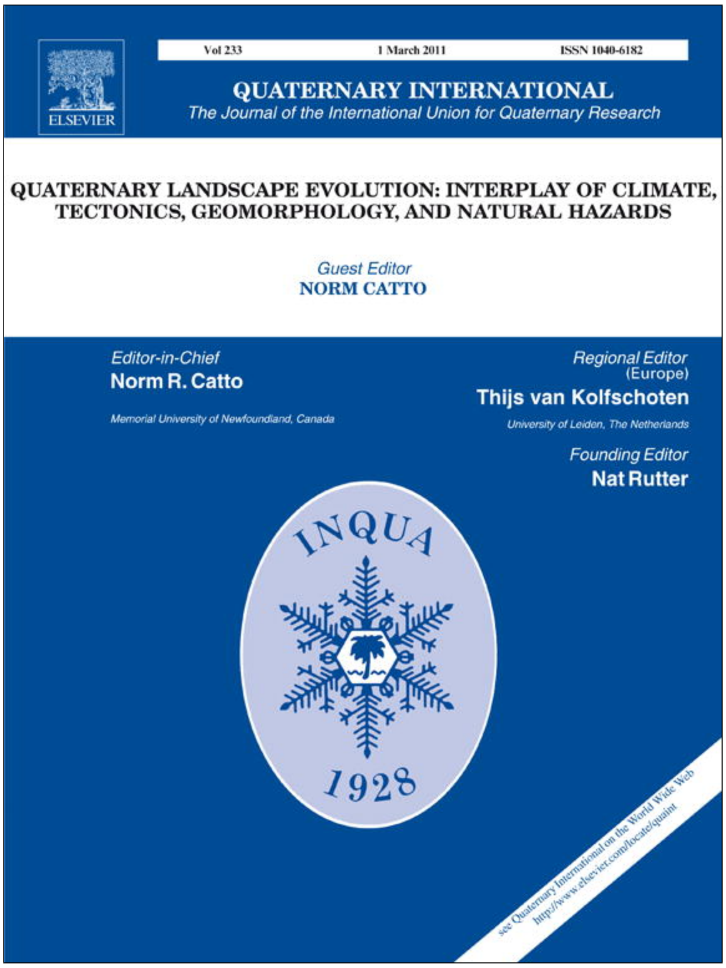
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# Morphometric characterization of del Molle Basin applied to the evaluation of flash floods hazard, Iglesia Department, San Juan, Argentina

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ABSTRACT

One of the main geological hazards that affect the Iglesia department is flash floods, produced by heavy seasonal rains, characterized by their high velocities and destructive power. These streams are generated in the watersheds of the mountainous region of the Cordillera Frontal. The del Molle basin was selected as a suitable case to evaluate the potential magnitude of flash floods in relation to their associated hazard level in Malimán de Arriba, located directly at the confluence of the tributaries with the Blanco River. This paper evaluates some of the hydrological aspects of a torrential regime basin that caused severe damage in Malimán during January 2010.

This work analyzes different morphometric characteristics of the El Molle basin in order to evaluate the flash flood hazard. For this purpose, the basin is divided into four sub-basins and some basic parameters (surface, perimeter, basin length, elevations and slope of the main riverbed) are calculated. These parameters allow approximate prediction of the behavior of the basin in the presence of a series of theoretical rainstorms which may generate unusual runoff volumes. The predicted flash floods were compared against the Malimán flash flood.



## 1. Introduction

Morphometric characteristics of a basin allow estimation of its hydrological behavior. This study, combined with geology and geomorphology studies, helps to construct a primary hydrological diagnosis. This diagnosis can be used to establish the possible behavior of the basin during rainstorms, its probable extent and impact, and to implement strategies of flash flood-control (Hungr, 2000).

Flash floods are one of the most common geologic hazards in the study area. According to NWS/NOAA (2010), a flash flood is a very fast flow that occurs generally in arid environments. It can also be defined as the rapid increase in water level in a stream as a result of heavy rains or the collapse of a natural or artificial dam. These flash floods grow in magnitude when the field infiltration rate is reduced by previous rains.

Most of the small towns in the Department of Iglesia (Fig. 1) are situated downstream of river basins from the Cordillera Frontal (Malimán, Colangüil, Angualasto) or Precordillera (Buena Esperanza). These villages have suffered flash floods during every summer period, which have caused material damage and several casualties, for example during 1913 and 1944 (Buena Esperanza). The elongated morphology of the main watersheds, coupled with their significant height difference (promoting rapid runoff), are the most important factors that control flow generation. For example, on 19 January 2007, heavy rains occurred over the Department of Iglesia, damaging the road that connects the farming communities of Angualasto, Buena Esperanza and Malimán.

