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Research on the spatial database management system of water resources in a river basin

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ABSTRACT

The planning, management, governance, and ecological protection of a river basin are becoming more and more important, which needs a great support of water resources data both spatial and attribute data. According to the characteristics of these data, a suitable thematic water resources spatial database management system (WRSDBMS) in river basin is proposed to manage these data integrally. In the thematic system, an extensible data model conforming to water resources data is proposed with the synthesization of traditional structured database system and unstructured spatial data management system. In the extendable data model, client/server structure is used, an extended model of Oracle is used to manage both spatial data and property data, and the spatial database engine is used to import/export spatial data to/from Oracle. The WRSDBMS system is finally used for water resources data management of Hanjiang river basin. It is clearly seen that the system is efficient and reasonable in integrated management of spatial and attribute data. And it may provide a strong support for the scientific management of the river basin.

Keywords: Water resources; Spatial database management system; River basin; Extendable data model; Oracle; Spatial database engine; GIS

1. Introduction

Water resources are the important basic natural resources and strategic economic resources on which all human beings and all living things depend on for survival [1]. Sustainable management of water resources poses enormous challenges in many parts of the world [2], and it is an important guarantee for the sustainable development of society [3,4]. River basin water resources as an important part of water resources provide an important support for the development of social economy in the basin. The sustainable development of the social economy cannot be separated from the integrated management of river basin water resources [5]. The integrated management of river basin water resources mainly includes planning, development, schedule, distribution, protection, and so on [6]. In order to implement the integrated management of water resources in the basin, rational and effective management of basin data is indispensable. Data management of river basin water resources is the foundation of water resources management.

For the study of data management of river basin water resources, many methods were used, such as reports, maps, CAD [7], database, and so on. However, in a river basin especially with a large area there are many kinds of data which have the characteristics of multisource and heterogeneous, spatial and massive, dynamic and variable, and structured and unstructured, so the traditional data management model can no longer achieve the integrated management of watershed data. For an instance, the reports method can be just used to store attribute information, the map method can be

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used to show the shape characteristics without attribute, the CAD method can be only used to manage graphic data, and the traditional database can be only used to manage attribute data. Therefore, it can be clearly known that the traditional management method cannot achieve the integrated management of both graphic data and attribute data.

Besides this, in order to manage watershed data efficiently, many management systems were developed, such as water quality management system (WQMS) and database management system (DBMS) have been used for watershed data management. However, these systems can just manage one type or partial types of data, for example, the WQMS is mainly used to manage the water quality data in the river basin, and the DBMS is generally used to store and manage attribute. As mentioned before, data in a river basin contain a variety of types and different characteristics, so a simple data management system which just manages a certain type of data is no longer satisfied.

As mentioned above, water resources data in river basin have many kinds of types and characteristics. In general, we can divide the data into two categories according to their characteristics, namely, attribute data and spatial data. And at the same time with the introduction of digital watershed and smart basin, the integrated data management of water resources in a river basin is becoming more and more urgent. Under this background, we try to propose a hybrid data model which can manage both spatial data and attribute data. And at the same time, we design and develop a water resources spatial database management system (WRSDBMS) to manage and operate the watershed data synthetically and efficiently with the traditional structured DBMS and unstructured geographical information system (GIS) under the consideration of data complexity and requirement analysis.

2. Data composition and characteristic of water resources in river basin

Data are the basis of database, while database is the support of DBMS. As river basin management system contains various complex data types, so data composition and data characteristics analysis is necessary and important for database system design and development.

2.1. Data composition

Data in WRSDBMS include different kinds of types which can be obtained through 3S technology [8]. But in general, they can mainly be divided into two basic types: spatial data and attribute data, according to the characteristics of data and requirement of spatial database management as shown in Fig. 1. From Fig. 1, spatial data in WRSDBMS can be divided into following types: (1) basic geographic data—used for describing the various basic information of geography, such as the administrative boundary of country and province, road network, river network, and so on; (2) remote sensing data—refer to data obtained through remote sensing satellites and unmanned aerial vehicles; and (3) topographic data—abstract representation of terrain data. They mainly include digital elevation model (DEM) data and a series of data derived from DEM data such as slope data and slope aspect data. The attribute data in WRSDBMS mainly include the following: (1) water resources thematic data—made up of hydrological data, hydraulic engineering data, hydro-environmental data, drought disaster data, and soil-water resources data; (2) planning data—the planning and management for a river basin is becoming more and more important, so many basin planning schemes and engineering design data will come on; (3) document data—in general, document data include some policies data, regulations data, notices flies, news files, and so on; and (4) other data—such as photos, videos, and metadata which are often needed to be stored in the computer.

