Preliminary Indications of the Transferability of IHACRES Model Parameters in Mountainous Rainfall Driven Rivers

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Abstract: The IHACRES model has been widely shown to be successful in modelling rainfall-runoff processes in a variety of environments including mountainous regions. Our objective was to determine if landscape features could be used to determine model parameters that could successfully be transferred to ungauged basins and the uncertainty of such estimates be simultaneously assessed. Here we report preliminary results where calibrated model parameters from a variety of mountain watersheds are compared to basin area, drainage density and other attributes derived from digital elevations models. These results indicate that some model parameters exhibit a relation to basin characteristics. However, noise in these relations limits the usefulness of the model for estimating hydrologic response at ungauged mountain basins.

1. INTRODUCTION

When data are sufficient, hydrologic models provide predictability of retrospective and future conditions. In the case of ungauged basins such data are never available and prediction in those basins requires alternative approaches. One approach is to use information from models for gauged basins as a basis for such modelling. Assessment of the statistical relationship between calibrated model parameters and watershed characteristics is expected to both capture information about the hydrologic processes and the assumptions of homeostasis.

In this work we have chosen to use IHACRES to model pluvial watersheds in mountainous regions. IHACRES is a relatively simple form of model based upon excess precipitation (Jakeman et al., 1990, Littlewood and Jakeman, 1994; Littlewood et al., 1997). Despite the simple formulation IHACRES has been shown to be suitable in a wide range of rainfall-runoff catchments (Wagener and Wheater, 2002). Our objective is to explore transferability of model parameters between watersheds, based upon watershed characteristics. Here we show preliminary results that landscape features derived from digital elevation models show a general relationship to some model parameters. Ultimately, we are intending on assessing five aspects: calibration verification,

record length, basin attributes, seasonal and climatic regime effects and time steps. If successful, we intend to extend the approach to conceptual models which are suitable in nival and glacial regimes (e.g., HBV).

Regionalization approaches to daily streamflow predictions have been previously reported (Kokkonen et al., 2003) for the Coweeta watershed. Here, we use a similar approach but on a vastly different scale. Kokkonen et al. (2003) considered 13 catchments within a 16 km^2 watershed, while we consider 23 watersheds ranging in size from 2.88 to 9500 km^2. If there is a relationship between model parameters and basin attributes, a wider range of watersheds might prove to be more distinguishing than a number of similar basins. This range would span the variety of basins for which estimates of streamflow might be desirable in rainfall systems on the Pacific Coast, since our desired output is a procedure for estimating IHACRES model parameters for ungauged basins in the mountainous regions of British Columbia (Whitfield et al., 2006).

2. DATA AND MODELLING OF WATERSHEDS

We present results for 23 watersheds on the west coast of North America where models were

successfully calibrated. These stations were selected from Oregon, Washington and British Columbia to cover a wide range of basin characteristics. The locations of the watersheds are shown in Figure 1.

Temperature and precipitation data were used from nearby climate observing stations, but frequently these were located some distance from the watershed. Another seven stations were considered but we were unable to calibrate them successfully using the same procedure.
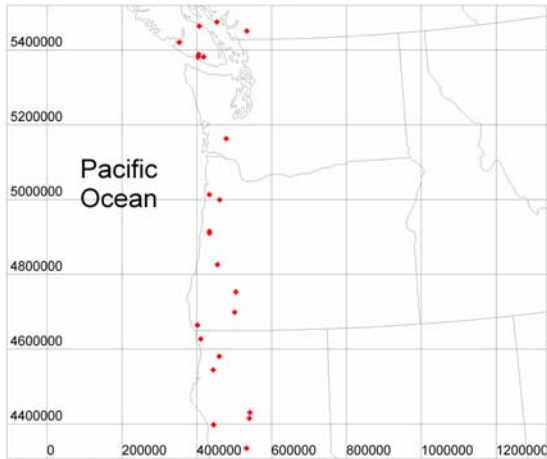

Figure 1. Locations of the 23 watersheds for which IHACRES models were calibrated.

Table 1 summarizes the six parameters describing the IHACRES model. For all watersheds we used the same configuration of single UH storages in the linear module (usually two in parallel) and a given pure time delay (which is usually 0 or 1 for daily data). We selected values for the catchment drying time constant (TauW) and the temperature modulation factor (f) in the non-linear module. The parameters in the linear module and the parameter 1/c (the volume-forcing constant) in the non-linear module were calculated automatically by the program. The coefficient of determination (D) and a percentage 'average relative parameter error' for the parameters in the linear module (%ARPE) are program outputs. We used the criteria that a good model is one that has a high value for D and a low value for %ARPE.

