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# Implementation methods and applications of flow visualization in a watershed simulation platform

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Computer-based flow visualization, which is an important approach to examine both the dynamic flow process and to elucidate the laws of fluid movement, can greatly facilitate our understanding of the complicated hydrologic cycle and provide insights into regional water resources management. Nevertheless, at present, few software tools can efficiently perform different flow visualizations for watershed modeling. In this study, a virtual watershed platform was developed and various implementation methods of flow visualization were assessed, such as scalar field visualization, vector field visualization, and visual water effects. In the platform, spatially distributed flow model results and georeferenced datasets are visualized in a virtual 3D environment. End users can conveniently explore modeling results within that environment. Based on analysis of the varying requirements of the flow visualization methods applied to watershed simulation, overheads associated with a user-determined switch between different systems were reduced, and the level of comprehensive information management and analysis of large volumes of watershed data was improved. This study shows that application of the watershed platform can enhance flow visualization in the water resources research community, and makes related water modeling more practical in support of water resources management.



## 1. Introduction

In recent years, with the rapid growth of computing capacity, more and more mathematical models have been increasingly used in water resources research and watershed management. These models formed different watershed simulation tools. These tools can provide a spatially and temporally detailed description of the basin-scale hydrologic cycle and simulate a variety of flow variables [1]. Watershed simulation requires a great amount of input data. Further, the models often produce gigabytes of output data that are both spatially distributed and temporally variant. Therefore, an integrated watershed simulation platform is not only a simulation tool but also a platform with data integration, simulation, data visualization and decision-making. In these platforms, efficient and informative graphic displays of the large amount of modeling data are very desirable to aid process interpretation and management decision-making.

Visualization technology takes advantage of computer graphics and image processing theory and methods to express laws and relationships hidden in vast amounts of data [2]. Therefore, rendering watershed scenes and expressing simulation data in intuitive ways have become the most effective means by which a virtual watershed platform displays information to users. The technique of virtual globes has become popular in the field of environmental and natural resources [3,4]. A 3D virtual globe presents geographic information in a way that perceives the 3D aspects of geographic features, thereby facilitating a more realistic perception of the actual environment. Google Earth [5], NASA World Wind [6] and ArcGlobe [7] are the most commonly used virtual-globe tools. However, because they were designed for general purposes, they were not specifically intended for watershed studies, and cannot easily process data of watershed models. The specific applications of the geosciences are very different from those of hydrology, and additional programming efforts are necessary for developing domain-specific applications. In the hydrology and geoscience communities, many 3D visualization tools have been developed [8–14]. However, few of them are able to conveniently handle the diverse data types involved in modeling and effectively visualize them. In addition, many existing tools do not display data in a georeferenced environment, and so it is difficult to display the data

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within background environments (e.g., terrain, landscape, and sunlight). The common way to solve this problem is the use of different systems to do simulation and visualization, and switching between various systems in the decision-making process. For example, when presenting flood control information, we use flow data to show only flow conditions (water depth and velocity distribution); when we wish to determine flood financial loss or emergency routing information, another visualization system should be used instead.

Because the water system is the crucial element in digital watershed simulation, the visualization of flow in that system is naturally of critical importance. Flow visualization is important for illustrating the dynamic flow process and for elucidating the laws of water movement, so it is an essential technique in digital watershed research. In a comprehensive watershed simulation, flow visualization techniques can provide an effective, intuitive, and comprehensive expression of flow information. The variety of available visualization methods can express flow information effectively, helping researchers understand and clarify the laws of water movement and flow data distribution [15].

Flow visualization techniques can be divided into two categories, scientific visualization and visual effects. Scientific flow visualization is used to show the distribution of various data, e.g., water level, water depth, flow velocity, and pollutant concentration, using methods of graphical drawing and surface coloring. Visual flow effects are used to simulate changes in shape and color of flow using computer graphics, enhancing the sense of reality for a virtual watershed environment.

