Computation of grid storage capacity from topographic index in hydrological modelling

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Abstract Recent advances in the field of GIS have made possible the development of distributed hydrological models. However, there are some unsolved problems in full real-time distributed hydrological models. In view of these problems, an alternative conceptual distributed hydrological model is proposed in this paper. Determination of water storage capacity for every grid cell has become an important problem in conceptual distributed hydrological models; taking the similarity between the maximum grid soil moisture deficiency and the grid topographic index into account, it was found that a logarithmic Weibull function relationship exists between them. Based on this, a method to calculate the grid storage capacity from the grid topographic index is proposed. The method was applied in a grid distributed hydrological model with non-compact structure. Results obtained show that in an ungauged basin it is possible to get some of the hydrological parameters from the geographic parameter set. The main conclusion of this paper is that the findings here suggest a promising alternative way for hydrological modelling.

Key words distributed hydrological model; topographic index; grid storage capacity; logarithmic Weibull function

INTRODUCTION

Recent developments in GIS have made it possible to develop a distributed hydrological model since the "blueprint for a physically-based, digitally simulated hydrological response model" was put forward by Freeze & Harlan (1969). As pointed out by Beven (2001), this blueprint was based on some descriptions for hydrological processes. Even though these descriptions about soil water flow, surface flow and river flow may be appropriate on a laboratory scale, when applied (for example, Darcy's law and Richards equation in unsaturated zone) in a distributed hydrological model, we have to determine whether their parameters and variables are consistent in scale, ranging from a few metres to a few kilometres (Bloschl, 2001). Problems will arise if these basic equations, which are used to build physically-based distributed hydrological models, are applied in real basins; there is a fundamental conflict (Beven, 1989, 1996, 2000). Considering the problems of localization, if the equations' localizations are permitted, complicated parameters should be introduced as a consequence. However, these parameters cannot usually be directly observed and some uncertainty exists. The simple implication is that different observed data will be needed to calibrate these parameters in order to study their sensitivity and spatial variability. The way to resolving this conflict does not depend on using more detailed process descriptions or collecting more observed data to determine some parameters and variables, but rather the only viable way is to look for a simple model based on existing information.

An approach, which entails the utilization of existing information, is proposed in this paper. This alternative method calculates some important parameters based on the grid of the DEM. Unlike the traditional conceptual lumped model, which applies on a basin scale, a classical conceptual model on a grid scale is used to form a conceptual distributed hydrological model. The parameters of this kind of model are also spatially variable and cannot be evaluated by just using traditional methods based on model parameter calibrations. So, the problem of rainfall–runoff and flow confluence in a unit grid is changed to a problem of PUB (Predictions in Ungauged Basins). Based on recent studies and experiments, hydrologists and geomorphologists have come to the conclusion that the rainfall–runoff process is controlled, not only by characteristics of precipitation, but also by some distinct relations between the runoff process and the characteristics of the underlying surface (e.g. topography, geomorphy, soil, vegetables, geology, etc.). The appearance of the concept of topographic index (Beven, 1979) made it possible to combine geomorphologic parameters and hydrological parameters well.

METHODS

It is difficult to determine the storage capacity for every grid cell if the conceptual hydrological model (e.g. Xinanjiang model) is applied on a grid scale. The curve of basin storage capacity in the Xin'anjiang model (XAJ) is consistent with the curve of topographic index cumulative frequency in TopModel. Though there are some descriptions about the spatial variability of saturation capacity, it should be noted that areas with large topographic index usually correspond to valleys in a basin prone to producing runoff because of a small water deficit. However, areas with a small topographic index usually correspond to the ridge and invariably cannot produce runoff easily because of large water deficit. Consequently, the topographic index is an indicator of the response of basin hydrological processes (Ren Li-liang, 2000).

This paper addresses the following questions:

- Are there some kind of relations between topographic index and storage capacity?
- How do we determine the relation if it does exist?

