Integration of Coupled Hydro-ecological Modeling in Poyang Lake Watershed Based on Digital Watershed Platform

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Abstract
In order to study complex environmental and ecological problems of Poyang Lake it is necessary to integrate or modify various existing models including hydrological, biological, social economic and other models with GIS techniques. This paper firstly discuses the construction of digital watershed platform for Poyang Lake, which is an integrated GIS environment for spatial data pre-processing and post-processing as well as an important foundation of hydro-ecological simulation, and then presents the integrated framework of coupled hydro-ecological modeling for Poyang Lake watershed (CHEMPLW) and its main functional components. CHEMPLW includes three parts: basic geodatabase, watershed data processing tools, and hydro-ecological models, while hydro-ecological models consist of four subsystems which are socio-human subsystem, land use/cover subsystem, watershed environment subsystem and river-lake/biological subsystem. Finally the integration method using ArcObject and Visual Basic is given.

Keywords
digital watershed platform; poyang lake; hydro-ecological coupled models

I. INTRODUCTION

Watershed or basin is a term to express a spatial unit of drainage network of a river and its tributaries. It means a geographical region with close, systemic and relatively independent natural features, such as topography, geomorphology and hydrology. Watershed's natural processes are closely interrelated with their attributes. Thus watershed as spatial unit of hydro-ecological coupled simulation has the special significance of geography and hydrology.

With the development of the ecology and environment, a large number of researches focus on those earth surface processes associated with watershed such as hydrological process, soil erosion process and nutrient transport process, and also increasingly focus on their responses to human activities. Thus, conventional hydrological methods have some difficulties in resolving those problems from ecology and environment. Those problems are not only involved hydrology, climatology and topography, but also largely involved biologic progress and its continuation(Yang, 2004). However, the correlation between hydrology and ecology are usually ignored in water science and water management. Thus how to study these problems is very important in the durative of ecology and environment. Many researches show that physically-based distributed hydro-ecological model is an effective tool for both simulating quantitatively the correlation between hydrology and ecology and understanding their interaction mechanism in a scale of catchment. With the rapid development of information technology, GIS and remote sensing are being increasingly used in parameter-distributed hydrological or hydro-ecological models and simultaneously they promote the progress of those models' development and application.

At present, many hydrological or environmental models are used to evaluate the management options in a watershed or to assess the impact of human activities on hydrology and environment. EPRI's Watershed Analysis Risk Management Framework (WARMF) provides a decision support system for analyzing watershed management strategies as well as calculating, allocating, and implementing total maximum daily loads (TMDLs) (Joel, 2000). WARMF has a user-friendly graphical user interface (GUI) which displays a watershed map and allows data input and viewing simulation results by the point-and-click method. On the other hand, some spatial decision support system is presented for watershed management. SDSS developed by Durga can be used for computing soil loss, land capability classification and engineering measures (Durga, 2004). It is helpful for the end users in avoiding the laborious procedures of soil erosion calculations and analyzing various thematic layers to get suitable watershed management practices. Developed by the U.S. Environmental Protection Agency's (EPA's) Office of Water, BASINS (Better Assessment Science Integrating Point and Non-point Sources) is a multipurpose environmental analysis system for use by regional, state, and local agencies in performing watershed-and water-quality-based studies to address three objectives: 1) to facilitate examination of environmental information, 2) to support analysis of environmental systems, 3) to provide a framework for examining management alternatives. BASINS system is configured to support environmental and ecological studies

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in a watershed context. The system is designed to be flexible. It can support analysis at a variety of scales using tools that ranging from simple to sophisticated (EPA, 2007). The GLOWA-Danube project aims at providing such an integrated, spatially explicit decision support system to enhance water related decision making in the Upper Danube river basin under conditions of global environmental change (Ernst, 2007). The DANUBIA model (the DSS's core engine) integrates 16 process models from 11 scientific disciplines ranging from hydrology to environmental psychology and from meteorology to tourism research. The model structure follows the structure of the domain: there are five components (landsurface, atmosphere, groundwater, river network, and actors). Each component encompasses up to six models. The actor component e.g. implements the "household", "demography", "economy", "water supply companies", and "tourism" models.

Although most of these models work on the basis of physically-based distributed hydrological model with a watershed perspective to be applied to simulate or assess environmental issues, such as soil erosion, non-point sources pollution, water quality and so on, few ecological components have been integrated in those models. However, ecology is an important field on the researches of lake complex environment system. Therefore it is difficult to study hydro-ecological issues by modeling method without ecological components in those models.