2.2. Data characteristics

Spatial data are used to describe the spatial entities in the real world which have the unstructured characteristics. Attribute data are generally used to describe the basic information of entities. The biggest difference between spatial and attribute data is the spatial characteristic [9].

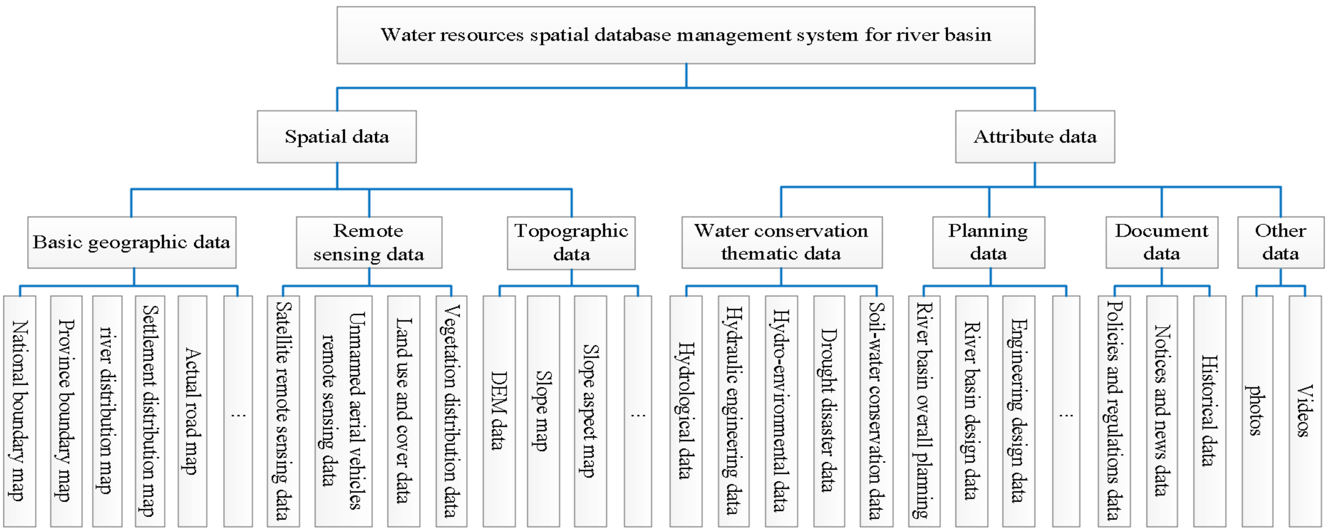

Fig. 1. Data composition of the water resources in river basin.

River basin as the entire area main stream and tributaries in a water system flows through, the data characteristics in which must be very special. From the composition of data in WRSDBMS, it can be clearly seen that water resources data in river basin have different characteristics. These characteristics contains the following: (1) multiplicity—data of river basin contain different types of data such as spatial data and attribute data which make data types varied; (2) multisource—basin data are derived from a variety of sources, and different types of data may be obtained through different approaches; (3) spatial and massive—basin data include spatial data, and with the increase of resolution the data volume is becoming larger and larger; (4) multiscale—data in basin system are different which makes the data multiscale; and (5) structured and unstructured—the watershed data have both attribute data that conform to the water industry standard and also very complex spatial data, so it need a combination of structured and unstructured storage.

In summary, the WRSDBMS for the river basin contains both basic geographic maps and water resources thematic maps, both remote sensing images and attribute data, both document files and media files, and both structured data and unstructured data [10].

3. System design

3.1. Requirement analysis

Spatial database system for water resources is based on geographical information and water thematic information [11]. According to the data composition and data characteristics of multisource and heterogeneous in the WRSDBMS, the traditional DBMS can no long meet the requirements of integrated management for the river basin. Therefore, in order to realize the integrated management to spatial and attribute data of water resources in the river basin, the WRSDBMS should include the following functions:

- Sorted storing function—to store information with different types and increase the retrieval efficiency of data, system should be able to judge the types of data and then store classifiably.
- Data import and export function—the basic functions of DBMS are able to store and manage the spatial data, and then to conduct analysis to spatial data, and to supply data support for decide-making system. The implementation of these functions must rely on the data import and export function, so the management system should supply this interface.
- Database management and maintenance function—in this system, Oracle is only used as a backend storage system, so the management system should have database object creation, editing, and data security functions.
- Spatial data operation function—different from the traditional database, the main function of spatial database is to be able to carry out related operations on spatial data, such as the creation, editing, and preservation of spatial objects; loading, removing, labeling, and rendering of layers; map-attribute interactive query and spatial data backup and recovery.