Through the analysis of data from nine basins around the Three Gorge of Yangtse River, we found that the shape of the distribution curve of topographic index is similar to that of the basin storage capacity, which is the parabolic curve shape (see Fig. 1). In Fig. 1, the y-axis is the difference of grid topographic index and the minimum of basin topographic index; the x-axis is a proportion between the numbers of the grid with topographic index less than some level and the total grid number. For purposes of analysis the storage capacity curve, which is calibrated using the lumped model, shall be taken as a known quantity (or statistical real value). In addition, the method of combine or total frequency is adopted where some points from two curves with the same proportion are collected and then fitted in a figure (see Fig. 2).

From Fig. 2 it can be seen that the curve fits the distribution curve of the logarithmic Weibull function well; here, the offset value zero is set to zero. The formula of this curve is given as:

$$\frac{W_i}{WMM} = \exp\left\{-\left[\frac{\ln(TI_i - TI_{\min} + 1)}{\alpha}\right]^{\beta}\right\} \tag{1}$$

where W_i is the grid storage capacity, WMM is the maximum basin storage capacity, TI_i the grid topographic index, $TI_{\min}$ is the minimum basin topographic index, α is a scale parameter, which reflect the grid scale, and β is a shape parameter.

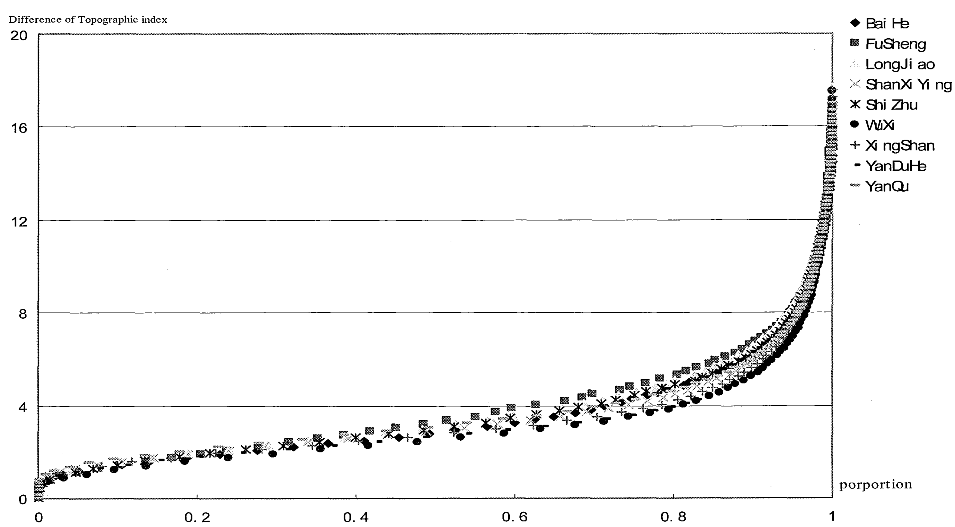

Fig. 1 Cumulative frequency curve of different basin's topographic index.

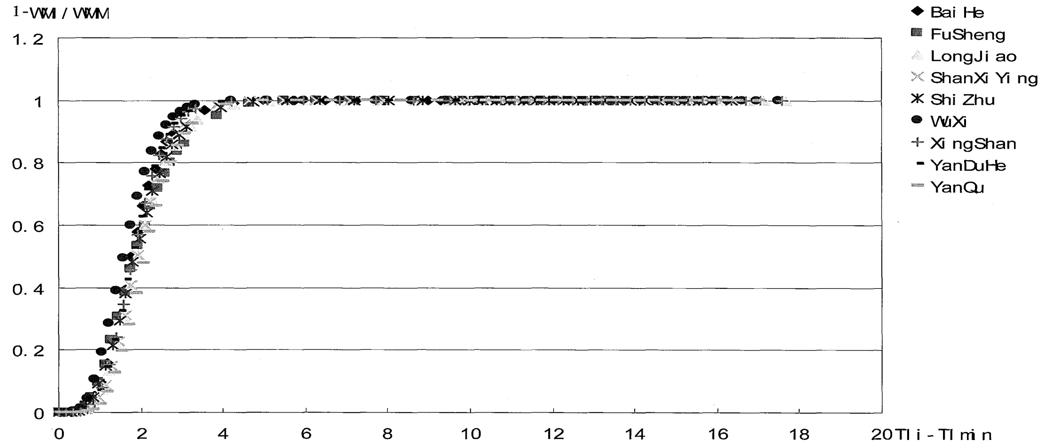

Fig. 2 Relation of topographic index and storage capacity.