Poyang Lake, located at the middle and lower reaches of Yangtze River in China, is the biggest freshwater lake with a unique natural environment and natural resources. It is one of ten Chinese eco-functional conservation regions, and also one of the important international ecological areas designated by WWF for its wide wetland and wildlife habitat. It plays an important role for maintaining regional and national ecological security. However, with the rapid development of Chinese economy there appear a lot of ecological problems, such as soil erosion, flood and waterlogging disaster, vegetation degraded and the biodiversity reduced, etc. In order to study complex environmental and ecological problems of Poyang Lake it is necessary to integrate or modify various existing models including hydrological, biological, social economic and other models with GIS techniques.

This paper firstly discuses the construction of digital watershed platform for Poyang Lake, which is not only an integrated GIS environment for spatial data pre-processing and post-processing but also an important foundation of eco-hydrological simulation, and then presents the integrated framework of coupled hydro-ecological modeling for Poyang Lake watershed (CHEMPLW) and its main functional components. Finally the integration method with ArcObject technique in Visual Basic development platform is given.

II. CONSTRUCTION OF DIGITAL WATERSHED PLATFORM FOR POYANG LAKE

Hydro-ecological process is an important coupled process in the complex ecological system of watershed-lake. It is not only related to meteorology, hydrology, soil, physics, chemistry and biology, but also related to industrial production and intensive culture, urban sprawl, population growth and land use/cover change, cropping system and agricultural management. Coupled simulation on hydro-ecology using a physically based and parameter-distributed model requires a lot of GIS-based digital spatial and non-spatial data. In order to deal with those spatial data it is essential to develop a digital watershed platform (DWP) for coupled hydro-ecological simulation. DWP is different from the term of 'digital watershed', which refers to a comprehensive technical system used to capture, store, manage, process and analyze the information on geographical background, fundamental facility, natural resource, cultural scene, ecological environment, population distribution, social and economic condition using the modern technologies of remote sensing, geographical information system, global positioning system, virtual reality, database, network and multimedia in the scale of watershed (Yang, et al, 2004; Wang, et al. 2005). Actually, digital watershed platform should be a set of application tools based on geodatabase for the data pre-process and post-process of hydro-ecological models. For this purpose, DWP for Poyang Lake was designed into two-layer configuration which consists of two parts: data layer and data process layer. Figure 1 illustrates the framework of DWP for Poyang Lake.

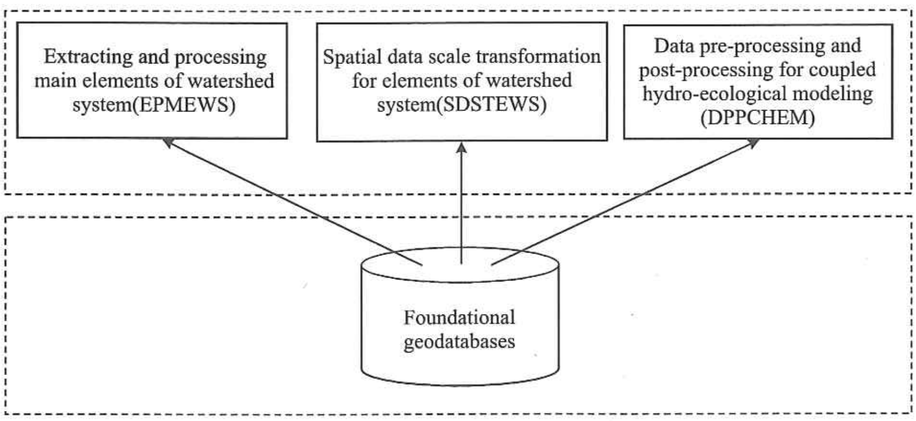


Figure 1. Structural diagram of digital watershed platform for Poyang Lake

A. Data layer

Data layer is the foundation of digital watershed platform of Poyang Lake and also the main data inputs of hydro-ecological modeling for Poyang Lake watershed. According to the data requirements of distributed hydro-ecological model system and national and international related data standards, based on cooperative researches with other related universities and research institutions, the basic geodatabases of Poyang Lake watershed were established. Data layer includes basic geographic information database, remote sensing image database, thematic database, socio-economic statistics database, text information database and metadata database. Basic geographic information database includes various scales of topographic maps, administrative boundary map, watershed boundary map, drainage network map of Poyang Lake watershed, etc. Thematic database contains a variety of scale of hydro-geological maps, soil map, land use/cover maps, the spatial distribution of soil erosion as well as meteorological data (precipitation, maximum and minimum temperature, solar radiation, evaporation, relative humidity and wind speed), agricultural management, water quality and water flow, socio-economic and demographic data, etc.

