Characterization of ephemeral rivers

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Abstract: *In steep morphology and irregular rainfall regime areas, the floods are presented with high proportion of solid materials transport. Although it is usual that hiperconcentrated flows are presented in semiarid regions, climate change will increase flash floods phenomenon, and will made necessary to control them to minimize their destructive effects.*
In order to design effective control and intake systems in semiarid areas, it is necessary to know hydrological and hydraulics characteristics of ephemeral rivers.
According to the results in Las Angustias Gully (Isla de la Palma-Spain), and based on their similarity to the semiarid watersheds of the Region of Murcia (Spain), the objective of this paper is applying and analysing the methodology, in order to establish a general criteria of calculation in these regions.
First results obtained in hydrology and sediment transport estimation of the Mergajón, Albujón Intermedia and Hoya de España Gullies will be presented and compared with the results in Las Angustias Gully.

Keywords: *Semi-arid region, sediment transport, resistance coefficient, ephemeral river, hiperconcentrated flow.*

1. INTRODUCTION

Semi-arid regions are characterized by an irregular rainfall which confers them, among other characteristics, reduced vegetation coverage or almost absent. In addition, a direct effect on the frequency and intensity of precipitation is being caused by climate change, so the precipitation is less frequent and more intensive. The combination of these two elements, heavy rains and potentially erodible areas, explains the fact that hyperconcentrated flows are becoming more usual. The torrential rainfall, scarce but very intense, make these gullies, generally inactive, can carry large amounts of water and sediment in these events.

There are three reasons that justify the study of specific intake systems for semi-arid regions: (1) it is not possible to use conventional intake systems (dam-reservoir) because the high concentration of sediment makes them useless in a short time period, (2) to take water, a very scarce and necessary resource, and (3) this type of structure makes possible to minimize destructive effects of flash floods.

To analyze the design parameters of specific intake systems, it is necessary to characterize the ephemeral rivers where these structures will be placed. The knowledge of the hydrological and hydraulic characteristics, typical of these areas, the quantification of sediment transport capacity are essential.

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 objectives of the Hidr@m group is to apply and analyze the methodology developed by Castillo et al. (2000 and 2009), Castillo (2004 and 2007), in order to establish a general criteria of calculation in these regions. Therefore, three gullies located in Albujón Gully (Campo de Cartagena), were studied and first results obtained in sediment transport estimation will be presented in this paper.

2. DESCRIPTION OF THE MEDITERRANEAN BASINS IN STUDY

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.

Albujón basin has moderate elevations although 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.

The Albujón Gully is formed by 17 sub-basins with areas of around 50 km^2. Three of them, Mergajón Gully, Intermedia Gully and Hoya de España Gully (Figure 1), have been selected for the application of the methodology developed in the Las Angustias Gully. Mergajón has been chosen because its similar geomorphological characteristics (area and slope), and hydrological and hydraulic characteristics with Las Angustias. The Intermedia and Hoya de España basins have different characteristics in slopes and in the grain-size distribution curves.