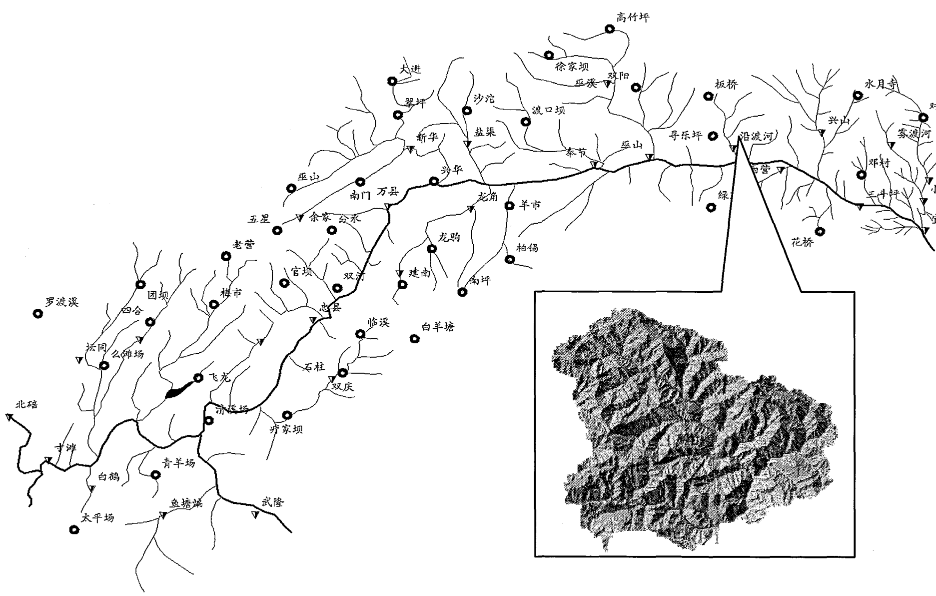
Fig. 3 Yanduhe River Basin.

STUDY SITE

To test the logarithmic Weibull function assumption, the Yanduhe Basin was chosen as the study site. The Yanduhe River Basin, situated in the south of the ShenNongjia virgin forest (Fig. 3), is the first order tributary of Yangtze River in the north bank and covers 601 km^2 of forested land at elevations between 200 m in the southern portion of the catchment and 3052.7 m in the northern parts, which is the highest peak of ShenNongjia virgin Forest. The basin has 26 tributaries with river network density of 0.2 km/km^2, river gradient of 9.5‰ while the sinuosity is 1.4 and vegetation cover stands at about 70%.

RESULTS AND DISCUSSIONS

The maximum basin storage capacity in the Yanduhe Basin, which can be determined by the XAJ model, is 156 while two types of grid resolution for DEMs, 3s and 30s were applied in this study area to obtain the spatial distribution of the basin storage capacity (Fig. 4). For every grid cell, the storage capacity was calculated and the cumulative curve was drawn to obtain the basin storage capacity curve (Fig. 5). The grid storage capacity was then applied to the distributed hydrological model (Shi Peng, 2006) to obtain the results for flood simulation (see Table 1).

