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Construction of a Distributed-network Digital Watershed Management System with B/S Techniques

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Abstract. Integrated watershed assessment tools for supporting land management and hydrologic research are becoming established tools in both basic and applied research. The core of these tools are mainly spatially distributed hydrologic models as they can provide a mechanism for investigating interactions among climate, topography, vegetation, and soil. However, the extensive data requirements and the difficult task of building input parameter files for driving these distributed models, have long been an obstacle to the timely and cost-effective use of such complex models by watershed managers and policy-makers. Recently, a web based geographic information system (GIS) tool to facilitate this process has been developed for a large watersheds of Jinghe and Weihe catchments located in the loess plateau of the Huanghe River basin in north-western China. A web-based GIS provides the framework within which spatially distributed data are collected and used to prepare model input files of these two watersheds and evaluate model results as well as to provide the various clients for watershed information inquiring, visualizing and assessment analysis. This Web-based Automated Geospatial Watershed Assessment GIS (WAGWA-GIS) tool uses widely available standardized spatial datasets that can be obtained via the internet oracle databank designed with association of Map Guide platform to develop input parameter files for online simulation at different spatial and temporal scales with Xing’anjiang and TOPMODEL that integrated with web-based digital watershed. WAGWA-GIS automates the process of transforming both digital data including remote sensing data, DEM, Land use/cover, soil digital maps and meteorological and hydrological station geo-location digital maps and text files containing meteorological and hydrological data obtained from stations of the watershed into hydrological models for online simulation and geo-spatial analysis and provides a visualization tool to help the user interpret results. The utility of WAGWA-GIS in jointing hydrologic and ecological investigations has been demonstrated on such diverse landscapes as Jinhe and Weihe watersheds, and will be extended to be utilized in the other watersheds in China step by step in coming years.
1. Introduction
Watersheds are considered the most effective geographical unit for water management. Because of their topographical delineation, they include an (somewhat) independent drainage network of streams. However, watershed limits are frequently incongruent with administrative boundaries. Managing a transboundary watershed of this kind is often complicated and requires what may be sparse resources of time, money and resources. The accurate depiction of earth surface processes and their responses to land cover, climate, or managerial change has been the goal of hydrologists for more than a century[1]. Spatially distributed models are by definition data-intensive, and if these models are to be applied on an operational basis, there is a critical need for automated PC-based procedures to store, access, and prepare data for modeling. GIS has been shown to be a valuable tool in providing watershed management solutions in the past. Geodatabases on soil structure, land use, vegetation and topography are paired with equations such as the Revised Universal Soil Loss Equation and models such as GIBSI (Gestion Intégrée des Bassins versants à l’aide d’un Système Informatisé) to provide decision makers with various management scenario outcomes.

This manuscript presents the Web-based Automated Geospatial Watershed Assessment GIS (WAGWAG) tool, a multipurpose hydrologic analysis system for use by watershed, natural resource, and land use managers and scientists in performing watershed- and basin-scale studies. It was developed under the following guidelines:

1. Provide a simple, direct, and repeatable method for hydrologic model parameterization
2. Use only basic, attainable GIS data
3. Be compatible with other geospatial watershed-based environmental analysis software
4. Be useful for scenario and alternative futures simulation work at multiple scales.

WAGWAG is an extension for the Environmental Systems Research Institute's ArcView versions 3.4, a widely used and relatively inexpensive PC-based GIS software package (trade names are mentioned solely for the purpose of providing specific information and do not imply recommendation or endorsement by the authors). The GIS framework is ideally suited for watershed-based analysis, which relies heavily on landscape information for both deriving model input and presenting model results from the other sources [2]. This facilitates comparative analyses of the results from multiple environmental assessments, thus making it particularly valuable for interdisciplinary studies, scenario development, and alternative futures simulation work. WAGWAG is distributed freely via the internet as a modular, open-source suite of programs (www.tucson.ars.ag.gov/agwa).

2. WebGIS general situation
The World Wide Web geographic information system is a new technology which expands and consummates geographic information system by using interactive network technology, and also it is a new technical method which unifies the geographic information system and the interactive net technology. People may conveniently gain on the Web browser for any kind of distributional geography space data and analysis from any WWW node through WebGIS. Its appearance enables GIS to move towards the society and realize GIS data-sharing, and it can serve for widespread social group. Because WebGIS is based on Internet and WWW environment and the distributed platform, it has several characteristics in the aspect of data management and the organization, such as supporting ultra-large data set, introducing large-scale database management system, picking-up the space data high quality, managing distributed data, uniting the data and system closely and so on[3].