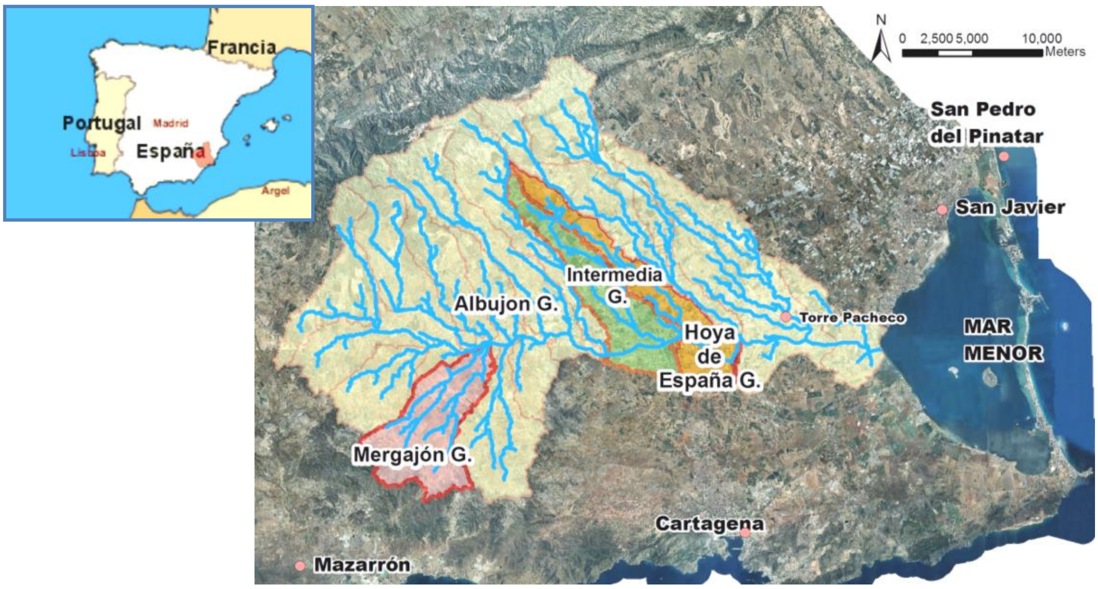


Figure 1 Situation of Mergajón, Albujón Intermedia and Hoya de España basins

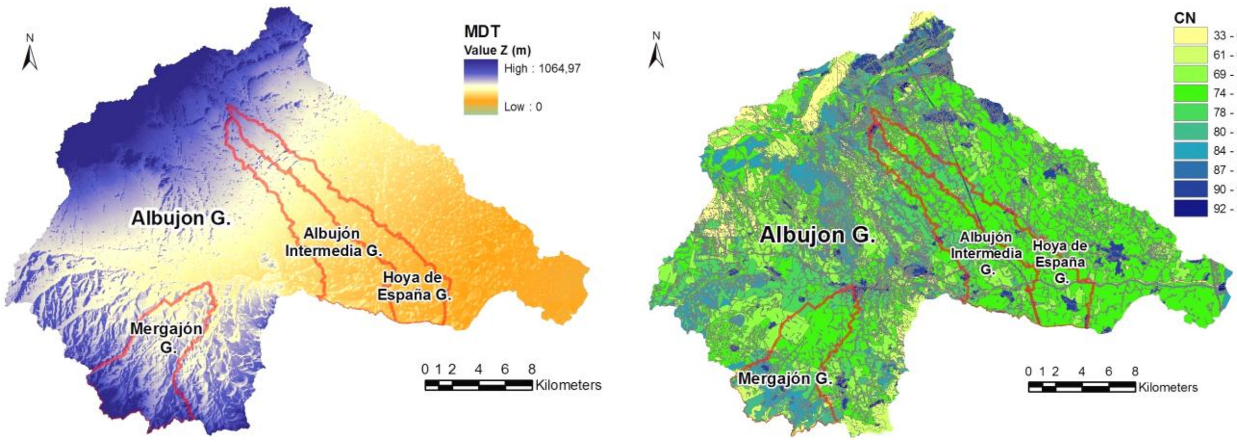
3. HYDROLOGICAL CHARACTERIZATION OF THE BASINS

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, among others, at first approximation, HEC HEC-HMS developed by U.S. Army Corps of Engineers of the United States of America (USACE), has been used for the calculation of flows.

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. Considering there is limited information on actual events in the basins, the SCS unit hydrograph has been chosen to model rainfall-runoff transformation. 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 (Las Angustias and Mergajón basins). However, for basins with medium-low slopes (Albujón Intermedia and Hoya de España basins), the kinematic wave method is more adequate to use.

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). Digital Terrain Model (DTM) of 4x4 m -developed in 2009 as part of project "Natmur-08", commissioned by la Consejería de Desarrollo Sostenible y Ordenación del Territorio of Región de Murcia - has been used. (Figure 2a).

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 $P_0 = 0.2 \cdot S$, where *S* is the potential maximum retention. The relationship between *CN* and P_0 is $NC = 5080/(50.8 + P_0)$. P_0 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 2b).



