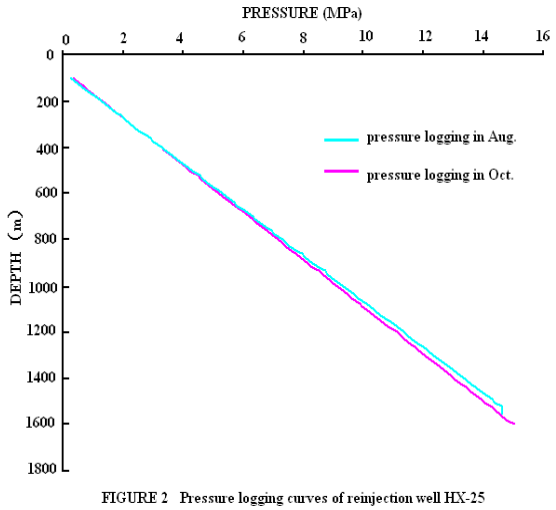

FIGURE 2 Pressure logging curves of reinjection well HX-25

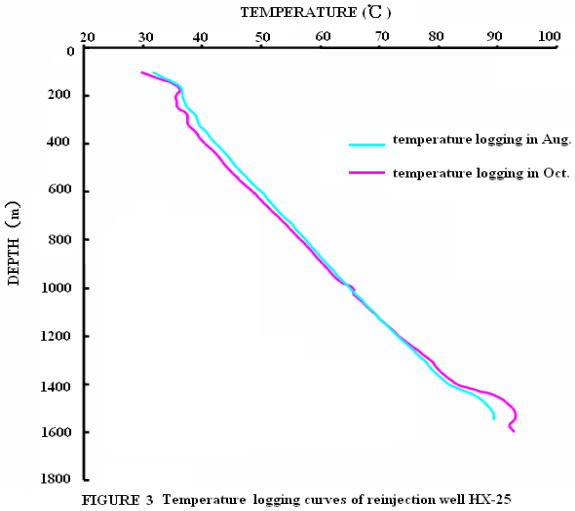

FIGURE 3 Temperature logging curves of reinjection well HX-25

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. The monitoring frequency of the normal points is twice per month. In order to obtain the overall observation data systematically and to analyze the dynamic nature of geothermal resources objectively, the layout of a key monitoring net is planned as follows:

(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.
(2) *Geology tectonics*: the key observation points are distributed along the main fracture zones or tectonic elements.
(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 were127 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 is in rural areas.

3.4 General analysis and annual reports

3.4.1 Monthly reports and the database

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

3.4.2 Synchronous monitoring

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.

