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GIS-Based Water Resources Management Information System (WAMIS) in Korea

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This paper briefly describes the classification of GIS-based model, and introduces some practical grid-based models such as TOPMODEL (Beven *et al.*, 1979, 1984), AGNPS (Young *et al.*, 1989), KIMSTORM (Kim, 1998; Kim *et al.*, 1998), and GRISMORM (Kim *et al.*, 2000). Current status of GIS data construction promoted by Ministry of Construction and Transportation (MOCT) and system development of water resources information by Korea Water Resources Corporation (KOWACO) is briefly described. Further research needs for GIS-based modeling will be emphasized with some recommendations on GIS data preparation and proper field observation data collection.

Key words : Geographic information Systems, Grid-based model, NGIS, WAMIS

INTRODUCTION

Geographical Information Systems (GIS) describe the spatial environment. Managing water resources is the functioning of hydrological and environmental processes. Such management and related simulation require data about the environment within which the processes occur. Thus GIS and water resources management are synergistic, and GIS can serve as a common data and analysis framework.

In integrating GIS and water resources information such as hydrology and water quality (H/WQ) modeling, there are three distinct themes to be solved: (1) issues of spatial data, including availability, access, common formats, resampling, and accuracy; (2) issues of modeling, including the development and structuring models; and (3) issues of systems, including the design of GIS, data models, GIS functionality, and user interfaces.

Related to theme (1), general information on GIS data quality, accuracy, standards, availability, proposed management and information systems, and reference guides are available from published reference materials. The number of facilities for computer-based searches is growing. Modelers now have access to growing resources for computerized searches for data, metadata, and other types of information, especially through client/server systems on the Internet. Typically, the client/server architecture provides direct access to open systems such Wide Area Information Servers (WAIS) and World Wide Web (WWW).

Related to theme (2), inspired by the rapid increasing power of computers and the GIS and digital terrain maps, distributed models in H/WQ have been developing rapidly since the first outline of a physics-based distributed model published by Freeze and Harlan in 1969 (Beven, 1996). The representative distributed models are ANSWERS (Beasley *et al.*, 1980), TOPMODEL (Beven *et al.*, 1979, 1984), SHE (Abbott *et al.*, 1986), THALES (Grayson *et al.*, 1992), AGNPS

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(Young *et al*., 1989). The detailed description of the models at a glance can be found in the book "Computer Models of Watershed Hydrology" (Singh, 1996).

Related to theme (3), the models recently have a tendency to be packaged as a user−friendly graphic user interface modeling system with the aid of GIS functional components and software engineering. These are MIKE SHE (Institute of Hydrology UK, SOGREAH, DHI, 1986), WMS (Brigham Young Univ.−Engineering Computer Graphics Lab., 1996), OWLS (Chen, 1996), GIS Hydrology Program at the University of Texas (Maidment, 1998).

In Korea, Government has accomplished NGIS (National Geographic Information Systems) project to provide base and selected thematic digital maps since 1995. Especially for water−related information, KOWACO (Korea Water Resources Corporation) launched to develop "Water Resources Management Information System (WAMIS)" in 1999. Also, there have been some efforts to apply and develop distributed models during the past few years. TOPMODEL and AGNPS are the main application models to storm runoff and nonpoint source pollution estimation in small watershed scale, respectively. Kim (1998) and Kim *et al*. (1998) developed grid−based KIneMatic wave STOrm Runoff Model (KIMSTORM) that predicts temporal and spatial distributions of overland flow, subsurface flow and stream flow in a watershed. Chae *et al*. (1999) developed GRID−based EvapoTranspiration estimation model (GRIDET) by using satellite imagery and GIS. Kim *et al*. (2000) developed GRId−based daily Soil MOsture Routing Model (GRISMORM) eventually to assess groundwater recharge.

This paper briefly describes the classification of GIS−based H/WQ model, and introduces the concept of distributed models; TOPMODEL, AGNPS and KIMSTORM, GRISMORM to understand what kind of GIS data are to be prepared and how to treat the data in water resources area. Present status of GIS data construction and system development of water resources information in Korea will be briefly described. Also research needs for distributed modeling will be emphasized with some recommendations concerning GIS data preparation and field observation data collection.

