# Hydrological and hydraulic characterization in semi arid zones. Analysis of model type, basin size and sediment transport formulae

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ABSTRACT: In semiarid regions with steep morphology and irregular rainfall regime areas, the floods are presented with high proportion of solid materials transport. Furthermore, climate change will increases flash floods phenomenon, and will make necessary to control them to minimize their destructive effects. In order to design effective control and intake systems in semiarid regions, it is necessary to know hydrologic and hydraulic characteristics of ephemeral rivers. According to the problem some semi-arid Mediterranean basins were studied in order to establish general criteria of calculation in these regions. Based on the results obtained in these basins with distributed and aggregated hydrologic models, in this paper the authors analyze the main hydrological and hydraulic properties, and discuss the formulations of roughness coefficients and sediment transport and its application in ephemeral streams.

## 1 INTRODUTION

The knowledge of the hydrological and hydraulics characteristics is essential in ephemeral streams typical of semiarid zones. In these places the hiperconcentrated torrential flows cause large floods with destructive effects on the environment and people. Currently, they are increased by climate change. It has a direct effect on the frequency and intensity of precipitation, so it rains more intense and less frequent in these areas. Therefore, the torrential rainfalls produce the concentration of resources in a limited number of events with high flows and water velocities. This is the case of several basins located in South East Spain.

According to the problem, these flows can not be taken with usual dam-reservoir system, because of the high concentration of sediment make them useless in a short time. To analyze the design parameters of specific intake systems, previously it is necessary to characterize the specific site in where these structures will be placed (Castillo et al., 2000, 2009, 2011).

Research on sediment transport has been done for decades, without obtaining a really satisfactory equation which interrelate the flow and sediment properties properly. Consequently, we have examined other experience in the sediment transport calculation for hyperconcentrated flows. We find in Spain some of them as Las Angustias Gully, located in the Isla de la Palma (Canary Islands).

According to the results presented at Las Angustias Gully, and looking at their similarity to the semi-arid watersheds of the Region of Murcia, one of the principal objectives of Hidr@m group is the hydrological and hydraulics characterization in semi-arid zones. For this reason, several comparative analyses have to be done.

First, lumped and semi-distributed software HEC-HMS (developed by the U.S. Army Corps of Engineers) were used. Several models in the Albujón gully were run to analyze the importance of the sub-basins size, precipitation pattern, transform model and routing model (Muskingum-Cunge and Kinematic wave). Also this software was applied in three sub-basins of Albujón Gully (Mergajón, Hoya de España and Albujón Intermedia gullies), and the results are compared with those obtained in Las Angustias gully.

Second, the results from lumped simulation obtained in Mergajón gully are compared versus physically-based distributed simulation, by means of MIKE SHE software (DHI Water & Environment). The results indicate us the similarity degree and the consistency between both models.

Finally, in order to obtain the hydraulic characterization and an estimation of sediment transport, it is analyzed the roughness coefficients, type of sediment, and the different flow characteristics. The methodology developed by Castillo et al. (2000, 2009) were utilized in the three cited sub-basins (Mergajón, Hoya de España and Albujón Intermedia).

## 2 DESCRIPTION OF THE BASINS STUDIED

The Albujón Gully, which is located in Región de Murcia (Spain), constitutes the principal natural drainage of the Campo de Cartagena region. The river basin has a total area of around 694 km$^2$.

Although Albujón basin has moderate elevations, its slopes increase between 0.4% close to the mouth and 5.8% in the header areas. Its morphology is dominated by great plain of irrigated crops in the lower part of the basin, fruits and herbs in the middle-high, and scattered areas of woodland in the mountains (coniferous, scrub and woodland). In reference to its lithology, the middle and lower area is dominated by glacis and crust edges, and in the lower area red clay and wider range of soils as carbonates and sandstones can be found. These formations give the soil a character less permeable and imperfect drainage.

Three sub-basins of the Albujón Gully, with areas of around 40-50 km$^2$ have been selected for the application of the methodology developed in the Las Angustias Gully, in order to obtain their hydraulic characteristics, manning coefficient and sediment transport. They are Mergajón Gully, Intermedia Gully and Hoya de España Gully.

Mergajón has been chosen because of its similar geomorphological characteristics (area and slope), and hydrological and hydraulic characteristics with Las Angustias Gully. The Intermedia and Hoya de España basins have different characteristics in slopes and in the grain-size distribution curves. (Figure 1 and table 1).


Figure 1. Situation of Albujon Gully, and three of its sub-basins: Mergajon, Albujon Intermedia y Hoya de España.

Table 1. Basin hydraulic characteristics.

| Basin | Area (km$^2$) | L (km) | i (m/m) |
|---|---|---|---|
| Albujón | 690 | 50.658 | 0.0110 |
| H. España | 28 | 27.241 | 0.0082 |
| A. Intermedia | 32 | 25.230 | 0.0082 |
| Mergajón | 52 | 12.874 | 0.0274 |
| Angustias | 49 | 12.982 | 0.0392 |

* i = average slope.