3.2. System framework design

The main functions of WRSDMS are to store and manage the water resources data in the river basin. As the water resources data contain many kinds of types, in order to realize the high-efficiency and reasonable management to these data, a suitable system structure is needed.

Under this requirement, the spatial DBMS of water resources in river basin is developed with client/server (C/S) model. According to the characteristics of the C/S structure, three layers such as client layer, middle layer, and server layer are further divided. The client side contains a series of operations of each function module, such as import and export, browse and display, and query and retrieve. At the server layer, many sub-databases corresponding to the data composition as introduced in Section 2.1 were constructed. In order to use these sub-databases to store water resources data, an extended model of Oracle is applied which can store both spatial data and attribute data. In order to access the spatial data, Spatial Database Engine (SDE) is used, and to guarantee the security and stability of database system and the high efficient access to massive data, the ActiveX Data Objects (ADO) technology is applied [12]. The SDE and ADO just make up of the middle side which is used to link the client side and server side as shown in Fig. 2.

3.3. Spatial database design

In general, spatial data are the spatial information expressed in symbolic form abstracted from spatial entities. A traditional spatial database is a collection of spatial data stored together. However, data in the WRSDBMS contain a variety of data types, not only general structured data but also unstructured spatial data. So, constructing a suitable spatial database to store these data is of great significance. The design of spatial database is a complicated progress with a constant modification. Normally, the design of spatial database contains the following stages: requirement analysis stage, conceptual structure design stage, logical structure design stage, physical structure design stage, database implementation stage, and database maintenance stage, as shown in Fig. 3.

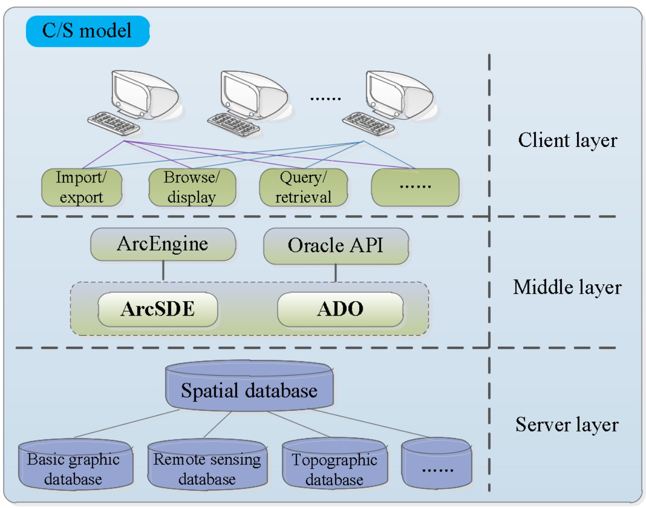

Fig. 2. Design of the system framework.

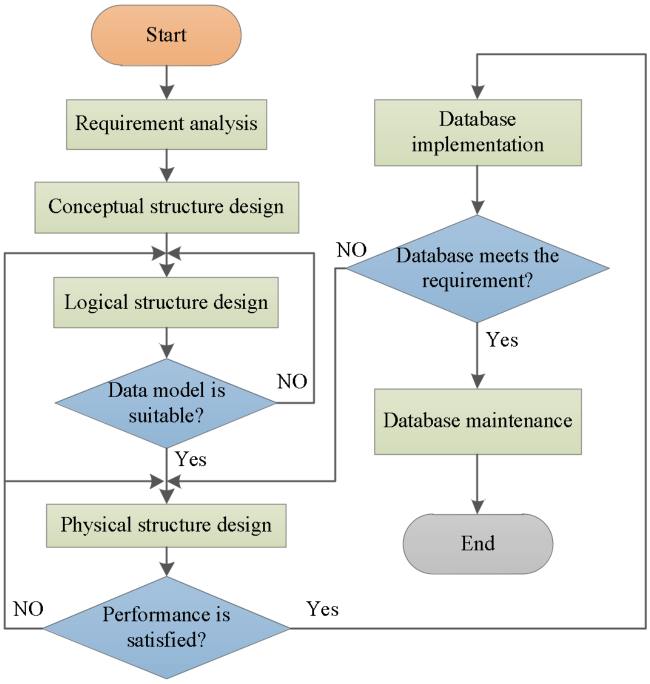

Fig. 3. Flow diagram of the water resources spatial database in river basin.