On January 23, 2010, at 19:00 as a result of heavy rainfall, a sizeable flash flood affected the town of Malimán de Arriba at the confluence of the del Molle basin with the Blanco River (Fig. 2a). As a result of the flash flooding, several homes were damaged (Fig. 2c), and most of the crops and farm animals were lost. The local school and irrigation channels also suffered severe damage (Fig. 2b). The bridge linking Angualasto and Buena Esperanza (located downstream of the study area), was damaged as well (Fig. 1). Unfortunately, there is no data about the volume of water precipitated this day or in previous days.

In various papers, morphometric analyses were used for basin characterization. Some include Miller (1953), Boulton (1968), Gregory and Walling (1973), Gardiner (1975), Majumdar (1982), Costa (1987), Nag (1998), Topaloglu (2002), Moussa (2003), Sreedevi et al. (2004), Srinivasa Vittala et al. (2004), Mesa (2006) and Esper Angillieri (2008), among others. In this paper,

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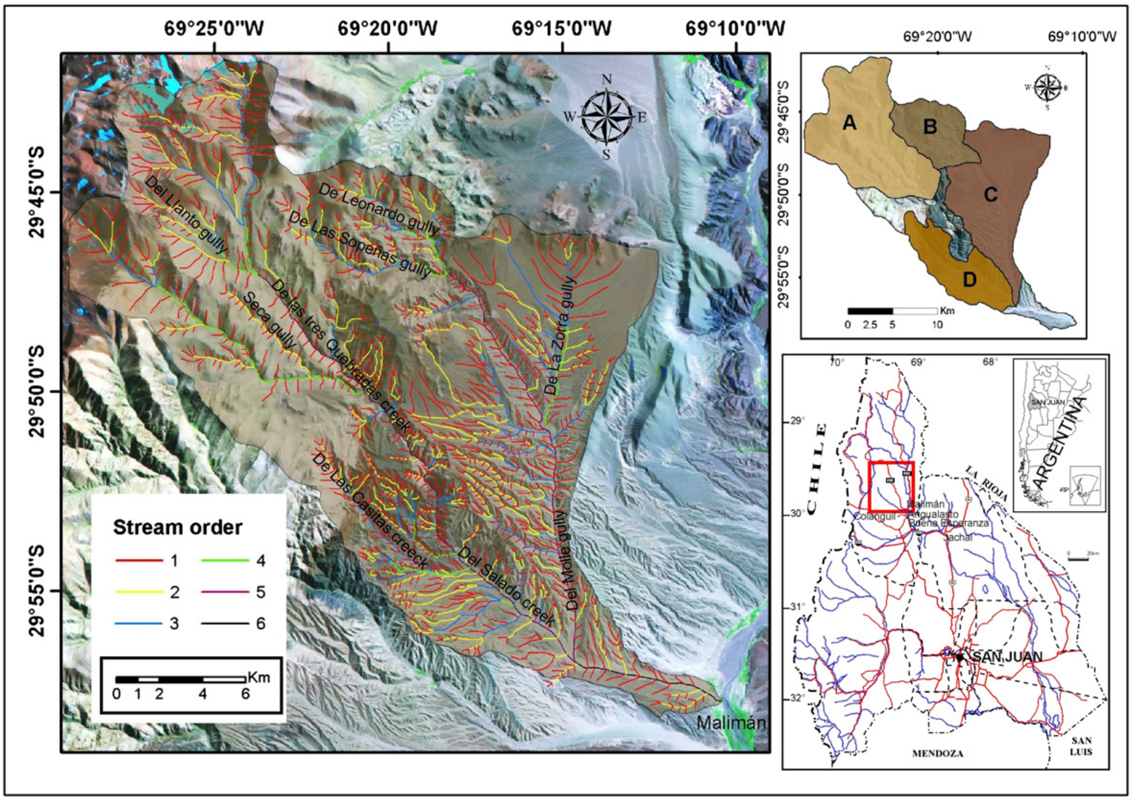


**Fig. 1.** Del Molle river basin and sub-basin location with the stream order.

morphometry and hydrographic characteristics of the del Molle Basin are studied using topographical maps, aerial photographs and satellite images in order to predict the approximate behavior of the basin during heavy rainfall and to calculate the potential hazard of flash floods that may affect the town of Malimán.