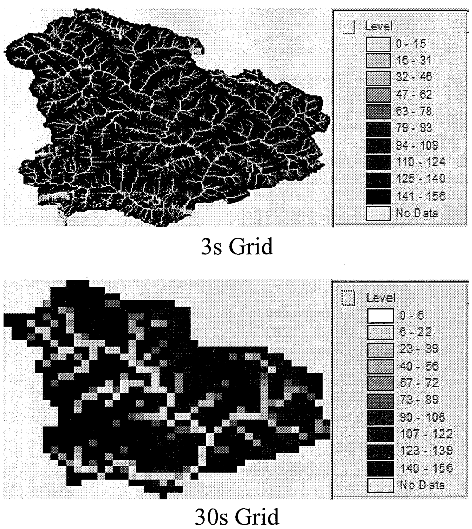

Fig. 4 Calculated distribution of basin storage capacity.

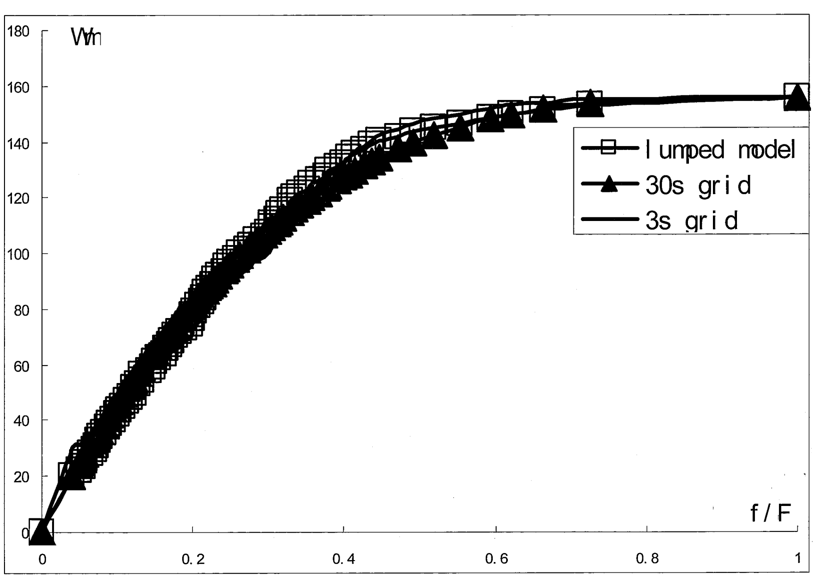

Fig. 5 Calculated cumulative curve of Basin storage capacity.

Table 1 Comparison of simulated and observed flood characteristic for Yanduhe watershed.

Flood Code	Precipi tation	Observed run-off depth (mm)	Calculated run-off depth (mm)	Error of run-off depth (%)	Observed peak flow (m^3/s)	Calculated peak flow (m^3/s)	Error of peak flow (%)	Deterministic coefficients
831004	181.4	176.7	172.3	–1.3	575	576	0.03	0.939
840723	176.1	144.4	148.7	4.3	1060	1062	0.2	0.969
850621	123.5	100.7	97.5	–2.0	476	480	0.9	0.932
860909	194.2	181.9	173	–4.0	844	841	–0.37	0.959
870821	104.2	94.1	91.3	–1.7	556	556	0.1	0.876

CONCLUSIONS

The development of computer technology and the improvement of GIS technology have enhanced the further development and improvement of distributed hydrological models. Based on the results indicated in Figs 3 and 4, the logarithmic Weibull function assumption is correct and the relation between topographic index and storage capacity can be developed via this assumption, as provided by equation (1). The formula makes it possible to use the basic GIS data, which is available everywhere now, and by so doing, makes the model reliable and physically based. The comparisons between the simulated and observed data are listed in Table 1; these results are realistic.

The approach described here can be improved further. The storage capacity was taken as a function of vegetation type or soil type and the topographic index as an exclusive influence factor; this assumption basically differs from the existing traditional knowledge. As such, detailed information about soil, vegetation, geology and other relevant landscape characteristics are needed to determine grid storage capacity that will improve the accuracy of runoff predictions. The main conclusion here is that it is very clear that these essential factors should be studied together in the study of grid storage capacity in the future.

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