Application of Three-dimensional Simulation Technology in Reservoir Regulation and Operational Management

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Abstract

Reservoir regulation and operational decision-making construct an extremely complex process, which shows the apparent semi-structured or unstructured characteristics. It is difficult to use only mathematical models to describe, and the models must be constantly amended and combined with practical experience in a variety of regulation schemes. In addition, the implementation of the regulation decisions requires high timeliness and intuition to provide information for the decision-makers. In this paper, combined with the 3DGIS technique, the virtual simulation technology and the reservoir optimization regulating models, a three-dimensional simulation environment of reservoir regulation and operational management is established to simulate the dam gates, river flow, dam discharging flow, and so on. These simulations are built on the real-time data of dam gates, calculating data of reservoir regulation and artificial controlling data. Therefore, the front of the system establishes the three dimensional simulation environment of reservoir regulation for inputting data and displaying result, the back of the system carries out computing the mathematical model of reservoir regulation to realize the integration of "Visualization" and "Calculation".

Keywords: Simulation technology; 3DGIS; Water conservancy project; Reservoir regulation; Visualization and Calculation Integration

1. Introduction

Reservoir regulation and operational decision-making is an extremely complex process, mainly manifested in such aspects as randomness of natural inflow, multiple and dynamic reservoir functions, uncertainty of regulation models and parameter selection, real-time of regulation, limitations of mathematical models establishing and solving techniques, and so no. These characteristic factors cause the semi-structured or unstructured features of the reservoir regulation decisions, so the decisions are difficult to describe with the mathematical models [1].

Traditional reservoir optimal regulation calculating and decision-making simulation are all made in the two-dimensional plane with the curves or tables to show the regulating results and the computing process. These methods are not intuitive and lead to a serious gap between the visualization and calculation in the reservoir regulation and operational management system. Usually, calculation cannot be guided by visualization, and the visualization cannot quickly reflect the result of calculation.

Therefore, the visualization and the calculation cannot interactive parallel to bring a lot of inconvenience and limitations in reservoir projects.

At present, the appearance and development of 3DGIS and three-dimensional virtual simulation technology provides a new technology platform for the reservoir regulation and operational management. Through establishing the three-dimensional, dynamic, real-time and visual virtual simulation environment of the reservoir regulation and operational management, the management personnel can intuitively and clearly see the whole or part, dynamic or static, history, reality or the future real scene in the process of project operation and management, query all kinds of real-timely monitoring information, and put forward their views and demands. The decision-makers can get the latest and most accurate information in the shortest time to make a quick judgment of future events and take appropriate countermeasures. In this way, it not only expresses the VR's three-dimensional scene of reservoir project intuitively and visually, but also shows the GIS's strong functions of spatial data storage, analysis, and three-dimensional terrain analysis to realize the integration of "Visualization" and "Calculation" [2].

2. Virtual Simulation Principles of Water Conservancy Project

2.1. Establishing three-dimensional virtual environment of water conservancy project

Virtual environment modeling is the virtual simulation application base of the entire water conservancy project, mainly including the three-dimensional visual modeling and the hearing modeling. The visual modeling mainly includes geometric modeling, motion modeling, object properties modeling, and models cutting. The hearing modeling usually only adds the interactive voice to the users and objects' activities.

For the project terrain, transferring the geographic feature data format to the virtual simulation data format according to its three-dimensional contour topographic map (stored in the format *.dgn or *.dxf) or DEM firstly, then posting the real aerial photos or satellite images. For all the project buildings, establishing the three-dimensional simulation geometry models of the dam, outlet structures, underground power station and factories and navigation buildings firstly, then posting the photorealistic textures to completely simulating the site scenarios. Finally, according to the actual contact between topography and project buildings, splicing the topography and the three-dimensional simulation model of project buildings to get the final three-dimensional virtual simulation geometry model of the whole project [3-12].

2.2. Application principle of project operational management virtual simulation

In the three-dimensional virtual environment, the motion characteristics of the object relate to the location change, interaction, collision, object capture, zoom, surface deformation, and so on. Every object with motion characteristics has its coordinate system. So the object location can be changed by changing the coordinate values of all the directions. According to the operation and management simulation application of water conservancy project, the project buildings have their movements such as opening and closing of the dam gates, the rotation of the sluice gates, the operation of turbine units, water level changing, flow pattern of gate discharge, and so on. All these actions need to set and control the spatial position coordinates and azimuth under certain conditions to achieve the three-dimensional motion simulation [13].