(a) (b)

Figure 2 (a) DTM of basin and its sub-basin (b) Curve Number *CN*

Sometimes 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). This particularity makes very difficult the use of methodologies based on satellite imagery and radar. 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, it was made a study that includes: (1) statistical analysis of maximum daily rainfall (2) the precipitation pattern, its value and the spatial and time distributions (design storms).

For statistical analysis of rainfall it were studied 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 analysed using the double mass method. After the rectification of some inconsistencies, the data obtained has been modified by a correction factor (a) 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: (b) factor proposed by Témez (1991) to take into account the spatial variability of the rainfall over the watershed area, and (c) curves proposed by WMO for calculating areal depth as a percentage of point precipitation values. The definitive values of correction factors and daily maximum precipitation for each watershed and return period are presented in Table 1.

To take into consideration the distribution of rainfall it has been considered a rainfall pattern according to the manner 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 1 Basins hydraulic characteristics

Correction factors for all basins: (a) = 1.13; (b) = 0.89; (c) = 0.99					**Daily maximum rainfall (mm)**					
Basin	**Area (Km^2)**	***L* (km)**	***i* (m/m)**	**Time (h)**	$P_{1.4}$	P_5	P_{10}	P_{50}	P_{500}	P_{1000}
Intermedia	48	25.230	0.0082	24	30	78	99	145	210	229
Hoya de España	48	27.241	0.0082	24	32	74	92	131	187	204
Mergajón	52	12.874	0.0274	24	36	92	118	176	257	281
Las Angustias	49	12.982	0.0392	24	101	166	195	257	344	370

The *SCS* rainfall-runoff transformation model 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: $T_{lag} = 0.35 \cdot T_c$, 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). Results are given in Table 2. Similarly, for the Muskingum-Cunge and kinematic wave channel routing models, several cross sections and roughness coefficients should be obtained from the MDT. Finally, it was obtained the stream flow hydrographs for each return period. In Table 3 we can see values of T_c and T_{lag} and the peak discharge for the different Albujón sub-basins, and the value of Las Angustias. Comparing results of Mergajón with Las Angustias, it is noticed that they are very similar either in precipitation as in liquid flow (for return periods larger than 50 years).

Table 2 T_c and T_{lag} values and peak outflow discharge for each basin

			Peak outflow discharge (m^3/s)					
Basin	**T_c (min)**	**T_{lag} (min)**	$Q_{1,4}$	Q_5	Q_{10}	Q_{50}	Q_{500}	Q_{1000}
Albujón Intermedia	512	179	5	68	106	198	336	379
Hoya de España	532	186	6	55	84	157	270	305
Mergajón	290	102	14	148	229	422	701	786
Las Angustias	180	63	121	277	350	519	762	836

If we analyse flows for the different basin in relation with area and rainfall then the liquid flows in Albujón Intermedia and Hoya de España, are much lower than the Mergajón (similar areas and reduced rainfall approximately in 18%). This fact is caused by their different watersheds shapes, which is reflected in the values of T_c and T_{lag}.

4. HYDRAULICAL CHARACTERIZATION. STUDY OF SEDIMENT TRANSPORT

Regarding the source of sediments, the transport may be divided in: (1) wash load which include very fine material and is transported in suspension, and (2) total bed transport which is transported on bed and in suspension (depending on the sediment size and flow velocity). 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 3 shows grain-size distribution curves of the four gullies analysed and Table 3 shows the principal hydraulic characteristics.

Table 3 Principal hydraulic characteristic of the basin

Basin	**Q_T m^3/s)**	**y/D_{84}**	**Q_{1000} m^3/s)**	**R_h/D_{50}**	**Q_T (m^3/s)**	**Weight conc. %)**	**σ_g**
Intermedia	Q_{10} =106	40	379	170	Q_{10} = 105.8	0.30	4.15
H. España	Q_{10} =84	4	305	87	Q_{10}= 105.8	0.32	2.79
Mergajón	$Q_{1.4}$ =14	23	786	442	Q_{50}= 105.8	0.28	5.03