THE CLASSIFICATION OF GIS−BASED MODEL AND TRENDS IN GIS−BASED HYDROLOGIC AND WATER QUALITY MODELING

GIS−based distributed models take an explicit account of spatial variability of processes, input, boundary conditions, and/or watershed characteristics. There are four model structures in distributed models, and most are based on topography; (1) models based on hydrological response units (HRUs) consisting of "homogeneous" subcatchments. This approach finds its best expression in the Finite Element Storm Hydrograph Model (FESHM) (Ross *et al*., 1979; Hession *et al*., 1987); (2) grid−based models. Some examples of this structure include TOPMODEL, ANSWERS, AGNPS, SHE; (3) TIN−based models. TINs have been used for dynamic hydrological modeling. These are found in Palacios−Velez and Cuevas−Renaud (1986, 1989), Silfer *et al*. (1987), Vieux *et al*. (1988), Maidment *et al*. (1989), Goodrich (1990), Jones *et al*. (1990), Djokic and Maidment (1991), Goodrich *et al*. (1991); (4) contour−based models. TAPES−C (Moore *et al*., 1988b; Moore and Grayson, 1991) and TOPOG (Dawes and Short, 1988) are examples of computer−based terrain analysis methods that use this approach (Moore *et al*., 1993).

During the past two decades of modeling development, distributed H/WQ models are today being used in practice at a fraction of potential. It is evident that the rapid advancement in GIS technology has revolutionized H/WQ modeling research. The trend in Korea is demonstrated by the grid−based practical models; TOPMODEL and AGNPS. This is because raster−based application of the model is easier and simpler than vector−based application.

TOPMODEL was originally developed to simulate the hydrological behavior of small upland catchments in the UK. As a distributed model that can make use of data on topographic, soil and vegetation information, TOPMODEL is well suited to implementation within GIS framework. The model represents an attempt to combine the computational and parametric efficiency of a lumped approach with the link to physical theory and possibilities for more rigorous evaluation offered by a distributed model.

AGNPS was developed to analyze and provide estimates of runoff water quality from agricultural watersheds ranging in size from a few acres to upwards of 50,000 acres. AGNPS is a distributed parameter, event-based model. It simulates the behavior of runoff, sediment, and nutrient transport from watersheds that have agriculture as their prime use. The model operates on a cell basis. Cells are uniformly square areas subdividing the watershed, allowing analyses at any point within the watershed.

Recently, some grid-based modeling efforts were performed by Kim (1998) and Kim, *et al.* (1998), Chae *et al.* (1999), Kim *et al.* (2000) in Korea. KIMSTORM predicts temporal variation and spatial distribution of overland flow, subsurface flow and stream flow within a watershed. The model adopts the single overland flowpath algorithm and simulates surface and/or subsurface water depth at each cell by using water balance of hydrologic components. The model programmed by C-language uses ASCII-formatted map data supported by the irregular gridded map (DEM, stream network and flow direction, land cover, soil type and Thiessen network) of the GRASS (U.S. Army CERL, 1993) GIS and generates the spatial distribution maps of discharge, flow depth and soil moisture of the watershed. The schematic representation of water balance components in a grid element is shown in Fig. 1 and flow diagram of the KIMSTORM model is shown in Fig. 2. GRISMORM is a grid-based daily soil moisture routing model. The model uses linear reservoir assumption which implies that logarithmic discharge is a linear function of time and a simple concept to incorporate the water balance of paddy fields is suggested. This approach predicts the temporal variation and spatial distribution of daily water balance components such as surface/subsurface runoff, soil moisture content, and evapotranspiration within the watershed. GRISMORM was

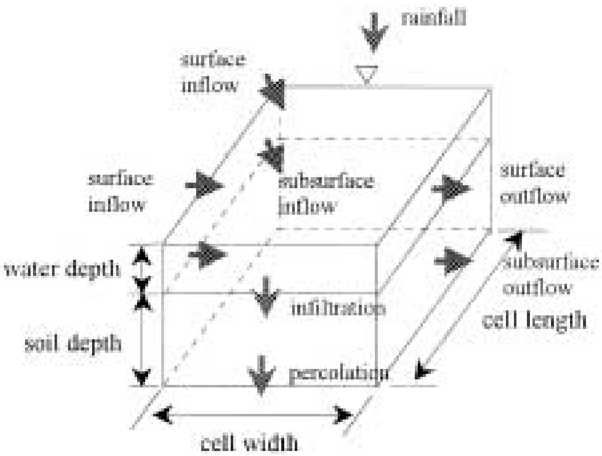

Fig. 1. Grid-based water balance components of KIMSTORM.