## 2. Study area

The del Molle river basin cover an area of 415.94 km$^2$ in Iglesia, a northwestern Department in the Province of San Juan. At the bottom of the basin lies the town of Malimán de Arriba (27° 57′S, 69° 10′W), a little town dedicated to the farming of mostly alfalfa (Fig. 1).

San Juan province has a general arid and semiarid climate. The total annual average precipitation is scarce: about 93.3 mm. Winter temperatures are generally mild, ranging between 1 °C and 18 °C; whereas summers are very dry and hot, with temperatures between 19 °C and 35 °C.

In the area of Malimán, average annual rainfall is below 44.9 mm. However, in the western mountainous area, rainfall is much higher, exceeding 300 mm (Minetti, 1986). During summer, the absolute maximum temperature for the area is 35.4 °C (February), while in winter the absolute minimum temperature recorded in Rodeo is −12.1 °C (July) (Data recorded at the Meteorological Station “Rodeo”, Iglesia Department). In the period between December and March, heavy rainfalls of short duration but torrential character are responsible for the generation of large flash floods. The area’s steep gradient rapidly drains these precipitated volumes of water, funneling them towards the Río Blanco.

## 3. Geology

In the Andean Frontal Cordillera, two tectonostratigraphic main groups can be recognized: a Gondwanan Basement of Devonian and Permo-Carboniferous marine sedimentary rocks, intruded by Upper Paleozoic granitic rocks; and an Andean continental volcanic and volcaniclastic unit, essentially Mesozoic and Palaeogene, intruded by Triassic to Miocene stocks (Ramos, 1999).

In the specific area of study, the oldest exposed unit corresponds to Upper Carboniferous-Late Permian. It consists of dark green lutites interbedded with sandstones and some conglomerates. This unit is unconformably overlain by a Permo-Triassic volcanic complex composed of pyroclastic, subvolcanic and intrusive rocks (andesites, dacites and rhyolites). Both units are intruded by Miocene rocks (granodiorites, andesites, dacites and granites). The Pleistocene is represented by glacial, alluvial and colluvial deposits and the Holocene by conglomerates, sands and marl occupying the valleys and riverbeds (Fig. 3).

## 4. Materials and methods

Both the del Molle basin and sub-basin delineation were made using aerial photographs (1:15,000), digital satellite imagery (Landsat 7-TM) and geological maps (1:250,000). Stream ordering followed Strahler (1964). The main stream length (Lcp) and basin length ($L$) were prepared after Schumm (1956). Elevations were obtained using topographic maps (1:100,000 and 50 m contour lines) and with topographical information obtained from the Radar Shuttle Topographical Mission (USGS, 2000). A digital elevation model (DEM) was interpolated (Fig. 4) and a slope map was obtained.

The morphometric characterization of basin and sub-basin was made using GIS technology. These morphometric parameters were divided into basic parameters: area ($A$), perimeter ($P$), length ($L$), basin order (On), stream order ($O$), maximum and minimum heights ($H$, $h$), total stream length (Ltc), main stream length (Lcp), total stream length of a given order (ln), number of stream


**Fig. 2.** a) Aerial view of Malimán de Arriba b) View to the east of the town of Malimán de Arriba, located directly downstream from the del Molle river c) Damage to houses of Malimán de Arriba.

segments of a given order (Nn); and derived parameters, obtained from the following equations:

| | | |
|---|---|---|
| Compactness index | $Kc = 0.28(P/\sqrt{A})$ | (Gravelius, 1914) |
| Circularity Index | $Rc = 4\pi A/P^2$ | (Miller, 1953) |
| Elongation Ratio | $Re = (\sqrt{4A/\pi})/L$ | (Schumm, 1956) |
| Form Factor | $Ff = A/L^2$ | (Horton, 1932) |
| Channel sinuosity | $S = Lcp/L$ | (Schumm, 1977) |
| Mean Width | $Wm = A/L$ | |
| Basin Relief | $Hr = H - h$ | (Hadley and Schumm, 1961) |
| Relief ratio | $Rr = Hr/L$ | (Schumm, 1956) |
| Melton's ruggedness number | $MRN = Hr/A^{0.5}$ | (Melton, 1957) |
| Drainage Density | $Dd = Ltc/A$ | (Horton, 1932) |
| Stream Frequency | $Fn = \sum N_n/A$ | (Horton, 1932) |
| Drainage Texture | $Td = \sum N_n/P$ | (Horton, 1945) |
| Bifurcation ratio | $Rb = N_{n-1}/N_n$ | (Schumm, 1956) |

The analysis of flow-rate gauging was made using the mathematical simulation model of Rain-Discharge Transformation (Arhymo). As this model was intended for the simulation of small basins, the authors decided to split the del Molle basin into a number of sub-basins, based on their morphometric and lithological characteristics.

