Design and Implementation of the Spatial Database for Reclaimed Water Utilization

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Abstract. In order to meet the application requirements of visual management and analysis of the information about recycled water use, the spatial database for the City Recycled Water Use is designed and constructed in this paper based on Geodatabase the spatial data model as well as UML and CASE as tools. The View Layer design, Concept design and Logic Design of the database of the recycled water use is explained in details. Then the application of the designed database to implement the Dianchi Lake Basin recycled water use in GIS platform is carried out and parts of the details is described in this paper.

Introduction

Water is a kind of natural resources that human beings rely on for survival. In recent years, with the rapid growth of urban construction, the scale of city area expands ceaselessly, so does the population. Modern cities are facing dual pressures from the lack of water resources and water pollution. Reclaimed water, known as the intermediate water, is a kind of non-drinking water purified from municipal sewage and effluent by sewage plant or reclaimed water treatment station. Its quality reaches national standard so that can be used in some extent. The recourse of reclaimed water is municipal sewage. With the features of huge amount, stabilizing, free from the influence of climate and other natural conditions, reclaimed water is the second city water source. It will find its source as long as municipal sewage continues to produce. With this, the utilization of reclaimed water has already become one of the effective ways to solve the shortage of water resources in cities.

So far, in order to reclaim water resources, many large and medium-sized cities in China have setup reclaimed water treatment and utilization systems in different scales. Reclaimed water utilization system consists of reclaimed water treatment plant, reclaimed water transmission pipeline network, reclaimed water users, reclaimed water intake points, etc. So the information of urban reclaimed water utilization has a typical feature of spatial distribution. It has become an inexorable trend to apply GIS technology into the information management of city reclaimed water utilization and to build a visual information system that puts it into reality.

In this paper, we have designed and built a spatial database for a reclaimed water utilization system on Dianchi Lake watershed, provided the data support for the GIS platform on city reclaimed water utilization.
Analysis of the Data Source of Reclaimed Water Utilization

The features of data from city reclaimed water utilization system are as follows:

(1) Scattering and Multisource

Many departments are involved in the planning, constructing and maintenance procedure of a single reclaimed water system. Data materials are scattering and the sources of data are numerous. So far, the main recourses of city reclaimed water utilization data include: city underground pipeline detection data, reclaimed water treatment plant data, reclaimed water pipeline network construction and completion data, reclaimed water pipeline network reform and maintenance data and reclaimed water user data.

(2) The Diversity of Data Formats

Due to the lack of unified standard on data collecting and storing of reclaimed water utilization within different departments, the data formats of reclaimed water utilization varies, so does the spatial reference system, geographic element definition and attribute information, making it extremely hard to manage and analyze the reclaimed water utilization information. So far, the main data formats of city reclaimed water utilization are: vector data, raster data, CAD data, Excel/Text data and paper map.

Therefore, before utilizing the data, it is necessary to handle the data for reclaimed water utilization. This process mainly includes: coordinate transformation, format conversion, digitization, etc. In order to ensure that the data is accurate and reliable, it is necessary to verify the geographic data which is uncertain in the spot by using GPS.

According to the features of reclaimed water system, reclaimed water utilization data needs to satisfy the following validation rules:

(1) The intake points of reclaimed water need to be fully connected to the pipelines.
(2) The pipelines for reclaimed water need to be fully connected to each other, i.e. no pipeline should exist outside of the pipeline network.
(3) The pipelines for reclaimed water have to be connected to the treatment plants.
(4) The user points for reclaimed water shouldn’t be isolated. They have to be connected to the pipelines through intake points of reclaimed water.

In order to ensure the accuracy and availability of reclaimed water utilization data, analysis, verification and processing for the validation of its spatial and attribute data need to be done according to the validation rules mentioned above.

Design of the Spatial Database for Reclaimed Water Utilization System

Design and partition of layers. In GIS, layers are the most basic information units. Any real geographical entity can be described by using multiple layers[2]. According to the application requirements of the managing and operating departments in Dianchi Lake watershed for reclaimed water utilization, as well as the requirements for the GIS software development, we organize and manage all the spatial data in reclaimed water utilization system by using layers in the city reclaimed water utilization spatial database. That is to say, features in one category are represented in one layer.