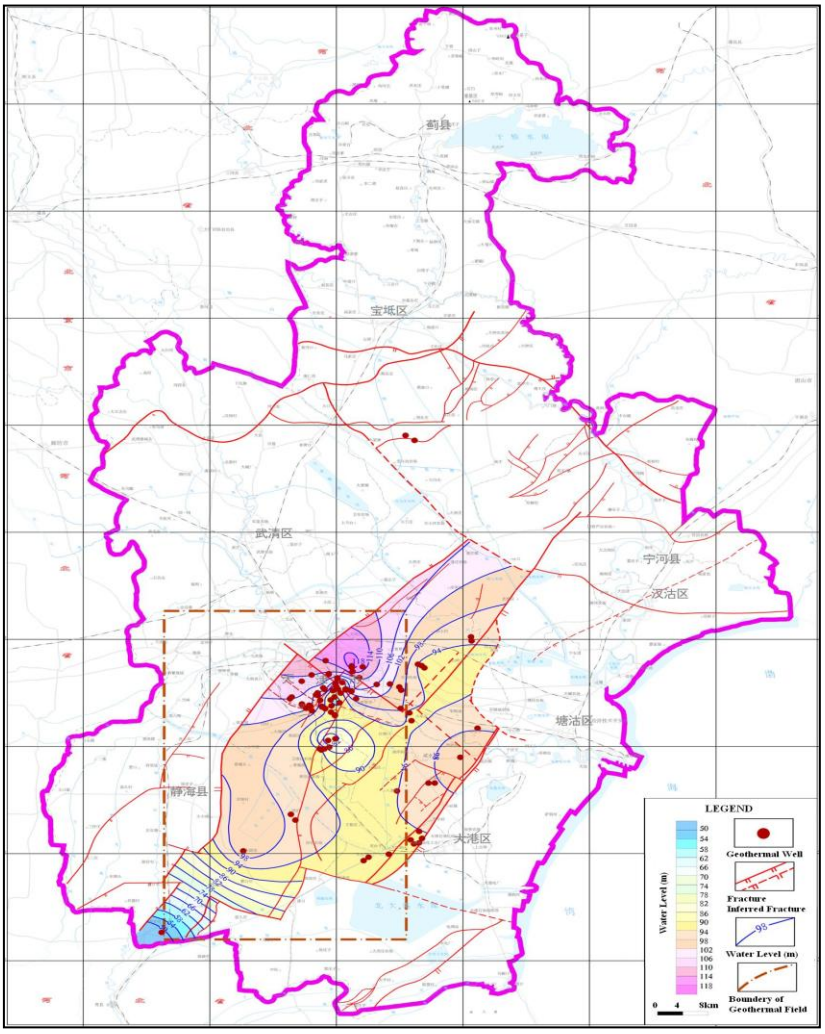

FIGURE 4: Contour of Water levels of Jxw reservoir in Proterozoic, 2007

3.4.3 Annual report

Mathematic modelling is an important tool to study the changes in geothermal reservoirs. Based on fieldworks, analysis in lab 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 geothermal reservoirs has been predicted. Suggestions on geothermal development and management are put forward in the report.