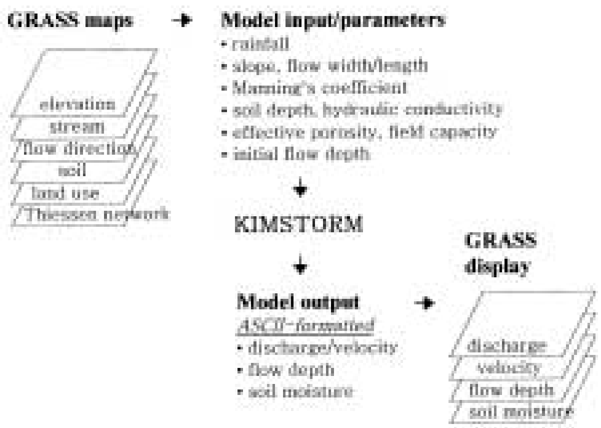

Fig. 2. Schematic diagram of KIMSTORM model.

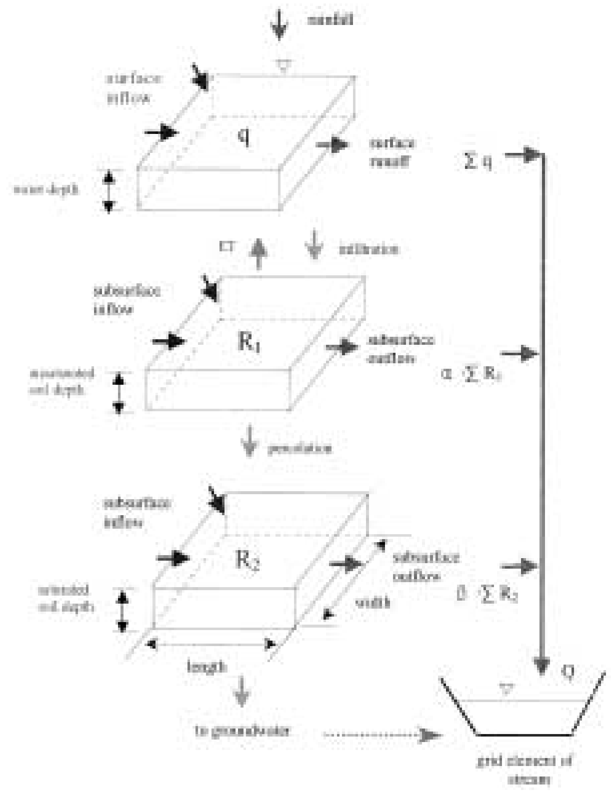

Fig. 3. Grid-based water balance components of GRISMORM.

