Hydrologic response of the drainage basins that intersect Las Grutas town, Argentina

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Abstract. The town of Las Grutas, in a semiarid region on the north west coast of San Matías Gulf (Argentina), is intersected by two drainage basins that are activated immediately after intense rainfall events. These events generate flows capable of producing local flooding, such as the flood of April 2004. The purpose of this study is to establish the hydrologic behavior of these geoforms and the manner in which the land use interacts with them. The lack of hydrometric records necessitates the explanation and prediction of hydrologic responses through empirical approaches such as fluvial morphometry and the USDA Soil Conservation Service curve number (1972), supported by Geographical Information System technology. The study area has characteristics that favor the concentration of runoff into streams during extreme events. First-order segments play an important role in the hydrologic response, showing great potential to receive surface runoff. The effect of urbanization produces an additional runoff of 17.3% and 2.1% in the respective basins. A potential increase in the number of these extreme events in the future due to climate change may lead to more disturbances in the urbanized area. The results of the present study will contribute to the implementation of measures to mitigate the consequences of floods.

Key words: Drainage basin, hydrologic response, fluvial morphometry, direct runoff, Las Grutas town.

Respuesta hidrológica de las cuencas de drenaje que intersectan el balneario Las Grutas, Argentina

Resumen. La localidad de Las Grutas está emplazada en una región semiárida, en la costa Noroccidental del Golfo San Matías (Argentina) y es intersectada por dos cuencas de drenaje que responden ante eventos de precipitaciones intensas. Estos eventos generan flujos capaces de producir riesgos de inundación local, tal como la inundación de abril de 2004. El objetivo de este trabajo es establecer el comportamiento hidrográfico de dichas geoformas y la manera en el cual los usos de la tierra interactúan con ellas. La falta de registros hidrométricos conduce a explicar y predecir respuestas a través de aproximaciones empíricas como el análisis morfométrico fluvial y el número de curva del Servicio de Conservación del Suelo de los Estados Unidos (1972), apoyados en sistemas de información geográfica. El área en estudio presenta características que favorecen la concentración del escurrimiento en cauces durante eventos extremos. Los segmentos de primer orden juegan un rol importante en la respuesta hidrológica. El efecto de la ur-

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banización produce un efecto adicional del 17.3 y 2.1% de escurrimiento en cada cuenca. El incremento potencial del número de eventos extremos en el futuro debido al cambio climático, podría conducir a mayores perturbaciones en el área urbanizada. Los resultados contribuirán a implementar medidas que mitiguen posibles consecuencias de los peligros de inundación.

Palabras clave: Cuenca de drenaje, comportamiento hidrológico, morfometría fluvial, escurrimiento directo, Las Grutas.

INTRODUCTION

The drainage basin is a well defined entity in which every component element affects its hydrologic response to rainfall input, in a complex interaction that tends to reach a dynamic equilibrium. Within the context of fluvial landscape, anthropogenic processes may result in irreversible changes to the land surface and drainage pattern (Larson and Booth, 2001). Las Grutas town, located in a semiarid climatic region on the north west coast of San Matías Gulf, Argentina, is intersected by two

drainage basins hereafter called *North Basin* and *South Basin* (Figure 1). These fluvial systems are activated immediately after intense rainfall events, which generate flows capable of producing urban flooding, such as the one in April 2004.

Fluvial systems can be described and measured in various ways (White *et al.*, 1998). Particularly in arid and semiarid lands where extreme rainfall events occur, non-gauged basins are often studied empirically (e.g., Navarro, 1986; Durbude and Purandara, 2001; Perucca and Paredes, 2005; Ayala *et al.*, 2006; Esper, 2008). In the present study, the lack of hydrometric records necessitates the explanation and prediction of hydrologic responses through empirical approaches such as fluvial morphometry and the application of the USDA Soil Conservation Service (SCS) Curve Number (CN), (1972), supported by Geographical Information System (GIS) technology.

Preliminary results concerning the hydrographic characteristics of the two study basins were documented in Genchi *et al.* (2008). Only a few studies have been reported in the study area but they are
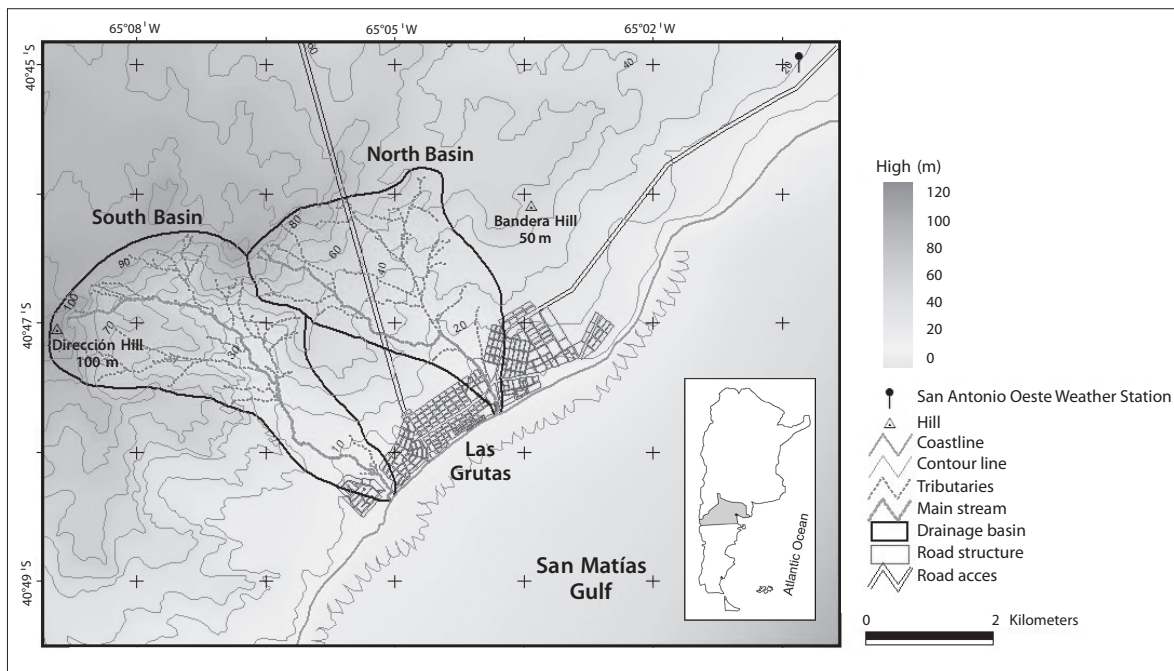

