



FLOOD PROCESSES AND MORPHOLOGICAL CHANGES IN AGGRADATIONAL EPHEMERAL RIVERS. RECONSTRUCTION OF THE OCTOBER 1957 FLOOD IN THE RAMBLA CASTELLARDA (SPAIN)

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ABSTRACT. During the latter half of the twentieth century, Mediterranean ephemeral rivers underwent a profound metamorphosis. Fluvial adjustment processes narrowed the channels, simplified their planform pattern and notably reduced sediment availability. Today, this makes it extremely difficult to analyse the behaviour of this type of river in former aggradational contexts, such as those seen at the middle part of the twentieth century. For this reason, this paper addresses a reconstruction and analysis of the 1957 flood that occurred in the Rambla Castellarda, a tributary of the Turia river. The research is based, among other sources, on a series of extraordinary, high-precision aerial photographs carried out a few weeks after the flood. These images make it possible to recreate the processes observed in this ephemeral river and map the post-event river forms. Results show the behaviour of a Mediterranean aggradational ephemeral stream, very different from the current processes, and allows a comparative reflection to be made about flood processes in different sedimentary contexts. The study reveals that in-channel agricultural activity was, together with floods, the most relevant factor conditioning the river channel adjustment trajectory in that sedimentary context. Finally, the analysis of the impact of the flood in the Tura river highlights the importance of overflows – and therefore the connection between channel–floodplain – both for in-channel processes and in the lamination of floods.

Procesos de crecida y cambios morfológicos en un río efímero agradacional. Reconstrucción de la riada de octubre de 1957 de la rambla Castellarda

RESUMEN. Durante la segunda mitad del siglo XX, los ríos efímeros mediterráneos han experimentado una profunda metamorfosis: han sufrido procesos de ajuste fluvial que han estrechado los cauces, han simplificado sus formas y han reducido notablemente la disponibilidad de sedimentos. Esto hace que sea extremadamente difícil analizar hoy el comportamiento de este tipo de ríos en contextos agradacionales previos, como el que tenían hasta la primera mitad del siglo XX. Por ello, este artículo aborda el análisis de la crecida de 1957 en la Rambla Castellarda, afluente del río Turia. La investigación se basa, entre otras fuentes, en una extraordinaria serie de fotografías aéreas de alta precisión llevadas a cabo pocas semanas después de la riada. Estas imágenes nos permiten reconstruir los procesos observados en este río efímero y cartografiar las formas del río post-evento. Los resultados muestran el comportamiento de un río efímero agradacional mediterráneo, muy diferente a los procesos actuales, y permiten hacer una reflexión comparativa sobre los procesos de inundación en diferentes contextos sedimentarios. El estudio revela que la actividad agrícola en el cauce fue, junto con las inundaciones, el factor más relevante que condicionó la trayectoria de ajuste del cauce del río en dicho contexto sedimentario. Finalmente, el análisis del impacto de la crecida del río Turia pone de relieve la importancia de los desbordamientos –y por tanto

de la conexión cauce-llano de inundación– tanto para los procesos en el cauce como en la laminación de las crecidas.

Keywords: Floods, ephemeral streams, aggradational processes, river forms, Rambla Castellarda.

Palabras clave: Inundaciones, ríos efímeros, procesos agradacionales, formas fluviales, Rambla Castellarda.