Once the basin and sub-basins were delineated, it was necessary to calculate the curve number (CN) for each sub-basin. CN is a standardized parameter developed by the Soil Conservation Service (1986), related to the soil characteristics (humidity, infiltration, etc.). It value ranges from 0 (high infiltration) to 100 (no infiltration) and it gives an illustration of the water retention capacity of the basin.

The following step entailed the simulation of discharges towards Malimán de Arriba.

Storms chosen for this study were that of December 26, 1967 which recorded 52 mm of rainfall with an intensity of 104 mm/h, and the one from February 26, 1981 with 40 mm of rainfall and an intensity of 48.9 mm/h (Data from the Colangüil Weather Station). Different scenarios were considered as regards the rainstorm area: homogeneous precipitation for the entire basin; precipitation in two sub-basins; and precipitation in only one sub-basin without any previous moisture condition. Previous rain was also considered (i.e. infiltration reduction). Finally, the return interval ($T$) and flow occurrence probability ($P$) were calculated, from rainfall data and

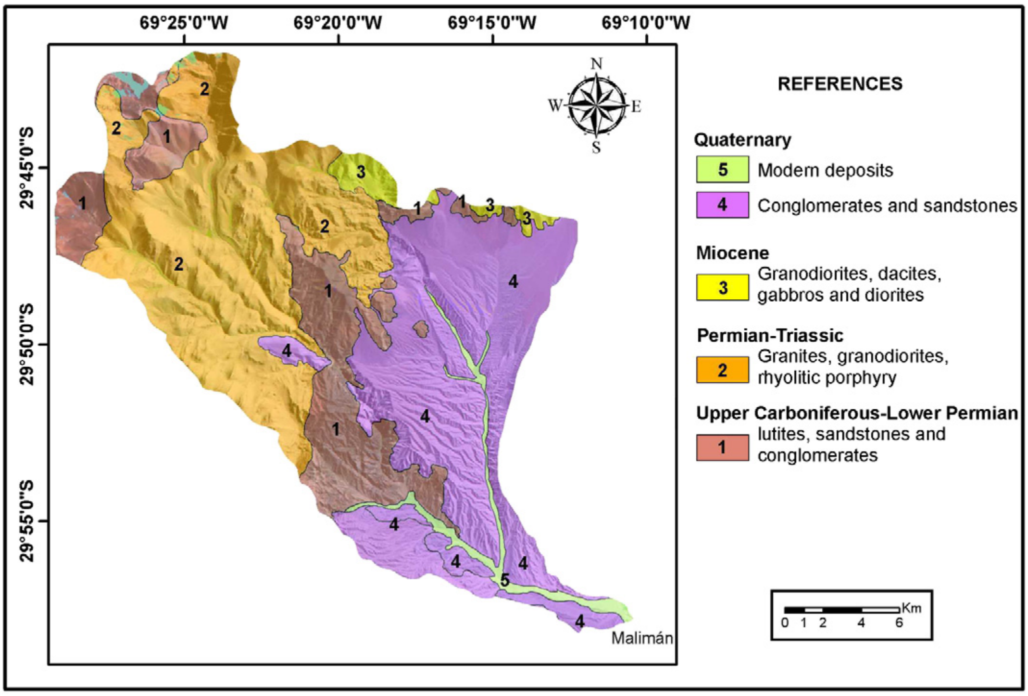


**Fig. 3.** Lithological Map.

the resulting discharges, by assigning probabilities to the different values using the Weibull (1939, 1951) equations

$$T = (N+1)/n$$

$T$ = Return interval; $N$ = total years of collected data; $n$ = order number of maximum daily rainfall per annum in descending order (independently of the date of occurrence

$$P = (1/T)*100\%$$

$P$ = probability of a storm of some magnitude in any year

$$P_{(o)} = 1-(1-P)^N$$

$P_{(o)}$ = probability of occurrence of a particular storm in a series of $N$ years.