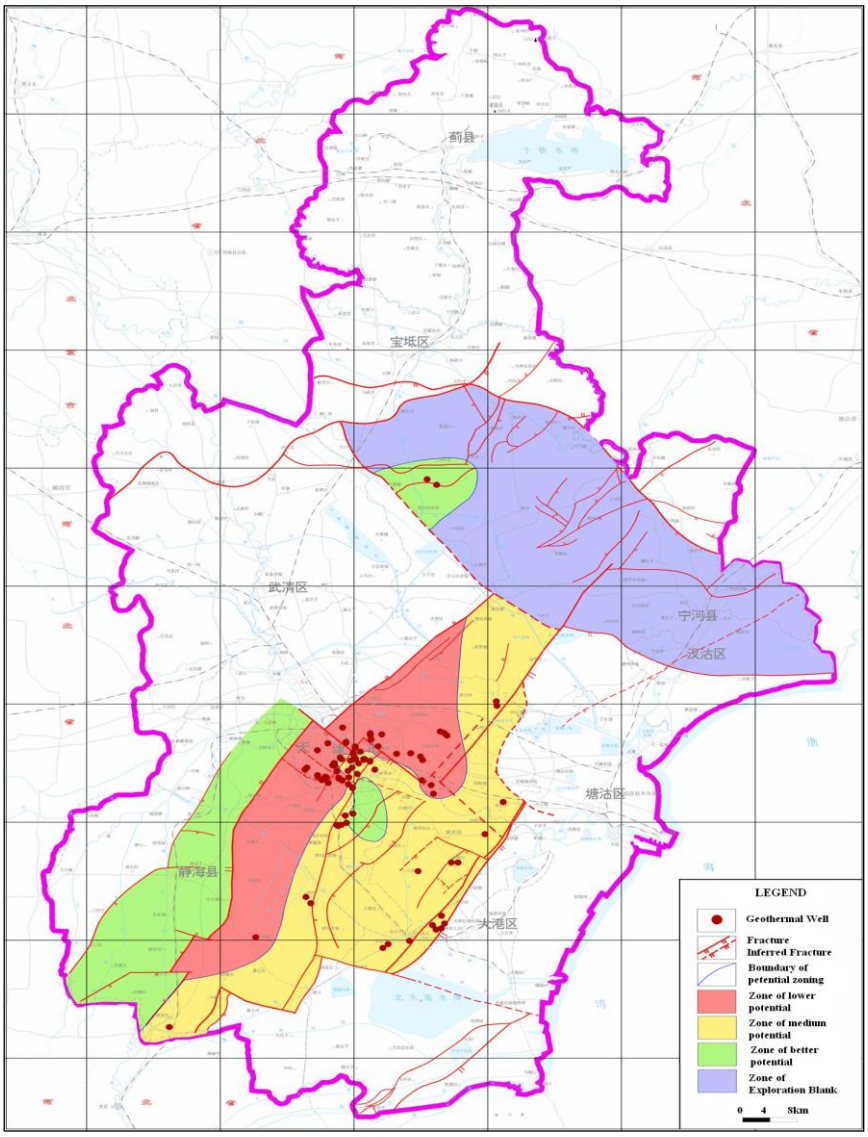

FIGURE 5: Zoning of development potential of Jxw reservoir in Proterozoic

4. AUTOMATIC METERING SYSTEM OF GEOTHERMAL WELLS

4.1 The components of geothermal intelligent management system

4.1.1 Management information system

Management information system (MIS) is a comprehensive, systematic subject, which is based on management science, information science, computer science, statistics and operations. MIS can be used for collecting, transferring, storing, processing, and utilizing information. It is not only a technical system, but also a management system and efficiently stores, process and manages the information by MIS.

4.1.2 Geographical Information System

Geographic Information System (GIS) is related to geographical information base on geographical databases. GISs collect, store, manage, operate, analyze, simulate and display space-related data and

through geographic modal analysis, provide a great of special and dynamic geographic information and management. It gives a comprehensive assessment, quantitaative analysis and decisions-making on geothermal monitoring. By using the functions of the spatial data analysis, GIS can put the data into a vector map and find the direct relationship between the map and the data. GIS can find the map information from the data and the data from the map. The system makes a detailed analysis on various types of information to successfully interpret the text data and map it.

4.1.3 Intelligent information system

Intelligent information system (IIS) is an application system where information technology and artificial intelligence technology are applied in specific fields. By using information processing techniques and computer intelligence, IIS can solve the problems through complex and large number of data processing and logic analysis. In the 1980s, with in-depth interdisciplinary research, operations research was applied to management information systems as a new intelligent information discipline in the Decision support system (DDS). Intelligent system plays an important role in realization of the intelligent judgment of the geothermal data. The system sends out the warnings signals, when the geothermal sites are improperly operated. This saves manpower and at the same time it limits the interference by the human factors.

4.1.4 Computer network

Network transmission is the media which should transmit the collected information accurately and efficiently. Up to now, the most common way is the three-tier network composed by the networking client, the server and the host. The outermost layer node of the typical three-tier network is a personal computer, which is connected to the local server. The computer stores data and manages hundreds of the external equipment used by clients. As long as the manager has a computer, which has been connected to the three-tier system, s/he will be able to retrieve the parameters from the local server and the host.

4.1.5 Wireless communications

The rapid growth of the communication technology is of great significant to the information system, especially the mobile communication. Because of the built-in wireless computer modem, it is easier to connect computers to one another and thus to increase their capacity and adaptability.

4.2 Function of intelligent management system

The development of the geothermal resources uses the monitoring capability of the system, especially to monitor the production volume, quality and the dynamic parameters. Its purpose is not only to collect the necessary dynamic data, but also to detect the situation of the system operation and to manage the collected data. The management system server receives dynamic monitored data from all remote data transmission terminals and organizes it. The software on the server can analyze the data and assess the situation of the system operation.

Microsoft Access is used as a database platform and Visual Basic 6 as a development tool. In order to provide humane management interface so that all the property information of the geothermal sites can be closely linked to the spatial information and enhance visualization of intelligent management system, geographical information system is included into the intelligent management system. The system includes historical data statistics, report creation, printing, trend forecasting, warnings and its disposal methods. The system can also be connected to any of the sites in order to monitor them.

To sum up, upper-management system with powerful management functions and control methods has the function to support a variety of communication networks, communication methods and

communication rules. Through monitoring all the geographical sites, the system can store information about the entire operation process. Therefore, in resource management, the human factor can be eliminated and it becomes a system with technical and standardized management, as is shown in Figure 6.