Secondly, we establish the correspondence of geographic target object's name or unique ID among the three-dimensional simulation model and the buildings' basic attributes, CAD files, and real-time monitoring data. Then we get the buildings' controlling and monitoring information related from the real-time monitoring data to update the state of motion of the three-dimensional geometric model. What's more, the variety of deformation monitoring, seepage monitoring, water quality and hydrological monitoring can be displayed and queried in the three-dimensional simulation environment by a variety of colors, property sheets, *etc*. The virtual simulation schematic of water conservancy project is shown in Figure 1 as follow.
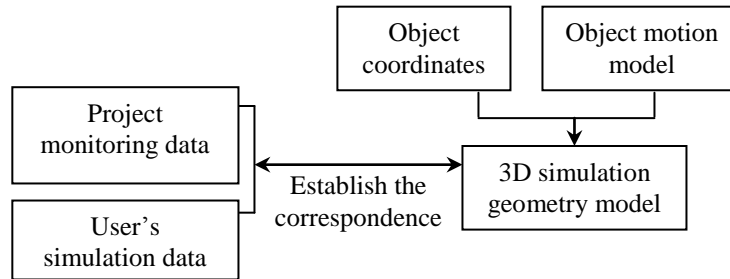

Figure 1. The virtual simulation schematic of water conservancy project

3. Three-dimensional Simulation System of Reservoir Regulation and Operational Management

Based on a reservoir, combined with the reservoir optimal regulation and operational management model and three-dimensional simulation technology to establish the three-dimensional simulation system integrated with real-time information inquiry, real-time water scheduling, dam gates control simulation and dam discharging simulation. This system provides a new technology platform for the automated regulation and operational management of the reservoir.

3.1. System goal and overall structure

The goal of this system is to establish the three-dimensional virtual simulation environment of the reservoir according to the reservoir area's DEM [6], high-resolution satellite remote sensing images and three-dimensional simulation models by 3DGIS, virtual simulation technology, multi-dimensional data fusion technology. With this simulation system, the users can make high-resolution browsing, querying, analyzing and simulating. At the same time, the system combines with the real-time data of reservoir regulation and program results to realize the three-dimensional simulation of real-time reservoir status and regulating program [12]. Therefore the overall structure of this system is shown in Figure 2.

3.2. Establishment of three-dimensional simulation models of reservoir

Three-dimensional simulation model is the basis to establish the three-dimensional simulation system, including the dam and the buildings models, reservoir area terrain model, water in the reservoir model, downstream river terrain model and river water patterns model, *etc*.
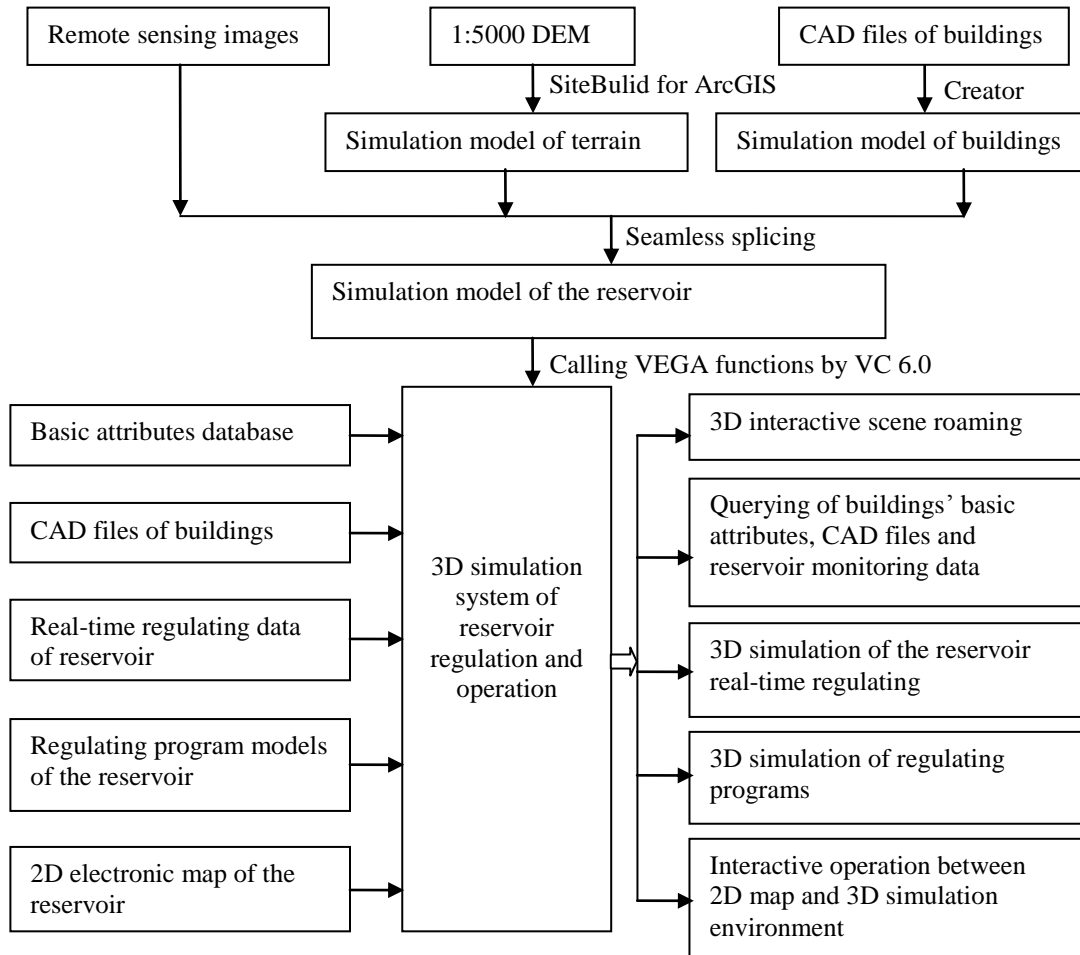
Figure 2. Overall structure of this system