1. Background Data

The background data in this project is a vector digital map with the scale of 1:10000. It mainly consists of the geographic elements in Kunming such as main roads, blocks, river system, green space, river course, enterprises and institutions, schools, etc. As the background map of spatial data model of reclaimed water system, it provides an intuitionistic and concrete elementary map reference for the whole project especially to the managers and users.
2. Business Data for the reclaimed water utilization system

Business Data for the reclaimed water utilization system includes six layers as follows:

(1) Reclaimed water pipelines layer. This is the pipe installation layer that pilots reclaimed water to users or intake points. This is a line features layer.

(2) Reclaimed water user points layer. This is the layer that puts the abstracted reclaimed water users on the map as points.

(3) Reclaimed water intake points layer. This is the layer that puts the water intake places on the map as points.

(4) Reclaimed water pumping station layer. This is the layer that puts the reclaimed water pumping stations on the map as points.

(5) Reclaimed water treatment plants layer. This is the layer that puts the location of treatment plants on the map as points.

(6) Sewage plant layer. This is the layer that puts the location of sewage plants on the map as points.

A concrete description of each layer for the reclaimed water system is shown in table 1:

Table 1. Business data layers list

<table>
<thead>
<tr>
<th>Name of layer</th>
<th>Entity type</th>
<th>Name of Layer</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reclaimed water pipeline</td>
<td>Line</td>
<td>zssgx</td>
<td>Pipelines that deliver reclaimed water</td>
</tr>
<tr>
<td>Reclaimed water user points</td>
<td>Point</td>
<td>zssyhd</td>
<td>Reclaimed water users</td>
</tr>
<tr>
<td>Reclaimed water intake points</td>
<td>Point</td>
<td>zssqsd</td>
<td>Location for taking reclaimed water</td>
</tr>
<tr>
<td>Reclaimed water pumping station</td>
<td>Point</td>
<td>zssbz</td>
<td>Location of pumping station</td>
</tr>
<tr>
<td>Reclaimed water treatment plant</td>
<td>Point</td>
<td>zssclc</td>
<td>Location of treatment plant</td>
</tr>
<tr>
<td>Sewage plant</td>
<td>Point</td>
<td>wsc</td>
<td>Location of sewage plant</td>
</tr>
</tbody>
</table>

**Conceptual design.** The conceptual design of spatial database is a design for the organization of information that does not rely on its management system. It’s an informative description towards the real world from the user’s perspective. So it gets rid of any dependence on software and hardware environment of spatial database. The model of conceptual data is an abstract concept set of geographic entities and phenomena. It is also the basis of logical data model and the semantic interpretation of geographic data[^4].

Aiming at the procedure and demand of city reclaimed water information management, we abstract the objects described in the reclaimed water utilization spatial database into Sewage plant, reclaimed water treatment plant, reclaimed water pipeline, reclaimed water user points, reclaimed water intake points and Reclaimed water pumping station. These entities are shown as rectangles in the following chart. Inside of each rectangle writes the name of each entity. We use rhombus and connecting lines to show the relation between each entity, as it shows in figure 1:
Due to the amount of attributes of reclaimed water utilization entities, the E-R diagram shown in figure 1 omits attributes of each entity, but it shows the relation between each entity. For example, the relation between reclaimed water treatment plant and sewage plant is described as 1:1, which means each sewage plant corresponds to one reclaimed water treatment plant. The relation between reclaimed water treatment plant and reclaimed water pipeline is described as 1:N, which means each reclaimed water treatment plant corresponds to multiple reclaimed water pipelines. The relation between reclaimed water user point and reclaimed water intake point is described as N:N, which means each reclaimed water user can take water from multiple reclaimed water intake points and each reclaimed water intake point can serve multiple water users. Figure 2 shows the relation between reclaimed water user and reclaimed water pipeline as well as their attributes.

**Design of logical structure**

1. Geodatabase

Geodatabase is the object-relation data model. It is based on relational database, and uses the object-oriented technology to organize and manage spatial data\(^3\).

The data interface and management framework provided by Geodatabase makes it much easier and more convenient for ArcGIS to manage geographic data. Geodatabase defines all the usable data types and methods to display, access, store, manage and process data. Geodatabase has the advantages of unifying stored spatial data, features and rules, relation intelligentialization and perfect user support. So in this paper we adopt Geodatabase as the spatial data model to build the reclaimed water utilization information system.
In Geodatabase, the way to organize data includes feature data set, raster data set, chart, etc. As a kind of theme database, the content of reclaimed water utilization spatial database are mainly vector data for reclaimed water utilization. So it mainly uses feature data set to organize data. The data object in the geographic database includes feature data sets, feature classes, object classes and relation classes.