## 3 HYDROLOGICAL CHARACTERIZATION OF THE BASINS

The characterization of the main hydrographic features in a basin is a very important issue in their hydrological studies. Attending to the characteristics of semi-arid and arid zones, the simulation hydrological model has to be chosen carefully. Salas (2000) points out that distributed models either continuous or event, are more flexible and more useful in semi-arid basins.

For this reason, we used two types of software:

1 HEC-HMS has been used to run a lumped and semi-distributed model, and
2 MIKE SHE has been used to run a physically based and distributed hydrological model. It covers the major processes in the hydrologic cycle and includes process models for evapotranspiration, overland flow, unsaturated flow, groundwater flow, and channel flow and their interactions.

In both models, there are common inputs, such as topography and rainfall, and other values of equivalent parameters.

For topography, a Digital Terrain Model (DTM) of 4x4 m developed in 2009 has been used. In the case of HEC-HMS model, the delimitation of the Albujón basin and aggregation of its sub-basins have been carried out using the Geospatial Hydrologic Modelling Extension (HEC-GeoHMS), ArcView GIS and its Spatial Analyst extension from the Environmental Systems Research Institute, Inc. (ESRI).(Figure 2).

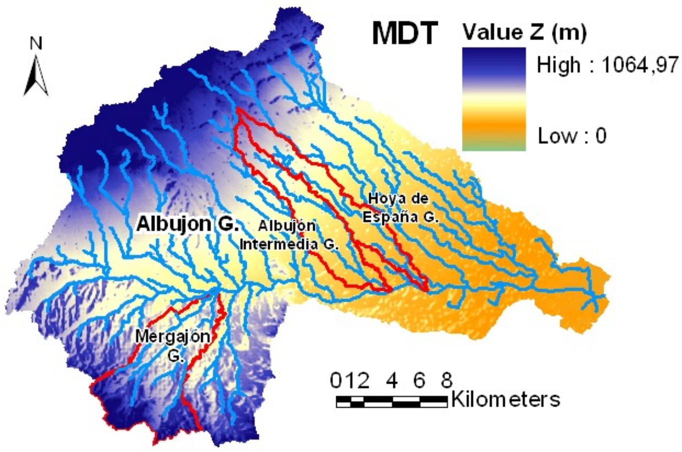


Figure 2. DTM of basin and three sub-basins.

For the precipitation, in semiarid areas it is not possible to make a prediction and estimation of rainfall due to few instrumentation and scarce hydro meteorological information (few rain gages with very short historical series). In this case it is necessary to apply various methodologies that use historical data to rain gauge and daily records of rainfall and storm patterns of design, to simulate the spatial-temporal variability of rainfall.

To obtain at each basin the maximum daily rainfall in different return periods (table 1), it was made a study that includes: (1) statistical analysis of maximum daily rainfall, and (2) the precipitation pattern, its value and the spatial and time distributions (design storms).

For statistical analysis of rainfall we studied the registers from 1933 to 2009 (17 rain gages) which are located close and inside Albujón watershed. In the data study has been taken into account the temporal and spatial distribution. Data from different rain gages were compared and analyzed using the double mass method. After the rectification of some inconsistencies, the data obtained has been modified by a correction factor which depends on numbers of data observed (World Meteorological Organization, WMO).

Then frequency distributions of this data were done with different theoretical distribution as TCEV, GEV, LP3, Gumbel and SQRT–Etmax. The rainfalls of each gage for each return period were obtained and it was taken the values which were more unfavourable. The required watersheds precipitations depths were calculated from gages, using Thiessen polygon method. Finally, other two factors correction was applied: factor proposed by Témez (1991) to take into account the spatial variability of the rainfall over the watershed area, and curves proposed by WMO for calculating areal depth as a percentage of point precipitation values.

To take into consideration the distribution of rainfall it has been considered a rainfall pattern according to the way in which these events occur in the study area. Based on a storm duration of 24 h and a time interval of 15 minutes, using alternating block method it was designed a hyetograph where 80% of rainfall were concentrated during hours 8 to 16, and the rest (20%) were distributed into 2 symmetric parts of 8 hours each one (from hours 0 to 8, and from 16 to 24).

Table 2. Daily maximum rainfall (mm).

| Basin | $P_{1.4}$ | $P_5$ | $P_{10}$ | $P_{50}$ | $P_{500}$ |
|---|---|---|---|---|---|
| Albujón | 33 | 79 | 99 | 142 | 204 |
| H. España | 32 | 74 | 92 | 131 | 187 |
| A. Intermedia | 30 | 78 | 99 | 145 | 210 |
| Mergajón | 36 | 92 | 118 | 176 | 257 |
| Angustias | 101 | 166 | 195 | 257 | 344 |

### 3.1 *Lumped and semi-distributed simulation-Analysis of basin size*

In order to analyze the importance of basin size, we ran several HMS models of Albujón Gully. We considered a lumped model by taking the whole basin, and semi-distributed models with disaggregated subbasins. (Figure 3).