The buildings of reservoir conservancy project include retaining buildings, discharging buildings, navigating buildings, powerhouse, *etc.* According to the CAD files of these buildings, establish these buildings three-dimensional simulation model with ratio of 1:1 in the software environment of MultiGen Creator [5] firstly, and then paste the real texture of the buildings to reflect the real buildings landscape. The establishing process is shown in Figure 3. What's more, establish the corresponding DOF model of the dam gate which needs make the motion simulation.

According to the 1:5000 topographic map of the reservoir, establish the DEM (Digital Elevation Model) of the reservoir and its downstream river in the software of SiteBuild 1.1 for ArcGIS. The establishing process is shown in Figure 4. Superimpose the terrain DEM on the satellite remote sensing images to get the natural geographical landscape of the real surface. The water model can be established with its surface data. Due to the need for the water level motion simulation, such as the rise and fall of the water to reflect the submerging of upstream reservoir area and the flood evolution of downstream reservoir river, the DOF model of water model should also be established [7].
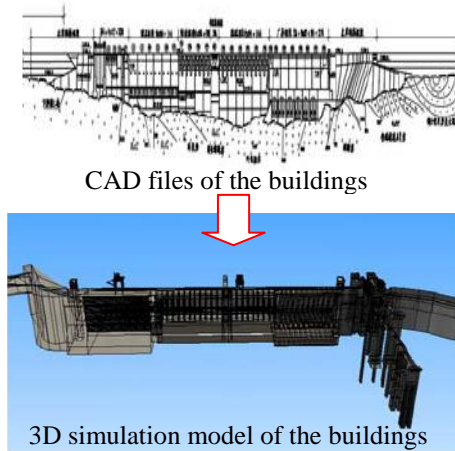
CAD files of the buildings

3D simulation model of the buildings

Figure 3. 3D simulation model establishing process of the reservoir buildings
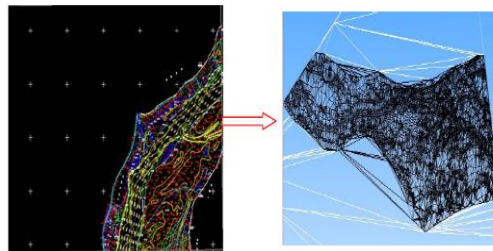