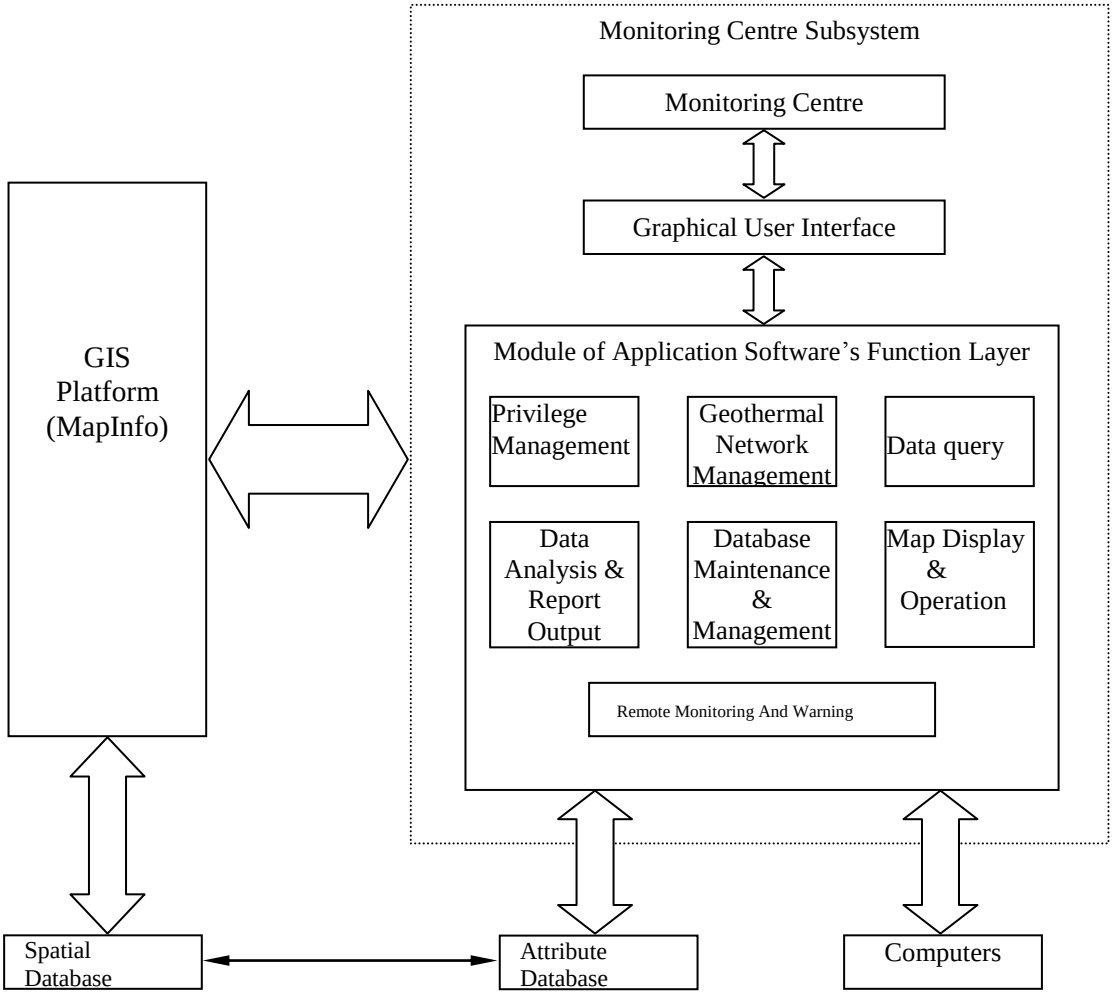

FIGURE 6: Sketch of configuration on internet management systems

4.3 Design of intelligent management system

4.3.1 Structural design of management system

There is a geographical information system, which can manage and monitor the dynamic city geothermal recourses on the data terminal as well as remote control geothermal management system based on geothermal information system. Because the control centre aims to achieve network management, it needs to develop a database system with client/server architecture in order to share data on the server (Oracle, Microsoft SQL Server).

(1) Oracle is the first commercialized relational database management system. It is a widely used client/server system with powerful functions. As a common database system, Oracle has comprehensive data management functions including storing large amount of data and definitions, manipulating data, concurrency control, security control, integrity control, fault recovery, interface with high-level language etc. Oracle supports a variety of distribution functions, especially the ones dealing with the internet. Oracle provides a fully functional development tool with a friendly interface,

which gives the user a good development environment. Oracle uses PS/SQL to operate and it is open, portable and scalable.

(2) Microsoft SQL Server is a typical client/server relational database management system, which uses Transact-SQL. It transmits requests and responses between server and client. Microsoft SQL Server can run on many operating systems. Microsoft SQL Server is reliable, available, scalable and manageable and offers, therefore, a complete database system solution for the project.