## 5. Results and discussion

From North to South, the del Molle river basin includes de las Sopeñas, de Leonardo, del Llanto, del Molle, Seca de las Tres Quebradas, del Salado and las Casitas creeks. This is a 6th order basin that was subdivided into four sub-basins (Fig. 1) for this study. It covers an area ($A$) of 415.94 km$^2$, has a perimeter ($P$) of 111.08 km, a total length ($L$) of 39.91 km and a mean width (Wm) of 10.42 km.

Its main stream length (Lcp) is 45.50 km, while the total stream length (Ltc) is 962.13 km. It has a dendritic drainage pattern. The

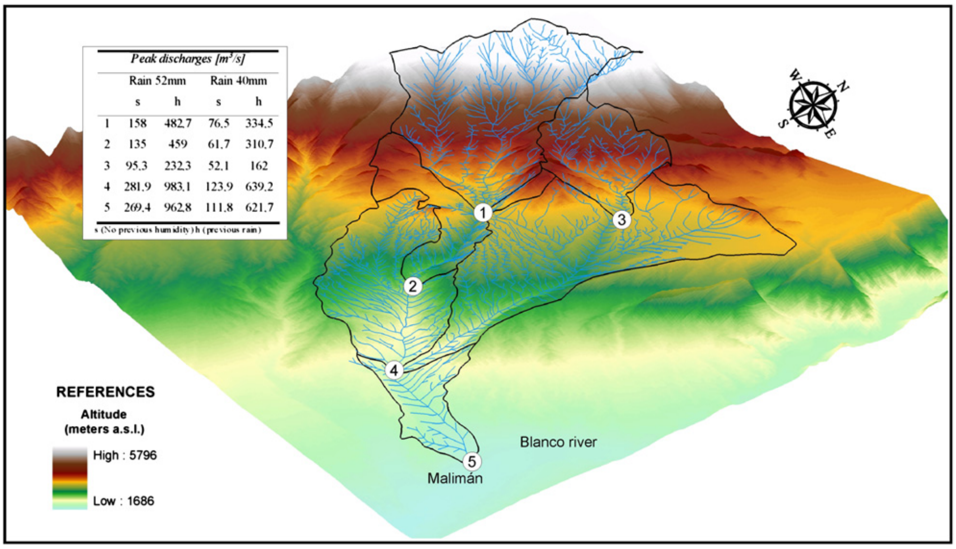


**Fig. 4.** 3D view of del Molle basin and simulated peak-discharges table.

**Table 1**
Del Molle basin morphometric parameters.

| Del Molle basin | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Basic parameters | | | | | | | | |
| | | *A* [km$^2$] | *P* [km] | *L* [m] | *H* [m asl] | *h* [m asl] | Tcl [km] | Mcl [km] |
| TBasin | | 415.94 | 111.08 | 39911.45 | 5639 | 1744 | 962.13 | 45.50 |
| Sub-basin | A | 135.07 | 55.44 | 18893.68 | 5639 | 2772 | | 21.70 |
| | B | 49.02 | 30.56 | 11966.75 | 4598 | 2841 | | 14.31 |
| | C | 117.42 | 59.16 | 20573.19 | 3420 | 1989 | | 22.73 |
| | D | 58.13 | 43.34 | 13377.78 | 3124 | 1989 | | 15.30 |

| Derived parameters | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Kc | Rc | Re | Ff | *S* | Wm [m] | Hr [m] | Rr | MRN | Dd [km/km$^2$] |
| TBasin | | 1.52 | 0.42 | 0.58 | 0.26 | 1.14 | 10421.54 | 3895 | 0.10 | 0.19 | 2.31 |
| Sub-basin | A | 1.34 | 0.55 | 0.69 | 0.38 | 1.15 | 7149.04 | 2867 | 0.15 | 0.25 | |
| | B | 1.22 | 0.66 | 0.66 | 0.34 | 1.20 | 4096.13 | 1757 | 0.15 | 0.25 | |
| | C | 1.53 | 0.42 | 0.59 | 0.28 | 1.10 | 5707.63 | 1431 | 0.07 | 0.13 | |
| | D | 1.59 | 0.39 | 0.64 | 0.32 | 1.14 | 4345.06 | 1135 | 0.08 | 0.15 | |