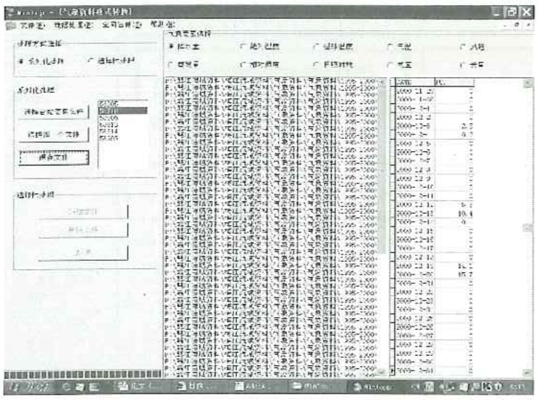
B. Data processing layer

Data processing layer in digital platform of Poyang Lake watershed includes the following three aspects: 1) extracting and processing main elements of watershed system (EPMEWS) using GIS, remote sensing and computer technologies; 2) handling with the spatial data scale transformation for elements of watershed system (SDSTEWS); 3) carrying out data pre-processing and post-processing for coupled hydro-ecological modeling (DPPCHEM).

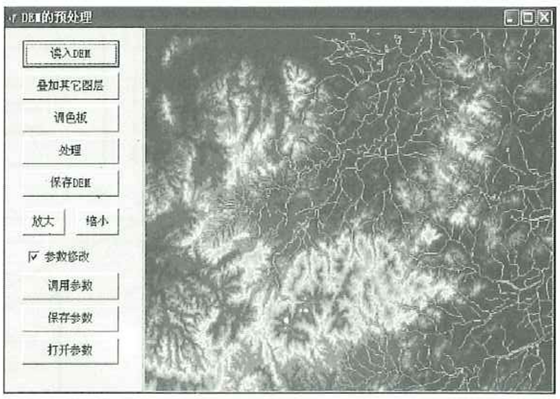
EPMEWS carries out mainly the spatial interpolation of meteorological factors, which include precipitation, temperature, evaporation, solar radiation, etc., to make up problems of low spatial resolution of meteorological data in the modeling of hydro-ecology because of limited weather stations in watershed or lost of data from those weather stations. The second effect of EPMEWS is mainly to exact or calculate vegetation parameters or vegetation structural parameters and other indices such as NDVI and LAI by the use of remote sensing technology for the dynamic analysis of hydro-ecology in watershed. The third one is to estimate other soil physical properties such as soil field water capacity, soil erosion-resistance character, soil withering parameter and soil available water content based on the existing soil physical properties.

Scale matching is an important scientific issue in hydrology and ecology. There exists the scale matching between ecological processes and hydrological processes, climate processes and hydrological processes when hydro-ecological simulation is conducted, in which measurement scale, observational scales and model working scale are involved. Therefore, it is very necessary to transform data from different processes from some kind of scale to another kind of scale. For example, in order to handle with the spatial heterogeneity of all elements of a drainage system distributed models divide a watershed into different small spatial units by using discretization approach (Lai, 2005). Those small units are known as subwatershed, subarea, and hillslope or grid cell. However, the ranges covered by those small units are different from that covered by administrative units, in which many socio-economic data are obtained by statistical methods. Therefore, these data got from administrative units have to be transformed into those data matching with divided small unit by discretization (James, 1995). The spatial scale and range of data can be transformed in SDSTEWS by the use of integrated GIS spatial analysis.

The pre-processing and post-processing of simulation data include mainly the management of spatial and non-spatial data, watershed delineation, data preparation of model for input and the visualization of modeling outputs. Data management in DPPCHEM means to manage the geographical information of watershed for necessary inputs of distributed models, and DPPCHEM mainly relies on GIS to manage spatial data and also provides the function of data query, retrieval, updating



(a) The interface of transformation for meteorological data



(b) The interface of watershed delineator

Figure 2. The interfaces of data process in DWP for Poyang Lake

and maintenance. Because the watershed delineation process is often a subjective one that depends not only on the hydrologic characteristics of a given location (and how it is represented by the data or information used), but also on the requirements of the delineator, a fully automated system is not practical for many purposes. Therefore, watershed delineation in DPPCHEM uses semi-automated techniques for delineating upstream areas, based on a user-selected outlet, and creating watershed and subwatershed data layers. The tools also facilitate the watershed and subwatershed attributing requirements.