We calibrated the model using selected ranges for the parameters (TauW and f) in the non-linear loss module. In a single run of the program, D and %ARPE are then tabulated by the program for each pair tauW-f to enable the operator to scan the results in search of the best pair. Ideally the maximum value of D and the minimum for %ARPE would occur for a single pair; in practice the maximum D and minimum %ARPE will define ranges of the catchment drying time constant and the temperature modulation factor. It is necessary,

therefore, for the operator to make a subjective trade-off between a high D and low %ARPE when selecting the optimal pair.

Table 1. Definition of IHACRES model parameters

Parameter	Name	Units
f	Temperature modulation factor	-
Vq	Proportion of effective rainfall which becomes quick flow	-
Ts	Quick flow reservoir time constant	days
Tq	Slow flow reservoir time constant	days
1/c	Volume-forcing constant	mm^{-1}
TauW	Catchment drying time constant	days

Since we are seeking to develop a statistical method for estimating the model parameters these estimators need to be as accessible as possible. We have used a GIS procedure being developed that estimates basin attributes from 25m digital elevation models [A. Viglio, pers. Comm.]. These attributes include estimated basin area, drainage density, average basin slope, average hillslope length, median basin elevation, length of main channel, and longest drainage path. We also included the published basin area.

3. RESULTS

Some example preliminary results are presented in Figure 2 and 3 for these 23 watersheds. Figure 2 shows a general relation between basin area and V_q, T_s, 1/c, and Tau W. T_q and f show no relation to basin area. There were several distinct outliers, shown circled in red in Figure 2 that occur in cases with low R^2.

In Figure 3 the model parameters are shown in relation to drainage density. Drainage density was chosen to show that it exhibits different relationships of model parameters to basin attributes than does published drainage area.

Table 2 shows the general relationship between model parameters and basin attributes. The temperature modulation factor (f) shows no relation to any of the basin attributes. Some attributes are similar to basin area, while others show distinct differences as in the case of drainage density (Figure 3). Most basin attributes show similar general relationships with model parameters. Most basin attributes exhibit a negative relation to V_q and positive relation to T_s.
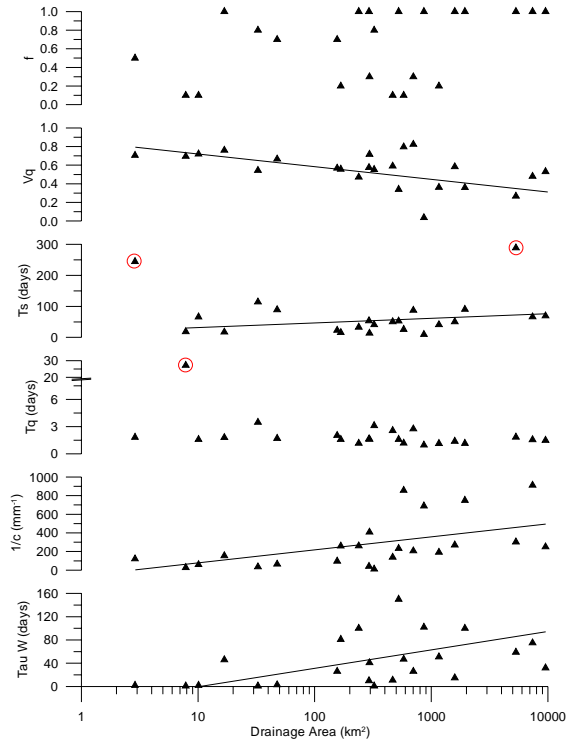
Figure 2. Model parameters from the 23 watersheds against published drainage area (km^2). Points that are circles in red are outliers from watersheds with low values of R^2.
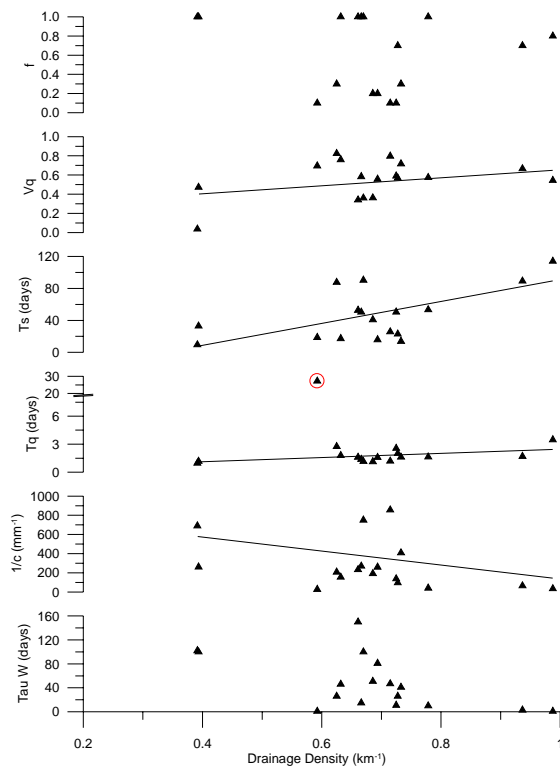