| O | Nn | ln [m] | Fn [n/km2] | Td [n/km] | Rb |
|---|---|---|---|---|---|
| 1 | 1234 | 542974.23 | 2.97 | 11.11 | 7.62 |
| 2 | 162 | 234899.15 | 0.39 | 1.46 | 3.77 |
| 3 | 43 | 95861.01 | 0.10 | 0.39 | 4.78 |
| 4 | 9 | 35672.94 | 0.02 | 0.08 | 4.50 |
| 5 | 2 | 45556.01 | 0.00 | 0.02 | 2.00 |
| 6 | 1 | 7170.88 | 0.00 | 0.01 | |

compactness index (Kc) of 1.52, the circularity index (Rc) of 0.42, the elongation ratio (Re) of 0.58 and the form factor (Ff) of 0.26, reveal an elongated basin with steep relief (Hr: 3895 m). The sinuosity (*S*) which has values close to 1 shows a rectilinear main stream indicating a high water flood speed, facilitated by steep slopes as shown by a relief ratio (Rr) of 0.10 for the whole basin and a moderate to high sediment supply.

Melton's ruggedness number (MRN) is lower than 0.3, indicating this basin is more susceptible to flows with low mass content. Drainage density (Dd) and Drainage Texture (Td) values reveal the existence of more impervious material towards the headwaters and slopes of the basin than in the lower areas. Lower order riverbeds are predominant according to a riverbed order analysis. The basin and sub-basin morphometric parameters are shown on Table 1.

Curve Number (CN) values assigned to each sub-basin are shown on Table 2. Values obtained by modelling rainfall/discharge (Table 3) show a high risk of flash floods with peak values in excess of 300 m$^3$/s (Fig. 4). When previous moisture conditions, i.e. rainfall events in the previous days are taken into account, outlet peak discharges increase.

Rainfall data from the Colangüil Weather Station (Table 4) shows an interval of recurrence ($T = (28 + 1)/1$) of 29 years and a probability ($P = 1/T$) of 3.45% for a rainfall of 52 mm happening in any year, and a probability of 30% for that same rainfall happening within 10 years. Meanwhile for a rainfall of 45 mm (higher than the one under study) the interval of recurrence becomes 7.25 years and the probability is 13.79% for the storm taking place on any year and 77% within 10 years.

**Table 2**
Curve numbers (CN) designed for each sub-basin.

| Sub-basin | *A* | *B* | *C* | *D* |
|---|---|---|---|---|
| CN | 80 | 80 | 65 | 70 |
| CN[a] | 94 | 94 | 83 | 87 |

[a] Previous humidity.

**Table 3**
Peak discharges (m$^3$/s) resulting from del Molle Basin.

| Peak discharges [m$^3$/s] | | | | |
|---|---|---|---|---|
| | Rain 52 mm | | Rain 40 mm | |
| | *s* | *h* | *s* | *h* |
| The whole basin | 269.4 | 962.8 | 111.8 | 621.7 |
| Sub-basins *A* + *D* | 158.6 | 589.2 | 67 | 386.2 |
| Sub-basins *B* + *C* | 118.2 | 369.6 | 56.7 | 238.3 |
| Sub-basins *C* + *D* | 77.2 | 328.4 | 26.6 | 196.9 |
| Sub-basin *D* | 41.6 | 151.3 | 16.5 | 94.4 |
| Sub-basin *C* | 38.2 | 187.4 | 10.9 | 108.8 |

s (No previous humidity conditions), h (previous rain).