- Conceptual design of spatial database—the goal of conceptual structure design is to abstract the requirements into conceptual models through comprehensive analysis and induction. The conceptual model is the abstract information structure generated from the real world, and it is made up of the basic elements of the real world and the connections between these elements. In order to design the conceptual structure, this paper chose entity–relationship (E–R) diagram model to describe these elements and the connections between them.
- Logical design of spatial database—logical structure design is the core of spatial database design. The basic role of logical structure design is to convert the conceptual model into a data model supported by DBMS in computer system according to the E–R model designed by conceptual structure design. In this paper, according to the data analysis in Section 2, the data in the system can be logically divided into national basic geography data, remote sensing data, water resources thematic data, and so on.
- Physical design of spatial database—the design of physical structure is to find a suitable storage format, location, and storage method to store database and data in database on a physical device in the computer system. A most suitable physical structure can realize the reasonable allocation of the physical space of spatial database and can also improve the data integrity, security, and effectiveness as much as possible. According to the requirement analysis of the system and the data characteristics, this paper chose the way of combination of Oracle and ArcSDE to store data.
- Data model and structure design—data structure model is mainly used to describe the type, content, and characteristics of data and also the relationship between data. Characteristic of water resource data in river basin has been introduced in detail in Section 2.2. According to these characteristics, WRSDBMS adopted a hybrid model to organize the data. In the hybrid model, the spatial data are stored in a series of files in some certain formats, and the attribute data are stored in RDBMS. To manage the attribute data, database interface programs such as Open Database Connectivity and Object Linking and Embedding Database can be used. The relationship between spatial data and attribute data is realized through a unique identifier generated inside the system.

More specifically, the spatial data in the hybrid model can be described into three files: main file (.shp file), index file (.shx file), and dBASE table (.dbf file). The .shp file is used to store the spatial data, the .dbf file is used to store the attribute file, and the .shx file is finally used to store the relationship between spatial data and attribute data.

3.4. Function module design

In order to realize the reasonable and effective management of watershed data, this paper has designed a series of function modules to ensure the system to organize the basin data more efficient.

- Database management module—this module mainly supplies the management of SDE and database project. Specifically, it mainly includes connection and disconnection of the database and new project, addition, opening, and storage of database project.
- Data import and export module—it is mainly used for the import and export operation of water resources data. The attribute data can be imported into the database through the designed forms and excel files, and also be exported to excel files. The spatial data can be imported and exported with the help of SDE.
- Data browse and display module—this module can offer a browse and display to data both in database and local host. In the system, the browse of data can be divided into three types, such as two-dimensional data, three-dimensional data, and metadata. For these types of data, this system supplies a corresponding view model to display the spatial information, attribute information, and metadata information.
- Spatial query and retrieval module—the query/retrieval models of map-to-attribute, attribute-to-map, and SQL query are one of the most important functions in the spatial management system. In this system, the query of map-to-attribute is divided into click query and regional query; the query of attribute-to-map is divided into attribute query and position query; and the SQL query can achieve the query to attribute.
- Database maintenance module—it mainly provides related functions of database management and object management. The function of database management concretely includes new creation, delete, and edit operation of sub-database, tablespace, and data files. Object management includes management about spatial objects and attributes objects. For attributes objects which contain tables, views, and indexes, the managements of them include new creation,

delete, edit, and save. While for spatial objects, managements not only include aforementioned functions but also should consider topology relationship management.

- Safety management module—this module offers the function of user security and database security. User security is designed to create, delete, edit, and set permissions for users who use the database system. Database security features include backup and recovery of databases.

4. System development and application

4.1. Development environment and method

The WRSDBMS is developed with the support of spatial information technology. Because the system involves the display and analysis of a large number of GIS graphics data, so the secondary development of GIS is used. Considering the convenience of flexible, easy to operate, cost, and other aspects, this system uses ArcEngine components for the secondary development of GIS. The system chooses Windows XP as operating platform, Visual Studio 2008 as software development platform, Oracle 10g as database support platform, ArcSDE 9.3 as SDE, ArcGIS Engine embedded component library as the core development tools, and C# as development language to develop the system.