Figure 1. Map of study area showing the drainage basins: *North Basin* (NB) and *South Basin* (SB), and terrain relief.

at regional scale and merely highlight the temporary regime of the drainage networks (e.g., Gelós *et al.*, 1992; Schillizzi *et al.*, 2003; Kokot, 2004).

The purpose of this study is to establish the hydrologic response of the NB and SB and the manner in which the land use interacts with them. Extreme rainfall events are becoming more common as a result of climate change, and it can be expected that this will lead to more disturbances in the urban area. The present results will contribute to the implementation of measures to reverse local effects of flood hazards on property values.

MATERIALS AND METHODS

A quantitative study of the drainage basins that intersect Las Grutas town was based on information available in cartographic products (e.g., geological and topographic charts) and aerial photos which were systematized with a GIS through the ArcGis 9.0 application. This research was complemented by direct observations and measurements on the ground.

The climatic data were obtained from the National Meteorological Service of Argentina. The only weather station in the region, San Antonio Oeste station, is 4.5 km from the town (40° 44'S; 64° 67'W) at 20 m above mean sea level (a.s.l.) (Figure 1). Decadal climatic statistics over a period of 40 years (1961-2000) and daily rainfall records (1981-2008) were used in this study.

The morphometry of the two drainage basins was analyzed. The drainage basins were delineated according to topographic criteria. Digital elevation models, aerial photographs (1:80 000) and topographic charts (1:100 000) were employed to identify fluvial geoforms. Direct measurements of morphometric parameters (e.g., area and perimeter of the basin, length and number of streams) were automatically obtained from GIS and visually controlled later, to detect possible interpretation errors. Indexes based on variables related to terrain relief, network topology and basin geometry were calculated (Tables 1, 2 and 3).

The SCS-CN (1972) method was employed to estimate the direct runoff for an isolated storm. Soil types within the study area, based on the Río Negro Province soil map (1:250 000), were classified into SCS hydrologic soil groups. Land use classes were mapped on the basis of visual interpretation of black and white aerial photos (right angle) at scales of 1:80 000 for the years 1963, 1986 and 2007.

Direct runoff was determined by (Chow *et al.*, 1994)

$$Qd = \frac{(P - 0.2S)^2}{P + 0.8S} \text{ if } P > 0.2S \qquad (1)$$

where Q_d is the direct runoff (mm), P is the storm precipitation (mm) and S the potential maximum retention (mm). CN and S are related by

$$S = 254 \left(\frac{100}{CN} - 1 \right) \qquad (2)$$

Table 1. Morphometry of the *North Basin* and *South Basin*

	Area (km²)	Perimeter (km)	Maximum Length (km)	Mean Slope (%)	Shape		
					Circularity Ratio (Gravelius, 1914)	Elongation Ratio (Miller, 1953)	Compactness Index (Schumm, 1956)
Formula and/or Symbol	A_b	P_b	L_b	S_b	$R_c = \frac{4\pi A_b}{P_b{}^2}$	$R_e = \frac{1.129 A_b{}^{0.5}}{L_b}$	$I_e = 0.28 \frac{P_b}{\sqrt{A_b}}$
NB	8.16	12.45	4.26	1.90	0.66	0.76	1.23
SB	10.01	15.05	5.88	2.44	0.55	0.61	1.34

Table 2. Morphometry of the drainage networks of the *North Basin* and *South Basin*

Parameter/Index	Formula and/or Symbol	NB	SB
Order Number (Strahler, 1964)	U	4	4
Main Stream Length (km)	L_f	5.43	7.33
Total Length of the Streams (km)	L_t	24.87	33.35
Mean Slope of the Main Stream (%)	$S_f = \dfrac{H_{max} - H_{min}}{L_f}$ H (height): m; L_f: m	1.65	1.36
Drainage Density (km, km²) (Horton, 1932)	$D = \dfrac{L_t}{A_b}$	3.04	3.33
Mean Bifurcation Ratio (Horton, 1945)	$\overline{R_b}$	3.3	4.0
Mean Length Ratio	$\overline{R_l}$	1.77	2.31
Drainage Frequency (km⁻²) (Horton, 1932)	$F = \dfrac{N_b}{A_b}$ N_b (Number of streams)	5.27	7.59
Torrential Coefficient (km⁻²) (Romero and López, 1987)	$C_t = \dfrac{N_{u=1}}{A_b}$	3.92	5.90
Time of Concentration (min)	Kirpich (1940) (min): $T_c = 3.978(L_f)^{0.77} S_f^{-0.385}$	71	96
	Johnstone and Cross (1949) (min): $T_c = 3.258 \left(\dfrac{L_f}{S_f} \right)^{0.5}$	59	75
	Témez (1978) (hours): $T_c = 0.3 \left(\dfrac{L_f}{S_f^{25}} \right)^{0.76}$ Sf: m m⁻¹; Lf: km	142	147