**Table 4**
Estimation of return periods and probabilities (Weibull, 1939, 1951).

| Year | Rain [mm] | Intensities [mm/h] | *n* | *T* | *P* [%] | 10 | 20 | 25 | 50 | 100 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | $P_{(o)}$ | | | | |
| 1967 | 52.0 | 104.0 | 1 | 29.00 | 3.45 | 0.30 | 0.50 | 0.58 | 0.83 | 0.83 |
| 1973 | 50.0 | s/d | 2 | 14.50 | 6.90 | 0.51 | 0.76 | 0.83 | 0.97 | 0.97 |
| 1982 | 50.0 | 22.7 | 3 | 9.67 | 10.34 | 0.66 | 0.89 | 0.93 | 1.00 | 1.00 |
| 1981 | 45.0 | 3.1 | 4 | 7.25 | 13.79 | 0.77 | 0.95 | 0.98 | 1.00 | 1.00 |
| 1970 | 36.0 | 17.2 | 5 | 5.80 | 17.24 | 0.85 | 0.98 | 0.99 | 1.00 | 1.00 |
| 1980 | 35.0 | 14.0 | 6 | 4.83 | 20.69 | 0.90 | 0.99 | 1.00 | 1.00 | 1.00 |
| 1975 | 30.0 | s/d | 7 | 4.14 | 24.14 | 0.94 | 1.00 | 1.00 | 1.00 | 1.00 |
| 1976 | 30.0 | 15.0 | 8 | 3.63 | 27.59 | 0.96 | 1.00 | 1.00 | 1.00 | 1.00 |
| 1969 | 27.0 | 2.2 | 9 | 3.22 | 31.03 | 0.98 | 1.00 | 1.00 | 1.00 | 1.00 |
| 1987 | 26.0 | 13.0 | 10 | 2.90 | 34.48 | 0.99 | 1.00 | 1.00 | 1.00 | 1.00 |
| 1989 | 25.7 | 8.6 | 11 | 2.64 | 37.93 | 0.99 | 1.00 | 1.00 | 1.00 | 1.00 |
| 1978 | 25.5 | 25.5 | 12 | 2.42 | 41.38 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 1979 | 25.5 | 14.2 | 13 | 2.23 | 44.83 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 1968 | 25.0 | 5.3 | 14 | 2.07 | 48.28 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 1972 | 25.0 | 8.3 | 15 | 1.93 | 51.72 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 1991 | 23.0 | 2.6 | 16 | 1.81 | 55.17 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 1986 | 22.5 | 5.6 | 17 | 1.71 | 58.62 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 1994 | 20.5 | 10.3 | 18 | 1.61 | 62.07 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 1983 | 18.0 | 24.0 | 19 | 1.53 | 65.52 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 1977 | 15.5 | s/d | 20 | 1.45 | 68.97 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 1990 | 14.0 | 6.2 | 21 | 1.38 | 72.41 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 1974 | 11.5 | 7.7 | 22 | 1.32 | 75.86 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 1993 | 11.5 | 2.9 | 23 | 1.26 | 79.31 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 1971 | 11.0 | 22.0 | 24 | 1.21 | 82.76 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 1992 | 10.0 | 1.2 | 25 | 1.16 | 86.21 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 1988 | 9.5 | 1.1 | 26 | 1.12 | 89.66 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 1984 | 4.0 | 1.0 | 27 | 1.07 | 93.10 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 1985 | 3.6 | 1.0 | 28 | 1.04 | 96.55 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |

Considering the main stream in the basin has a mean stream flow below 3 m$^3$/s and although a validity of only 50% is considered, the results show a high risk of flash floods. The resulting stream flow rates obtained by modelling using Arhymo are only approximations. The validity of these results is controversial as it is difficult to predict their spatial extent of a storm when continuous hydrometeorological records from the headwaters of the basin and sub-basins are not available. In general, weather stations are located in the valleys.

## 6. Conclusions

The morphometric characteristics of the Del Molle basin show that lower order streams mostly dominate this elongated basin. The river network is of 6th order and the general pattern of the basin is dendritic, with underlying homogeneous rocks (mainly granites and granodiorites). Drainage density values (Dd) reveals impervious materials, especially in the headwaters of the basin. Melton's ruggedness number (MRN) suggests high susceptibility to flash flooding, with low amounts of sediment transported.

The values obtained for discharge point to a probability of a serious flash floods hazard, with high peak discharges that can cause severe damage to Malimán de Arriba situated downstream of the del Molle basin. Considering previous conditions, i.e. rainstorms on previous days, the peak discharges of basin outflows can be multiples of their average values.

Based on rainfall records, a recurrence interval of 7.25 years was calculated for a flood event, with a 13.79% probability of occurrence of flooding in any year and a 77% probability of occurrence in 10 years.

Population rearrangement in the area is unlikely. The inhabitants of Malimán have remained there for several generations and their housing and economic activities are concentrated in the vicinity. It is therefore advisable to implement remediation/mitigation measures in order to reduce and diminish human losses within the population caused by flash floods.

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## References

Boulton, A.G., 1968. Morphometric analysis of river basin characteristics. Journal of Hydrology 6 (2), 227.

Costa, J.E., 1987. Hydraulics and basin morphometry of the largest flash floods in the conterminous United States. Journal of Hydrology 93, 313–338.

Esper Angillieri, M.Y., 2008. Morphometric analysis of Colangüil river basin and flash flood hazard, San Juan, Argentina. Environmental Geology 55, 107–111.

Gardiner, V., 1975. Drainage Basin Morphometry. British Geomorphological Group, Technical Bulletin 14, 48 pp.

