Parameterisation of hydrological model

FOR APPLICATION IN UNGAUGED BASINS

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SUMMARY

From a classical point of view, hydrological models can only provide warnings on key points of the river drainage system, previously identified as risk points and with available hydrological records. However, the new ideas about flood warning and active control strategies require tools able to take into account the particular spatial and temporal characteristics of a given storm, put in interaction them with the geomorphological and hydrographic characteristics of the area being affected and produce real-time forecasts of the flood risk whatever it could be the location potentially affected at a given moment. Unfortunately, most of locations sensitive to flash flood occurrences (campings, industrial areas, road bridges, etc.) are located in ungauged basins and have no available flow measurements in their proximity. Therefore, the problem of how to issue sensible flow forecasts on ungauged basins should be addressed.

This report summarizes the research activities made for GRAHI-UPC staff inside of FLOODSite EC-Project related with the estimation of parameters of a distributed hydrological model based on the relationship of physical, geomorphological and hydraulics characteristics of the catchments with their parameters, i.e., based on the link between distributed catchment characteristics and hydrological model parameters.

The estimation parameters methodology was developed using the distributed conceptual rainfall-runoff model DiCHiTop (Corral, 2004) on the 1000 km$^2$ Besòs river basin. Using information from 7 level gauges inside the Besòs catchment, parameter calibration was made for all these points. Then distributed characteristics and calibrated parameters of each subcatchment were statistically analyzed to evaluate their relationships. It was focused on: 1) analysis of topography and derived drainage features (for example local slopes) in relation to model routing parameters; and 2) analysis of land use and vegetation cover, as well as topography via the topographic index, as descriptors of runoff generation process. From these analyses, a proposition of parameter distribution based on distributed catchment information was formulated.

The proposed methodology for parameter regionalisation was extended and validated on a test case area on the Catalonia region, the Anoia catchment (904 km$^2$). This basin is located inside the area covered by the warning centre of the Water Agency of Catalonia (ACA).
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1. Introduction

1.1 Background

Several efforts have been devoted during past decades to develop physical models with a high spatial description but at a high computational cost and also at a considerable need in information (generally unavailable). In the current hydrometeorological practice, particularly in rainfall-runoff modeling, it is common to use conceptual models where parameter values are not directly linked to measurable variables. In spite of this, it is assumed that some accessible information has strong relation to hydrological processes (e.g. geomorphology, land use, vegetation cover, soil types, etc).

Several studies have also been focused to relate physiographic features of the catchment to model parameters (see a general review in e.g. Bloschl (2005)). Typical distributed catchment information has the format of raster maps with a variable resolution (generally between 20 and 1000 m), and normally available from different authority organisms. For example, topography is provided by means of a DEM, and data processing to build the drainage system of the basin is well known but in development (Tarboton, 1997). Tested algorithms to process this kind of data can be used to obtain the adequate distributed catchment information compatible with model requirements. However, many times these studies are made inside a lumped approach, thus invalidating their possible application in catchments with moderate to high spatial variability (for instance the rainfall input).

Other studies have introduced catchment variability using distributed modeling (see for example (Dunn and Lilly, 2001), using the UK Hydrology of Soil Types HOST), and finding some relationships with model parameters. Anyway, there is still a lack of knowledge and applications in this sense, in particular looking for generalized concepts allowing the important catchment information for hydrological purposes to be identified. Also, because of its ability to combine expert or prior knowledge with data to reduce parameter uncertainty, other studies are involved in the application of the Bayesian theory on the parameter regionalization problem (Campbell et al., 1999, Vicens et al., 1975), or have evaluated the relationships between calibrated lumped parameters with lumped basin features to the derivation of a priori distributed parameters based on distributed basin features (Moreda et al., 2006). This framework seems to be interesting to infer improved parameter description from the large scale results to the small scale modeling.

Finally, during last years different authors have remarked large uncertainty associated with the estimation of a one single set of parameters for hydrological model using the previous approaches in ungauged basins. These stem from model structural uncertainty, parameter uncertainty, randomness in natural processes, uncertainty in data and regionalization approach. Therefore, they have proposed to use an ensemble of parameters set based on relationships between physical characteristics and response characteristics of watersheds, and regionalizing response characteristics as constraints on these ensemble model predictions (McIntyre et al., 2005, Wagener and Wheater, 2006). This last approach (actually under permanent development and improvement) was not included in this study because its implementation on operational framework is not easily realizable in its actual stage.

1.2 Objectives

The present study attempts to devise a consistent methodology to transfer the knowledge contained in calibrated parameters of a distributed hydrological model in gauged basins to the estimated parameters of the same hydrological model but in ungauged catchments. The derivation of these values is investigated identifying mathematical linear relations between parameters and physically measured properties and features of watersheds. Then performance of these proposed relationships is evaluated using others gauged watersheds as ungauged basins, and making comparison between hydrological estimations using estimated and calibrated parameters.
2. Definition of a methodology for regionalization of hydrological model parameters

In this section, the methodology for regionalization of parameters is described and the results of its implementation in a basin are presented. First, the proposed methodology to derive model parameters from distributed physical features of watersheds is presented. Then, the hydrological model used in this study, DiCHiTop, is introduced. Next, physical and hydrological characteristics of the basin used as reference to investigate and infer regionalization relationships, the Besòs catchment, are shown and commented. Next, the proposed methodology is used into the Besòs catchment and an evaluation of the performance of found relationships are included. To conclude, final relationships between model parameters and physical characteristics are presented and described.