4.3.2 Designs for geographic information system

At present, the applications of GIS are: geospatial data management, comprehensive analysis and evaluation, spatial query and spatial analysis, cartography, the establishment of special information system and regional information system, combination of geographic information system and remote sensing image processing system. Because GIS is very strong professional specialized software, you can not solve all the problems by relaying only on GIS, a specific function must be developed through secondary development function and it must ensure seamless integration which provides users a unified operation interface, as shown in Figure 7.

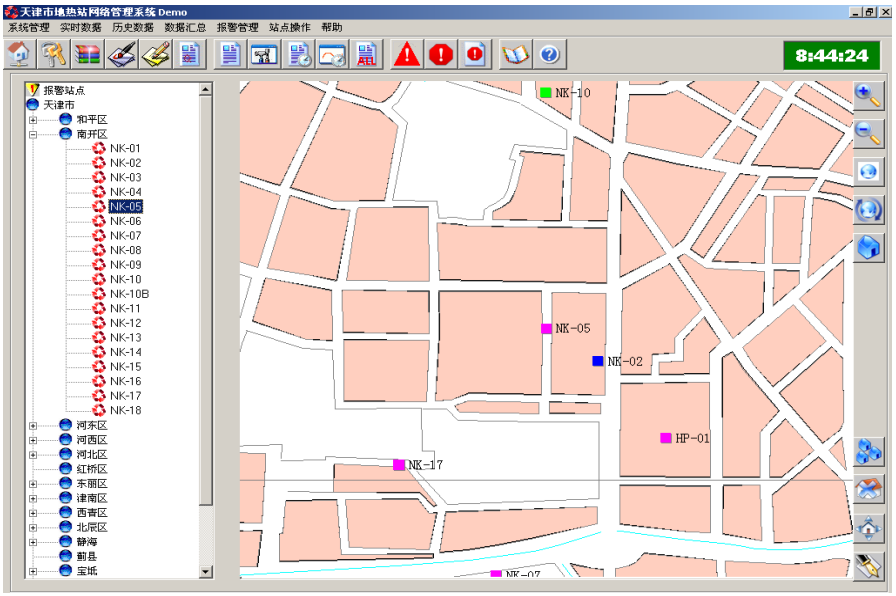

FIGURE 7: The management interface of geothermal information monitoring (GIS)

An integrated GIS mainly consists of four parts: computer hardware system, computer software system, geographic data (or spatial data) and system management operator. The core of it is the computer system (hardware and software). Spatial data reflects the geographic content of GIS, the management and users decide the work methods of the system and the way in which the information is displayed. The structure design and function structure design of the GIS software is shown in Figures 8 and 9.