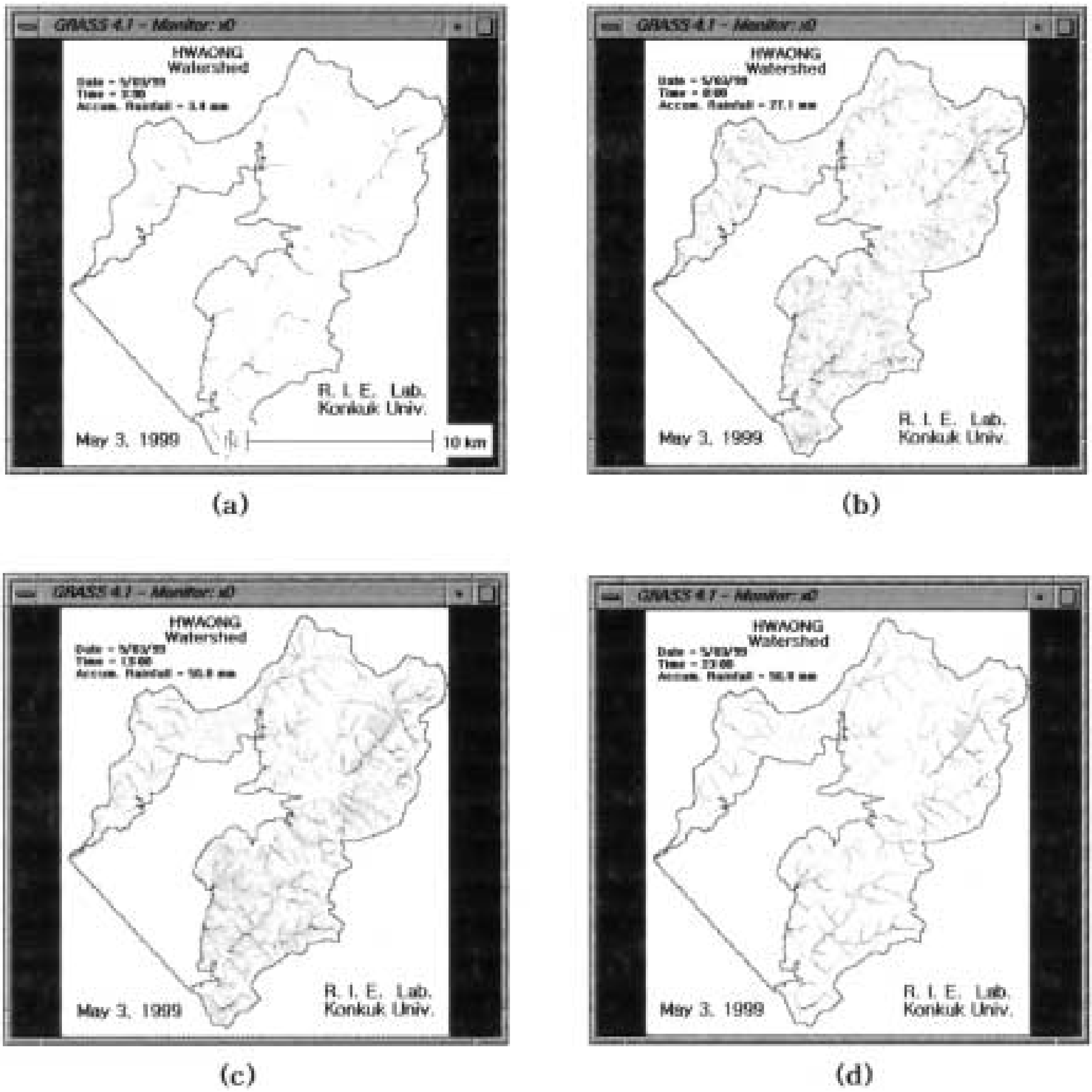

Fig. 4. Spatial distribution of surface and channel runoff after (a) 1 hr, (b) 5 hrs, (c) 10 hrs, (d) 20 hrs of rainfall (Hwaong tideland reclaimed watershed, May 3, 1999).

also coded in C language and uses irregular gridded data such as elevation, stream, land use and soil information with ASCII−formatted map data. The daily results for each component are generated as ASCII−formatted map data, and displayed on GRASS GIS. The schematic representation of the flow system is shown in Fig. 3.

Model can offer distributed results, that is, the spatial variations of H/WQ variables at any grid −point in the watershed. Fig. 4 is an example of the distributed results of KIMSTORM applied to Hwaong watershed (162.3 km^2) located in the tideland reclaimed area of South Korea. The figure shows the temporal and spatial distribution of saturated overland/stream flow depths within the watershed. From this result, we can determine where the overland flow originated and how much water at each source area contributed knowing only the stream flow at the watershed outlet. Grid−based modeling approach can also provide information that is important for investigating the loss of soil due to erosion and the transport of non-point source pollutants.

DISCUSSIONS AND THE NEED FOR GIS-BASED MODELING

The traditional H/WQ models of lumped conceptual type are well suited to deal with the main part of current water resources and water quality assessment, flood and drought forecasting, but more advanced tools, that is, distributed models are required for integrated watershed planning/management/restoration tool and predictive capability on the effects of man-induced impacts. The future of H/WQ models will be shaped by increasing societal demand for integrated environmental management; growing need for globalization by incorporation of biological, chemical, and physical aspects of the hydrologic cycle; rapid advances in remote sensing and satellite technology, GIS; mounting pressure on transformation of models to user-friendly levels.

We may doubt whether distributed models are based on the correct equations to describe hydrological reality at the grid element scale; they estimate effective parameter values for those equations at the element scale; they are properly tested in terms of simulating the internal state variables. These problems have been discussed extensively. Beven (1996) deeply touched these problems, and he finally concluded that the distributed approaches would be extremely valuable. Then what do we have to do from now on? We need more concern and application/development of the distributed models for water resources and environmental quality problems. Attempts to explain the H/WQ behavior of paddy fields should be involved.