2.1 Proposal for a regionalization methodology

During this study, we used a regionalization methodology based on derivation of multiple linear regressions between basins properties to define model parameters. This approach allows take advantage of statistical interdependencies between parameters and physical features to obtain prediction expressions for ungauged basins. This technique is similar to some of methods of regionalization published recently (see e.g. Bloschl (2005), Merz and Bloschl (2004), Moreda et al. (2006)). Relationships are proposed analyzing the correlation between the model parameters and the watershed properties, and then taking accounts their mutual correlations. Proposed relationships are evaluated, first using statistical measures as such multiple correlation coefficient, and then analyzing the simulated flows using calibrated and estimated parameters. Therefore, the following steps are used to derive the DiCHiTop parameters based on watersheds features:

1. Compute correlation between model parameters. This step allows analyze the interdependency of model parameters, identifying possible redundancies in the selected hydrological model.
2. Compute correlation between basin physical features. Features of basin can have strong correlation indicating that they should be almost equivalent when one of them is selected to describe a parameter. If one of these well-correlated features is not available during the estimation process of parameter in an ungauged basin, an equivalent relationship should be defined with one of others well-correlated characteristics without an important reduction in the performance of the prediction.
3. Compute correlation between each model parameter and all basin properties. This step allows identify which of the basin features are most related with each of model parameters. Properties well correlated with one parameter should be combined to predict it adequately.
4. Define relationships for each model parameter based on previous computed correlations. A set of mathematical relationships is proposed for each model parameter combining the highest correlated features with that parameter. Only one feature should be selected for a relationship of each set of physical characteristics of basins with a mutual high correlation. In this study were used a maximum of two basin properties to define any relationship for parameters prediction.
5. Evaluate the relationships. Each proposed relationship is verified using multiple correlation statistics and analyzing the simulated flows using calibrated and estimated parameters.
6. Use the best-inferred relationships to derive all model parameters of an ungauged basin. Between all proposed mathematical expressions, those with the best multiple correlation values and the best performance to simulate flows are flagged as recommended relationships for prediction of parameters in ungauged basins. Other expressions with higher performance are flagged as auxiliary relationships. These should be used instead of recommended
relationships when some of basin features of last ones are unknown for the watershed in study, but basin features used in the auxiliary relationships are known.

This proposed methodology was implemented during this study in the Besòs basin using the DiCHiTop Hydrological model. Next, hydrological model details and main characteristics of basin used to validate the methodology are described. Then results obtained during this process are shown and commented.

2.2 Description of DiCHiTop Hydrological Model

The rainfall-runoff model used in this study is called DiCHiTop. DiCHiTop is a grid-based model able to use distributed rainfall fields and was developed for the simulation of intensive hydrometeorological events. Although the approach of the model is lumped for each distinct hydrologic cell, the use of a grid of interconnected cells with a fine resolution can simulate completely the characteristics of a distributed model. The DiCHiTop model consists of three concepts: for each distinct hydrologic grid (1) the loss model and (2) the propagation model, and (3) the integration model for the total watershed.

The basin is split into square hydrological cells (in this study, with a resolution of 1 x 1 km$^2$). At this cell scale, a lumped model is applied to transform precipitation inputs into flow. Depending on the degree of urbanization of each cell, the chosen lumped model in rural areas is TOPMODEL (Beven and Kirkby, 1979) or the Soil Conservation Service (SCS) loss function (Mockus, 1957, Rawls et al., 1992) in urban cells.

The Diffusive Wave Unit hydrograph with Muskingum parameters (DWHM) (Szymkiewicz, 2002) is applied to the runoff generated at each cell making a classification of basin cells between hillside path cells and river path and using different parameters in each case. The hydrograph at the basin outlet is finally calculated as the linear combination of all transferred cell hydrographs (see a general scheme of the model in Fig. 1).