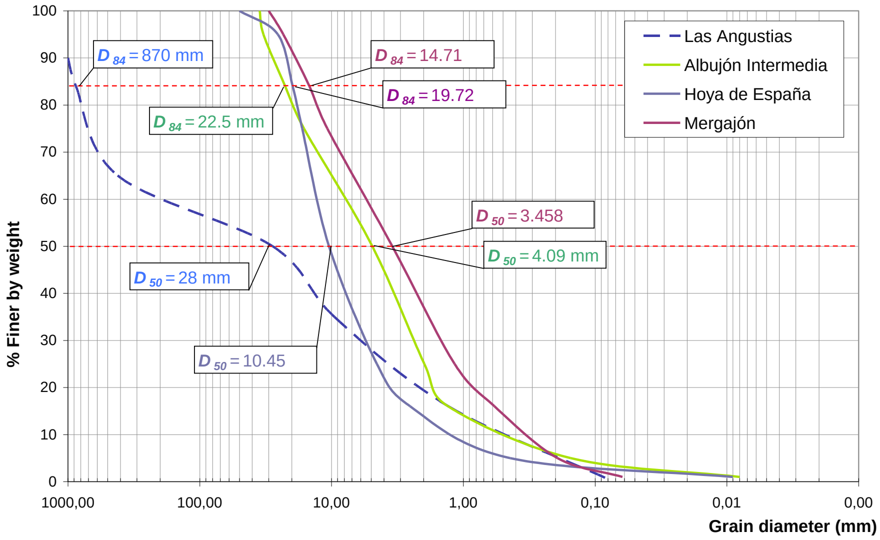


Figure 3 Grain-size distribution curves o the gullies showing D_{85} and D_{50}

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 and Marin (2009), four aspects are checked to determine hydraulic characteristics of the flow: (1) macro roughness, (2) bed form resistance, (3) hyper concentrated flow, and (4) bed armouring phenomenon.

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]. 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. Nevertheless, bed armouring phenomenon does occur 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 3).

For the estimation of the roughness coefficient in the case of macro rough flows, different formulae analysed, Castillo et al. (2009, 2000) have been applied. The formulae are calculated coupling iteratively the hydraulic characteristics with the sediment transport and so, to obtain grain mean roughness. Table 4 shows those formulations which best fitted to the mean value.

Table 4 Resistance coefficient for macro-rough flows

FÓRMULAE	OBSERVATIONS
Bathurst (1985): $C^* = 5.62\log[d/D_{84}]+4;\quad 0.3 \le d/D_{84} \le 50$	d= Depth (m) $0.4\% \le S_0 \le 4\%$;
Fuentes and Aguirre (1991): $C^* = 5.657\log\left[d/D_m\right]+1.333+0.737\left[1/(d/D_m)\right]$ $0.3 \le d/D_{50} \le 77$	d= Depth (m) $0.001\% \le S_0 \le 6.55\%$
García Flores (1996) (Supercritical Regimen): $C^* = 5.756\log\left[d/D_{84}\right]+3.698;\quad 0.30 \le d/D_{84} \le 100$ $n = 0.111d^{1/6}/[2\log(d/D_{84})+1.2849]$	d= Depth (m)
Van Rijn (1987): $C^* = 5.75\log(12R_f/3D_{90})$	R_f= Bed total hydraulic Radius (m)

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 roughness. 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).

4.2. Estimation of Sediment transport

Castillo et al. (2009) analysed 12 formulations which have been applied to evaluate sediment transport capacity from each gully. Liquid flows of different return periods (between 1.4 and 1,000 years) have been calculated. Table 5 shows those formulations, which results are placed around the mean values, and Figure 4 shows the mean transport capacity. 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.