In research on scientific flow visualization, common flow information can be classified as scalar and/or vector. For scalar flow information, color is usually used to represent the scale of the flow data, and isolines or isosurfaces are added to provide an intuitive representation of their distribution. In research into the problems of watershed water, isolines and isosurfaces are used widely in research and development of 3D visualization systems [16,17]. Vector flow information is partitioned into four methods: 1) direct, 2) geometric, 3) texture-based, and 4) feature-based [18]. Texture-based methods are typically used in practice. Texture images can express the flow distribution of a vector field through texture. Common visualization methods include line integral convolution (LIC) [19–21] and image-based flow visualization (IBFV) [22–28].

A number of physical and non-physical mimic methods are available for research into the visual effects of rivers. Physical mimic methods can realistically show the flow effects of water movement, but they require solution of the complex Navier–Stokes equations, which cannot be done on standard computers and is not suitable for real-time rendering of flow effects [29,30]. Non-physical mimic methods mainly include simple texture mapping, normal texture mapping, wave function transformation, particle systems, Perlin noise [31], and cellular automata [32]. Among these, wave function transformation and normal texture mapping are used most widely. Wave function transformation is used to alter vertices of the water surface directly and to simulate the dynamic process of the wave state [33–35]. Normal texture mapping is used to change the normals of the water surface, and it is complemented by the light of the perturbation to achieve the convex and concave effects of flow and visualize water fluctuations [36,37].

There have been many achievements in single-flow visualization techniques with regard to both scientific flow visualization [18–28] and visual flow effects [29–37]. However, the visualization of flow state using a computer still has considerable overhead associated with calculation of the shape, light, shadow, and texture of the flow. Furthermore, for flow shape, the Navier–Stokes equation must be used to calculate 3D motion, which is very time consuming. Thus, it is difficult to produce a detailed visualization of flow over a large area [30–32]. In addition, because of the increasing demand for data fusion in watershed research, flow visualization must integrate geographic and monitoring information for effective implementation of data mining and interactive multilevel analysis [2,12,14,16,17].

To achieve functions in which different types of simulation results may be visualized according to various demands in watershed simulation, we designed and developed a digital watershed platform that can display georeferenced data sets in a virtual 3D environment. We investigated methods for implementation and efficient rendering of flow visualization techniques, such as scalar field visualization, vector field visualization, and visual water effects. In conjunction with the watershed simulation application, we evaluated data fusion methods of different flow visualization technologies in an integrated platform, providing a reference for the comprehensive application of flow visualization techniques to a watershed area.

## 2. Platform framework

We developed a 3D virtual watershed platform, in which relatively independent function modules were integrated based on the characteristics and needs of various applications. The framework of this platform was divided into three levels, as in the following and Fig. 1.

Data level: (1) The geographic information system, 3D building object, digital elevation model (DEM), and remote sensing data were collected and processed, and a 3D terrain model was established. (2) Flow data of the monitoring site (including water depth and level, flow rate, and water pollutant concentration gradient) were collected and stored in a database. Through calculation and simulation of the water dynamic model, these data were transformed into large-scale mesh data as model input for various components of the platform.

Module level: (1) A 3D graphics rendering engine was developed and a 3D virtual environment was established based on the watershed terrain model. (2) Based on the update cycle spatial size, read and write frequency, and concurrent requests for all types of terrain data, appropriate data organizations were selected in different ways. For example, the DEM and remote sensing imagery are large data with lower update frequency. They need not be written in the platform but have frequent requests for reading, so they were organized within a pyramid structure file system. Model result data were updated frequently and must be loaded dynamically; these data can be stored within the file system and organized by file naming rules. Monitoring and other attribute data were stored in a space–attribute database and managed by the data management system. (3) An extension module was established and integrated via a standard interface using various professional model components, e.g., simulations of flow, ship navigation, and floods.

Display level: (1) The GUI and 3D virtual watershed environment were established. Based on the 3D visualization and spatial analysis function of the platform, such as distance and area measurement, cross-section cutting and visualization, and visibility analysis, the flow visualization techniques were combined with the terrain and professional application models. Then, we implemented the watershed simulations using various applications. (2) The flow visualization module comprised an important part of the platform. In terms of functional requirements, that module was needed to realize the scientific visualization and visual effects of the overall framework. Regarding technological requirements, the flow visualization module was needed to execute real-time rendering of the large volume of data and implement the fusion of multiple data sources based on the simulation platform.