![Diagram of DiCHiTop Hydrological Model](image)

*Fig. 1. General Scheme of DiCHiTop Hydrological Model (after Corral (2004))*

A more complete description of DiCHiTop is shown in Berenguer et al. (2005), Corral (2004), and Corral et al. (2000).
Therefore, DiCHiTop model has five parameters that usually are found by calibration:

- $t_0$, transmissivity coefficient at saturation, computed as $\ln(t_0)$ in (m$^2$/h), (TOPMODEL)
- $m$, exponential variability of conductivity with water deficit, in (m), (TOPMODEL)
- $v_R$, the river velocity, in (m/min), (DWHM)
- $v_s$, the hillslope velocity, in (m/min), (DWHM)
- $FS$, global correction factor of Curve Number (CN) cell values (SCS)

### 2.3 Besòs Basin

The Besòs basin (1024 km$^2$) crosses areas with a high economic importance (e.g. the Barcelona metropolitan region where more than one million of inhabitants live inside of this watershed), and it is a typical example of a Mediterranean complex catchment. It is quite heterogeneous, from forested mountains over 1000 m to rural planes that have been suffering a continuous urbanisation process during last decades. The river network of the Besòs basin (shown in Fig. 3) has a set of tributaries flowing mainly in North-South direction discharging after few kilometers into the main river that flow in E-W direction. The main subcatchments of Besòs basins are (in E-W order): the Mongent river, the Congost river, the Tenes river, the Caldes rivelet, and the Ripoll river. After receive all its tributaries the Besòs river cross the Littoral mountains through the narrow “congost de Montcada”, and ends into the Mediterranean sea forming a delta. Nowadays, the Besòs delta is completely invaded by the urban areas of Barcelona, Badalona, Sant Adrià and Santa Coloma cities. Considered few years ago one of the most degraded rivers in Europe, the urban sector crossing Barcelona to the outlet have had a strong modification converting the delta zone in a modern urban area that includes a riverside park, a convention center and a harbor. Besòs is a river with a strong torrential character because its huge periodic floods (2000 to 3000 m$^3$/s) but that in dry seasons may disappear. High slope of river produces that these floods may affect quickly high urbanized areas.

Besòs basin is instrumented nowadays by several telemetered sensors, and the area is well covered by the Spanish Weather Service (INM) radar of Puig de les Agulles (the maximum distance to the radar site is 60 km), and also by the Catalan Weather Service (SMC) radar of Puig d’Arques (at a range between 50 and 90 km) (see Fig. 2). Inside of the Besòs basin there are seven discharge stations located on different rivers. Ripoll River has two stations, one located to measure its superior region (code 142) and other one just in its outlet (code 143). Each one of Caldes, Tenes and Monget catchments have a discharge station close to its outlet (codes 139, 138 and 136, respectively). Congost watershed only have one stream gauge located to measure the drained water of its higher region. Finally, Besòs river has a discharge station located just upstream of its outlet (code 145). A detailed view of Besòs basin is shown in Fig. 3.
Statistical Analysis of physical characteristics of catchments

Initial two steps of regionalization methodology proposed in 2.1 are related with statistical evaluation of interdependency of calibrated model parameters and physical features of basin. Physical data of Besòs subcatchments were computed from official DEM, land use and vegetation cover maps published by the Catalan Cartographic Institute. DEM have a resolution of 45 m, and vegetation and land use maps correspond with observed situation in 2002 with a resolution of 30 x 30 m. Physical features of analyzed for each subcatchment of Besòs basin were:
Average Curve Number, $CN$. Curve numbers were computed from land use map at a spatial resolution. Then Average Curve Number was defined as the average of Curve Numbers of all cells inside of each subcatchment.

Percentage of Urban Area, $PURB$. Computed from land use map as the fraction of total area of watershed that contains buildings, houses, highways, pavement roads, squares, bridges and any other infrastructures with a very low infiltration capacity.

Percentage of Forest Area, $PFOR$. Computed from land use and vegetation cover maps, as the fraction of total area of watershed covered by forest, woods, and any other dense vegetal coverage but agricultural lands.

Percentage of Rural Area, $PRUR$. Computed from land use and vegetation cover maps as the fraction of total area of watershed no included in the previous two criteria, i.e., no urban nor forest areas.

Average Hillside Slope, $S_s$. Computed from DEM as average slope of 1 km$^2$ cells flagged as hillside cells. An accumulation threshold was used to distinguish between the hillside and river cells. Cells with an accumulated area greater than this threshold area are flagged as river cells; the others as hillside cells.

Average River Slope, $S_r$. Computed from DEM as average slope of 1 km$^2$ cells flagged as river cells.

Global Topographic Index, $\lambda$. Defined as the mean value of the topographic cells within the subcatchment cells.

Manning’s roughness coefficient, $n$. Defined empirically from suggested values in Chow et al. (1988) based on typical cross section, mean vegetation condition and bed characteristics of main stream of subcatchment.

![Table 1](attachment:Table1.png)

Table 1 shows computed values of physical features of each watershed used in this study. Subcatchment codes correspond with stream gauges located in Besòs basin and described above (see 2.3). Table 2 summarizes the inter-dependency among the physical features (correlation between each of properties). It can be seen that soil properties are highly correlated. The Topographic index, the percentage of forest areas and hillside slope are highly correlated to one another as expected.