Table 5 Sediment transport formulations that best performing

FÓRMULAE	OBSERVATIONS
Meyer- Peter and Müller (1948): $\gamma(K_s/K_r)^{3/2} R_s I = 0.047\gamma'_s D_m + 0.25\gamma'^{2/3}_s \rho^{1/3} \left(g_{BT}/\gamma_s\right)^{2/3}$ $K_r = \frac{26}{D_{90}^{1/6}}; K_s = \frac{B^{2/3} K_m K_w}{\{K^{3/2}_w (B+2d) - K_m^{3/2}\, 2d\}^{2/3}}; K_m = \frac{1}{n}; K_w = \frac{1}{n_w}$	g_{BT} =Unit total bed transport in weight (T/ms); b = width (m); d = depth (m); n_w=roughness coefficient of banks
Einstein and Barbarrosa (1952): $i_B g_{Bi} = \Phi_* i_b \gamma_s \left(g\Delta D_i^3\right)^{1/2}; g_{BT} = g_B + g_{BS}$ $i_S g_{Bsi} = i_B g_{Bi} \{P_E I_1 + I_2\};\ i_{BT} g_{BTi} = i_B g_{Bi} \cdot \{1 + P_E I_1 + I_2\}$ $g_{BT} = \sum_{i=1}^{n} i_{BTi} g_{BTi}; \Psi_* = \xi Y(\beta/\beta_X)^2 \Psi'; \xi = f(D_i/X), Y = f(D_{65}/\delta')$ $X = 0.77\Delta'\ si\ \Delta'/\delta' > 1.8; X = 1.39\delta'\ si\ \Delta'/\delta' < 1.8; \beta = \log 10.6 = 1.025$ $\beta_X = \log(10.6X/\Delta'); \Psi' = \Delta\left[D_i/(R'S)\right]; E = a/d; a = 2D_i; z = w/(K\beta U'_*)$ $\Delta' = \frac{K_S}{\chi}; K_S = D_{65}; \chi = f(K_S/\delta'); U'_* = \sqrt{gR'S}$	$P_E = 2.303\log(\frac{30.2d}{\Delta'})$ $I_1 = 0.216 \frac{E^{Z-1}}{(1-E)^Z} \int_E^1 \left(\frac{1-y}{y}\right)^Z dy$ $I_2 = 0.216 \frac{E^{Z-1}}{(1-E)^Z} \int_E^1 \left(\frac{1-y}{y}\right)^Z \ln(y) dy$ d = depth (m); S= slope;
Bathurst et al. (1987): $\phi = (2.5S^{3/2}/[(\Delta+1)D_{50}(g\Delta D_{50})^{1/2}])[q - q_c];$ D_{50}: $q_c^* = \frac{q_c}{g^{1/2} D_{50}^{3/2}} = 0.15S^{-1.12}$; D_{16}: $q_c^* = \frac{q_c}{g^{1/2} D_{16}^{3/2}} = 0.21S^{-1.12}$	S= slope; q= unit liquid flow; q_c= critical flow; Δ = dimensionless apparent specific gravity.
Yang S. (2005): $C = \frac{g_t}{Vh} = k \frac{\gamma_s}{\gamma_s - \gamma} \frac{\tau_o}{Vh} \frac{u'^2_* - u_{*c}^2}{w}$; k = 12.5 k = 12.5 Alb. Intermedia, Hoya España and Angustias; k= 6 Mergajón u'^2_* = grain-shear velocity; u_{*c}^2 = Shields grain critical-shear velocity, w=particle fall velocity; τ_o=shear stress; γ= specific weight of water.	C= weight total sediment concentration; g_t =total bed transport per width; h= hydraulic radius or water depth; V=mean velocity; d=sediment size; γ_s=specific weight of sand.

To compare the proportions of bed transport and suspended bed transport, we applied Einstein-Barbarossa method. Figure 5 and Table 6 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. Aguirre et al. (2000) point that for slopes between 0.01 and 0.20, bed transport can reach about 50% of total bed transport.