III. THE STRUCTURE OF CHEMPLW

Water is an important and active element in ecological system, for which was selected as a key linkage of hydro-ecological model structure for Poyang Lake watershed. Analyzed the features of both eco-processes and eco-system of Poyang Lake watershed, socio-human subsystem, land use/cover subsystem, watershed (includes both physical rivers and lakes) environment subsystem and river/lake biological subsystem were integrated into hydro-ecological modeling system of Poyang Lake (Figure. 3). The integrated framework is in loosely coupled (Lai, 2003). The watershed environment subsystem is the key part of both whole modeling system and the hydro-ecology coupled modeling. The land use/cover sub-system is to provide dynamic boundary condition for modeling. The outputs of watershed environment subsystem can turn into the inputs of the river-lake/biological subsystem modeling.

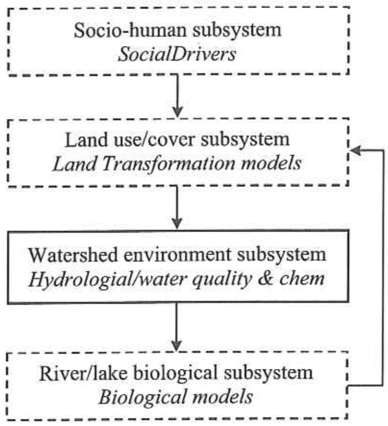


Figure 3. Subsystem Structure of coupled hydro-ecological modeling system of Poyang Lake watershed

In the land use/cover subsystem, Land Transformation Model (LTM) was used to predicate the pattern of the land use/cover in the future, and which is a model based on GIS by simulation arithmetic of neural networks. It combined historical land use/cover data, and included huge amount of policies, social-economical and environmental space-time driving forces (Pijanowski, et al. 2000). LTM is a spatial model which can simulate the land use/cover change in the future by inputting historical data of land use/cover. The digital geographic information data layer can be used in the LTM, and also includes transportation land use layer, population distribution layer, land use/change data from remote sensing image and the protected land such as protection area or wetland.

Watershed environment subsystem consists of both surface water models and groundwater models. Surface water models include Hec-GeoHMS, and SWAT, which are suitable at the midst and large scale modeling. Groundwater models include MRI-DARCY, Visual ModFlow and MT3. Surface and groundwater models can provide the counterpart of the surface hydrological units by the Digital Elevation Model. Many kinds of transmit and geo-chemical models can be used in the hydrological model to evaluate the possible influence of land use change with Poyang lake basin environment.

River/lake biological subsystem includes aquatic production model, lower food chain model and land system model. The fluctuation in aquatic species and quantities and other changing in the aquatic system exert an important influence on the subsystem of resource estimate and the land use change. The lower food chain model provides some respond variable, which relate to the rapid assessment methods (EPT index, IBI index, the diversity of insects) of land change and hydrological subsystem (Yaffee, 1999; Hinz, et al., 1998). Then the related module of the land environment has been integrated. However, those models are not the center of the Poyang lake hydrology-ecology coupled model, which just provide some respond varieties for the former.

IV. INTEGRATION FRAMEWORK OF CHEMPLW

In fact, CHEMPLW is a coupled system which consists of three parts: geodatabase, data processing tools and hydrological and biological application models for ecological purposes (sees Figure. 4). Therefore, it has to be integrated under GIS environment to complete spatial data management, transformation, visualization and so on.

In this project, ArcObjects (AO for short) was used as GIS integrating environment. AO consists of a series of COM modules which include 11 components, 25 component libraries, more than 1500 classes and 1600 interfaces, support wide variety of data format, and is a useful platform for developing applications of ArcGIS, ArcCatalog and ArcScene. Especially, the ArcEngine Developer Kit provides a series of embeddable ArcObjects components that can be used independently without the support of ArcGIS Desktop (Han, 2005). CHEMPLW was integrated with ArcObjects controls of ArcEngine platform by using Visual Basic. The integration approach was in loosely-coupled pattern, namely, data exchanges between integrated user interface and coupled hydro-ecologgical models in different subsystem are implemented by reading or writing data files which are some intermediary documents for data exchanges. Data format in those data files was defined according to the requirements of input files of different models. The advantages of this method are coupled hydro-ecological simulation can be implemented