4.2. Main function modules development

4.2.1. Development of browse and display module

This module supports a browse and display to both spatial data and attribute data not only in spatial database but also in the local host. As the display of attribute data is simple relatively, here, we just discuss how to browse and display the spatial data of water resources in the river basin. In this spatial DBMS, many interfaces were used such as IGxDialog, IGxObjectFilter, pGxFilter, IGxDataset, IFeatureLayer, and IEnumGxObject. First, define the dialog box with IGxDialog interface. Second, filter the objects of non-FeatureClass types with the interface IGxObjectFilter. And then define the enumerators and data sets with interfaces of IEnumGxObject and IGxDataset. Next, judge whether the enumerators are empty, if the enumerators are empty reset them and add the selected objects in GxDialog dialog box to data set. After the empty judgment to enumerators, the next step is to check whether the data sets are empty or not. Finally, use AddLayer method to load objects in data sets. The flow diagram of browse and display module is shown in Fig. 4.

4.2.2. Development of query and retrieval module

In the query of mass spatial data, the spatial query operation of massive data often becomes the bottleneck of performance [13]. In order to realize the high-efficient query of data, secondary development based on GIS components was applied. The query and retrieval module in this spatial DBMS contains two kinds of query types: map query and attribute query. Map query can be further divided into three types, namely, query based on attribute, query based on location, and query based on SQL expressions. Attribute query can be further partitioned into two types: identify query and region query.

- Map query—considering the length and repeatability issues, here, only the flow diagram of query based on attribute is introduced as shown in Fig. 5. The main interfaces used in the development of map query module are IHookHelper, IEnumLayer, IQueryFilter, and IFeatureCursor. From Fig. 5, first, judge the current map whether it is empty. Then, choose a layer from the current map under the premise of the current map not empty. After that, enter query conditions and construct query expressions. Next, judge the correctness of expressions and whether there are query results. Finally, show the query results and highlight them on the map.
- Attribute query—attribute query as stated above is divided into two ways. The identify query can be implemented by the function of Identify with IIdentifyDialog and IidentifyDialogProps interfaces. The region query can be further divided into three ways: select with a region, select with a circle, and select with a polygon. Here, taking consideration of the length and repeatability issues, we just discuss the development of attribute query module by region. From the flow diagram of attribute query based on regional query shown in Fig. 6, the following steps should be included: (1) check whether the current map is empty; (2) choose the current map if the current map is not empty; (3) choose the query way and use the clsQueryByPolygon class to define a region; (4) filter the features by ISpatialFilter interface and select the features; (5) judge whether the selected features are needed; and (6) use IFeature interface to highlight the selected feature and show the attribute of the selected feature by IFeatureCursor and IFeature interfaces and ArrayList method.

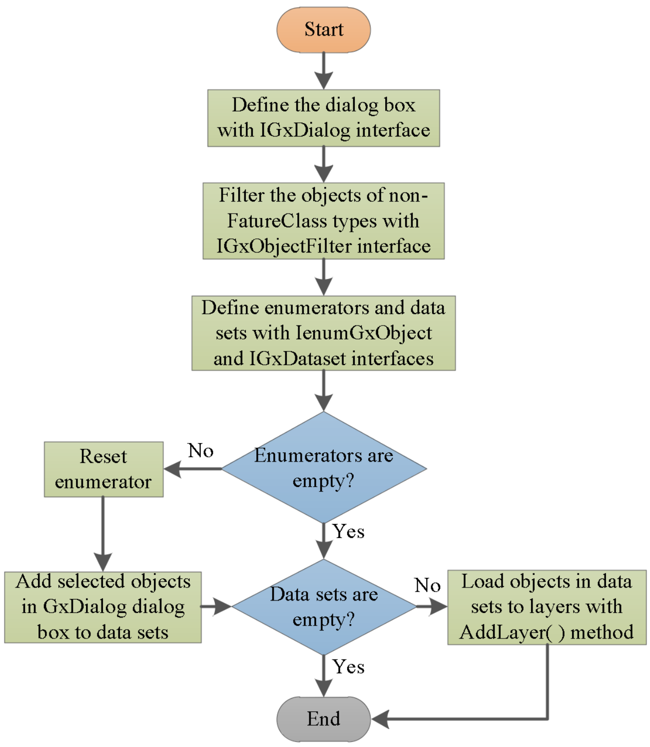

Fig. 4. Flow diagram of the browse and display module.