![Table 2](attachment:Table2.png)
2.5 **Statistical Analysis of calibrated model parameters**

The DiCHiTOP model was calibrated independently for each subcatchment of Besòs basin. An automatic multi-event calibration was applied to define optimal set of parameters for each watershed. Rosenbrock method (Rosenbrock, 1960) was used as search algorithm but handled through a expert-manual procedure. SAIH rain gauges data for each rainfall event were interpolated using a simple minimal curvature interpolator (spline) to obtain a distributed rainfall field at each time step. A total of 5 rainfall events at a ten-minutes time step were used. Rainfall events correspond with important discharges occurred between 1998 and 2003 in this basin. Looking for introduces the variability of model parameters in this regionalization process, the set of rainfall events were divided in two groups and parameters were calibrated independently for each set. Discharge data for stream gauges with codes 139 and 142 were not available for selected events and therefore these watersheds were discarded for posterior analyses. Nash-Sutcliffe efficiency (NSE) (Nash and Sutcliffe, 1970) was used as statistic to evaluate the performance of the DiCHiTop model to simulate the observed flows.

Table 3 shows the DiCHiTops parameters obtained after the calibration process for each rainfall event sets. Examples of simulated discharges using these calibrated parameters for some Besòs subcatchments are illustrated in Fig. 4. In general, performance of simulated flow compared with observed discharges is good in all watersheds, expect for Ripoll River (code 143) where the worse NSE values were obtained in both events sets. In particular, this watershed has the highest values of CN and PURB features and therefore influence of FS parameter in performance of hydrological model is greater than the other parameters. These reasons implied to retry this catchment for posterior analyses. FS parameter values converged around a value of 0.6 for almost all watersheds after the calibration process. A similar analysis using a mayor number of rainfall events and basins should clarify the range of variation of this parameter but in this study, this parameter was assumed constant for similar basins that those analyzed here, and was put out for posterior analyses.

**Table 3. DiCHiTOP calibrated parameters**

<table>
<thead>
<tr>
<th>Watershed Code</th>
<th>( v_R )</th>
<th>( v_S )</th>
<th>( m )</th>
<th>( t_0 )</th>
<th>FS</th>
<th>NSE</th>
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<tr>
<td>135</td>
<td>9.4</td>
<td>115</td>
<td>0.024</td>
<td>-1.3</td>
<td>0.6</td>
<td>0.72</td>
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<tr>
<td>136</td>
<td>9.4</td>
<td>177</td>
<td>0.020</td>
<td>-2.0</td>
<td>0.6</td>
<td>0.79</td>
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<tr>
<td>138</td>
<td>5.4</td>
<td>116.0</td>
<td>0.042</td>
<td>2.7</td>
<td>0.6</td>
<td>0.65</td>
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<tr>
<td>139</td>
<td>6.5</td>
<td>328.0</td>
<td>0.052</td>
<td>2.6</td>
<td>0.6</td>
<td>0.75</td>
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<tr>
<td>142</td>
<td>6.0</td>
<td>90.0</td>
<td>0.032</td>
<td>2.9</td>
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<td>143</td>
<td>5.8</td>
<td>160.0</td>
<td>-0.020</td>
<td>0.0</td>
<td>0.6</td>
<td>0.74</td>
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<tr>
<td>145</td>
<td>4.6</td>
<td>360</td>
<td>0.080</td>
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<td>0.5</td>
<td>0.29</td>
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<tr>
<td>143</td>
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<td>0.33</td>
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<td>145</td>
<td>5.0</td>
<td>134.0</td>
<td>0.041</td>
<td>2.3</td>
<td>0.6</td>
<td>0.71</td>
</tr>
<tr>
<td>145</td>
<td>5.4</td>
<td>356.9</td>
<td>0.023</td>
<td>2.53</td>
<td>0.6</td>
<td>0.81</td>
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</tbody>
</table>

Using the calibrated parameters values of remaining watersheds, correlation statistic was used to evaluate degree of interdependency between them. Table 4 shown the correlation values between each of calibrated parameters with the others. Some degree of correlation between the DiCHiTop parameters is observed. This codependency could affect the result of automatic calibration. However as calibrated parameters were derived driving the automatic calibration by an expert hydrologist that evaluated multiple criteria, we consider the effects of parameter intercorrelation were weakened.
Table 4. Correlation between model parameters

<table>
<thead>
<tr>
<th>Model parameters</th>
<th align="right">$v_S$</th>
<th align="right">$v_R$</th>
<th align="right">$m$</th>
<th align="right">$t_0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hillslope velocity, $v_S$</td>
<td align="right">1.00</td>
<td align="right"></td>
<td align="right"></td>
<td align="right"></td>
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<tr>
<td>River Velocity, $v_R$</td>
<td align="right">-0.31</td>
<td align="right">1.00</td>
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<td align="right"></td>
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<tr>
<td>Exponential variability of conductivity, $m$</td>
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<td align="right">0.61</td>
<td align="right">1.00</td>
<td align="right"></td>
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<tr>
<td>Transmissivity coefficient at saturation, $t_0$</td>
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<td align="right">0.50</td>
<td align="right">0.75</td>
<td align="right">1.00</td>
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2.6 Estimation of Parameters from physical features