Figure 4. Establishing process of terrain DEM

Finally, seamlessly splice the terrain DEM, the buildings' 3D simulation model and water model to form the overall scene simulation model of the reservoir and its downstream area. The establishing process is shown in Figure 5.
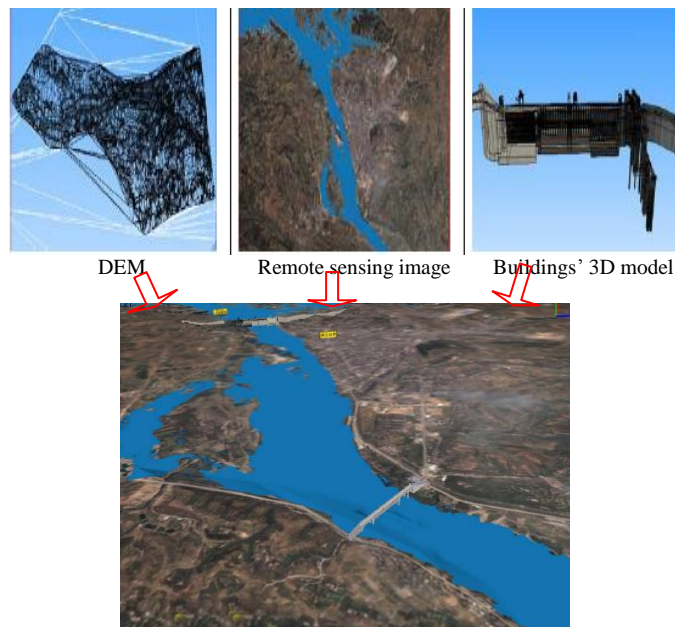

DEM   Remote sensing image   Buildings' 3D model

Figure 5. Establishment of 3D simulation models of reservoir

3.3. System Functions

1) Three-dimensional Simulation Scene Interactive Roaming

This function can be realized by using Visual C++ 6.0 to call the MultiGen VegaPrime function library to make fully interactive roaming from global to local range. In this system, the two-dimensional navigating electronic map is embedded which the navigator is set in. Therefore, this system can realize the functionality of 2D map navigating and 3D scene roaming [9]. The interactive roaming operation includes such functions as follows and the system interface is shown in Figure 6.

• Display the corresponding location and view in 2D map when user roaming in the 3D virtual scene.

• Not only jump to the corresponding position in 3D simulation scene when changing the navigator's position in 2D map, but also jump to the corresponding position in 2D map when changing the observer's position in 3D virtual scene.

• Not only highlight display the target object in 3D virtual scene when querying the target object attributes in 2D map, but also highlight display the target object in 2D map when querying the target object attributes in 3D virtual scene.

• Achieve two-way query of spatial information and attribute information.

• Dynamically call the 3D virtual scene of the target area when user selecting a region in 2D map instead of calling the 3D virtual scene at the beginning of the program.
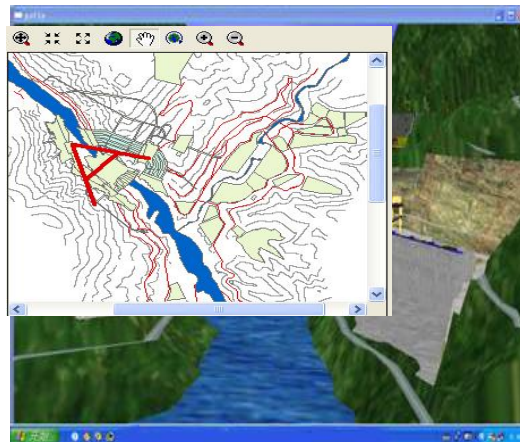

Figure 6. Interactive roaming between the 2D map and 3D scene

2) Data Management and Query

In this three-dimensional simulation system, the observer can query and display the target object's basic attributes, CAD files and monitoring data, such as the dam gates' basic attributes, gates' real-time opening height, gates' CAD files, *etc.*, to achieve the effect of "where roaming and where querying".

Firstly, establish the correspondence of geographic target object's name or unique ID between the three-dimensional simulation model and the buildings' basic attributes, CAD files, and real-time monitoring data when designing the database.