The Curve Number (CN) of Soil Conservation Service (SCS) has been used for estimating abstraction from storm rainfall. It was selected because it is the most extended and probed method, and it is widely accepted for use in Spain.

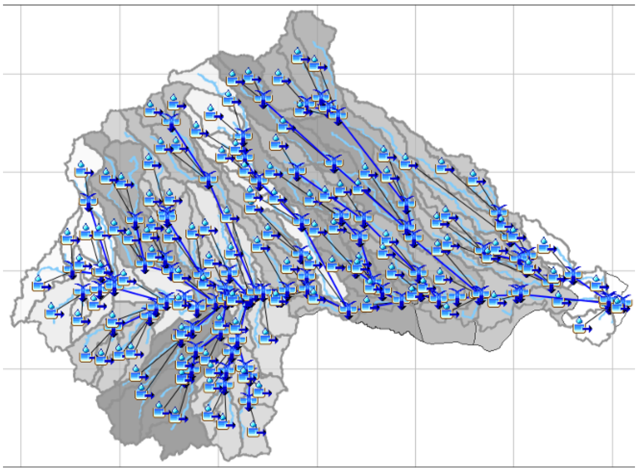

Figure 3. Semi-distributed model of Albujón.

Watersheds' Curves Numbers (*CN*) have been calculated using the Spanish version of the SCS method. In this version, *CN* is estimated using the parameter $P_0$ "runoff threshold", which was defined by Témez (1991) as $P_0=0.2S$, where $S$ is the potential maximum retention. The relationship between *CN* and $P_0$ is $NC=5080/(50.8+P_0)$. The $P_0$ value was estimated as function of terrain slope, soil type, land use, and antecedent moisture. According to these parameters a map of *CN* was obtained (figure 4).

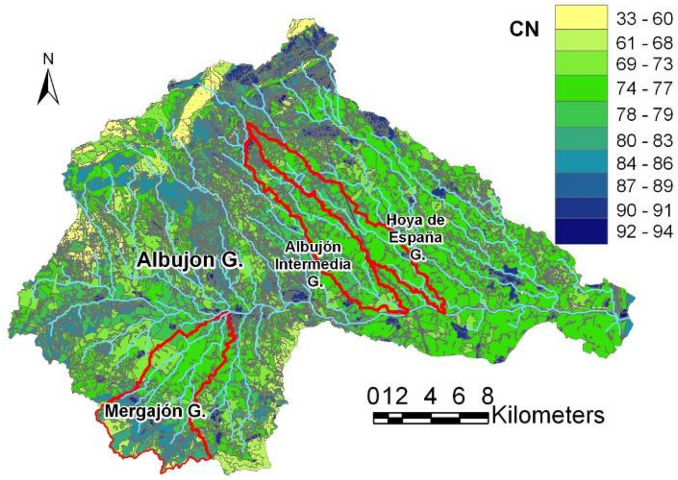


Figure 4. Curve Number *CN* of the basins.

For modeling channel flow we applied two different routing models depending on the river slope. Thus, for rivers with medium-high slopes (>1%) the Muskingum-Cunge routing model has been selected. However, for basins with medium-low slopes (<1%), the kinematic wave method is more adequate to use.

Considering there is limited information on actual events in the basins, the SCS unit hydrograph has been chosen to model rainfall-runoff transformation.

It requires the calculation of lag time, $T_{lag}$, normally as function of concentration time, $T_c$.

In Spain is usual to use the following expression: $T_{lag} = 0.35T_c$, where $T_c = 0.3(L/i^{0.25})^{0.76}$. $L$ is main course length (km) and $i$ is the slope (m/m) (Témez 1991).

The results of all simulations are shown in table 3. As we can see, the lumped model simulation gives lower values than those obtained in the semi-distributed simulations. These differences are greater than 100% for low return period and decrease to about 10% for return periods greater than 10 years.

Table 3. Peak outflow discharge values for each model of Albujón Gully.

| Simulation | Nº sub-basin /area km$^2$ | $Q_{1.4}$ | $Q_5$ | $Q_{10}$ | $Q_{50}$ | $Q_{500}$ |
|---|---|---|---|---|---|---|
| Lumped | 3 / >100 | 48 | 423 | 1414 | 2663 | 4514 |
| Semi-distributed | 18 / <50 | 89 | 985 | 1553 | 2947 | 5052 |
| Difference | (%) | 102 | 133 | 10 | 11 | 12 |

Likewise in order to calculate the sediment transport of the three sub-basins chosen and Las Angustias, their peak flow have been obtained (table 4).

