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A Flood Prediction Geographic Information System

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ABSTRACT

The paper discusses a GIS that derives kinematic wave model parameters using stream network, elevation, and basin boundary data. Various approaches are being investigated for estimating several parameters not directly obtainable from the GIS data. Additional work is planned to determine the most feasible approach and to fully test the system on a variety of basins.

INTRODUCTION

This paper describes a project dealing with the use of a geographic information system (GIS) for hydrologic forecasting. This is an ongoing project in the National Weather Service (NWS) that uses a kinematic wave model. Discussion is given to the background of problems leading to the project, objectives, system components including the model and data bases, approach being taken, a sample case, and future directions.

The NWS has the mission of providing river forecasts nationwide. For most large gaged rivers, hydrologic model parameters have been derived and site specific forecasts are issued primarily using unit hydrographs. However, for many small basins (i.e., 10 to several hundred square miles) parameters have not been derived and generalized area forecasts are issued (e.g., expect moderate rises on small creeks in the county). In the future, the NWS would like to provide more site specific forecasts for smaller basins and newly gaged areas. To do this effectively for many basins requires sound and easy means of deriving model parameters.

Parameter estimation methods often rely on time consuming fitting with rainfall and streamflow data. Also, the required historical data is often inadequate for many small basins (Clarke, 1973). Thus, an alternative method was sought that would be more automated and rely more on easily measurable basin characteristics. Also, three geographic data bases were obtained by the NWS. GIS technology has found useful application in hydrology and seemed to be a potentially feasible alternative (Hill et.al., 1987; Ragan and White, 1985). Since procedures using basin properties are not typically employed in the NWS (with some exception, Sheridan, 1953), a model amenable to a GIS was needed. While various models and synthetic techniques exist, a kinematic wave model was chosen because of its physical basis and other salient features (see MODEL).

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OBJECTIVES

The project goal is develop and test a GIS for deriving kinematic wave model parameters for use in small or newly gaged basins. The system is constrained to using digital data that will be readily available nationwide to the NWS. Specific objectives are: 1) Define the approach for deriving parameters directly from the GIS data; 2) Identify possible approaches for deriving information (e.g., basin area) that may have to be inferred indirectly from the GIS data; 3) Identify possible approaches for deriving any parameters (e.g., roughness) that cannot be obtained from the digital data; 4) Define which approach(es) is most feasible; and 5) Evaluate the GIS performance on small test basins. The performance evaluation will asses several criteria including accuracy, efficiency, ease of use, and amount of user input required.

THE SYSTEM: Model and Data Bases

The kinematic wave model (KWAVE) produces a hydrograph by routing of surface runoff to a watershed outlet (Schaake,1971). It was chosen because required parameter input can be tied to observable watershed properties. Also, it potentially may give improved forecast accuracy since it is non-linear and can handle spatially varied rainfall input For this project, the SCS curve number, which has been used in GIS's (Ragan and White, 1985), serves as the surface runoff component. However, the curve number is to be fitted for each basin in the project. KWAVE uses a finite difference solution and requires: 1) Basin segmentation into channel and overland flow segments; 2) Length of each segment,; 3) Two kinematic parameters for each segment derived from slope, roughness, and channel shape. The overland flow segments represent the myriad of small channels that cannot be defined but are the mechanism for conveying lateral inflow to the channel. This type of model has been applied on a variety of small basins (Schaake, 1973; Ross and Shanholtz, 1979). Further, the system could be used to estimate a unit hydrograph if desired (Hjelmfelt, 1984).

Geographic data containing gridded elevations, stream networks, and basin boundaries are obtained from the DMA half mile topography data base, the EPA River Reach data base, and the USGS hydrologic units basin boundary data base. The system relies almost totally on these data. The GIS reads the necessary geographic data and estimates the KWAVE parameters which are then filed (Figure 1). These parameters are then used in the real-time KWAVE model for any rainfall events that occur. Any parameter that cannot be defined from the geographic data are obtained from a file of regional values.