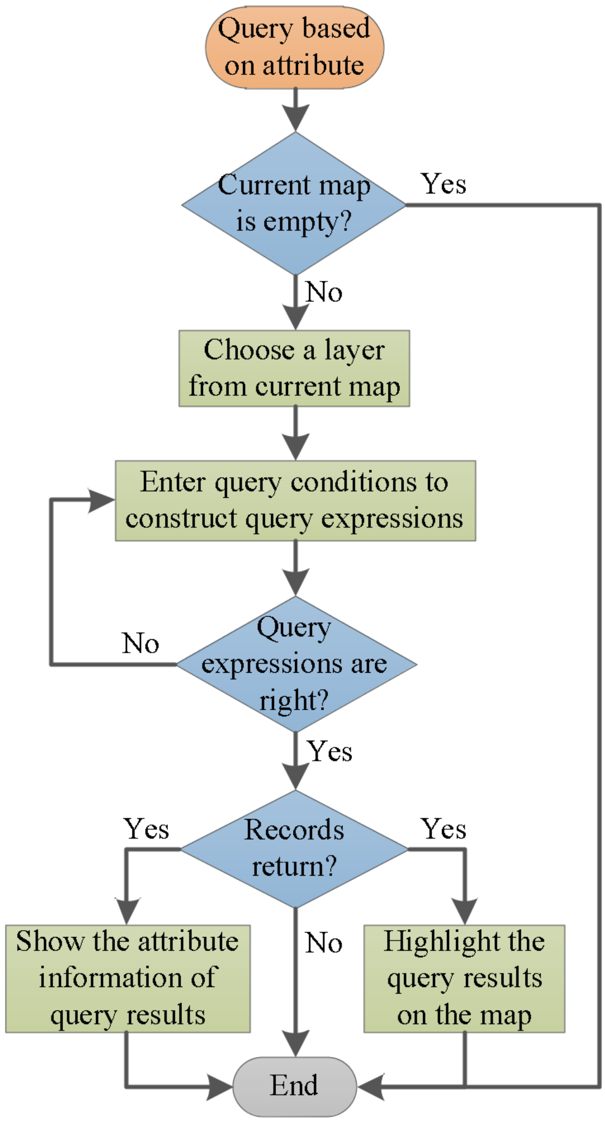

Fig. 5. Flow diagram of the map query based on attribute data.