Table 4. Peak outflow discharge values (m$^3$/s) of Albujón subbasins' and Las Angustias.

| Subbasin | $T_{lag}$ (min) | $Q_{1.4}$ | $Q_5$ | $Q_{10}$ | $Q_{50}$ | $Q_{500}$ | $Q_{1000}$ |
|---|---|---|---|---|---|---|---|
| Intermedia | 179 | 3 | 48 | 76 | 144 | 246 | 277 |
| H. España | 186 | 3 | 37 | 58 | 109 | 186 | 210 |
| Mergajón | 102 | 15 | 147 | 227 | 421 | 701 | 785 |
| Angustias | 63 | 121 | 277 | 350 | 519 | 762 | 836 |

## 3.2 *Distributed simulation. Analysis of model type*

At first approximation we built a MIKE SHE model of Mergajon Gully, in which only the overland flow process was included because we just required an event simulation. To implement the Mike SHE model we used input values equivalent to those used in our HMS model. They included precipitation, topography, and detention storage value *DS*, which was assimilated to $P_0$ value.

We ran the simulation in three different rainfall scenarios. Graphics results are in figure 5 and 6, and in table 5 we can see the values for all the simulations calculated.

Comparing the maximum outflow values and time to reach them obtained in HEC-HMS model and MIKE SHE model, we can see that the results calculated by MIKE SHE are higher than HMS for low return period (T1.4 years). Nevertheless the values are similar in both models for T50 years, and MIKE SHE model results are lower than HMS model for T500 years.

Times to peak flows are very similar in two models, except in the case of T1.4 years in where the MIKE SHE model is until five hours greater than HMS model.

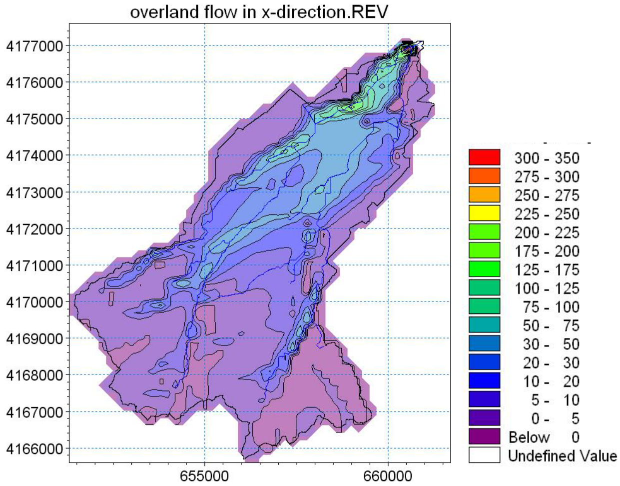


Figure 5. Maximum overland flow in x direction for T500 years.

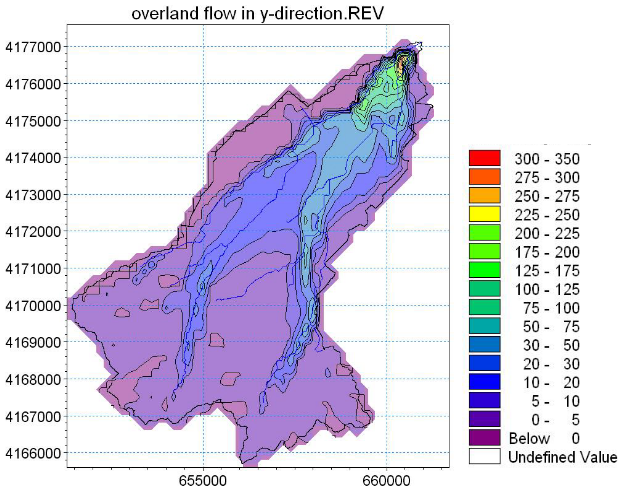


Figure 6. Maximum overland flow in y direction for T500 years.

Table 5. Peak outflow discharge values and time to reach them.

| | $Q_{1.4}$ | $Q_{50}$ | $Q_{500}$ |
|---|---|---|---|
| $DS$=$P_0$ (mm) | 14 | 14 | 14 |
| *NC* | 78 | 78 | 78 |
| HEC HMS $Q_{max}$ (m$^3$/s) | 14 | 422 | 701 |
| Time to peak flow (h) | 14:15 | 13:45 | 13:45 |
| Mike SHE $Q_{max}$ (m$^3$/s) | 24 | 421 | 559 |
| Time to peak flow (h) | 19:09 | 13:36 | 13:10 |

# 4 HYDRAULIC CHARACTERIZATION. STUDY OF SEDIMENT TRANSPORT

With regards to the source of sediments, the transport may be divided in:

1 wash load which include very fine material and is transported in suspension

2 total bed transport which is transported on bed and in suspension (depending on the sediment

size and flow velocity). This type of transport is to be discussed below.

