MODELING UNGAUGED WATERSHEDS

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INTRODUCTION

• Q1 Models of• watershed hydrology are irreplaceable tools in today's research and practice. Their areas of application are wide reaching, from water management and flood forecasting, to their use as load models for water quality studies. A vast number of these models have been developed since the 1960s and they differ in temporal and spatial discretization, processes described, and in the constituent equations used. However, there are also similarities that have consequences for the way these models are commonly applied. All models of watershed hydrology aggregate the real hydrologic system on a particular element scale in space and time. The spatial scale might vary from grid cells of tens of meters to models that treat the whole catchment as a single unit, and the temporal scale might vary, for example, from 15-minute intervals to monthly time steps. It is common to assume homogeneity of processes or watershed characteristics on scales smaller than the one applied, that is, parameters are assumed to be effective on a certain scale (Fig. 1), although the heterogeneity of the real world on smaller scales is sometimes described by distribution functions (2). The characteristics of each model element, for example, storage or infiltration capacity, are described by parameters within the model. A common problem is that the scale on which these characteristics can be measured are usually different, mostly smaller, than the scale of the model element. The effect of this difference between model and measurement scale is that one has to revert to alternative methods to estimate model parameters. The usual approach is to observe the responses of the real hydrologic system, for example, streamflow, and compare them to predictions of the model. The modeler then adjusts the model parameters, in a process usually referred to as calibration, until model predictions and observations are as close as possible. Calibration can be performed using manual or automatic techniques and the available literature on this subject is immense. Between 3 to 10 years of observations are required for calibration, depending on the model complexity and the informational content of the data (3). Shorter periods can suffice when the data sufficiently trigger the response modes of the model (4).

Alternatives to model calibration have to be found when no or insufficient time series of the variable under investigation are available for this process. This is a common problem, even in countries that have extensive measuring networks such as the United Kingdom that has more than 1400 gauging stations (5). It is also possible that sufficiently long streamflow time series are available but that the modeling objective is the prediction of a different variable, for example, groundwater levels. Then, a calibration with respect to the variable under study

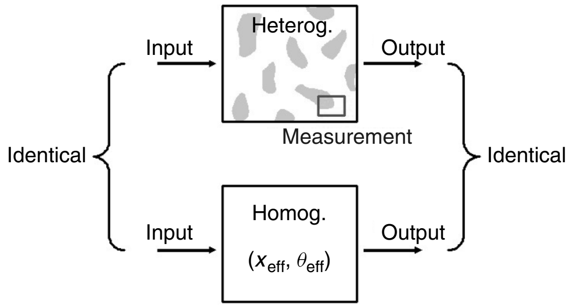

Figure 1. Definition of effective parameters and differences in scale between measurements and hydrologic modeling. (Modified from Reference 1).

would not be possible. With respect to the modeling of ungauged watersheds, there is also a difference whether the required predictions are limited to particular events or whether continuous simulation is required. Some reasonable estimates for event-based models can be derived, but this is not the case for continuous models where the predictions are highly uncertain (6). These two cases are therefore treated separately here.

MODELING THE EVENT-BASED WATERSHED RESPONSE

Empirical models are usually used for modeling individual events. In these models, the response characteristics of watersheds (e.g., mean annual flood or the percentage runoff) are related to watershed descriptors (e.g., area, drainage density, or dominant soil types) using regression equations (7;8, p. 301).

Another empirical approach that is very popular for event-based modeling in ungauged watersheds in many parts of the world is the curve number (CN) method. This approach was originally developed by the Soil Conservation Service for watersheds in the United States (9;10, pp. 147 et ff.). The basis of this technique is the assumption that the ratio of direct runoff to total precipitation is equal to the ratio of retained water to the potential maximum retention. The value of the potential maximum retention S can be calculated using values for CN:

$$S = \frac{1000}{\text{CN}} - 10, \tag{1}$$

where S is calculated in inches. Actual values for CN (0–100) given in tables or graphs are a function of soil type, land use, and antecedent moisture conditions (10, pp. 148–149), which makes this approach so attractive for modeling ungauged watersheds. These graphs and tables were originally derived from measured rainfall-runoff data on a small watershed or hillslope scale (8, p. 184).