PRESENT STATUS OF GIS DATA CONSTRUCTION AND SYSTEM DEVELOPMENT OF WATER RESOURCES INFORMATION

In many cases, all relevant data for GIS-based model do not exist and even the existing data is most often not easily accessible due to the lack of suitably computerized databases. For many years, high expectations have been directed to remote sensing techniques for providing spatial data of use in distributed hydrological models. DEM with several resolutions and land use/vegetation mapping with image processing software are now available. Another important development improving the availability of data is the application of GIS and GPS techniques. Korea has accomplished NGIS (National Geographic Information Systems) project since 1995. Base maps such as contour, stream centerline, road, administration and selected thematic maps with the scale of 1 : 1,000, 1 : 5,000, 1 : 25,000 were finished at the end of 2000.

Recently, the second stage of NGIS project to provide necessary thematic maps such as land use by aerial photogrammetry, detail river information (polygon), soil information and several ecological information was launched and it will be continued to 2005. The government determined the amount invested 4.42 thousand billion won. KOWACO (Korea Water Resources Corporation) is one of the main NGIS users. They started to develop "Water Resources Management Information System" in 1999, and it will be continued to 2011 with three stages; data management system (1999), analysis system (2000～2005), decision support system (2006～2011). The system is composed of eight main field of information, that is, HUM (Hydrologic Unit Map), water level & discharge, dam operation, groundwater, weather, river, water use and water quality (http://wamis.kowaco.or.kr/). In 1999, KOWACO developed HUM with 1,175 cataloging units of South Korea. Now they are trying to fill up HUM contents such as DEM, stream, soil, land use/cover, meteorological data and statistical data etc.

As a preliminary study, KOWACO (2001) performed to develop essential contents of water resources unit map, and to make plans for the construction of contents as framework data. To accomplish this purpose, (1) the presentation of application field based on water resources unit map through the task review of water resources-related Ministry; (2) suggestion of common information in the field of water resources and their production principles and techniques; (3) determination of detailed contents and their short & long-term programs for practical use; (4) planning of framework data development; (5) example construction of framework data and data management system were included as research scope. In this study, soil map, land cover/use map, ground water related information, meteorological information were suggested as the framework data in water resources in addition to NGIS framework data (DEM, stream network, road map, administration boundary etc.). If this work progresses well, it will accelerate GIS−based water resources management by the development and application of distributed modeling.

CONCLUSIONS

Morton (1993) called the GIS−based distributed model as "mediating model". There is enough evidence from a number of publications that the distributed models are not as bad as might first appear. TOPMODEL, AGNPS, MIKE SHE and KIMSTORM are the good examples. These are proved to be successful in the prediction of internal H/WQ state variables. One key difference between GIS−based model and other models in widespread use such as the Corps of Engineers HEC−1 and HEC−HMS, is that GIS−based model may contain fewer conceptualizations of hydrologic components (e.g., unit hydrograph). This does not mean that GIS−based model is necessarily superior, only that GIS−based modeling represents a different approach and distributed result. Spatially−distributed modeling offers the capability of determining the value of any H/WQ variable at any grid−point in the watershed at the expense of requiring significant more GIS data input than traditional approaches.

The problem is that distributed models have in general had less data available than they could have used. Thus, the hydrological science needs the development of new measurement techniques, especially with respect to spatial data and their heterogeneity. Fortunately, new data sources are emerging and rapidly being developed, such as remote sensing data, new in−situ soil moisture and water quality sensors and weather radar data. In addition, the widespread use of GIS and other data base systems are gradually making the existing data much more easily available and applicable as described in the previous section. So, I am sure that the distributed models coupled with WAMIS can be a practical tool in integrated water resources and environmental management.

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<국문적요>

GIS 기반의 수자원관리정보시스템(WAMIS)

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본 고는 GIS기반의 모델종류를 전반적으로 분류하고, 수자원 및 환경분야에서 적용성을 인정받고 있으며, 그 활용성이 높은 대표적인 분포형 수문/수질모델인 TOPMODEL (Beven 등, 1979, 1984), AGNPS (Young 등, 1989), KIMSTORM (Kim, 1998; Kim 등, 1998) 그리고 GRISMORM (Kim 등, 2000)의 개념을 간단히 소개하고자 한다. 또한 현재 건설교통부에서 추진하고 있는 국가GIS의 현황 및 계획 그리고 한국수자원공사에서 추진하고 있는 수자원종합정보관리시스템(WAMIS)의 추진내용을 파악하므로서 향후 수자원과 환경분야에는 어떠한 GIS자료들이 필수적으로 요구되는지, 이와 더불어 현장자료 수집은 어떠해야 하는지를 고찰하였다.