Presently, along with new technical and the hardware equipment renews, the application domain is widespread day by day. People's request for using information is also unceasing deepening and developmental. And these provide extremely broad prospects for development of application of WebGIS. For example, digital Earth involves main technologies such as computer, network correspondence, remote sensing, global positioning system, geographic information system as well as magnanimous data storage processing, image intelligence processing, database technology and so on, majority of these technologies may manifest in WebGIS. Similarly, the construction of digital watershed also utilizes these technologies, and WebGIS is the key to integrate these technologies.
3. Hydrology model for forecasting and dispatching management of watershed

Hydrology model for watershed is playing a vital role in researching hydrology rule and solving actual production problem [4]. About flood prevention and disaster decreased, the hydrology model is the core part of modern real-time flood forecasting and dispatching system. It is the key technology to increase the precision of forecast and the length of forecast period. About sustainable use of water resources, the hydrology model is rationale for appraisal, development, utilization and management of water resources. About water environment and ecosystem protection, the hydrology model is the main platform for constructing surface pollution model and ecology appraisal model. In addition, the hydrology model is an effective tool for analyzing and researching climatic change and the influence of human activity to the flood, the water resources, and the water environmental. At present, the distributed hydrology model which is tight bond based on physical foundation is the important research direction of hydrology simulation, and it already has obtained successful application in the water conservancy and correlation domain, just as the Xin'anjiang model.

The Xin'anjiang model is a conceptive basin rainfall runoff model. This model divides the entire basin into many unit basins, carries on runoff yield and concentration to each unit basin, and obtains the unit basin flow out rate. Then it takes flood routing of river course that exports-following and adds each unit basin flows together, at last obtains the basin total outflow. The core of the model is the stored-full runoff and the calculation module based on storage capacity curve of the basin. The model mainly adapts in moist and half moist area, it has high calculation accuracy and good application in hydrologic forecast work at home and abroad. The flow chart of Xin'anjiang (three water sources) model see Figure 1 [5]. In the chart, inputs are p as rains and EI as evaporating dish transpiration rate, outputs are Q as outlet section total flow and E as evapotranspiration. In the square is the state variables, outside the square is the model parameter.

The Weihe watershed has the great natural precipitation. This is dissimilar with other northwest local watershed. It is not belong to arid or semi-arid region, but is divided into half moist area. Therefore the Xin'anjiang model can carry on the hydrology simulation well on this watershed.

![Figure 1. Flow chart of Xin'anjiang (three water sources) model](image)

4. GIS data and distributed database

4.1. Characteristics of GIS data
Sections should be numbered as follows: GIS has already stepped into the development stage that technical-driven changing to application-driven. The application of GIS in the project level and department level has obtained huge benefit, but when it penetrates into the process of commercialized and socialized, meets unprecedented difficult problem which is data-sharing. Data is the most expensive part in the GIS project. At present, we are facing the condition one is, there are massive GIS data resources along with the GIS widespread application; condition two is, GIS system was considered as the information isolated island, respective department always choices different GIS platform according to own special details and application demand, and this makes data-sharing difficult[6].

The distribution of GIS resources has the geography feature, special topic and object-oriented, therefore, the spatial database of GIS system should be had region, special and object-oriented laminations. The region lamination are the horizontal distribution of spatial data, this is decided by the regional characteristic of GIS resources. The special lamination is the vertical distribution of spatial database, this is decided by the vertical distribution of spatial database. The special lamination is usually advantageous discrimination for each different department's specialized data in identical physiographic region. The object-oriented lamination is regarded as classified the spatial data according to the attribute of itself, and it is usually divided into zero-dimensional, one-dimensional, two-dimensional and three-dimensional objects. The zero-dimensional object is point object, the one-dimensional object is line object, and the two-dimensional object is region object. For example, the departments' location is belong to point object; road and river is one-dimensional object; And the administrative division of township can be regarded as region object in a city geography system.

The digital Earth project and also its sub-project digital watershed are facing the question how to manage and use the magnanimous GIS data. Therefore, when constructing a WebGIS digital watershed system, the construction of database is the most important.

4.2. General situation of distributed database

The distributed database system is a database that physical dispersion and logical collection. It uses the network to connect several logical units which are belonged to different geographical position but need some level degree control and management. They compose a unified database system together, and it is unification of distributed character and central tendency. The distributed database system has following characteristics [6]:

(1) Physical distribution: data stored in distributed database are not saves in one node, but in many nodes which connected by network;

(2) Logical integrity and visit transparency: data stored in distributed database system are physical dispersion in each node, but logically is actually in a whole, and can be visited transparently by any user;

(3) Node autonomy: data on each node managed by spatial database node itself, it has the autonomous handling ability, and completes application by itself;

(4) Certain data redundancy: The distributed spatial database system enhances usability and reliability of the system by certain redundancy mechanism, and it also can improve system performance.