These parametrically simple event-based models have been applied with some success (7,11). However, there is a trend to move from event-based models to those that provide continuous simulation because the initial conditions for event-based models are a major source of uncertainty. A recent workshop report on challenges in hydrologic predictability noted "in watershed rainfall-runoff transformation ... initial and boundary conditions

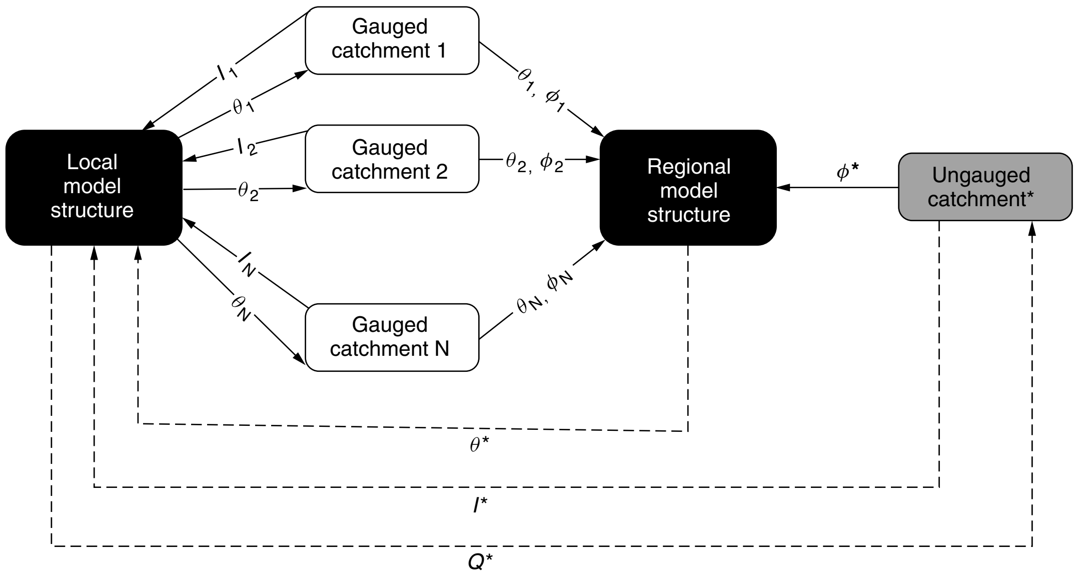

Figure 2. Schematic description of the statistical regionalisation approach. (Modified from Reference 6).

are the critical issues" (12, p. 17). This problem has led to a more holistic approach to flood management in some countries. In the United Kingdom, for example, there is a move to replace event-based modeling with continuous approaches (13,14).

MODELING THE CONTINUOUS WATERSHED RESPONSE

Several approaches to estimating parameters in ungauged watersheds are available for continuous simulation models. The two most common approaches are (1) the derivation of regression relationships between model parameters and watershed characteristics (5,6,15–17) and (2) estimation of parameter values from measurable watershed (mainly soil) properties (18–23).

In the first approach, a chosen model structure is calibrated to a large number of watersheds for which sufficiently long and informative observations are available. An attempt is then made to derive regression equations that predict its value using a combination of several watershed characteristics. A separate equation is commonly derived for each model parameter. The parameter values in the ungauged watershed can then be estimated using the derived equations and a prediction can be made. Figure 2 shows a typical procedure for extrapolating parameters from gauged watersheds using regression analysis (6). The steps are as follows (Fig. 2): (1) Select catchments and their characteristics. (2) Select and calibrate the local model structure. (3) Select and calibrate the regional model structure. (4) Predict flow at the ungauged site. Currently, this is probably the most often applied technique; however, Wagener et al. (6) found considerable uncertainty in typical predictions using this approach.

Sometimes, it might be possible to derive at least some of the model parameters directly from measurable watershed characteristics. The scale difference between model parameters and measurements might be relatively small for some parameters if the model uses a very fine spatial distribution, or simple equations can be used to derive these parameters from a combination of watershed characteristics. Koren et al. (22), for example, show how storage capacities can be estimated from soil properties such as field capacity and wilting point. These properties are usually derived from point samples analyzed on the laboratory scale. This makes using these values for lumped parameter estimation questionable because *there is generally no theory that allows the estimation of the effective values within different parts of a heterogeneous flow domain from a limited number of small scale or laboratory measurements* (8). On the other hand, this approach does not assume that all the model parameters are independent as in the earlier mentioned regression technique. The idea of Koren et al. (22) is therefore rather to derive good initial estimates for a subsequent calibration procedure in gauged watersheds, that is, to reduce the calibration effort, and also for ungauged watershed and distributed modeling approaches. Very few examples can be found in the literature where models, using only measured parameters, have been applied without further calibration. It is unlikely that reliable predictions can be obtained by this approach from the current generation of model structures.

CONCLUSION

The ungauged problem is currently an area of extensive research and it can be expected that considerable progress will be made during the coming years (6,24,25). The complexity of the problem requires a holistic approach that can be provided only by a wide variety of hydrologists working on different topics. However, the potential value of the scientific outcome is very high. Current predictions in ungauged watersheds have to be considered as very uncertain though and must be used carefully in decision-making.

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