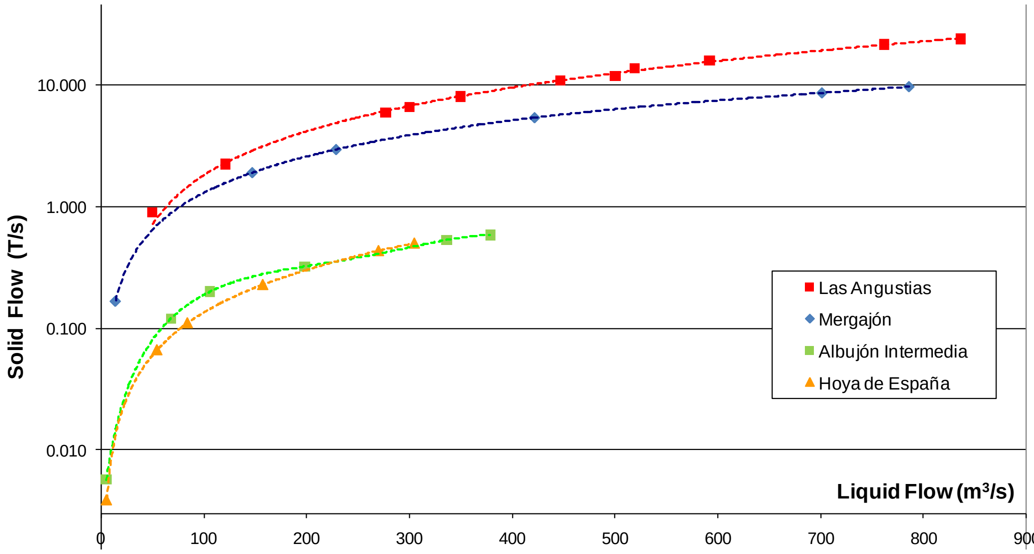


Figure 4 Comparison between total bed transport (T/s) in function of liquid flow (m^3/s)

In contrast to this, in rivers with low slope, the 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 6, 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.

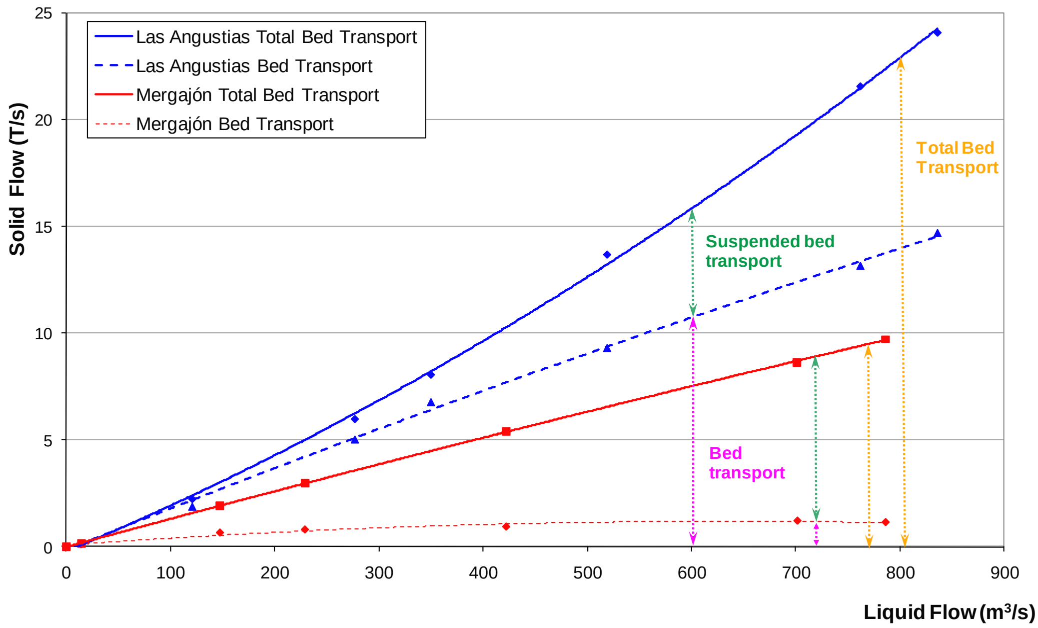


Figure 5 Comparison between Las Angustias and Mergajón basins

Table 6 Main results of bed transport and suspended bed transport proportions

Basin	***$Q_{T1.4}$* (m^3/s)**	***Bed transport***	***Suspended bed transport***	***Q_{T1000}* (m^3/s)**	***% Bed transport***	***Suspended bed transport***
Angustias	121	84 %	16 %	836	61 %	39 %
Mergajón	14.3	70 %	30 %	786	12 %	88%
Intermedia	5.2	88 %	12 %	379	51 %	49 %
Hoya España	5.6	97 %	3 %	305	66 %	33 %