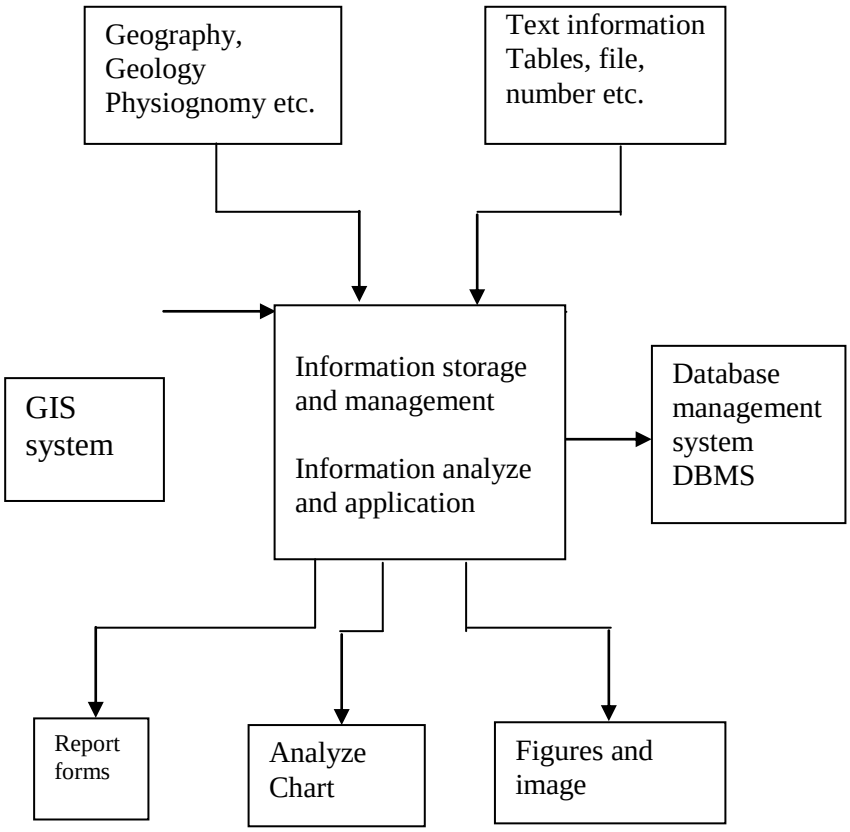

FIGURE 8: Geographical information system (GIS) structure design

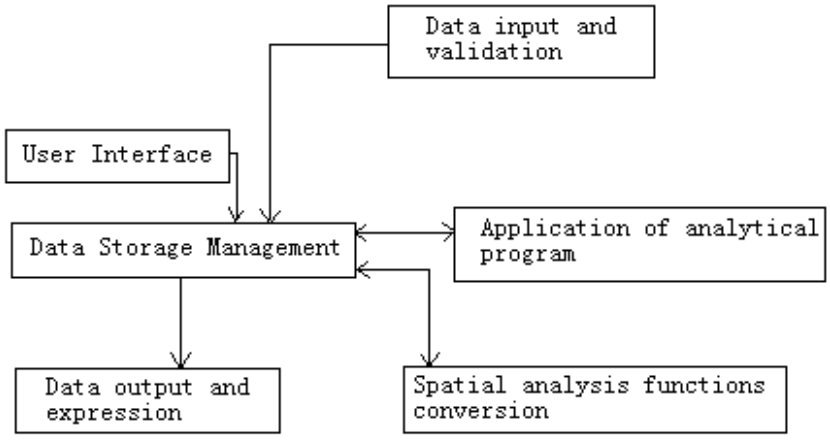

FIGURE 9: Function structure design of the GIS software

The system primarily consists of five subsystems：chief menu management subsystem, GIS analysis subsystem, terrestrial heat analysis system, terrestrial heat database operation platform and bottom database. It combines information management, resource assessment and scientific decision-making into one part and combines scientific evaluation of resources and decision-making into another part. GIS technology will integrate the geothermal engineering analysis as the foundation of resource evaluation.

4.3.3 Management subsystem structure

Cluster system can effectively improve system availability. If server A or the application procedures collapse, the B server of the cluster system will take over the responsibilities of the server; the system will still work, shortening the downtime of the application program.