In the realization of this system, use the mouse to pick up the target directly in the 3D simulation scene. According to the idea of collision detection, when a target object selected, firstly record the coordinate (x,y,z) of this mouse clicking point. Then with this point and

current viewpoint to construct a ray to make collision detection with the target object (Namely intersection operation) in 3D simulation scene to get the first target with highlight displaying and its name or unique ID [10]. By the name or ID of the target the user can query the appropriate information in the buildings' basic attributes database, CAD files and real-time monitoring database. The CAD file of the reservoir is queried shown in Figure 7.
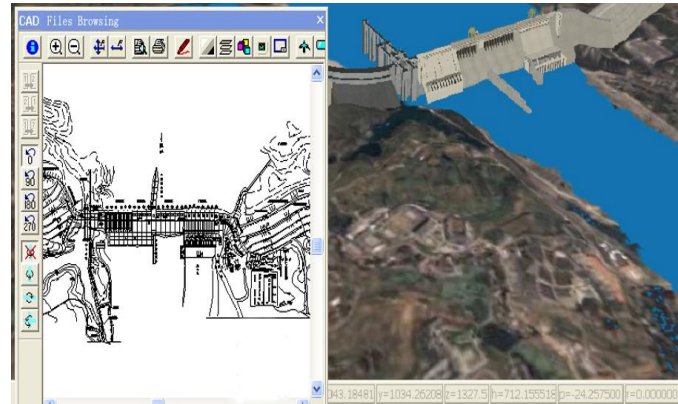

Figure 7. The CAD file of the reservoir querying

3) Calculation of the Reservoir Storage Capacity and Submerged Area

The reservoir storage capacity and submerged area under the conditions of different upstream water levels have a guiding role in the project resettlement planning, flood loss estimation, construction scale, the size of hydraulic structure, installed capacity of hydropower station, roads and sites layout, and so on. So it is very necessary to calculate the reservoir storage capacity and submerged area at the stage of the water conservancy construction. The traditional calculating method is: firstly, based on DEM and three-dimensional terrain analysis method of GIS, the corresponding flood control storage capacity, overlapping reservoir storage capacity, usable reservoir storage capacity, dead reservoir storage capacity and submerged area are calculated under the conditions of pre-flood water level, checking water level, design flood level, the normal water level and dead water level [8]. Then by using mathematical interpolation method, the curve of water level and storage capacity is derived. However, the traditional method generally calculates the corresponding reservoir storage capacity and submerged area only under the conditions of characteristic water levels which is not continuous, and the calculating process is not intuitive.

In this system, we will achieve the calculation of the reservoir storage capacity and submerged area under the conditions of any different upstream water levels. The three-dimensional virtual scenes of the whole reservoir are simulated by VR system, including the surrounding terrain and landscape, surface scene and underwater topography, *etc*. Sluicing water status is simulated by particle system and the dialog interfaces for inputting all kinds of water levels are provided. And at back-end the three-dimensional terrain analysis function library of GIS achieves the calculation of reservoir storage capacity based on DEM of upstream reservoir. Then the calculating results are transferred back to the reservoir three-dimensional virtual scene at front-end. In this way, "Visualization" and "Calculation" of water conservancy project are organically integrated, and the entire calculating process is very visualized and intuitive [2]. The real-time visualizing and calculating of upstream reservoir storage capacity of the reservoir is shown in Figure 8.

4) Three-dimensional Simulation of the Reservoir Regulation

   This system provides a wide choices of reservoir regulating models, including the conventional experience regulating model, flood forecasting & pre-vent regulating model, instruction regulating model, optimally regulating model, interactively regulating model, *etc.*. These models have been developed into the standard modules. According to the predicting upstream runoff and meeting the different circumstances and users' needs, a regulating model is selected to form the reservoir regulation program [10-11].
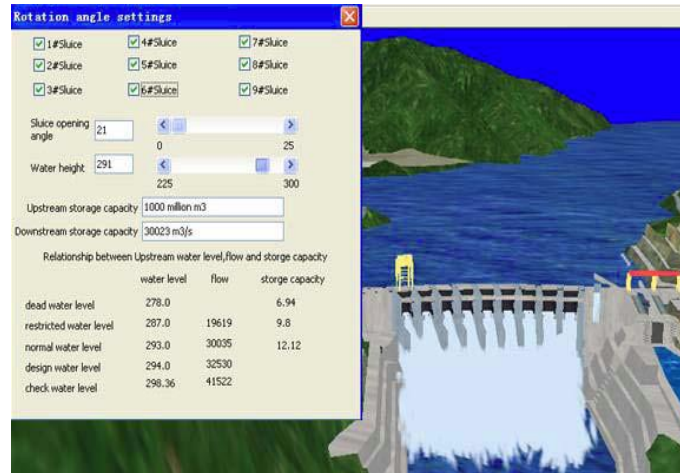

Figure 8. Visualizing and calculating of upstream reservoir storage capacity

   Interactively regulating model usually makes the results of the optimal regulation as the baseline comparing with the other interactively generated. The process of interactively generating other regulation programs is shown as follows.