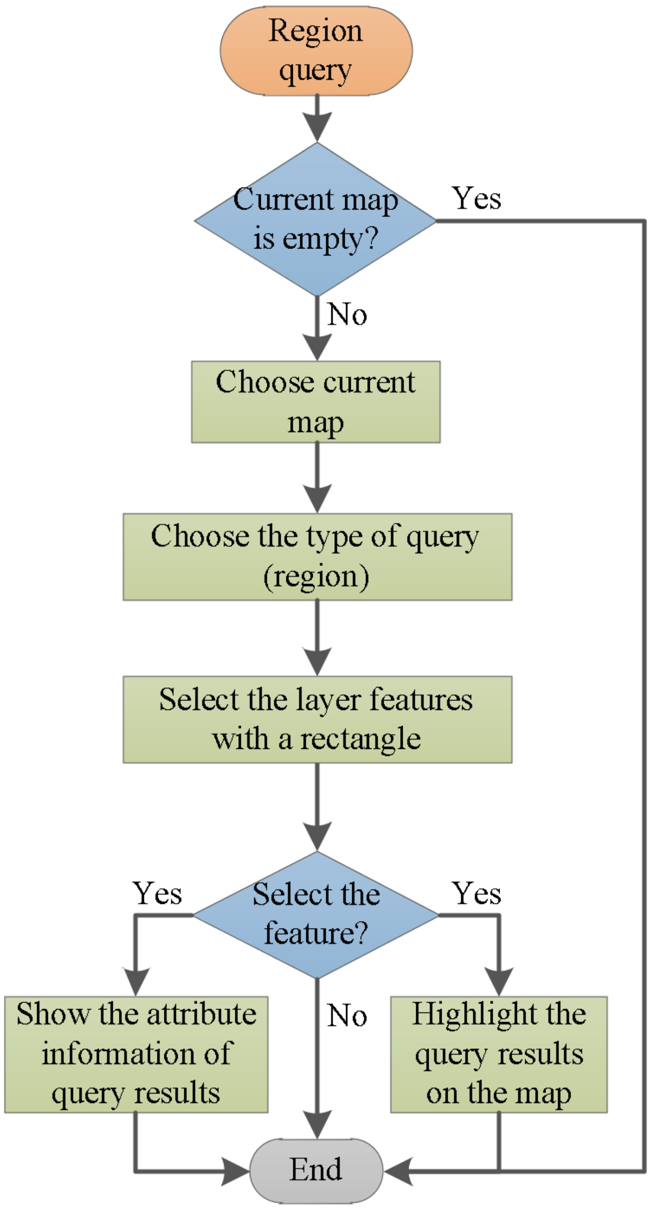

Fig. 6. Flow diagram of the attribute data query based on a region.

4.3. System application

According to the system requirements analysis, the system interface can be divided into four chunks: data management area, layer management area, function area, and layer display area. The data management area is mainly used to load the spatial data stored in the database; the layer management area is mainly used to display the currently loaded layer name, layer category, etc.; function area is mainly used to distinguish between different functions which has sub-functions, such as database maintenance is divided into database management and object maintenance; and layer display area is mainly used for the map data display.

As mentioned before, the water resources data management system includes many functions as introduced in Section 3.4. Considering the length of the article, here we just display the browse and display module and the query and retrieval module. The main interface of browse and display module is shown in Fig. 7. In the figure, it can be obviously seen that hydrologic station layer and Hanjiang river basin layer are loaded in the system. And through a series of operations, the attribute of hydrologic station is displayed under the map. This suggests that the graphic data and the attribute data of the spatial data can be displayed at the same time. In other words, the system can truly realize the integrated management of water resources data in river basin.

The main interface of query and retrieval module is displayed in Fig. 8. Fig. 8 shows a query of a hydrologic station in Hanjiang River basin. Through query operation, the selected hydrologic station is highlighted in the map, and the attribute of the selected station is shown in a pop-up window and highlighted in the attribute tables. This quick query and retrieval suggests that the spatial DBMS can well achieve the association between spatial data and attribute data. And it also indicates that the system can manage the water resources data both spatial and attribute integrally.