The feature data set has the function to organize vector data, which is mainly used in storing vector feature class. All the feature classes in feature data set have the same spatial reference, which is named feature dataset in the Geodatabase.

In ArcGIS, feature class indicates feature set that has the same geometric characteristics. For example, point set assumes shapefile or feature class in Geodatabase. It has the form of a “chart” logically, in which stores the spatial and attribute information of feature classes[4].

The object class is a chart that does not include spatial information. It is mainly used to store attribute information of geometric elements.

The relation class is used to indicate the connection between different objects. Connections can be made within feature classes, charts and between feature classes and charts.

2. Logical design of reclaimed water utilization spatial database

The design of reclaimed water utilization spatial database for the Dianchi Lake watershed adopts Geodatabase, the brand-new object-oriented spatial data model.

The name of the reclaimed water utilization spatial database is “recycled water system”. It consists of three feature data sets: elementary information data set, point feature set and line feature set. That is to organize and manage all the reclaimed water spatial data through layers. And fully connect data from different layers by using index. The hierarchy of the reclaimed water utilization spatial database is shown in figure 3.

Fig. 3. Hierarchical diagram for reclaimed water utilization spatial database
Due to the complexity of the GIS platform of this project, only the attribute lists of reclaimed water pipelines and user points are given in Table 2 and Table 3.

### Table 2. List of reclaimed water pipeline data structure

<table>
<thead>
<tr>
<th>Name of field</th>
<th>Alias</th>
<th>Data type</th>
<th>Field description</th>
</tr>
</thead>
<tbody>
<tr>
<td>gxID</td>
<td>Id</td>
<td>Integer</td>
<td>Pipeline number</td>
</tr>
<tr>
<td>gc_name</td>
<td>Name of project</td>
<td>String</td>
<td>name of the pipelines</td>
</tr>
<tr>
<td>RoadName</td>
<td>Road</td>
<td>String</td>
<td>name of the road where pipeline locate</td>
</tr>
<tr>
<td>RoadStarting</td>
<td>Starting point of the road</td>
<td>String</td>
<td>where a pipeline starts</td>
</tr>
<tr>
<td>RoadEnding</td>
<td>Ending point of the road</td>
<td>String</td>
<td>where a pipeline ends</td>
</tr>
<tr>
<td>GX_Length</td>
<td>Length of a pipeline</td>
<td>double</td>
<td>Length of the pipeline on this road</td>
</tr>
<tr>
<td>GX_Material</td>
<td>Material of a pipeline</td>
<td>String</td>
<td>Material a pipeline uses</td>
</tr>
<tr>
<td>Diameter</td>
<td>Diameter</td>
<td>double</td>
<td>diameter of a pipeline</td>
</tr>
<tr>
<td>Construction_time</td>
<td>Construction time</td>
<td>Date</td>
<td>when to construct</td>
</tr>
<tr>
<td>Construction_unit</td>
<td>Construction unit</td>
<td>String</td>
<td>Builder</td>
</tr>
<tr>
<td>Classification</td>
<td>Classification</td>
<td>String</td>
<td>Main pipeline/Branch pipeline</td>
</tr>
<tr>
<td>GX_Belongto</td>
<td>Belong to whom</td>
<td>String</td>
<td>The plant that the pipeline belongs to</td>
</tr>
</tbody>
</table>

### Table 3. Structural list of reclaimed water user data

<table>
<thead>
<tr>
<th>Name of field</th>
<th>Alias</th>
<th>Data type</th>
<th>Field description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Id</td>
<td>Id</td>
<td>Integer</td>
<td>Identification Number</td>
</tr>
<tr>
<td>W_user</td>
<td>Water user</td>
<td>String</td>
<td>User name</td>
</tr>
<tr>
<td>gxID</td>
<td>Owned pipeline</td>
<td>Integer</td>
<td>Pipeline that belongs to the users</td>
</tr>
<tr>
<td>WGNO</td>
<td>Number of water meter</td>
<td>String</td>
<td>Number of water meter in sewage plant</td>
</tr>
<tr>
<td>S_time</td>
<td>Start time</td>
<td>Date</td>
<td>When to begin using reclaimed water</td>
</tr>
<tr>
<td>U_type</td>
<td>User type</td>
<td>String</td>
<td>Corporation/individual</td>
</tr>
<tr>
<td>Rw_use</td>
<td>Use of reclaimed water</td>
<td>String</td>
<td>Description for the use of reclaimed water</td>
</tr>
<tr>
<td>S_way</td>
<td>Water supply mode</td>
<td>String</td>
<td>Direct supply/intake point</td>
</tr>
<tr>
<td>Cs_time</td>
<td>Date to begin measure</td>
<td>Date</td>
<td>Begin to measure water supplement</td>
</tr>
<tr>
<td>Ce_time</td>
<td>Date to end measure</td>
<td>Date</td>
<td>End to measure water supplement</td>
</tr>
<tr>
<td>zsscID</td>
<td>Belong to whom</td>
<td>String</td>
<td>The reclaimed water plant that users belong to</td>
</tr>
</tbody>
</table>
Realization of the reclaimed water utilization spatial database