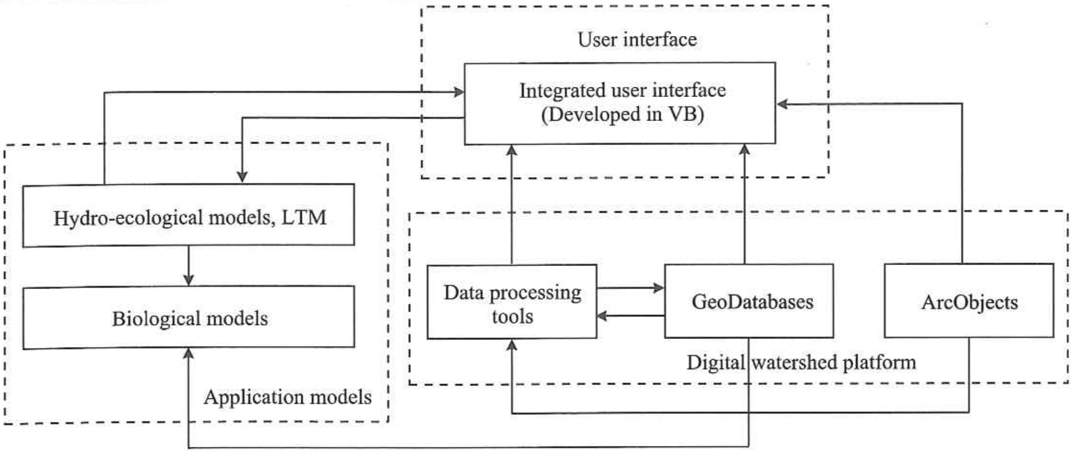


Figure 4. Integration of coupled hydro-ecological modeling system for Poyang Lake watershed based on ArcObjects

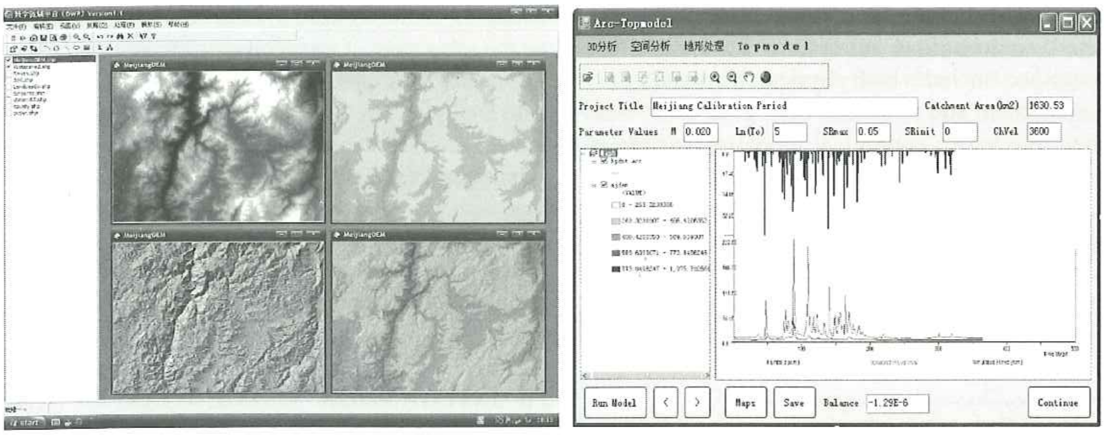


Figure 5. The interface of CHEMPLW

easily on the basis of existing hydrological or ecological models by integrating GIS functionality into coupled modeling system.

Additional, a group of standard protocols were adopted for information exchange in coupled hydro-ecological models, in which different data format and units can be standardized and using GIS function joined sub-modules and components of models. Meanwhile, the integrated coupled modeling system includes the validation and evaluation of results as well as error diffusion of model framework, data quality of spatial variables, sensitivity identification of survey error.

V. CONCLUSIONS

After the introduction of the concept of the digital watershed platform and described its implement, this paper mainly addressed the construction of CHEMPLW and its integrating method using Visual Basic on the platform of Esri ArcObjects. CHEMPLW mainly includes four subsystems which are socio-human subsystem, land use/cover subsystem, watershed environment subsystem and river-lake/biological subsystem, and each subsystem consists of many models. Water is a focus in many scientific researches of Poyang Lake (and its watershed). The implement of CHEMPLW can provide a tool to study, assess and predict various ecological problems which are related to water for scientific researchers and also provides a decision tool to explore various management options for watershed managers.

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