APPROACH

The basin is segmented at junctions in the river data. Each segment is idealized as a uniform channel receiving lateral inflow two symmetrical planes of overland flow (Figure 2). For each segment, the geographic data yields the channel length, drainage area, overland flow length, channel slope, and overland flow slope. Roughness and channel shape cannot be inferred from the geographic data so are assigned regionalized values.

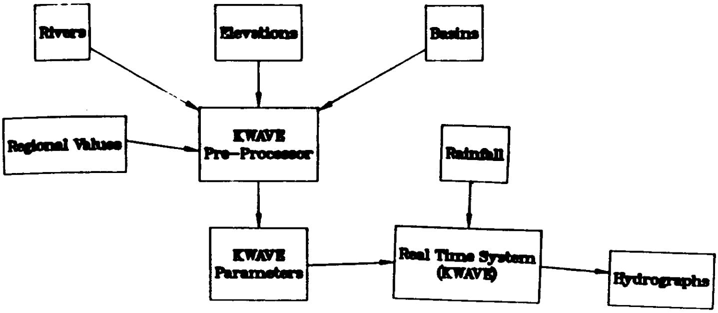


Figure 1. System Architecture

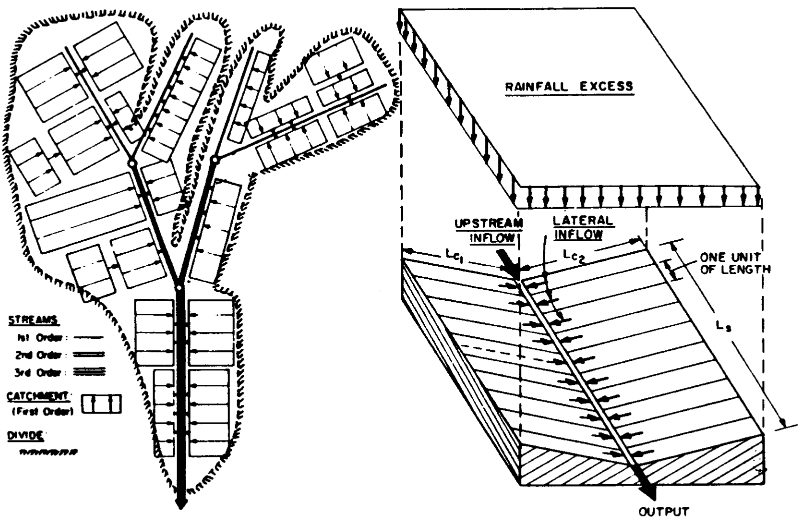
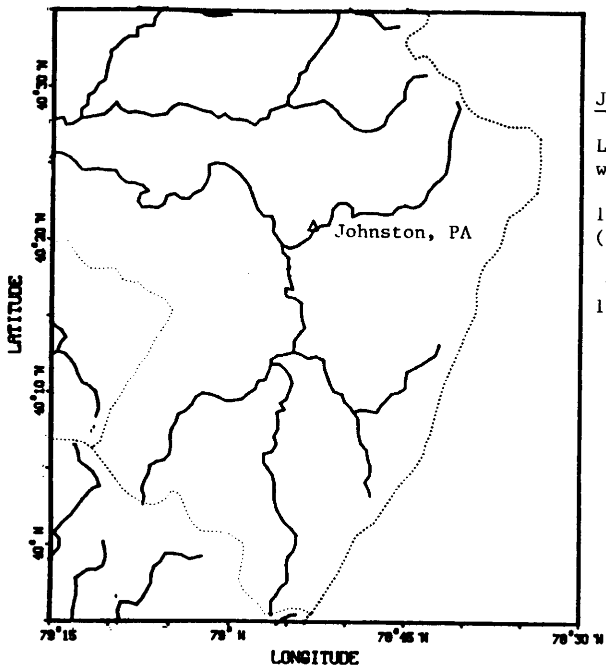


Figure 2. Concept of segmentation and the idealized segment

The software for the basic approach is completed, however, several approaches are being investigated to address some existing questions, such as how to to regionalize values. Also, the basin boundary data do not always coincide with the user's outlet (e.g., Johnstown Figure 3). Another potential problem is that small areas may have a short digitized channel resulting in a poor overland flow length.