The selection of physical features that influence a given model parameter was made using correlation statistics and multiple regression. Table 5 shows correlation between physical properties and each model parameter. Some derived physical properties were added to that table, e.g. inverse of Manning’s roughness coefficient, looking for hidden nonlinear dependences. A strong correlation in Table 5 indicates a possible relationship between a parameter and a feature. Hillslope velocity parameter has a strong correlation with both hill and river slopes. River velocity parameter has high dependency with percentage of urban areas, curve number and Manning’s roughness coefficient, reflecting its relation with fast response of urban zones and with a good description of hydraulics features of streams. DiCHiTop parameters related with TopModel are strong correlated with both hill and river slopes of cells and with global Topographic index. Influence of nonlinear transformations of features is limited and does not increase significantly interdependency of those features with parameters.

Table 5. Correlation between model parameters and physical properties

<table>
<thead>
<tr>
<th>Physical properties</th>
<th align="right">$v_S$</th>
<th align="right">$v_R$</th>
<th align="right">$m$</th>
<th align="right">$t_0$</th>
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<td>$CN$</td>
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<td align="right">0.73</td>
<td align="right">0.88</td>
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<td>PURB</td>
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<td>$S_s$</td>
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<td align="right">-0.62</td>
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<td>$S_s^{0.5}$</td>
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<td align="right">-0.50</td>
<td align="right">-0.64</td>
<td align="right">-0.92</td>
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<tr>
<td>$S_r$</td>
<td align="right">0.97</td>
<td align="right">-0.49</td>
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<tr>
<td>$S_r^{0.5}$</td>
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<td align="right">-0.52</td>
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<td align="right">-0.92</td>
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<tr>
<td>$\lambda$</td>
<td align="right">-0.81</td>
<td align="right">0.49</td>
<td align="right">0.58</td>
<td align="right">0.84</td>
</tr>
<tr>
<td>$n$</td>
<td align="right">0.78</td>
<td align="right">-0.59</td>
<td align="right">-0.69</td>
<td align="right">-0.76</td>
</tr>
<tr>
<td>$1/n$</td>
<td align="right">-0.71</td>
<td align="right">0.63</td>
<td align="right">0.76</td>
<td align="right">0.73</td>
</tr>
</tbody>
</table>

Previous results allow identify the main features that could help to estimate an unknown parameter. But how these features should be combined to define the parameter remains unknown. Therefore different mathematical expressions for each one of parameters should be proposed and tested. In this study, simple linear combinations of features were preferred to predict parameters and maximum number of features to be combined was set in two. The selection of which features should be combined to estimate one particular parameter was made based on previous results but helped by the expert knowledge of a hydrologist. Proposed mathematical relationships are presented in Table 6. Multiple correlation statistic was used to evaluate the performance of these relationships. In general, all proposed relationship have an elevated value of multiple correlation, but just that one with the highest degree of correlation for each parameter (values in bold in Table 6) would be used to estimate it in ungauged basins. In particular, we preferred mathematical relationships made with “pure” physical features as PURB or $S_s$ instead of derived or subjective variables as $CN$. Type column in
Table 6 indicates if that mathematical relationship is a recommended (R) or an alternative (A) equation to estimate a given parameter.

Table 6. Tested relationships between physical properties and parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mathematical Relationship</th>
<th>Multiple correlation</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>( v_s )</td>
<td>( v_s = -5.0 + 0.5 \cdot S_s )</td>
<td>0.95</td>
<td>R1</td>
</tr>
<tr>
<td>( v_r )</td>
<td>( v_r = 576.39 - 32.55 \cdot S_r^{0.5} - 10943.2 \cdot n )</td>
<td>0.59</td>
<td>A1</td>
</tr>
<tr>
<td>( v_r )</td>
<td>( v_r = -452.36 + 247.84 \cdot S_r^{0.5} + 16.95 \cdot PURB )</td>
<td>0.72</td>
<td>R2</td>
</tr>
<tr>
<td>( m )</td>
<td>( m = -0.54433 + 0.009263 \cdot CN + 0.00043 \cdot S_s )</td>
<td>0.72</td>
<td>A2</td>
</tr>
<tr>
<td>( m )</td>
<td>( m = -0.0367 + 0.0028 \cdot PURB + 0.0013 \cdot S_s )</td>
<td>0.83</td>
<td>R3</td>
</tr>
<tr>
<td>( t_0 )</td>
<td>( t_0 = -8.884 + 0.2901 \cdot CN - 0.3256 \cdot S_s )</td>
<td>0.93</td>
<td>A4</td>
</tr>
<tr>
<td>( t_0 )</td>
<td>( t_0 = 7.298 + 0.0826 \cdot PURB - 0.3059 \cdot S_s )</td>
<td>0.93</td>
<td>R4</td>
</tr>
</tbody>
</table>