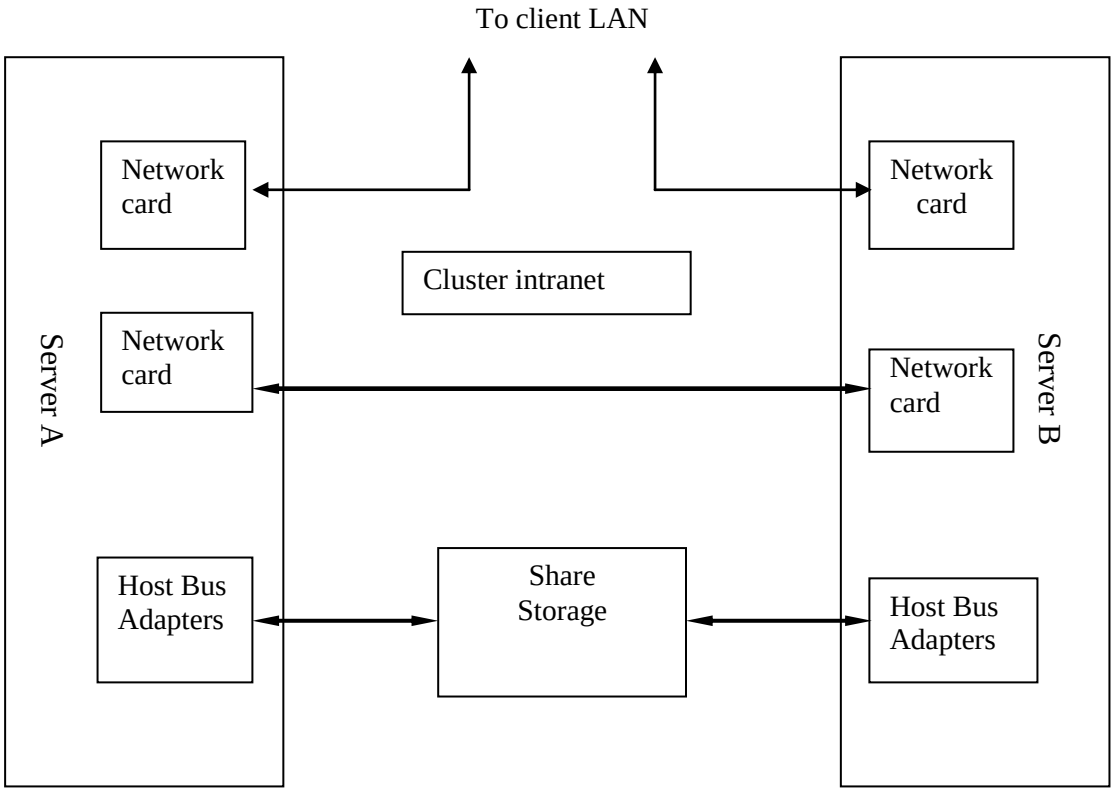

FIGURE 10: Topological structure of the control centre

4.3.4 Visualization management

Geographic information systems use electronic maps in MapInfo format, which possess the same functions as a common electronic map with enlarging, decreasing, roaming and full size show etc. In addition, based on the special requirements of the geothermal systems, with the database connection, the module increases special features, such as showing site information, adding new sites and deleting the site, editing site (adjusted basic information, etc.), shifting sites, convenience of the site management and updates information. By clicking on a site in the list an electronic map appears in a pop-up window, with detailed information about the site.

4.3.5 Alarm module

Due to the distribution of scattered geothermal stations the monitoring effort is weak and time-consuming. Therefore, an alarm, an automatic processing of accidents has become the important function of the management systems. When a data error appears, through functional relationship between mining flow, submersible pump current and frequency judgment, the alarm will whistle and immediately notify the master control management system and accurately display the point of irregularities at the site location and the name of the site in the electronic map. The management system will add the site and the fault conditions to the database and record and store it for future reference.

4.3.6 Communication module

The systems mainly monitor the data transmissions between the monitoring systems and the management systems; the communication system design has, therefore, become very important.

(1)*Telephone communication* (wired communication)
Transmission of data through the telephone network is a very common. Only telephone lines and modems around the monitoring system of the geothermal site need to be installed and the data transmission can be realized. The use of telephones is widespread, because of the stable performance, commonality and lower installation costs.

(2) *Broadband Network communication* (the Internet)
Data transmission through the Internet increases speed, reliability and stability. However, due to the initial installation cost for broadband network installation is more expensive to fit a geothermal station with a broadband network. The more popular ADSL has the characteristics of a broadband network but works without a cable.

(3) *Wireless communication*
Data transmission via mobile networks supports a wide range of communication designs, which can be applied to different geothermal sites under different circumstances. It fulfils various geothermal networking requirements and has powerful universal ability. But since it is wireless, the quality of signal will be influenced by the environmental conditions at each location. If a geothermal station is located in a basement it will affect the quality of signal transmission. Therefore, wireless communications are not suitable for geothermal stations; cable communications are more reliable.

4.3.7 Data transmission module

When the management system communicates with the monitoring system, it is one-to-many communication and it needs cycle inquiry. It is relatively simple for a monitoring system to initialize the communication with the management system, because it is a one-on-one communication. In order to avoid potential conflicts appearing in bi-directional communication, the system allocates different periods of time for each form of communication. Each geothermal station will upload the data of one day in to the management system. The monitoring system uploads the abnormal data. It has a priority level, so if unusual circumstances appear, the situation will be reported immediately.