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1. Introduction

In the middle of the twentieth century, most of the intermittent rivers and ephemeral streams (IRES) of the Spanish Mediterranean basins had a wide channel with a braided pattern when crossing their floodplains and alluvial fans. This morphology was the response of the IRES to past climatic conditions and to a specific context of anthropic action (Hooke, 2006). On the one hand, in the transition between the nineteenth and twentieth centuries, the region had undergone the final pulses of the Little Ice Age (Barrera-Escoda and Llasat, 2015), a particularly humid period characterised by a frequent recurrence of floods (Benito *et al.*, 2008). These conditions, favourable to the mobilisation of sediments, occurred in some basins whose headwater areas featured scarce vegetation cover, due to pressures exerted by the rural population. Since the eighteenth century, overgrazing, the mass terracing of slopes, and the extraction of firewood or charcoal had significantly reduced the biomass (Beguiría *et al.*, 2006). The slopes exported significant amounts of sediment, which formed large deposits of gravel on the riverbeds (Conesa, 1987; Segura-Beltran and Sanchis-Ibor, 2013; Conesa and Pérez, 2014; Calle *et al.*, 2017).

During the second half of the century, these conditions drastically changed. The rural exodus, the reduction of the cultivated and grazed area, and the reforestation policies contributed to a significant recovery of the vegetation in the mountainous areas. In addition, many river channels suffered intense gravel mining in-stream, and in many others sediment flow was interrupted by dikes and dams. Consequently, most Mediterranean IRES have undergone fluvial adjustment processes that have notably reduced sediment availability, have narrowed the channels and have simplified their pattern (from braided to single thread) (Liébault and Piégay, 2002; Surian, 2021). These processes and forms have been documented in the Iberian Peninsula (Batalla, 2003; Martín-Vide *et al.*, 2010; Beguiría *et al.*, 2006; Rovira *et al.*, 2005; Martínez-Fernández *et al.*, 2016), France (Liébault *et al.*, 2005;) and the Italian Peninsula (Surian *et al.*, 2009; Scorpio *et al.*, 2015; Magliulo *et al.*, 2021).

As a result of these adjustment processes, the current river forms are radically different from the aggradational morphology they had at the middle of the twentieth century. For this reason, addressing the analysis of a flood that occurred in an IRES in 1957 gives us the opportunity to document and understand a phenomenon that cannot currently be observed. The reconstruction of the effects of this flood that occurred more than sixty years ago would be extremely difficult, since the post-event information is very limited, especially in ephemeral rivers and in floods that do not affect urban areas. However, in this case there is a series of photographs of exceptional quality, made expressly by the Spanish Company of Aerial Photogrammetric Works (CEFTA) a few weeks after the extraordinary flood occurred in the Turia river basin, which seriously affected the city of Valencia (Portugués *et al.*, 2016). In addition, the flood took

place a few months after the photographs of the 1956–57 flight of the United States Army (Series B) were taken, which portray the condition of the channel prior to the flood.

The objective of this work is to reconstruct the flood of 14 October 1957 in the Rambla Castellarda -a tributary of the Turia river- with two main aims: first, to document the processes that took place in that event and the resulting forms; and second, to reflect on the implications the changes that occurred in the riverbeds may have on current floods and in fluvial adjustment processes.

2. Study area. The Rambla Castellarda and the flood of 14 October 1957

The Rambla Castellarda is an IRES located in the Region of Valencia that is a tributary of the Turia river (Fig. 1 and 2). It has a basin of 447 km², between 112 and 1,568 m above sea level, and drains part of the south face of the Sierra de Javalambre and the Sierra de Andilla mountains. These predominantly calcareous reliefs are compartmentalised by small grabens filled with quaternary materials (Higueruelas, Alcublas, Oset and Artaj valleys), resulting from the different compression and distension phases that shaped the Iberian Range (Pérez Cueva, 1985). The transition between these mountains and the Turia river is established by a wide Pleistocene alluvial piedmont, only interrupted by some Mesozoic calcareous hills and by an outcrop of Miocene marls near the Turia river. Flash floods in ephemeral streams (Camarasa, 2021) are recurrent in this basin.