Table 3. Morphometric characterization of the orders of the *North Basin* and *South Basin*

Parameter/Index	Formula and/or Symbol	Basin	U=1	U=2	U=3	U=4
Stream Length (km)	L_u	NB	12.51	6.63	4.06	1.65
		SB	17.28	8.42	4.05	3.58
Number of Streams	N_u	NB	32	8	2	1
		SB	59	13	3	1
Mean Length of the streams(km)	$\overline{L_u} = \dfrac{L_u}{N_u}$	NB	0.39	0.82	2.03	1.65
		SB	0.29	0.64	1.35	3.58
Length Ratio (Adimentional)	$R_l = \dfrac{\overline{L_{u+1}}}{\overline{L_u}}$	NB		2.12	2.45	0.73
		SB		2.21	2.08	2.65
Bifurcation Ratio (Adimentional) (Horton, 1945)	$R_b = \dfrac{N_u}{N_{u+1}}$	NB		4	4	2
		SB		4.5	4.3	3
Drainage Frequency (km-²) (Horton, 1932)	$F = \dfrac{N_u}{A_b}$	NB	3.92	0.98	0.24	0.12
		SB	5.89	1.29	0.29	0.09
Drainage Density (km km-²) (Horton, 1932)	$D = \dfrac{L_u}{A_b}$	NB	1.53	0.81	0.50	0.20
		SB	1.73	0.84	0.41	0.36
[Note: the main text refers to '1st order', '4th order' etc. If you use 'U = 1' etc in Table 3, you need to explain 'U']						

where CN is a variable coefficient based on land use, soil group and vegetal cover. This CN is adjusted to the previous moisture conditions in terms of the accumulated rainfall for a period of five days before the storm event (dry, < 13 mm; normal, 13 to 28 mm; wet, > 28 mm). Accumulated rainfall prior to the selected event indicates a wet condition. Thus, the adjustment to this condition is expressed by

$$CN_w = \frac{23CN_n}{10 + 0.13CN_n} \qquad (3)$$

where CN_w and CN_n correspond to wet and normal conditions, respectively. Lastly, the weighted CN value of each basin was calculated as

$$CN_w = \frac{23CN_n}{10 + 0.13CN_n} \qquad (4)$$

where A_{Hsg} is area of the hydrologic soil group (%).

STUDY AREA

Geomorphology and Geology

The study area is on the north west coast of San Matías Gulf, over a littoral pediment (Genchi *et al.*, 2008) which is joined to the foot of an ancient alluvial plateau. The area is characterized by a low topographic relief with a mean slope of 1.6%. There are two isolated hills called Bandera and Dirección, whose elevations are 50 and 100 m a.s.l., respectively (Figure 1). The coastal area is strongly dominated by landforms that result from marine erosion, such as active cliffs and wave-cut platforms.

The pediment is covered mostly with Holocene colluvial deposits, which come from the alluvial plateau and lower units such as Tertiary marine

and fluvial sediments (Martínez *et al.*, 2001). The pediment originated through tectonic, fluvial and aeolian processes (Ayesa *et al.*, 1995). Marine sandy-clay sediments corresponding to the Gran Bajo del Gualicho geological formation come to the surface, sometimes half covered with Quaternary colluvial material (Martínez *et al.*, 2001).

Climate

The study area is in a semiarid zone under marine influence. In terms of the Gaussen (1954) aridity index, this area is subdesert with approximately 270 dry days. The months of May, June and July are considered semi-wet. The continentality index of Currey (1974), expressed as the amplitude of the annual oscillation of temperature, is 1.03, which indicates a type of oceanic climate.

The mean annual temperature is 15.1° C. The mean annual relative humidity is 57% and reaches its maximum values in winter (70%). The mean monthly evapotranspiration estimated according to the Christiansen (1968) equation ranges from 180 mm in summer to 35 mm in winter. The predominant wind direction is north-west from March to November, and south-east during summer months. The mean annual wind speed is 5.05 m s^{-1}.

The study area is at the southern boundary of the South Atlantic subtropical anticyclone. Precipitation occurs as rain with a mean annual value of 227.2 mm for the period 1910-2000. Annual precipitation had a positive trend over that period (Figure 2). Variation among months is moderate (Figure 3), with a standard deviation of 4.6 for the twelve mean monthly values.

The extreme daily rainfall for each month over the period 1981-2008 (Figure 3) ranged between 33 and 102 mm d^{-1}. The heaviest rain (102 mm d^{-1}) represented 46% of the total annual precipitation for the year 2004. In addition, this event of intense and abundant rainfall corresponds to the historical maximum.