The main properties of sediment and its transport are: the particle size, shape, density, sedimentation velocity, porosity and concentration. Two types of information are required: the characteristic diameters of the bed material and hydraulic information (flow characteristics). Figure 7 and table 6 shows grain-size distribution curves of the four gullies analyzed and table 6 and 7 shows the principal hydraulic cha-racteristics.

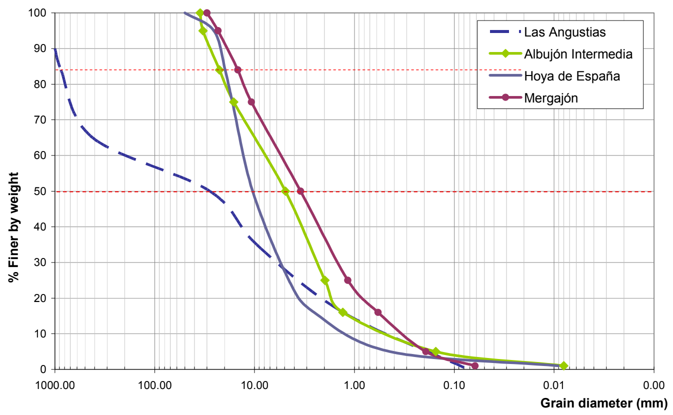


Figure 7. Grain-size distribution curves o the gullies.

Table 6. Grain-size distribution of the gullies.

| Basin / Diameter | $D_{16}$ (mm) | $D_{50}$ (mm) | $D_{84}$ (mm) |
|---|---|---|---|
| Las Angustias | 1.3 | 28 | 870 |
| Intermedia | 1.3 | 4.9 | 22.5 |
| Hoya de España | 2.5 | 10.5 | 19.7 |
| Mergajón | 0.6 | 3.5 | 14.7 |

### 4.1 *Estimation of Manning resistance coefficient*

The calculation of the flow characteristics depends mainly on the resistance coefficient, hydraulic radius and longitudinal slope. Following the methodology applied in Castillo et al. (2009), four aspects are checked to determine hydraulic characteristics of the flow:

1 macro roughness
2 bed armouring phenomenon
3 bed form resistance
4 hyper concentrated flow.

In all the studied cases we are facing a macro roughness problem with low return periods flows because of $y/D_{84} < 50$, where $y$ is depth (m).

Nevertheless, bed armouring phenomenon happens in Mergajón and Albujón Intermedia Gullies because size distribution typical deviation is extended or graduated ($\sigma_g > 3$), but it is not presented in Hoya de España Gully (table 7).

On the other hand, neither bed form resistance nor a possible rise of resistance for the variation in flow density and viscosity are explicitly taken into account because of $R_h / D_{50} < 2.000$ -where $R_h$ is hydraulic radius- and for the sediments concentration in weight is inferior to 10% in all of cases (table 8).

Table 7. Principal hydraulic characteristic of the basin (1).

| Basin | $Q_T$ ($m^3/s$) | $y/D_{84}$ | σg |
|---|---|---|---|
| Intermedia | $Q_{50}$ | 40 | 4.1 |
| H. España | $Q_{50}$ | 4 | 2.8 |
| Mergajón | $Q_{1.4}$ | 23 | 5 |

Table 8. Principal hydraulic characteristic of the basin (2).

| Basin | $Q_{1000}$ ($m^3/s$) | $R_h/D_{50}$ | $Q_T$ ($m^3/s$) | Weight conc. (%) |
|---|---|---|---|---|
| Intermedia | 277 | 170 | $Q_5$ | 0.30 |
| H. España | 210 | 87 | $Q_{1000}$ | 0.32 |
| Mergajón | 786 | 442 | $Q_5$ | 0.28 |

For the estimation of the roughness coefficient in the case of macro rough flows, the methodology described in Castillo et al. (2000, 2009), have been applied. We used 9 different formulae as Limerinos (1970), Bathurst (1985), Fuentes & Aguirre (1991), Van Rijn (1987), Garcia Flores (1996), Jarret (1984), Strickler (1973), Grant (1997) and Bathurst (2002).

The formulae are calculated coupling iteratively the hydraulic characteristics with the sediment transport and so, to obtain grain mean roughness.

Table 9 shows those formulations which best fitted to the mean value, in the three subbasins studied.