Figure 3. Model parameters from the 23 watersheds against drainage density (km^2). Points that are circles in red are outliers from watersheds with low values of R^2.

Table 2. Summary of relationships for model parameters in relation to basin attributes. The symbols are used as follows: + positive relationship, - negative relationship, 0 relationship of zero slope, / no evident relationship.

Basin Attribute	f	V_q	T_s	T_q	1/c	TauW
Average Basin Slope	/	0	0	-	+	+
Average Hillslope Length	/	-	+	0	0	/
Calculated Drainage Area	/	-	+	-	+	+
Published Drainage Area	/	-	+	-	+	+
Drainage Density	/	+	+	+	-	/
Length of Main Channel	/	-	+	0	+	+
Longest Drainage Path	/	-	+	-	+	+
Median Basin Elevation	/	-	+	0	/	/

4. DISCUSSION

There is a general relation between some model parameters and basin attributes as shown in Figures 2 and 3, Table 1. While there is some indication of relationships in this simple linear analysis there is considerable variability and noise. Further work will be needed to resolve whether the noise present in individual relationships may be resolved using multivariate techniques such as neural networks that may make model parameters adequately predictable. We have only considered a limited number of attributes that are generally felt to be hydrologically relevant.

The lack of an observed relation between basin attributes and the temperature modulation factor (f) may be related to the seasonal variability in climate of these mountain/maritime regions. For example, there can be significant differences in seasonal temperature and precipitation lapse rates in mountain catchments of the Pacific Northwest. Observed climate records, typically representative of valley-bottom climates, may not be representative of the seasonal variability of basin-averaged temperature and precipitation assumed by the model.

There may also be bias introduced into parameter values due to the choice of climate station to pair with the hydrometric station. We recognize that in the present case many of the climate stations are some distance from the watershed where that data is being applied. An alternative would be to use either a reanalysis model approach or a regional climate model to derive basin-wide proxy climate records (Whitfield et al., 2002). Previous

experience suggests that this approach may provide an unbiased climate input from which regional parameter relations could be established.

Even with parsimonious hydrological models (such as IHACRES), the spatial variability of climate may overwhelm parameter identifiability in mountain catchments. Even if regional parameter relations can be established, applying local climate (i.e., station) to predict hydrological response might produce wildly wrong results.

The results presented here are preliminary; other watersheds from other mountainous regions in Italy and elsewhere are being modelled. We shall be assessing if other refinements will reduce the noise in the relationship, and we shall explore using a neural network approach to estimating model parameters which might better resolve the relationships between parameters and basin attributes. Similarly, we need to weight more heavily models with good performance statistics [D and R^2] than those than perform less well.

Despite these shortcomings, at the scales we have considered there is evidence that basin attributes might be used to estimate the range of model parameters that might be applied in ungauged basins. At the very least, this range of parameters could serve as the basis for establishing estimates of streamflow with an expression of uncertainty obtained from a distribution of model parameters.

It appears that there is potential for basin attributes to serve as a basis for transferring IHACRES model parameters from modelled to ungauged watersheds and perhaps to estimate the associated uncertainty. In many mountainous regions including the Pacific Northwest, and the Italian Alps, snow is a significant portion of the precipitation input and water storage. Presently, other conceptual models such as HBV are being used to model watersheds where snowfall is important. Perhaps parameters from those conceptual models can also be estimated from basin attributes.

5. CONCLUSIONS AND RECOMMENDATIONS

While our results are preliminary, a general relationship between basin attributes and the conceptual model IHACRES's parameters has been shown. While many of the attributes show similar relationships to model parameters, there are distinct differences between most of the attributes considered. This pattern suggests that a multivariate or neural network approach might result in better resolution.

Some additional considerations, such as alternative resolution of climate data, and of differences between summer and winter may also improve the estimation of the model parameters.

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