The distributed database system has nimble architecture, and can adapt distributed management and control mechanism. The reliability of system is quite high, and the speed of response of partial application is quick. Also the expansibility is good; it may make nice data-sharing of different region and department. All these may decompose and disperse GIS data, and it can solve the problem of dispersed geographical location and massive quantity for GIS data, also it’s easy to integrate a system that has efficient information-sharing mechanism.

5. The construction of digital watershed system

5.1. Data organization for digital watershed based on WebGIS
The digital watershed involves many types of data, mainly includes map data, image data, measured data, text material data as well as multimedia data and so on, as shown in Figure 2.

**Figure 2.** Data source of the digital watershed

The map data is one of main data for digital watershed. It may make macroscopic and microscopic analysis in the application of digital watershed. The map used to establish the digital watershed is extremely widespread, and it besides each kind of national standards scale topographic map, the land-use chart, the soil type chart, the vegetation type chart, the weather station and hydrologic station distribution map and so on, all are the main map data. All these map data will be separately loaded to the digital watershed system as independent layers, and their attributes can be obtained through inquiry.

The image data is also an important data in digital watershed. It includes rich resources and environmental information, and it is one kind of large area, dynamic and near real-time data. It could be colored image synthesized by multi-wave band, also can be single wave band image that has been processed and has certain significance. But the remote sensing image is generally large, and it easy to lengthen reaction time in page’s transmission process. Therefore, how to speed image data transmission in the network should be a question which is worth considering.

The data gained from detection, sampling and experiment have many characteristics such as accurately, real-time, dynamic, strong pertinence and so on. They are the main data sources which provide parameters for many kinds of models, and then the model can carry on hydrological simulation. For instance, there are many conventional meteorological data such as precipitation, maximum and minimum temperatures, evaporation, and also there are many conventional hydrological data such as runoff, sediment discharge and so on. The observation data from station involve extremely large data. For example, one watershed contains many sub-basins, each sub-basin contains many hydrological and meteorological stations, and each station contains many kinds of observation data each year and there are several or even several dozens years’ data. So many data should be orderly organized with various attributes when stored into the digital watershed system. These observation data will follow the station map layers to load into the system, and the data can be extracted as records according to users’ inquiry condition, and then it can generate report forms or graphs arbitrary. Moreover, during expanded application construction to the digital watershed, there are many relationships between these massive observation data as well as map data. So finding the relationship between data and data, data and layers will be helpful to construct digital watershed application-decision system.

Moreover, there are other kinds of data such as related text material, multimedia information and so on, and they are also component of the digital watershed. They include natural condition, social economy condition, correlation laws and regulations which are all related to the watershed. When establishing the digital watershed, it must make simple literal introduction as well as correlation
explanation to this watershed, these may demonstrate on independent web pages. And it has the characteristics such as comprehensive, intuitionistic and so on.

This system database uses Oracle 9i. Oracle 9i is a large-scale distributed relational-object database which is based on high-level structured query language (SQL), namely fused object-oriented technical and Internet network application development technology in the relational database foundation. The large and middle scale management system, especially development of GIS and image information management system, requests large data processing with high speed. And Oracle database precisely has the characteristic. Its storage capacity is massive, and the data speed of data processing is quick. Meanwhile, Oracle is a cross-platform system, so it can provide many methods of exploitation that uses may choose the suitable one.

The spatial data in this system contain vector data and grid image data: Vector data are spatial data mostly being different ground objects or different types of thematic. Each kind of these space data store as a spatial table in database, and corresponding to the layers in Map Guide; it uses the ORDIMAGE object type which is in Oracle interMdia to save and manage the grid image data. Moreover, the observation data from weather station and hydrologic station will all be saved as general relational table.

5.2. The structure of digital watershed system

This system takes Weihe watershed which located the intersection of Shanxi, Gansu and Ningxia as an example. It uses multi-layer distributed application model, and this may divide the system into data layer, logical layer and expression layer effectively. The biggest advantage of multi-layer structure designing is its expansive ability and load-balancing ability. Figure. 3 is the system structure diagram.

This development language of network in this system is JSP (Java Server Page). It may produce dynamical and interactive Web server application procedure very conveniently, and could output colorful dynamic pages. Using Oracle for JDBC for visiting to Web page from database is very easy. It is extremely convenient for customers visiting database real-time, and so this realizes WebGIS visiting exterior data real-time. The technology of JSP usually unifies with Java Servlet, and it may insert Java code section and transfer exterior Java module to mark languages such as HTML and XML. Also it may use JavaBeans and EJBs Enterprise as front processing tools. JavaBeans realizes complex commercial logic and dynamic function perfectly, and the hydrology model inserted in this system just utilizes JavaBeans.