Between 12 and 14 October 1957, a storm swept most of the Valencia Region, causing a dramatic flood of the Turia river in the city of Valencia (Marco and Mateu, 2007; Portugués *et al.*, 2016). The storm was caused by a relatively typical atmospheric situation in the region: an atmospheric depression at high levels that coincides with a low-pressure cell anchored over the Gulf of Cádiz. It drove an E and SE flow over the Gulf of Valencia that was channelled through the Iberian reliefs and generated abundant rainfall. The hydrological analysis carried out after the event (Cánovas, 1958) and its recent review (Marco and Mateu, 2007; Puertes and Francés, 2016) have shown that the two peaks of the Turia hydrograph that ravaged the city of Valencia on 14 October were generated downstream of the last dam (Benagéber). The main precipitation nucleus was located over the Rambla Castellarda and Rambla Primera sub-basins (García and Carrasco, 1958; Armengot, 2002; Núñez and Riesco, 2007), causing flash floods.

The hydrological response of the Turia basin was conditioned by an episode of rainfall that had occurred in the first days of the month (Table 1), which had left the soils of the region close to saturation. Some days later, at the end of the afternoon on 13 October, moderate rainfall was recorded throughout the Rambla Castellarda basin, which increased in intensity after midnight, mainly in the middle and lower zones. In Andilla and Alcublas 100.5 and 167.5 mm were recorded on the 14th; while downstream, in Casinos and Lliria, 200 and 225 mm were recorded respectively (Table 1 and Fig. 1). The most intense precipitation took place in the surroundings of Villar del Arzobispo, whose rain gauge was overflowing at the time of the consultation; for this reason, the 235 mm recorded there during the 14th must be considered to be a lower value than that of the actual precipitation. According to García and Carrasco (1958), the water began to flow through the Rambla d'Artaix between 6:00 p.m. and 8:00 p.m. on the 13th, but the flood did not occur until the night of the 14th, reaching a first peak around at 4:00 in the morning, which decreased after 6:00. The rains continued after sunrise, and very heavy rainfall was recorded again between 8:00 a.m. and 2:00 p.m.