Type and hydrologic soil group

Aridisol is the main soil order in the low rainfall zone of Argentine Patagonia, east of the Andes range. These *soils* have little pedogenetic development and very low organic matter content (<1%). The soil domains are Calciorthids (Typical subgroup), Paleargids (Petrocalcic subgroup) and Camborthids (Lithic subgroup). The former consists of coarse texture on the surface (fine gravels) and silt loam in deeper horizons. It is well drained and belongs to hydrologic group B with moderate permeability (Monsalve, 1999). Paleargid soil contains petrocalcic and argillic horizons that were formed under climatic conditions that differed from the present ones (Tchilinguirian and Pereyra, 2001). It, too, belongs to hydrologic group B. Lithic Camborthid soils occur in the upper part of the basins between streams. The marine clays present evidence of translation and deposition (Martínez *et al.*, 2001). This soil corresponds to hydrologic group C with low permeability (Monsalve, 1999) and occupies an area of approximately 1.13 (13.8%) in the NB and 0.83 km^2 (8.3%) in the SB (Table 4).

Vegetal cover

The study area belongs to the Monte phytogeographical Province, Estepa Arbustiva (shrubby steppe) District, Monte Austral Típico Unit (Cabrera, 1976; León *et al.*, 1998) which is characterized by a shrubby steppe with several strata and low vegetal cover. The lower and middle strata, with heights varying between 0.5 and 1.5 m respectively, have the greater coverage (León *et al.*, 1998). The upper stratum reaches 2 m in height and has a dispersed distribution. The shrub stratum is dominated by *Larrea divaricada*, a perennial < 1.5 m in height, whose leaves are adapted to arid conditions.

Land use

The economy in the study area is dominated by tourism in search of sunshine and beaches, and it is significantly associated with urban land use. The boom in tourism has led to accelerated urban expansion during the past two decades, primarily parallel to the coastline; the urbanized area was only 0.07 km^2 in 1963, 1.4 km^2 in 1986, but 3.7 km^2 in 2007 (Figure 4). Urbanization represents 5.6% of the NB and 2.4% of the SB (Table 4).

Rural activity has little economic importance and is limited by low precipitation. Agriculture is confined to irrigated crops under intensive production systems with conservation treatment. Olive
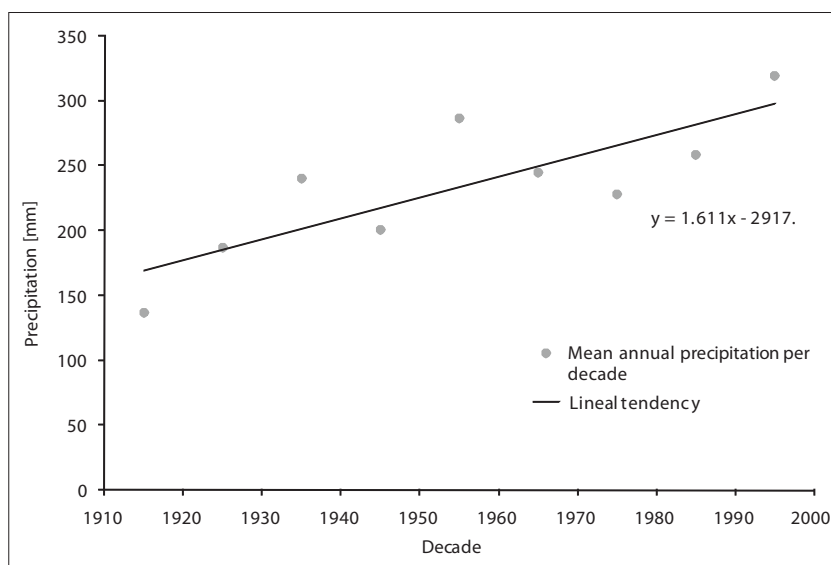
Figure 2. Mean annual precipitation trend per decade for the period 1910-2000.
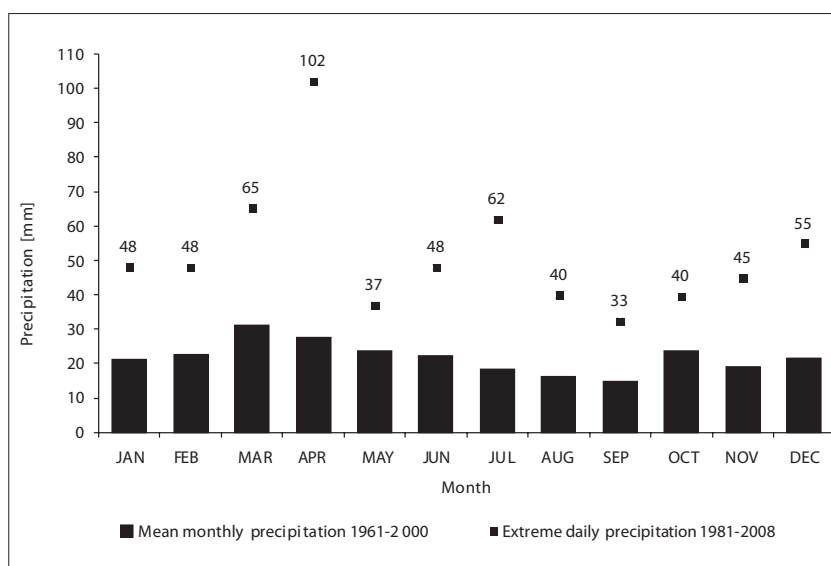
$$y = 1.611x - 2917.$$

Figure 3. Mean monthly precipitation (1961-2000) and extreme daily precipitation (1981-2008).

groves (*Olea europaea*) occupy 0.86 km² (8.6%; Table 4 and Figure 4). Extensive livestock production, mainly sheep, is geographically *dispersed* near the town (Plunkett and Gastaminza, 2004).