Table 9. Resistance coefficient for macro-rough flows.

| FÓRMULAE | OBSERVATIONS |
|---|---|
| Bathurst (1985):<br>$C^* = 5.62\log[d/D_{84}] + 4; \quad 0.3 \le d/D_{84} \le 50$ | $d$= Depth (m)<br>$0.4\% \le S_0 \le 4\%;$ |
| Fuentes and Aguirre (1991):<br>$C^* = 5.657\log[d/D_m] + 1.333 + 0.737[1/(d/D_m)]$<br>$0.3 \le d/D_{50} \le 77$ | $d$= Depth (m)<br>$0.001\% \le S_0 \le 6.55$ |
| García Flores (1996)<br>(Supercritical Regimen):<br>$C^* = 5.756\log[d/D_{84}] + 3.698;$<br>$n = 0.111 d^{1/6}/[2\log(d/D_{84}) + 1.2849]$ | $d$= Depth (m)<br>$0.30 \le d/D_{84} \le 100$ |
| Van Rijn [11]:<br>$C^* = 5.75\log(12R_f/3D_{90})$ | $R_f$=Bed total hydraulic Radius (m) |

As an example, the results obtained by the application of formulae in Mergajón Gully are presented in Figure 8. Certain tendency to decrease in $n$ values with increasing the flow rate is observed, although this tendency is less pronounced than that presented in Las Angustias Gully ($n$ media is represented by a gross dot line). In general, the mean values of $n$ decreases exponentially

The Manning coefficients obtained from the different analysed methods show some spread, but in general, these values tend to diminish when the flow increases. These values of grain roughness are more significant in Las Angustias Gully, compared to the total value of Manning. They have been increased by 0.01 units to considerer the shape of the section and the existing vegetation. The coefficients for the calculation of sediment transport are: Las Angustias (0.104 -0.062), Mergajón (0.033 - 0.032), Intermedia Albujón (0.035 - 0.033) and in the Hoya de España (0.037 - 0.034).

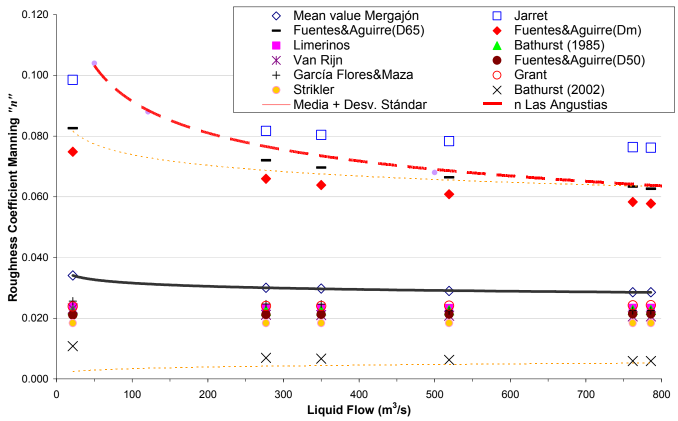


Figure 8. Manning resistance coefficient *n* versus flow rate. Mergajón and Las Angustas gullies.

## 4.2 *Estimation of sediment transport*

Castillo et al. (2009) analysed 12 formulations that have been applied to evaluate sediment transport capacity in each gully. These are: Meyer-Peter & Müller (1948), Ackers-White (1990), Yang (1976), Einstein & Barbarrosa (1952), Yang (2005), Smart & Jaeggi (1983), Mizuyama & Shimohigashi (1985), Van Rijn (1987), and Aguirre-Pe et al. (2000).

Liquid flows of different return periods (between 1.4 and 1,000 years) have been calculated.

As an example, in figure 9 is presented the results obtained for Mergajón Gully through the application of the formulae.

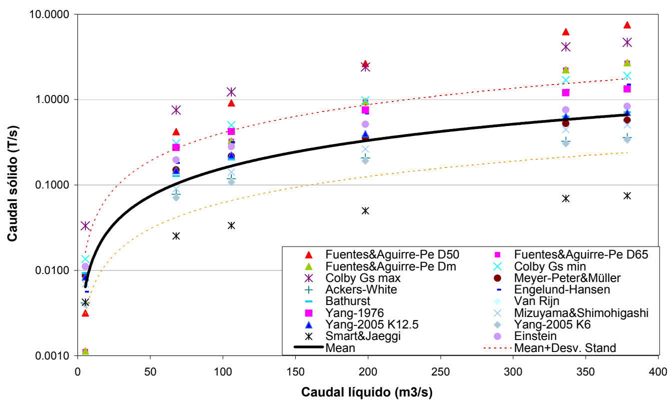


Figure 9. Solid flow versus liquid flow in Albujón Intermedia gully.