5. SUMMARY AND CONCLUSIONS

Albujon basin has two types of sub-basins, mountain and alluvial watersheds. In this paper the hydrologic and hydraulic characterization of three Albujon sub-basins have 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, comparing the results obtained, it can be concluded that 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. Also, we can say that for alluvial rivers, the use of the kinematic wave channel routing is more appropriate than Muskingum-Cunge model. Finally, although the use of event models semi-distributed is recommended for the case of basins with little or no data of events. However, it is necessary to study these ephemeral rivers with distributed models and compare the results.

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 emphasis on the importance of sampling in the calculation of sediment transport.

6. ACKNOWLEDGMENTS

The research is part of the project PEPLAN: "Hydrological modelling in Semi-Arid Regions. Subproject 3: Modelling of intakes in ephemeral rivers". The authors are grateful for financial support of Consejería de Universidades, Empresa e Investigación of Comunidad Autónoma of Región de Murcia.

7. REFERENCES

Aguirre-Pe J., Olivero M.L. and Moncada A.T. (2000), *Transporte de sedimentos en cauces de alta pendiente*, Ingeniería del Agua, Vol.7, No. 4, pp. 353-365.

Bathurst, J.C. (1985), *Flow resistance estimation in mountain rivers,* J. Hydraulic Engineering, ASCE, Vol.111, No 4, pp. 625-643.

Bathurst J.C., Graf, H. and Cao, H.H. (1987*), Bed load discharge equations for steep mountains rivers,* in John Wiley and Sons, "Sediment transport in gravel bed rivers", N.Y, USA, Cap.15, pp. 453-491.

Castillo, L., Santos, F., Ojeda, J., Calderón, P., and Medina, J.M. (2000), *Importancia del muestro y limitaciones de las formulaciones existentes en el cálculo del transporte de sedimentos, XIX IAHR,* Córdoba, Argentina.

Castillo, L. (2004), *Estimation of sediment transport and dominant flow in hyperconcentrated flows, ICHE-2004*, Brisbane, Australia.

Castillo, L. (2007), *Discussion about prediction of bed material discharge,* J. Hydraulic Research, Vol.45, No.2, pp. 425-428.

Castillo, L., Martín Vide, J.P., and Marín, M.D. (2009), *Coeficientes de resistencia, transporte de sedimentos y caudal dominante en regiones semiáridas, I JIA, 2009,* CEDEX. Madrid.

Einstein, H.A. and Barbarrosa, N. L. (1956), *River Channels Roughness*, ASCE Vol.177, pp. 440-457.

Meyer-Peter, E. and Müller, R. (1948), *Formulations of the Bed-load Transport, II IAHR,* Stockholm, pp. 39-64.

Fuentes, R. and Aguirre-Pe, J. (1991), *Resistance to flow in steep rough streams*, J. Hydraulic Engineering, Vol.116, No 11, pp. 1374-1387.

García Flores, M. (1996), *Resistencia al flujo en ríos de montaña, XVII IAHR* Guayaquil, Ecuador.

Salas, J.D. (2000), *Hidrología de zonas áridas y semiáridas,*Ingeniería del Agua, Vol.7, No4,pp.409-429.

Témez, J.R. (1991), *Generalización y mejora del método racional, Versión de la Dirección general de Carreteras de España,* Ingeniería Civil, CEDEX-MOPT, No 82, pp. 51-56.

Van Rijn, L.C. (1987*), Mathematical modelling of morphological processes in the case of suspended sediment transport,* Delft Hydraulics Communication No. 382.

Yang, S.Q. (2005), *Sediment Transport Capacity,* J. Hydraulic Research, IAHR Vol.43, No 1, pp. 12-22.