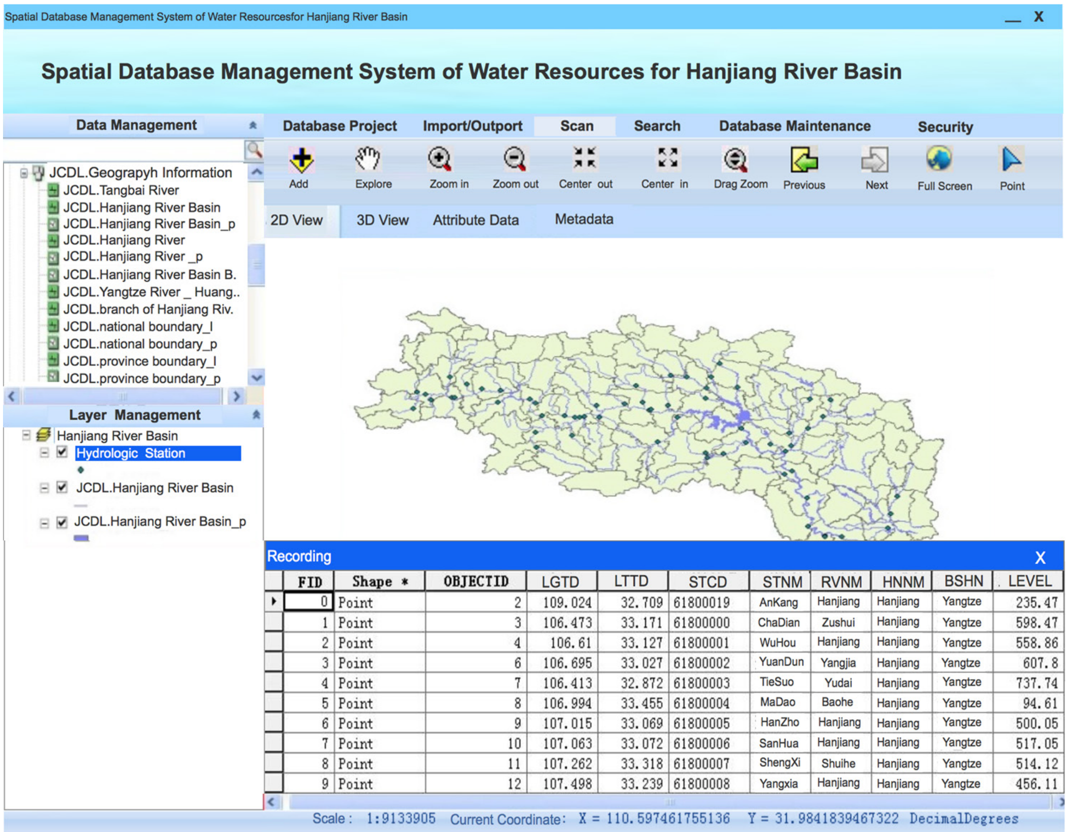

Fig. 7. Main interface of browse and display module of the system.

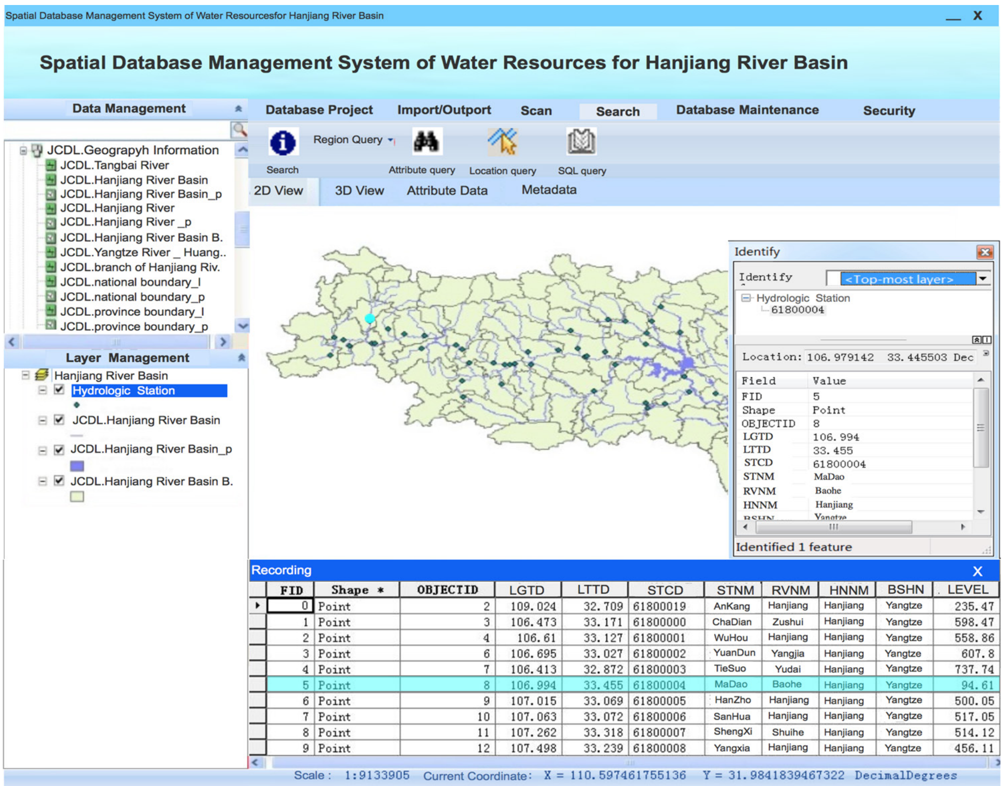

Fig. 8. Main interface of query and retrieval module the system.

5. Conclusion

In order to implement the integrated management of water resources data of a whole river basin, this paper proposed a WRSDBMS to manage both spatial data and attribute data. The WRSDBMS is a thematic spatial DBMS which integrate the traditional DBMS and the GIS system. The traditional DBMS system is very useful to management the structured attribute data, but cannot be used to deal with unstructured spatial data. Because water resources data in a river basin contain not only attribute data but also massive spatial data, in order to manage these data integrally an extended model of Oracle with SDE was proposed in this paper. The structured attribute can use the traditional relational database system Oracle to manage and the unstructured spatial can use the extended model with SDE to manage. From the function module design of the WRSDBMS, this system contains a lot of functions, such as import and export, browse and display, query and retrieval, and database management, which can ensure the integrated management of map and attribute.

The proposed WRSDBMS system can realize the integrated management to water resources data in the river basin. And it is believed that this system with extended model can be useful and meaningful for the management of the water resources data in the river basin in the future.

Acknowledgments

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