Terrain analysis is being investigated to enhance the resolution of the basin and river data for better drainage area and overland flow length estimates. It uses elevation data to "grow" a basin from a specified outlet (Ragan and Fellows, 1985). Alternatives are being considered that use terrain analysis but constrain it with a user specified drainage size or with the existing basin and river data.



Johnstown basin

Little Conemaugh Rvr
wooded, mountainous,
some agriculture
183 square miles
(initial estimate
in GIS = 42 square
miles)
1 segment

Figure 3. Map of Johnstown, PA area from the GIS

An approach is still needed for roughness and channel shape since these cannot be obtained from terrain analysis. Several approaches being considered are nominally assigned values (Arcement and Schneider, 1984), (i.e., the current approach), regional geomorphic drainage area relationships for channel shape, and regionalized index watersheds. Index watersheds would have fitted roughness and shape values which would be used on any basin in the same physiographic region.

The test phase will use a variety of basins with fitted "optimum" parameters. Differences between parameters estimated from each approach and optimum values will be identified and used with parameter sensitivity analysis to evaluate the accuracy potential of each alternative. The most feasible approach(es) will be identified by trying to maximize accuracy and minimize subjective user input. Finally, the performance of the system will be tested on a variety of storms in each basin using the most feasible approach.

EXAMPLE CASE

A test was done on the Little Conemaugh river near Johnstown, PA, using the July, 1977 event that averaged 10 inches of total rainfall. With only the outlet location specified the GIS estimated the initial parameters (Table 1). Drainage area was estimated from a regional geomorphic area-stream length relationship since no terrain analysis exists and the basin data was inadequate (see Figure 3). The drainage area estimate was very low so the actual size was input and a corresponding correction made to the overland flow length. The main channel presented no problem since it was digitized nearly to the basin divide. Roughness and channel shape were assigned nominal values.

The simulation using the non-fitted nominal roughness values was very close to the observed peak stage and time (Table 2). Sensitivity analysis of the variables not directly obtained from the GIS indicated that the overland flow length (or overland flow roughness) had the greatest effect on the results (Figure 4). No conclusions are extrapolated to other basins but further testing will be done to see how results compare.

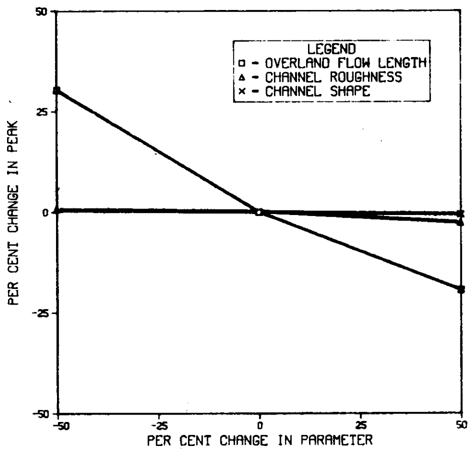


Figure 4. Sensitivity Analysis

Table 1. Parameter Estimates

Parameter	Channel	Overland Flow
Length (mile)	19	4.8
Slope (feet/mile)	25	190
Roughness	.06	0.5
Shape	10	-

Table 2. Simulation Results for Peak

	Observed	Simulated
Stage (feet)	18.1	18.0
Time to Peak (hours)	6	6

SUMMARY

The initial development phase of the GIS is complete. However, several questions remain that may require enhancement of the system. The current configuration uses nominal default values for roughness and channel shape, and an area versus stream length relationship to obtain drainage area when the basin data is inadequate. The next phase will investigate terrain analysis and regionalization approaches to establish how results can be improved. Once complete, the GIS will be tested on a variety of basins.

The potential value of the GIS is very high. It will give a sound and easy means of deriving kinematic model parameters for many small basins. Such basins are ungaged or lack adequate historical rainfall and streamflow data to do traditional parameter fitting. Further, the GIS has potential value in larger basins where it can be used to subdivide and parameterize the basin into small segments giving better results for spatially varied rainfall events.

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