   Firstly, arbitrarily modify vent flow or forecasting inflow flood based on experience;

   Secondly, re-calculate the regulating flood amount to get the corresponding water level and reservoir storage capacity and the number of sluice holes and flood flow;

   Thirdly, save the regulation programs and display it in the 3D simulation scene;

   Repeat the above steps, the different regulation programs can be generated for the decision-makers to choose.

   According to the dam discharging flow, reservoir controlling water level and other parameters, the number and height of the opening sluice roles can be determined in this system, shown in Figure 9.
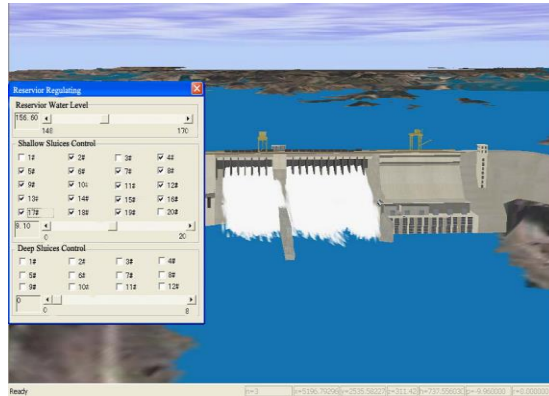
Figure 9. The three-dimensional simulation of the reservoir regulation

4. Conclusions and future work

At present, the 3DGIS and simulation technology have been widely used in plan, regulation and operational management of water conservancy project, virtually reproducing of watershed geographical landscape, simulating of flood routing, decision-making of flood control, *etc.*. This system applies the three-dimensional simulation technology in the reservoir regulation management and provides the program of visualization and calculation integration. Based on a reservoir, combining the reservoir optimal regulation model with three-dimensional simulation technology, this system raises the efficiency and level of the project operation and management, and provides a new concepts and technology platform for the water engineering.

In the future, this model and the system will be improved to make them more intelligent and adaptive.

Acknowledgements

References

[1] M. J. Zhang, "Virtual Reality System", Science Press, Beijing, **(2003)**, pp. 1-300.
[2] R. P. Hu, D. P. Wang and W. J. Long, "Research on the Visualization and Calculation Integration System of Water Conservancy Project based on VR-GIS", Geoinformatics 2010, **(2010)**.
[3] J. Y. Gong, D. S. Du and J. Zhu, "Moern Geographic Information Technology", Science Press, Beijing, **(2004)**, pp. 1-426.
[4] D. H. Zhong and H. D. Liu, "Engineering Visualization Aided Design Methods and Application", China WaterPower Press, Beijing, **(2004)**, pp. 1-248.
[5] Z. R. Gong, "Vega Programming", National Defense Industry Press, Beijing, **(2003)**, pp. 1-357.
[6] P. Han and Z. H. Xu, "Geographic Information System Development: ArcObjects Methods", Wuhan University Press, Wuhan, **(2005)**, pp. 1-461.
[7] F. Wu, J. Y. Wang and Z. H. Tian, "Display Mechanism Based on Multi-Source Spatial Data", Journal of Geomatics, Wuhan, vol. 31, **(2006)**, pp. 25-27.
[8] S. C. Tong and J. J. Zhou, "Study of the approximate method of calculating the flood control capacity of mountainous reservoirs", Journal of hydroelectric engineering, no. 4, **(2003)**, pp. 74-82.

[9]   H. J. Xu and S. Y. Chen, "Numerical-analytic method for reservoir backwater storage flood routing", ShuiLi XueBao, no. 3, **(2002)**, pp. 69-73.
[10] G. G. March, B. Lessarh and E. Gharbi, "Kriging technique for river flood representation", Journal of Hydraulic Research, vol. 28, no. 5, **(1990)**, pp. 629-643.
[11] D. Z. Sui and R. C. Maggio, "Integrating GIS with hydrological modeling: practice, problem and prospect", Computer Environment and Urban System, no. 23, **(1999)**, pp. 33 – 51.
[12] Z. Chen, "A hydrographic network database of China (HNDC) for simulation of hydrographic models", Proceedings of international conference on modeling geographical and environmental systems with geographical information systems, **(1998)**, pp. 716-721.
[13] K. KNachtrebel, "Application of geographic information system in hydrology and water resources management", IAHS International, **(1993)**.

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