MORPHOMETRY OF THE DRAINAGE BASINS AND STREAM NETWORKS

The town of Las Grutas is intersected by two fluvial systems that drain to the sea. The NB and SB cover an area of 8.2 and 10 km², respectively (Genchi *et*

al., 2008), (Figure 1), and are elliptical to circular (Table 1).

The hydrographic basins have a NW-SE orientation that follows the morphostructure (Figure 1). The altitudinal range is 0-80 m in the NB and 0-100 m in the SB, and their highest elevations are in the contact zone at the edge of the alluvial plateau. The mean slope of the NB (1.9%) is similar to that of the SB (2.4%).

The stream system is ephemeral and influent (Aparicio, 1997). The streams carry water only immediately after intense rainfall events (Hoyt,

Table 4. Curve number (USDA Soil Conservation Service, 1972) in relation to land use and soil cover in the *North Basin* and *South Basin*, under normal moisture conditions

Land use/cover	NB						SB					
	B Hydrologic soil group			C Hydrologic soil group			B Hydrologic soil group			C Hydrologic soil group		
	Area%	CN	Product	Area%	CN	Product	Area %	CN	Product	Area%	CN	Product
Agricultural: Cultivated land with conservation treatment	0	-	-	0	-	-	8.6	81	697	0	-	-
Scrubland-Herbaceous: Mixture of shrubs and grasses being those the main element	80.6	56	4513	13.8	70	966	80.7	56	4519	8.3	70	581
Urban [1]	5.6	83	465	0	-	-	2.4	75	180	0	-	-
Total	86.2		4978	13.8		966	91.7		5396	8.3		581
Weighted CN	59.4						59.8					

[1] The CN was obtained from the mean of the CN corresponding to urban land use (residential, commercial, etc.) and degree of sealing of the streets or roads (pavement, gravel, dirt, etc.).

1942; Wisler and Brater, 1959; Aparicio, 1997; Raghunath, 2006). The water table lies permanently below the streambed throughout. Water table depth varies between 60 and 85 m (Olivares and Sisul, 2005).

The drainage networks are composed of narrow streams whose maximum width at the mouth varies between 6 and 8 m. Most of the low-order streams are not well defined. Their cross-section is usually U-shaped. The slope above this is steep in the middle-low stretch. Accumulated sediments spatially discontinuous in the lower basin section take the form of debris cones showing the highest degree of erosive activity. During heavy storms, debris and fine material frequently become mobilized.

The drainage network is dendritic in both basins (Howard, 1967; Figure 1). It is associated with a soft structure with horizontal layers of Holocene colluvial deposits and Tertiary marine and fluvial sediments. The angles of confluence between two streams are approximately 45° (Figure 1). According to the Strahler method of ordering, the fluvial systems are fourth-order basins (Genchi *et al.*, 2008). The variation of the logarithm of number of streams and the logarithm of mean stream length against orders indicates a strong relationship in both basins (Figure 5). These relationships confirm the Horton geometric progression laws (Horton, 1945).

The mean bifurcation ratio, which indicates the average variation of the number of segments between consecutive orders (Horton, 1945; Strahler, 1964), has a relatively high value in both NB and SB (Table 2). The drainage frequency, defined as the ratio between the number of streams of all orders and the basin area (Horton, 1932), is 5.3 km^{-2} for the NB and 7.6 km^{-2} for the SB. The torrential coefficient (Romero and López, 1987), represented by the drainage frequency of first-order segments, encompasses approximately 75% of the total drainage network (Table 2). Drainage density, defined
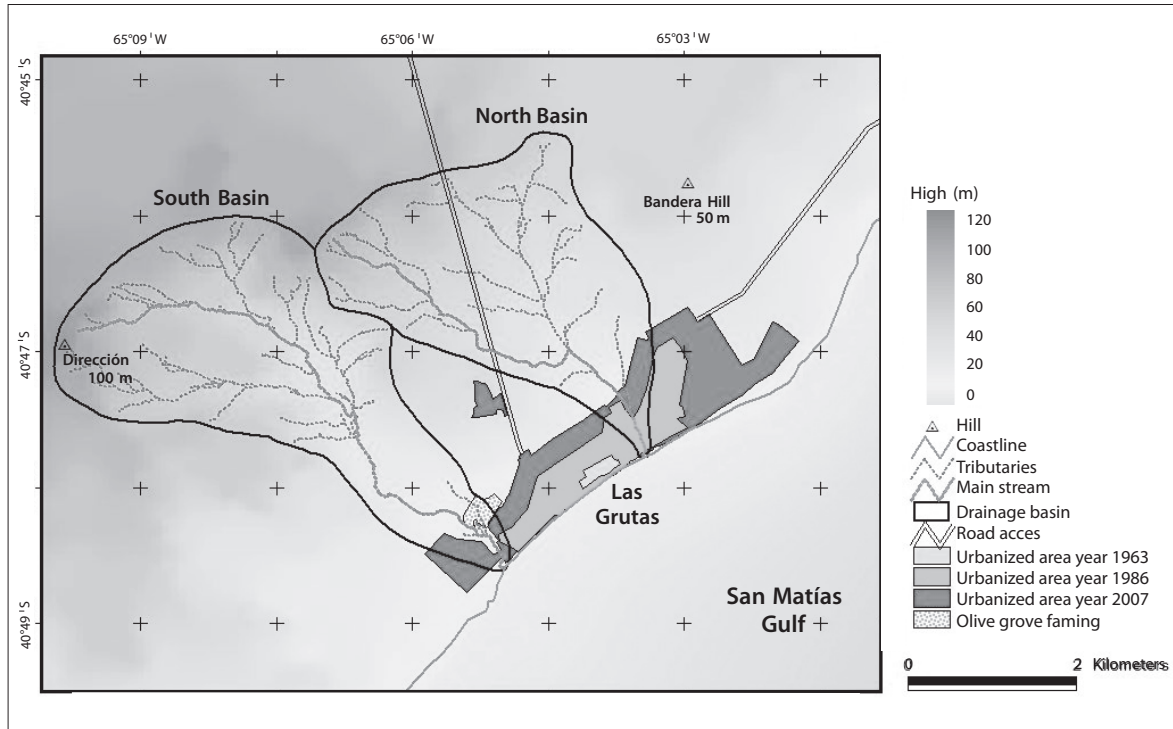
Figure 4. Land use types in the study area, showing also the urbanization from 1963 to 2007.
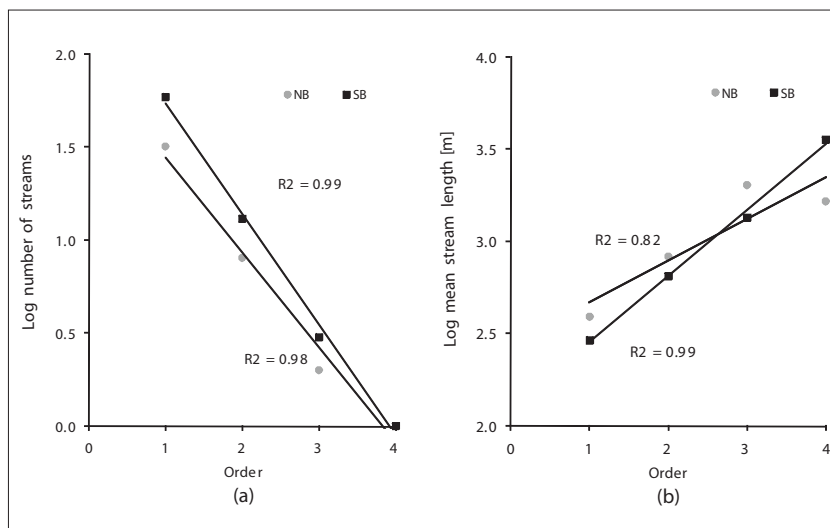