As an additional evaluation criterion, model parameters for all subcatchment of Besòs basin were estimated from its physical features using the above-recommended (R1, R2, R4 and R4) mathematical relationships. Then, DiCHiTTop model was used to simulate discharges using these estimated parameters. NSE statistic was used to evaluate performance of discharge simulations. Results are summarized in Table 7 and it should be compared with previous results using calibrated parameters reported in Table 3. As it was expected, performance of simulations using estimated parameters by mathematical relationships was worse than model results using calibrated parameters. Some examples of simulated discharges in Besòs basin using calibrated and estimated model parameters are shown in Fig. 4. In general, flows computed using estimated parameters follow tendencies of observed discharges, but its accuracy seems depend of the watershed and the rainfall event. Fig. 4a and Fig. 4b show hydrograms for two different rainfall events observed at the same station (code 135). Simulated flows using the calibrated parameters have a good agreement with the observed ones in both events. However, simulated discharges using estimated parameters show just a good agreement for the first case. Basins code 138 and 145 shown good performances in both rainfall events sets, but watershed code 135 and 136 had good results on only one rainfall event set.

Table 7. DiCHiTOP estimated parameters for Besòs subcatchments

<table>
<thead>
<tr>
<th>Watershed Code</th>
<th>( v_s )</th>
<th>( v_r )</th>
<th>( m )</th>
<th>( t_0 )</th>
<th>FS</th>
<th>NSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>135</td>
<td>10.4</td>
<td>142.00</td>
<td>0.01762</td>
<td>-1.70</td>
<td>0.6</td>
<td>0.27</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.80</td>
</tr>
<tr>
<td>136</td>
<td>5.05</td>
<td>181.36</td>
<td>0.03339</td>
<td>2.45</td>
<td>0.6</td>
<td>0.41</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.05</td>
</tr>
<tr>
<td>138</td>
<td>6.30</td>
<td>154.24</td>
<td>0.03216</td>
<td>1.55</td>
<td>0.6</td>
<td>0.67</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.40</td>
</tr>
<tr>
<td>139</td>
<td>6.20</td>
<td>176.81</td>
<td>0.03162</td>
<td>1.60</td>
<td>0.6</td>
<td>---</td>
</tr>
<tr>
<td>142</td>
<td>9.95</td>
<td>44.07</td>
<td>0.02345</td>
<td>-1.22</td>
<td>0.6</td>
<td>---</td>
</tr>
<tr>
<td>143</td>
<td>4.60</td>
<td>351.21</td>
<td>0.07086</td>
<td>3.86</td>
<td>0.6</td>
<td>---</td>
</tr>
<tr>
<td>145</td>
<td>5.35</td>
<td>269.50</td>
<td>0.04873</td>
<td>2.69</td>
<td>0.6</td>
<td>0.62</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.46</td>
</tr>
</tbody>
</table>
Fig. 4. Examples of simulated discharges in Besòs subcatchments.

a) 17/02/2003 event for station code 135; b) 11/11/1996 event for station code 135; c) 04/12/1996 event for station code 145; and d) 09/12/2002 event for station code 145. In each case, slight dark lines correspond with observed discharges, bold dark lines show simulated discharges using
calibrated parameters, and dashed red lines indicate simulated discharges using estimated parameters.

3. Validation Results

The relationships identified and tested above based on Besòs basin characteristics are required to estimate DiCHiTop parameters in ungauged watersheds around Catalunya. Therefore, Anoia basin was selected to evaluate the performance of the recommended mathematical relationship outside of Besòs basin’s boundaries. In this section, a description of main characteristics of Anoia basin is presented and then results of the evaluation of regionalization methodology are included and commented.

3.1 Anoia Catchment

The Anoia catchment is a typical Mediterranen catchment located in central Catalunya (NE Spain) (Fig. 2). The Anoia region is part of the Barcelona province. The neighborhood of Anoia region is also known as the Cava region, due to the production of the Catalan champagne as an important economic activity. The Anoia catchment covers an area of approximated 905 km².

Anoia catchment has a high percentage of rural land uses where non-irrigated crop fields, conifer forests and wine yards are frequent. The appearance of urban zones is low and is mostly important in the centre and the southeast of the catchment. The center has as large city, the capital Igualada, surrounded by road infrastructures and pastures, and Martorell and Sant Sadurni d’Anoia cities are located in the southeast.

The river network of the Anoia catchment is illustrated in Fig. 5. The Riu Anoia is the main river of the catchment in which the smaller streams (Rieras) and rivers (Rius) drain. The Anoia catchment is divided into three watersheds by three discharge measurement stations. The first one (code 186) is located near the town Jorba and measures the discharges of the Riera de Clarina, Riera Gran and Riera de Rubio after forming upstream the Riu Anoia. The watershed of next station (code 189) surrounds the town Sant Quintí de Mediona and drains into the Riu de Bittlets. The last stream gauge (code 190) is located just downstream of the confluence of the Riu Anoia and the Riu de Bittlets, near the town Sant Sadurní d’Anoia. The Riu Anoia is a tributary of the Riu Llobregat, the second largest river in Catalunya.