5.3. The function structure of digital watershed

![System structure diagram](image)

Figure 3. System structure diagram

5.3. The function structure of digital watershed
This system realizes functions through concrete function module, and different module corresponding to different user class. There are two kinds of user in this system, one is common clients and the other is administrators of the watershed. The achievement demonstration part in the common client module is the watershed information issue system, it has independent page system. Users should register and be judged the jurisdiction rank in the website, and then it will demonstrate partial or complete map contents to the user. There are map-operation and the map-inquire for this sub-module’s function design. Map-operation function contains map cruise, zoom-in and zoom-out, point selection, measure, buffer analysis and so on; Map inquiry function, not only realize space and attribute bidirectional inquiry, but also increase dynamic link, and it may click to look over detailed situation of each meteorological or hydrologic station, including basic information, picture introduction, station material inquiry, report and graph production and so on (home page of the website see Figure 4). The module designed for common clients see Figure 5 to show.

![Figure 4. Home page of the website](image)

![Figure 5. Module designed for common clients](image)

The superintendent module besides has all functions of common clients module, but also increases database operation to manage users, homepage information as well as station material in the watershed system. Moreover, it also has all function of the achievement demonstrate part, and besides map operation and map inquiry. But also increase hydrology simulation function sub-module foundation for the superintendent module (take Xin'anjiang model as example). It codes the hydrology model and loads services to the web. Then hydrology simulation work will be carried on some sub-basin by using
network database or users’ local data. The module designed for Admin of the webpage is seen Figure 6, and the effects of digital Weihe website while WebGIS operating see Figure 7 and Figure 8.

![Figure 6. Module designed for admin of the webpage](image)

![Figure 7. Distance measure](image)

![Figure 8. Diagram of hydrological simulating](image)

### 6. Analysis of system performance optimization

Along with the development of WebGIS, users’ requirements for data browsing, inquiry and analysis are higher and higher. Therefore, enhancing service performance and satisfying users’ demand becomes the urgent matter in development of WebGIS. This part ponders and analyzes how to enhance the system performance effectively from two aspects which are distributed database construction of data and inquiry optimization.

The performance of WebGIS for digital watershed system is limited while transmitting mass map data. From the database design angle, besides the technology which has used, also can optimize system by changing database construction of data to enhance system performance. In this system, spatial data is divided into certain special layers according to the characteristics of spatial objects, each layer saves as a data sheet in database. Thus, a traditional map decomposes several special tables superimposition. And it can reduce the map exaggeration time, moreover because the map contains sole entity element, each table occupies less space. On the other hand, we usually don’t use all the layers one time, only transfer some or several layers that actual need, and thus system resources occupied and consumption time when transmitting will have big improvement. Moreover, in the grid image data memory aspect, block storage, highly effective compression and pyramid structure technology, enables mass and high clear images have efficient demonstration and high transmission like general images.

If inquiry for not only one data server in the distributed database system (called this inquiry for overall situation inquiry), it must carry on optimize and decompose the overall situation inquiry. The inquiry optimization of distributed database system has two kinds of different goals: One kind of goal is minimum total cost takes as standard; the other kind of goal is short inquiry response time take for each as standard. Of specifically speaking, generally in the long-distance correspondence network, the speed of data transmission among stations is slower many times to transmission between memory and floppy disk in the single plane situation. Therefore, in this kind of distributed inquiry environment, the inquiry response time compare to the time communication needs can be ignored, and reducing the
correspondence expense becomes the essential target. In the high speed local area network, the transmission time must be much shorter than the response time. In this case, the response time takes optimized goal \[8\]. In this system, because of the big jurisdiction difference among client side users, and the jurisdiction indicates to a certain extent how many data may gain. In control department, it takes data bank administration and data maintenance, therefore first should consider the question of response time; while major part of common client are long-distance correspondence network client side, its jurisdiction has graduation limit, therefore it should take minimum total cost, namely reducing the correspondence expense is the just standard.

7. Conclusion
The digital watershed is one kind of multi-level structure, and it has widespread application prospect. Its integrity and systematic total view will bring brand-new situation of watershed management like flood-control to reduce disaster and water resources regulation. Because of many superiorities of WebGIS, the watershed GIS developing mainstream will certainly to be watershed WebGIS. Open style solution, lower and lower construction cost, more and more intellectualized construction method, WebGIS will realize processing of spatial data and data sharing maximum convenient and effective. Watershed WebGIS will be certainly to impel environmental protection, resources development, traveling development and electricity energy development of the watershed enormously.

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