The principal formulations which results are around of the mean value in all the basins studied are the following:

– Bathurst et al. (1987):

$$\phi = (2.5S^{3/2}/[(\Delta+1)D_{50}(g\Delta D_{50})^{1/2}])[q-q_c] \tag{1}$$

where $S$ = slope; $q$= unit liquid flow; $\Delta$ = dimensionless apparent specific gravity, and $q_c$= critical flow, that can be calculated with one of these expressions, depending on the variable $D_{50}$ or $D_{16}$:

$$q_c^* = \frac{q_c}{g^{1/2}D_{50}^{3/2}} = 0.15S^{-1.12}$$

$$q_c^* = \frac{q_c}{g^{1/2}D_{16}^{3/2}} = 0.21S^{-1.12}$$

– Meyer- Peter & Müller (1948):

$$\gamma\left(\frac{K_s}{K_\gamma}\right)^{\frac{3}{2}} R_s I = 0.047\gamma'_s D_m + 0.25\gamma_s'^{\frac{2}{3}}\rho^{\frac{1}{3}}\left(\frac{g_{BT}}{\gamma_s}\right)^{\frac{2}{3}} \tag{2}$$

where:

$$K_s = \frac{B^{2/3}K_m K_w}{\{K^{3/2}{}_w(B+2d) - K_m{}^{3/2}2d\}^{2/3}}$$

$$K_r = \frac{26}{D_{90}^{1/6}};\ K_m = \frac{1}{n};\ K_w = \frac{1}{n_w}$$

$g_{BT}$ = unit total bed transport in weight (T/ms); $B$ = width (m); $d$ = depth (m); $D_m$ = diameter (m), and $n_w$ = roughness coefficient of banks.

– Einstein & Barbarossa (1952):

$$g_{BT} = g_B + g_{BS} \tag{3}$$

where $g_{BT}$ = unit total bed transport in weight (T/ms); $g_B$ = unit bed transport in weight ,and $g_{BS}$ = unit suspended bed transport in weight. They are calculated as:

$$g_{BT} = \sum_{i=1}^{n} i_{BTi} g_{BTi};\quad i_B g_{Bi} = \Phi_* i_b \gamma_s (g\Delta D_i^3)^{\frac{1}{2}}$$

$$g_{BS} = \sum_{i=1}^{n} i_S g_{BSi};\quad i_S g_{Bsi} = i_B g_{Bi}\cdot\{P_E I_1 + I_2\};$$

being:

$$i_{BT} g_{BTi} = i_B g_{Bi}\cdot\{1 + P_E I_1 + I_2\}$$

$$\Psi_* = \xi Y(\beta/\beta_x)^2\Psi';$$

$$\xi = f(D_i/X);\ Y = f(D_{65}/\delta');\ K_s = D_{65};$$

$$\beta_x = log(10.6X/\Delta');\ \Psi' = \Delta`[D_i/(R'S)];\ \Delta' = \frac{K_s}{\chi}$$

$$P_E = 2.303\,log\left(\frac{30.2d}{\Delta'}\right)$$

$$I_1 = 0.216\frac{E}{(1-E)^Z}\int_E^1\left(\frac{1-y}{y}\right)^Z dy$$

$$I_1 = 0.216\frac{E^{Z-1}}{(1-E)^Z}\int_E^1\left(\frac{1-y}{y}\right)^Z ln(y)dy$$

– Yang (2005):

$$C = \frac{g_t}{Vh} = k \frac{\gamma_s}{\gamma_s - \gamma} \frac{\tau_0}{Vh} \frac{u_*'^2 - u_{*c}^2}{w} \qquad (4)$$

where $C$ = weight total sediment concentration; $g_t$ = total bed transport per width; $h$ = hydraulic radius or water depth; $V$ = mean velocity; $d$ = sediment size; $\gamma_s$ = specific weight of sand; $w$ = particle fall velocity and $\tau_o$ = shear stress.

In the same way we have calculated the values of the other three basins. The comparison between them can be seen in Figure 10.

It can be appreciated that solid flow of Albujón sub-basins are lower than Las Angustias. Only Mergajón results are comparable with those obtained in Las Angustias, being that results lower than Las Angustias. The difference between them increases as the liquid flow increases.

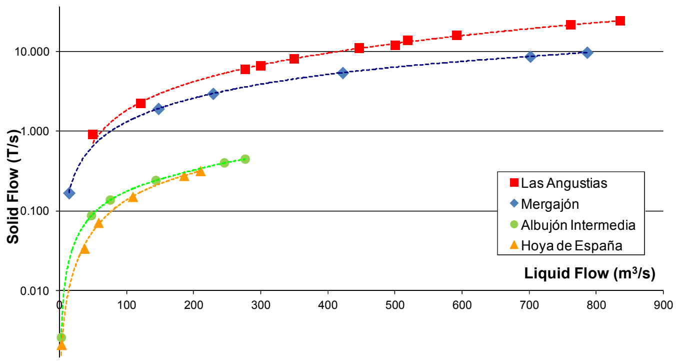


Figure 10. Total bed transport in function of liquid flow.