Figure 5. Horton's laws (1945) applied to the drainage nets of the NB and SB. (a) number of streams, (b) mean stream length.

as the ratio between the total stream length and the basin area (Horton, 1932), is approximately 3 km km^{-2} in each basin (Tables 2, 3; Figure 6).

The main stream length measured from baseline to the farthest point in the basin (Schumm, 1956) is 5.4 km for the NB and 7.3 km for the SB. The mean slope of the main stream is low in both cases (Table 2), although it reaches values of up to 4 in the upper part of each basin (Figure 7). The NB presents partial slopes with values slightly higher
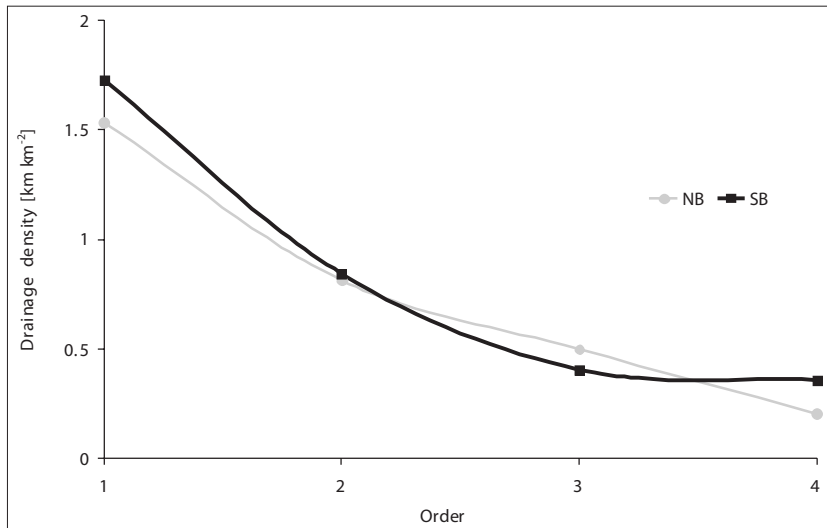
Figure 6. Distribution of drainage density of the *North Basin* and *South Basin* according to the order number.

than in the SB, although the gradient of the main stream of the SB is not constant and is significantly steeper in the middle part (Figure 7a).

The time of concentration is defined as the time required for a parcel of water originating at the most remote part of the drainage basin to reach the basin outlet (Singh, 1992). According to the Kirpich (1940) formula the time is 71 min for the NB and 96 min for SB, while according to Johnstone and Cross (1949) the time is 59 min and 75 min, respectively. In contrast, the Témez (1978) formula indicated values of 142 min (NB) and 147 min (SB), (Table 2).

DIRECT RUNOFF FROM THE HYDROGRAPHIC BASINS FOR AN ISOLATED STORM

The direct runoff from a watershed depends on the total rainfall, land use, vegetal cover, hydrologic soil group and previous humidity. The selected storm corresponds to the historical maximum (102 mm d^{-1}). Accumulated rainfall prior to this storm was 44 mm, which indicates a wet condition. A uniform distribution of rainfall across the surface of the NB and SB was assumed, taking into consideration the relatively small surface covered in both.