Gravelius, H., 1914. Flusskunde. Goschen Verlagshan dlug Berlin. En Zavoianu, I. 1985. In: Morphometry of Drainage Basins. Elsevier, Amsterdam.

Gregory, K.J., Walling, D.E., 1973. Drainage Basin Form and Process: A Geomorphological Approach. Wiley, New York, 456 pp.

Hadley, R.F., Schumm, S.A., 1961. Sediment Sources and Drainage Basin Characteristics in Upper Cheyenne River Basin. United States Geological Survey, Water-Supply Paper 1531–B, 198 pp.

Horton, R.E., 1932. Drainage basin characteristics. American Geophysics Union Transactions 13, 350–361.

Horton, R.E., 1945. Erosional development of streams and their drainage basins. Hydrophysical approach to quantitative morphology. Geological Society of America Bulletin 56, 275–370.

Hungr, O., 2000. Analysis of debris flow surges using the theory of uniformly progressive flow. Earth Surface Process and Landforms 25, 483–495.

Majumdar, J., 1982. Morphometric analyses of the 4th order drainage watersheds of the Khowai river basin, Tripura, India. Some preliminary results and observations. Journal of the Indian Society of Remote Sensing 10 (3).

Melton, M.A., 1957. An Analysis of the Relation Among Elements of Climate, Surface Properties and Geomorphology. Office of Naval Research, Department of Geology, Columbia University, New York. Technical Report 11.

Mesa, L.M., 2006. Morphometric analysis of a subtropical Andean basin (Tucumán, Argentina). Environmental Geology 50, 1235–1242.

Miller, V.C., 1953. A Quantitative Geomorphic Study of Drainage Basin Characteristics in the Clinch Mountain Area. Virginia and Tennessee. Technical Report 3. Office of Naval Research, Department of Geology, Columbia University, New York.

Minetti, J.L., 1986. El régimen de precipitaciones de San Juan y su entorno. CIRSAJ-CONICET-UNSJ. Informe técnico 8, 19–22. San Juan.

Moussa, R., 2003. On morphometric properties of basin, scale effects and hydrological response. Hydrological Processes 17, 33–58.

Nag, S., 1998. Morphometric analysis using remote sensing techniques in the Chaka Sub-basin, Purulia District, West Bengal. Journal of the Indian Society of Remote Sensing 26 (1–2).

NWS/NOAA, 2010. Glossary. http://www.weather.gov/glossary/ (accessed 18.05.10.).

Ramos, V.A., 1999. In: Caminos, Roberto (Ed.), Las provincias geológicas del territorio argentino. Geología Argentina. Anales, vol. 29. SEGEMAR, Buenos Aires, pp. 41–96 (3).

Schumm, S.A., 1956. Evolution of drainage systems and slopes in badlands at Perth Ambos, New Jersey. Geological Society of America Bulletin 67, 597–646.

Schumm, S.A., 1977. The Fluvial System. John Wiley & Sons, New York, 338 pp.

Sreedevi, P.D., Subrahmanyam, K., Ahmed, S., 2004. The significance of morphometric analysis for obtaining groundwater potential zones in a structurally controlled terrain. Environmental Geology 47, 412–420.

Srinivasa Vittala, S., Govindaiah, S., Honne Gowda, H., 2004. Morphometric analysis of sub-watersheds in the Pavagada area of Tumkur district, South India using remote sensing and GIS techniques. Journal of the Indian Society of Remote Sensing 32 (4).

Strahler, A.N., 1964. Quantitative geomorphology of drainage basin and channel networks. In: Chow, V.T. (Ed.), Handbook of Applied Hydrology. McGraw Hill, New York, pp. 4–76.

Soil Conservation Service, 1986. Urban Hydrology for Small Watersheds, second ed. United States Department of Agriculture, Washington, TR-55.

Topaloglu, F., 2002. Estimation of instantaneous peak flows in Seyhan river basin using regional regression procedures. Turkish Journal of Agriculture and Forestry 26, 47–55.

USGS, 2000. Shuttle Radar Topography Mission, 3 Arc Second. In: Global Land Cover 347 Facility. University of Maryland, College Park, Maryland.

Weibull, W., 1939. A statistical theory of the strength of materials. Ingeniors Vetenskaps Akademien, Handlingar 151, 45–55.

Weibull, W., 1951. A statistical distribution function of wide applicability. Journal of Applied Mechanics 18, 293–297.