To compare the proportions of bed transport and suspended bed transport, we applied Einstein-Barbarossa method. Table 10 and 11, and figure 11 show that in Las Angustias, for the lowest flows, the bed transport is really higher than suspended bed transport (84% vs 6% for $Q_{1,4}$ = 121 m$^3$/s), ratio which increases until 61% vs 39% for $Q_{1.000}$ = 836 m$^3$/s. In Mergajón, with low return period flows ($Q_{1,4}$ = 14 m$^3$/s) the ratio of bed transport is higher than suspended bed transport (70% vs 30%). However for higher liquid flows ($Q_{1000}$ = 786 m$^3$/s) the bed transport is much lower than suspended bed transport (12 % vs 18%), an inverted trend to Las Angustias.

Table 10. Main results of bed and suspended bed transport rates (1).

| Basin | $Q_{1.4}$ (m$^3$/s) | Bed transport | Suspended bed transport |
|---|---|---|---|
| Intermedia | 5.2 | 88 % | 12 % |
| H. España | 5.6 | 97 % | 3 % |
| Mergajón | 14.3 | 70 % | 30 % |
| Angustias | 121 | 84 % | 16 % |

Table 11. Main results of bed and suspended bed transport rates (2).

| Basin | $Q_{1000}$ (m$^3$/s) | Bed transport | Suspended bed transport |
|---|---|---|---|
| Intermedia | 379 | 51 % | 49 % |
| H. España | 305 | 66 % | 33 % |
| Mergajón | 786 | 12 % | 88% |
| Angustias | 836 | 61 % | 39 % |

Aguirre et al. (2000) point that for slopes between 0.01 and 0.20, bed transport can reach about 50% of total bed transport.

In contrast to this, in rivers with low slope bed transport can be around 5 to 20 % of total bed transport. Mergajón Gully, although can be considered as a mountain river based on its slope (0.027), has a grain-size characteristic curve typical of an alluvial river. This fact explains the inverted trends regarding to Las Angustias. Albujón Intermedia and Hoya de España Gullies although can be considered properly as alluvial river, however according to the values shown in table 9 and 10, the rates of bed transport are higher than suspended transport in all flows. The reason of this performance could be that in these basins flows are lower than in Mergajón and these flows are not able to mobilize all suspended bed transport.

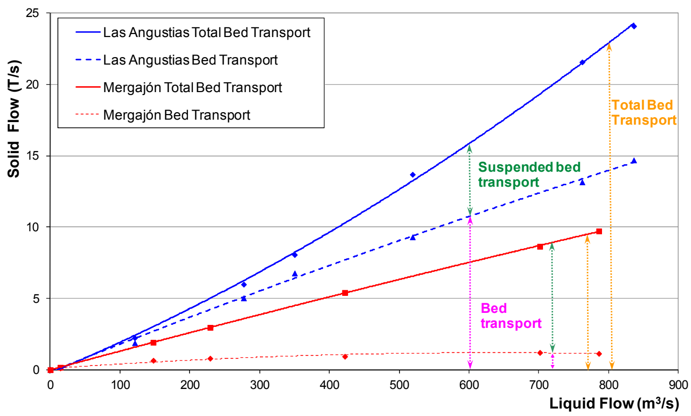


Figure 11. Total bed transport in function of liquid flow.

## 5 SUMMARY AND CONCLUSIONS

In this paper the hydrological and hydraulic characterization of two types of semiarid basins, mountain and alluvial watersheds has been made: Mergajón Gully which can be classified as mountain river basin, and Albujon Intermedia and Hoya de España Gullies which can be categorized as alluvial river basin.

Regarding to hydrological characterization of ephemeral rivers, we made two different simulations using lumped and semi-distributed software (HEC-HMS) and distributed software (MIKE-SHE).

By analyzing the results of HEC-HMS models, it can be concluded that basin size area is an important variable, so lumped model simulation gives lower values than those obtained in the semi-distributed simulations. Also it's important to choose the correct formulae for calculating $T_{lag}$ and $T_c$, and to make an appropriate design storm that represents spatial and temporal variability of rainfall in the area. As well, we can say that for alluvial rivers (slopes<1%) the use of the kinematic wave channel routing is more appropriate than Muskingum-Cunge model.

Comparing lumped simulation versus physically-based distributed simulation the results of the studied basins indicate us the similarity degree and the consistency between both models. As a conclusion in this issue we can say that even when the use of event models semi-distributed is recommended for the case of basins with little or no data of events, the study of these ephemeral rivers with distributed models results a very interesting option for improve the knowledge of the different physical process in these hydrological systems.

Finally and with regard to characterization and calculation of sediment transport capacity, the study shows that the methodology proposed is adequate for ephemeral rivers. In addition we want to emphasize on the importance of sampling in the calculation of sediment transport. The results presented point to the importance of sampling in the calculation of sediment transport. Thus, the characteristic diameters plotted on the grain size distribution curve can overvalue or undervalue its estimated capacity of transport.

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