The amount of precipitation falling as rain totaled 102 mm over a period of 18 hours, with a

persistent character between 22:00 (April 4th) and 05:00 h (April 5th), (Figure 8). According to the storm hyetograph, the highest intensity was 0.30 mm min^{-1} between 00:00 and 03:00 h (Figure 8).

The weighted CN for normal moisture conditions is 59.4 in the NB and 59.8 in the SB (Table 4), whereas the adjusted CN for wet conditions is 77.4 and 77.1, respectively. According to the latest values, the potential maximum retention is 75.3 and 74.3 mm. The direct runoff is 61.1 (NB) and 61.6 mm (SB). The mean runoff coefficient estimated as the ratio between drained volume and fallen precipitation is 0.51 for both basins.

DISCUSSION

The present functioning of fluvial geoforms depends on their history (Hoffmann *et al.*, 2008) and evolves in a complex interaction that tends to reach a dynamic equilibrium. Both NB and SB are inherited from earlier climatic periods. It is clear that, with the advent of dry conditions the contemporary fluvial landscape was abandoned (Cooke *et al.*, 1993) by the processes that formed it. The drainage probably changed from perennial to ephemeral, with the stream system apparently retaining its form, particularly the drainage density.

The study area consists of a low-energy fluvial environment in which massive discharges were the
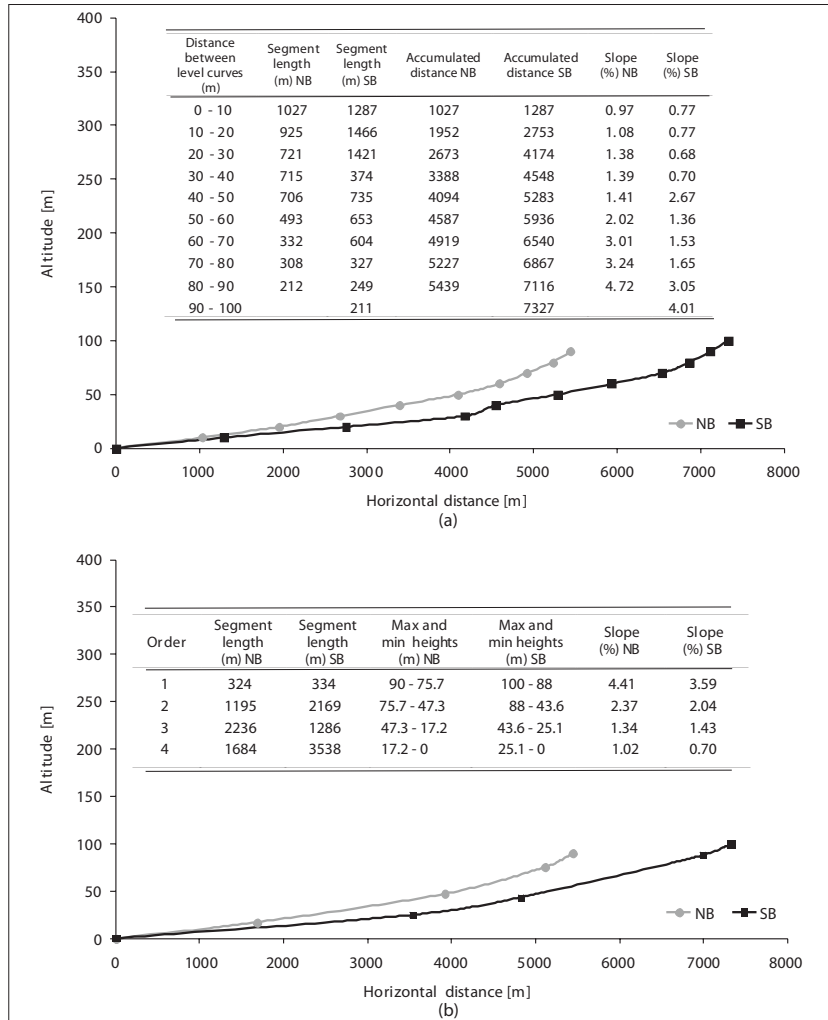
Distance between level curves (m)	Segment length (m) NB	Segment length (m) SB	Accumulated distance NB	Accumulated distance SB	Slope (%) NB	Slope (%) SB
0 - 10	1027	1287	1027	1287	0.97	0.77
10 - 20	925	1466	1952	2753	1.08	0.77
20 - 30	721	1421	2673	4174	1.38	0.68
30 - 40	715	374	3388	4548	1.39	0.70
40 - 50	706	735	4094	5283	1.41	2.67
50 - 60	493	653	4587	5936	2.02	1.36
60 - 70	332	604	4919	6540	3.01	1.53
70 - 80	308	327	5227	6867	3.24	1.65
80 - 90	212	249	5439	7116	4.72	3.05
90 - 100		211		7327		4.01

(a)

Order	Segment length (m) NB	Segment length (m) SB	Max and min heights (m) NB	Max and min heights (m) SB	Slope (%) NB	Slope (%) SB
1	324	334	90 - 75.7	100 - 88	4.41	3.59
2	1195	2169	75.7 - 47.3	88 - 43.6	2.37	2.04
3	2236	1286	47.3 - 17.2	43.6 - 25.1	1.34	1.43
4	1684	3538	17.2 - 0	25.1 - 0	1.02	0.70