Constructing the reclaimed water utilization spatial database by using UML and CaseTools. UML static diagram includes class diagram, object diagram and Package diagram. Class diagram describes the static structure of a class in a system. It does not only define classes in a system, but also shows the connection between different classes such as relevance, dependence, convergence, etc. as well as the inner structure of a class (properties and methods). The relation that a class diagram describes is static, which is valid through the whole life cycle of a system. The advantages of designing database structure by using UML are as follows: (1) Compared with E-R diagram, UML has stronger capability to express data. (2) It can realize various relations between all kinds of objects (such as relevancy), and all these relations can be completed by using triggers or stored procedures when realizing the database. (3) It can help design APIs for the developed database by using the unified standard in order to enhance the robustness of the whole system. (4) It can be directly used in tests on different levels, helping expose the design problems of the system as soon as possible.\[5\]

The CASE tool mainly uses Office Visio to model the database, then outputs XML file that can be identified by ArcGIS software and to build the relative data structure automatically. Many frequently-used data types can be created by using Case Tools, making it much easier to design database. For example, data set, geometric network model, feature class, class object, etc.

The procedure to design and build Geodatabase by using UML and CASE Tools are as follows:
(1) Build the frame of the Geodatabase in UML;
(2) Convert UML model into Geodatabase frame by using Schema Wizard in ArcCatalog software.
(3) Load feature classes and charts in Geodatabase by using simple data loading function in ArcCatalog software and Editor, ObjectLoader tools in ArcMap.\[3\]

The outcome of the procedures mentioned above in this project is shown in figure 4.

![Fig. 4. UML model for reclaimed water utilization business data](image)

After the UML model design of city reclaimed water utilization spatial database by using Visio, firstly, we export an xml file according to this UML model by using ESRI XML Export in Visio software. Then do the syntax check on the exported xml file by using the macro provided by ESRI. After that, we import the xml file into the existing recycled water system geographic database by
using Schema Wizard in the CASE tool to generate the frame of geographic information database. By means of this two procedures, the construction of Geodatabase frame is completed.

After the generation of the content tree by using Schema Wizard, it is necessary to set up additive attributes of feature classes. And setting up the spatial reference attributes is the most important. After that, complete the frame of the Geodatabase in Schema Wizard. As it shows in figure 5.

![Fig. 5. Geodatabase generated by UML model](image)

**Importing reclaimed water utilization data.** After completing the frame of Geodatabase by using UML and CASE tool, it becomes natural to load reclaimed water utilization data into Geodatabase by using Load in ArcCatalog software. After loading reclaimed water utilization data into recycled water system.gdb, we can examine and manage all the data in the spatial database. Figure 6 shows the reclaimed water user data in ArcCatalog.

![Fig. 6. User data of reclaimed water system in ArcCatalog](image)

**Visualization of the data in spatial database.** In this paper, we have designed and built the city reclaimed water utilization spatial database based on the method mentioned above. And developed a GIS platform in order to manage and analysis the reclaimed water utilization information in Dianchi Lake water shed visually.

Figure 7 and figure 8 are the impression drawings of reclaimed water user checking and pipeline attribute checking on GIS platform.

![Fig. 7. Visual management of reclaimed water users](image)
Summary

In this paper, we designed and built a reclaimed water utilization spatial database that put spatial data and attribute data together. And realized the effective storing and managing of reclaimed water utilization in Dianchi Lake watershed, provided comprehensive and accurate city reclaimed water utilization data and scientific decision support for departments related to city planning and constructing. This helps raise the efficiency and level of management of departments related to city sewage disposal and reclaimed water utilization.

It becomes inevitable to utilize city reclaimed water to solve the shortage of water resources in many cities. GIS technology provided powerful technological support for the information management of reclaimed water utilization due to its unique spatial data managing and analyzing function. With the popularization of reclaimed water utilization, we can see the bright future of reclaimed water utilization managing system based on GIS.

Reference