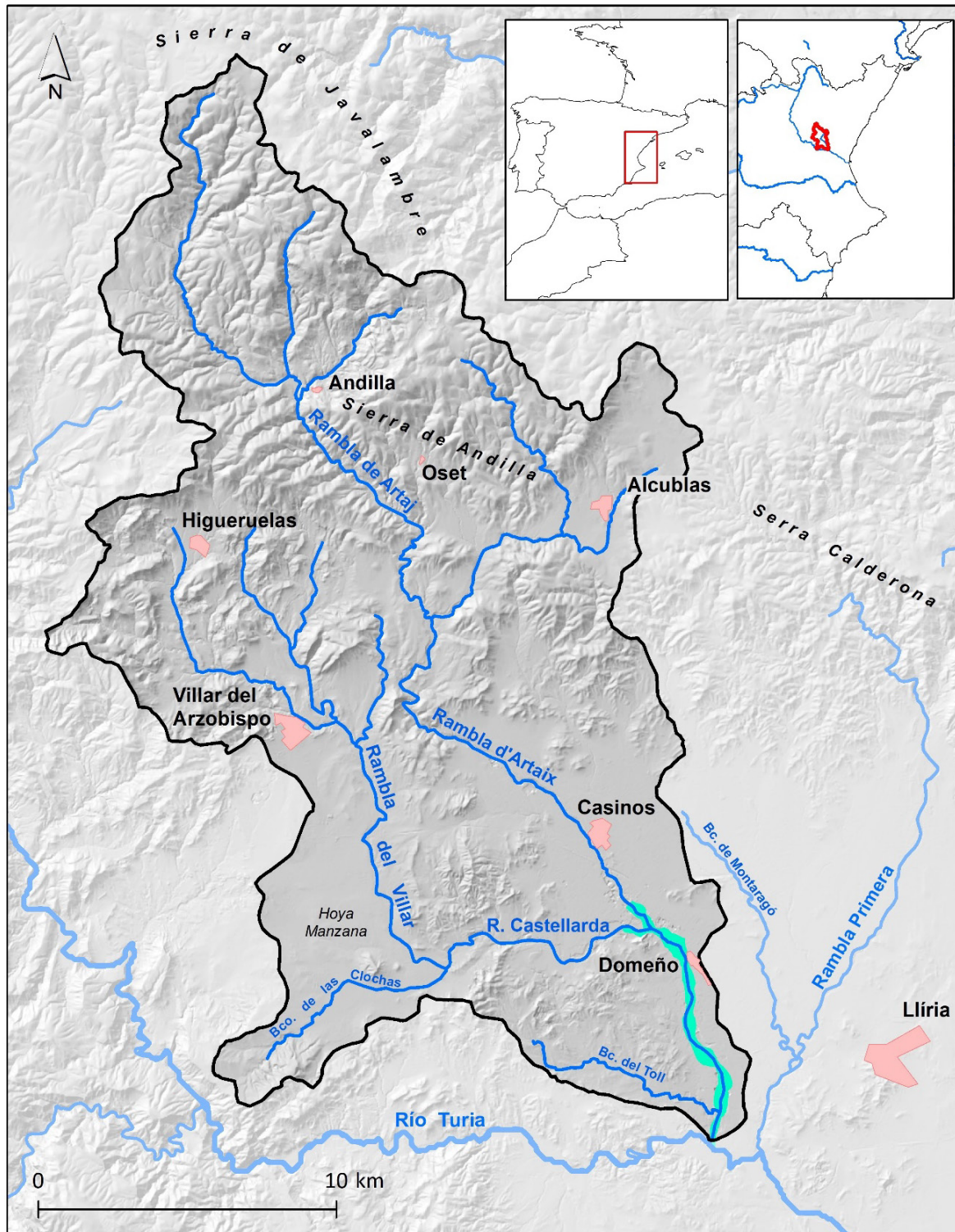


Figure 1. Rambla Castellarda basin and study area highlighted in turquoise.