(b)

Figure 7. Longitudinal profile of the main stream of the basins showing part of the slope between level curves (a) and orders (b).
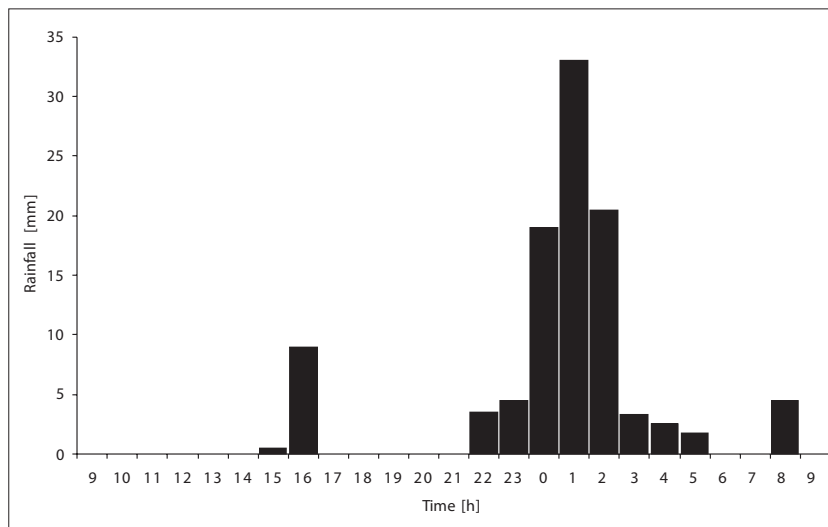

(a)

Figure 8. Hourly storm hyetograph from April 4th at 09:00 h to April 5th at 09:00 h, with a period of high intensity between 00:00 and 03:00 h.

important land-forming agents. The present-day functioning of the fluvial systems is characterized by a temporary regime whose streams exhibit surface flow after extreme rainfall events. Sometimes, these events represent up to 20-40% of the total annual precipitation. In addition, the path of the storms usually exhibits a movement from NW to SE, coinciding with the orientation of the fluvial systems.

The morphometric properties of the two drainage basins are similar. The runoff is affected by maximum discharges, typical in small basins (Chorley, 1971). First-order segments are important in the hydrologic response. In both basins, these segments concentrate the highest density (~50%) and frequency (~75%), (Table 3), showing great potential to receive surface runoff during extreme rainfall episodes. The resultant time of concentration, which is influenced by the low slope of the main stream principally on the middle and lower segments, tends to raise the discharge time. Therefore, in the presence of heavy rainfall, all these characteristics indicate a potential increase in peak discharges and in durations of high flows in the lower stretches of the drainage networks. In addition, the U-shaped cross sections also show that the potential deepening of the valley during a storm is rapidly obliterated by post-storm conditions such as sedimentation of material, which is transported by the wind.

The dominant hydrologic soil group is B, which is characterized by moderate infiltration and slight runoff. The remaining soil group (C), of moderately high runoff potential, occupies a small area in the headwaters. The basins are covered mainly by shrubby steppe whose hydrologic condition is constant in response to the widespread prevalence of the extensive production system. The sparse cover favors surface runoff; however, the predominance of the hydrologic soil group B reduces the value of CN. Although the weighted CN obtained for the two basins are similar, they do differ somewhat (Table 4). The effect of urbanization (Chow *et al.*, 1994) produces an additional runoff of 17.3% for NB and 2.1% for SB; the significantly greater effect in the NB is due to a major urban area and to a large number of paved roads, which cause a progressively greater fraction of precipitation to enter

the channel rapidly. In contrast, the CN value for the SB is higher in the presence of cultivated land.

The direct runoff resulting from the isolated storm was estimated at about 60% of the total rainfall (102 mm d^{-1}) in both basins. This extreme runoff event, which was exacerbated by wet antecedent conditions, caused urban flooding with significant water depth and velocity in zones of flow concentration, especially in the lower area of the NB. In addition, the rapid runoff on saturated soils made it very erodible

Rapid urbanization of the town in the past two decades has caused its margins to reach both fluvial systems (Figure 4). Urbanization did not change the natural disposition of the streams but a large number of buildings are situated near the main stream. In addition, anthropogenic disturbances in the lower parts of the drainage basins (e.g., small channeled stretches, artificial fillers and stabilization of the bank with blocks) obstruct and redirect the runoff into the surrounding areas and contribute to increased flooding risks.

CONCLUSIONS

The study area presents characteristics that favor the concentration of runoff into streams during extreme events. The possibility of large flows is affected mainly by the physical property of the basins, whereas the anthropogenic effects are still small, but are increasing rapidly. Flood risks are higher in the lower basin of each fluvial system. The lack of a urban management plan best suited to the geomorphologic environment has allowed buildings to be constructed in vulnerable areas.

A risk factor is always present. An event of unprecedented severity may occur at any time (Chow *et al.*, 1994). In this sense, the potential increase in the number of these extreme events in the future due to climate change may lead to more disturbances in the urbanized area that have to be taken into account in the field of spatial planning.

Morphometric analysis and the SCS-CN method provide a quantitative physical description of fluvial landforms, which is able to explain and predict potential hydrologic effects (Maderey,

1973; Linsley *et al.*, 1988). However, further research focusing on the elements of complex fluvial response is needed. A suitable understanding of the hydrologic behavior requires stream discharge gauges and a detailed temporal scale within each extreme rainfall event, which will be systematized in hydrological models.

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