Physical features of Anoia subcatchments were computed (Table 8) from the same data sources and using the same criteria that with Besòs basin in section 2.4. Main differences with Besòs features are the PURB feature, where Anoia watersheds show less regions with urban uses remarking the strong agricultural development of this region nowadays, and in the $S_k$ feature, where Anoia watersheds have less inclined bed rivers.

Table 8. Physical properties of Anoia subcatchments

<table>
<thead>
<tr>
<th>Subcatchment Code</th>
<th>Physical Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\bar{CN}$</td>
</tr>
<tr>
<td>186</td>
<td>64,91</td>
</tr>
<tr>
<td>189</td>
<td>59,70</td>
</tr>
<tr>
<td>190</td>
<td>63,26</td>
</tr>
</tbody>
</table>
3.2 Hydrological simulation of Anoia basin using estimated parameters

Anoia basin was used to test the mathematical relationships derived from physical and hydrological characteristics of Besós basin. First approach in the estimation process of model parameters for Anoia basin was to use the recommended relationship of Table 6 for each one of them, e. g., $v_s$ parameter was estimated from $S_g$ using the R1 relationship or $v_r$ parameter was estimated combining $S_g^{0.5}$ and PURB features using the R2 relationship, but now using physical features of the new catchments. This initial evaluation revealed that some of recommended relationships have serious limitations to be used in new catchments. For example, R2 relationship could estimate negative river velocities for basins with low percentages of urban areas, or R1 relationship cannot be used in watersheds with hillside slopes greater than 20% because in this case negative values of hillside velocities are derived, as well.

Knowing these restrictions, alternative relationships can be used in the watersheds were recommended relationships becomes inapplicable. Therefore, model parameters of all Anoia watersheds were estimated using either recommended or alternative relationships. In particular, recommended relationships were used to estimate $v_s$ and $m$ parameters, and alternative relationships for $v_g$ and $t_0$ parameters. DiCHiTTop estimated parameters for all Anoia subcatchments are summarized in Table 9.
Table 9. DiCHiTOP estimated parameters for Anoia subcatchments

<table>
<thead>
<tr>
<th>Watershed Code</th>
<th>$v_S$</th>
<th>$v_R$</th>
<th>$m$</th>
<th>$t_0$</th>
<th>FS</th>
<th>NSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>186</td>
<td>4.785</td>
<td>206.28</td>
<td>0.0653</td>
<td>1.433</td>
<td>0.6</td>
<td>0.55</td>
</tr>
<tr>
<td>189</td>
<td>5.225</td>
<td>205.90</td>
<td>0.0175</td>
<td>1.776</td>
<td>0.6</td>
<td>-0.89</td>
</tr>
<tr>
<td>190</td>
<td>4.465</td>
<td>261.64</td>
<td>0.0498</td>
<td>1.896</td>
<td>0.6</td>
<td>0.54</td>
</tr>
</tbody>
</table>

Evaluation of the methodology of estimation of parameters for watershed code 186 was made using a set of three rainfall events that happened during years 1998, 1999, and 2000. Two examples of simulated discharges using estimated model parameters from physical features are shown in Fig. 6 (a and c). In both examples, peak times are well computed but maximum observed flows are systematically underestimated using these parameters. These results seem indicate problems with the estimation of parameters associated with runoff production but not with routing parameters, i.e., bad estimation of $m$ and $t_0$ parameters. Looking for a way to handle with this problem, new simulations of flow were made for the same rainfall events but using a $t_0$ parameter equal to a half of its originally estimated value. Fig. 6 (b and d) show simulated discharges after this change. Improvements in quality of simulations are evident and NSE values increase significantly (a global NSE value of 0.88 instead of 0.55) in both rainfall events.

Fig. 6. Examples of simulated discharges in watershed code 186 of Anoia basin

a) 03/09/1999 rainfall event. Flow simulated using estimated parameters from physical features; b) Same as a) but flow simulated using a half of estimated $t_0$ value; c) 09/06/2000 rainfall event. Flow simulated using estimated parameters from physical features; and d) same as c) but using a half of estimated $t_0$ value. In all cases, slight dark lines correspond with observed discharges, and bold dark lines show simulated discharges.
Test on watershed code 189 were made using a set of three rainfall events occurred in 2000, 2001, and 2003. Two examples of simulated discharges using estimated model parameters from physical features are shown in Fig. 7 (a and c). In these cases, peak times are well computed but volume of simulated flow are clearly overestimated. These results seem indicate problems with the estimation of parameters associated with infiltration processes but not with routing parameters, i.e., bad estimation of m or \( t_0 \) parameters. Again, new simulations of flow were made for the same rainfall events but modifying the previously estimated values of parameters. In particular, value of m parameter was duplicated in these new simulations. Fig. 7 (b and d) shows the new simulated discharges after this simple change. Quality of simulations was improved in both rainfall events, remarking the problems of proposed relationships with the estimation of parameters related with TopModel.