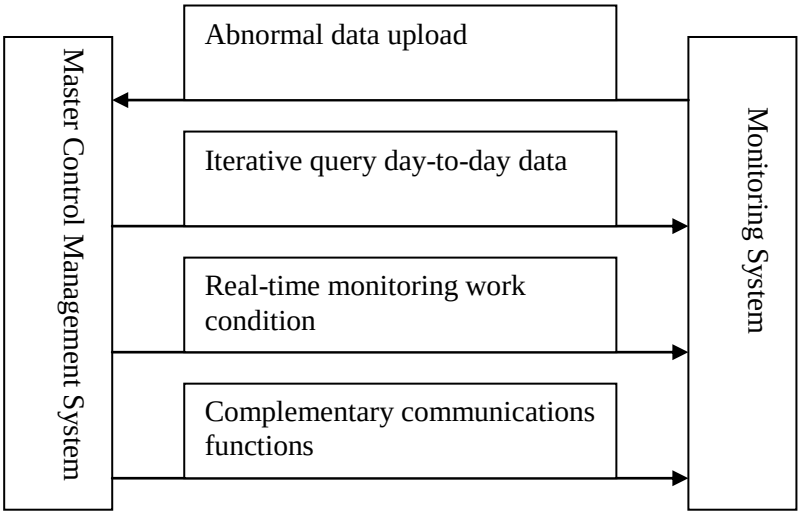

FIGURE 11: Sketch of communication structure

The management system software possesses many functions, such as uploading real-time data, data painting curve, making lists, and dynamic displays based on real-time data. This real-time communications happens at specific times, and as long as the alarm did not sound (automatic alarm system own the highest level of priority), managers can monitor the operational status of any site at any time, as is shown in Figure11. The setup satisfies the geothermal station management requirements and effectively avoids unnecessary conflicts. When a site uploads abnormal data the documentation can be carried out directly through this function, and it will provide the managers with information on appropriate reactions.

4.3.8 Statistics module

Statistics are an important function of geothermal intelligent management. Management systems provide the data of the site showing the daily, monthly, and yearly fluctuation in the curve of the flowrate and water level of geothermal wells. It is convenient for managers to analyze the trend of geothermal production at any time, including the production rate of every geothermal site in detail; the situation of payment and charge, and the situation of errors if they have occurred. In addition, the module also manages the data of failures at sites and keeps records of those sites. The records can be searched and operational aspect can be viewed. The design also includes database module, output module, user rights management module etc. The design further strengthens the database information management, data classification and retrieval, as well as the security of thermal management systems and ensures secrecy.

5. 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.

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.

REFERENCE

Axelsson, G., 2003: *Essence of geothermal resource management*. Edited by Fridleifsson, I.B. and Gunnarsson, M. Lectures on the sustainable use and operating policy for geothermal resources--Short course prior to the International Conference IGC2003. United Nations University Geothermal Training Programme, p.249.

Guo, C., Wang Q., Xu, Y., 2001: *Design and implementation of a communication mechanism for WEBGIS based on a distributed component model*, Computer Supported Cooperative Work in Design[J], 12:558~561

He M., Li C., Zhu J., et al, 2004: *China Middle-Low Enthalpy Geothermal Engineering Technology*, Beijing, Science Publishing House, P62-70

Song D., Wang K., Xu, P. et al., 2007: *The annual of the Mineral Resources in Tianjin,* Tianjin Bureau of Land Resources and Housing Administrative. 43p.

Wang K., 2005: *The Sustainable Development and Utilization of Geothermal Resources in Tianjin, CHINA*, Proceedings World Geothermal Congress 2005.

Wang K., Han J., Wang, Y., 2007: *The policies research about reinjection, comprehensive utilization and sustainable development of geothermal resources in Tianjin,* Transactions of the workshop of Development and Protection of Geothermal Resources in China. p. 121-127.

Wang Kun, 2001: *Application of isotopic technique on establishing hydrothermal concept model*, Journal of Science in China, Dec. 2001, 4.

Wang. H., 2007: *Application of Wince windows controlling center and PLC in geothermal development and utilization.* Transactions of the Workshop of Development and Protection of Geothermal Resources in China. p.82-85.

Zeng, M., Ruan, C. et al., 2007: *The annual report of dynamic monitoring of geothermal resource in Tianjin*, Report in Chinese, sponsored by Tianjin Bureau of Land Resources and Housing Administrative.

Zhu Jialing, et al., 2006: Geothermal Exploitation and Utilization Technology [M], Beijing, P260-268