**Fig. 7. Same as in Fig. 6 but for station 189.**

- **a.** 20/12/2000 rainfall event. Flow simulated using estimated parameters from physical features;  
- **b.** Same as a) but flow simulated using a double of estimated m value;  
- **c.** 14/11/2001 rainfall event. Flow simulated using estimated parameters from physical features; and  
- **d.** same as c) but using a double of estimated m value. In all cases, slight dark lines correspond with observed discharges, and bold dark lines show simulated discharges.

Finally, using four rainfall events occurred in 1997, 1998, 1999 and 2000, an evaluation of performance of regionalization technique was made in watershed code 189. Fig. 8 (a and c) show two examples of simulated discharges using estimated model parameters from physical features. Again peak times seem well simulated, indicating a good estimation of routing parameters, but shapes of simulated and observed hydrographs are not quite similar, showing another time the above-mentioned problems in estimation of m and \( t_0 \) parameters. Looking for better simulations estimated \( t_0 \) value was modified in a similar way of adaptation made in station 186, i.e., it was used a half of its estimated
value. The new simulated discharges are shown in Fig. 8 (b and d). Again, this simple change improved the quality of simulations in both rainfall events.

Fig. 8. Same as in Fig. 6 but for station 190.

a) 24/05/1998 rainfall event. Flow simulated using estimated parameters from physical features; b) Same as a) but flow simulated using a half of estimated $t_0$ value; c) 09/06/2000 rainfall event. Flow simulated using estimated parameters from physical features; and d) same as c) but using a half of estimated $t_0$ value. In all cases, slight dark lines correspond with observed discharges, and bold dark lines show simulated discharges.

4. Conclusions and final remarks

This report summarizes the activities made for GRAHI UPC staff (Partner 40) inside of Task 1 of FLOODsite EC-Project. In particular, they were related with the estimation of parameters of a distributed hydrological model based on the link between distributed basin characteristics and hydrological model parameters.

During this study, a regionalization methodology based on derivation of multiple linear regressions between basins properties to define model parameters was described and tested. This approach allows take advantage of statistical interdependencies between parameters and physical features to obtain prediction expressions for ungauged basins. This technique is similar to some of methods of regionalization published recently (see e.g. Bloschl (2005), Merz and Bloschl (2004), or Moreda et al., (2006)).
Definition of mathematical relationships between model parameters and physical features was made based on the natural characteristics of five subcatchments of Besòs River, and the five parameters of the DiCHITop hydrological model. DiCHITop model was calibrated for these watersheds via a multi event approach. Then a set of mathematical relationships, combining some physical features, was defined to estimate those calibrated parameters. After a statistical evaluation of performance of each expression, better-fit mathematical relationships were classified in two groups: (1) recommended or (2) alternative relationships. First group indicates the best performance relationship for each model parameter, and second group is conformed by the other good-fitted, but no best-fit, relationships.

Proposed mathematical relationships were used to estimate DiCHITop parameters of Besòs watersheds, and then those estimated parameter used to simulate flows. Comparison between flow simulations made with calibrated parameters and estimated parameter revealed, in this case, flows computed using estimated parameters follow tendencies of observed and calibrated discharges, but its accuracy seems depend of both the watershed in simulation and the rainfall event.

The objective of this study is to identify relationships that allow estimate DiCHITop parameters in ungauged watersheds around Catalunya. Therefore, Anoia basin was selected to evaluate the performance of the recommended mathematical relationship outside of Besòs basin’s boundaries. Based on physical features of three watersheds inside of Anoia basin, DiCHITop parameters were estimated. Hence, physical characteristics of Anoia basin are different than Besòs watershed, mainly percentages of urban areas and river slopes, some of recommended-type relationships proposed unacceptable model parameter values. This problem can be solved using one of alternative-type relationships in those cases where recommended relationships fail. However, this analysis revealed a serious difficulty in the applicability of these expressions in watersheds located outside of, or with different characteristics than, Besòs subcatchments. A redefinition of mathematical relationships that involve in the estimation of each model parameter a number of physical features greater than that was used in this study could solve this problem.

In spite of previous problem, acceptable DiCHITop parameters for the three Anoia watersheds were estimated using both recommended-type and alternative-type expressions. Then those parameters were used to run the hydrological model and compute discharges. Comparison between simulated and observed discharges allows discover, a good agreements of simulated hydrographs with observed peak times indicating a good estimation of routing parameters via prediction expressions, but serious disagreements in the shape of hydrographs suggesting a inadequate estimation of parameters associated with runoff production and infiltration. Additional flow simulations using simple changes in the proposed values of parameters related with Topmodel were made and performance of simulations was improved.

In conclusion, results seem indicate the strongest potential of methodology used in this study to define relationships between model parameters and physical features of basins and to use them to estimate model parameters in ungauged catchments. Also, this study allows identify some problems and difficulties in the implementation process of this methodology, and their prediction expressions, outside of its original definition domain. Evolution of the methodology analyzed in this report and redefinition of relationships for prediction of model parameters will continue until the end of activities of GRAHI-UPC in Task 23 of FloodSide EC-Project.
5. References