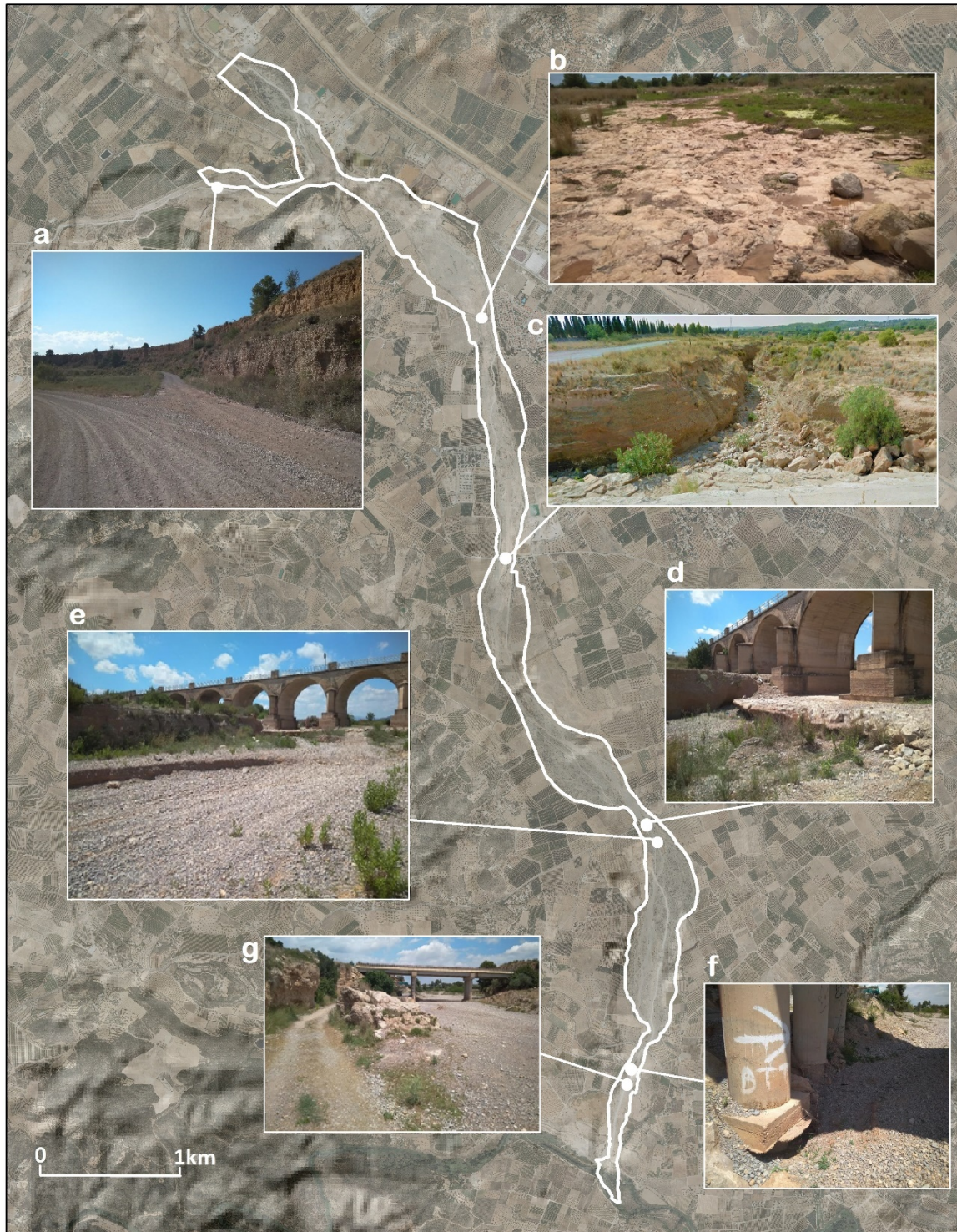


Figure 2. Study area and photographs taken in spring and autumn 2021, which show current processes, mainly as a result of the current sedimentary deficit: a) Rambla Castellarda converted into a road for gravel transport trucks; b) Exhumed crusts in the bed of the river next to the ford of Domeño; c) Fluvial incision next to the ford of Casas de Pablo; d) Undermining of the CV-376 bridge foundation; e) Microterraces generated by the recent incision downstream of the CV-376 bridge; f) Undermining of pillars under the CV-364 bridge; g) Rambla Castellarda at its narrowest section, downstream of the CV-364 bridge.

Table 1. Rainfall (mm) in different observatories of the Castellarda basin during the first fortnight of October.
See Figure 1 for location.

	October 1957												
	Daily										Accumulated		
	1	2	3	4	5	12	13	14	15	From 1 to 5	From 12 to 15	From 1 to 15
Andilla		38.7	33.3	28.2	0.2		2	9.5	100.5	42	100.4	154	254.4
Alcublas	4.7	29.6	38.5	25			8.6	9.8	167.5	116.5	97.8	302.4	400.2
Villar del Arzobispo		43	27.5	38				18	235*	42	108.5	295*	403.5*
Casinos		47.5	14	26				11	200	15	87.5	226	313.5
Lliria		48	26	31				11	225	221	105	457	562
Lliria (HS)		55	26	30				10	175	195	111	380	491

* Villar del Arzobispo's figures for the 14th are considered to be an underrepresentation, since the rain gauge was overflowing when the observation was made. Source: Instituto Nacional de Meteorología (García and Carrasco, 1958)

Based on these records and the consultations made, García and Carrasco (1958) concluded that the flood at the Rambla Castellarda had a double peak – at dawn and noon on 14 October – that was slightly ahead of the peak in the city of Valencia. Puertes and Francés (2016) have refined this information using hydrological simulation techniques and have calculated a peak of 862.3 m³/s for the first wave, which took place at 02:00 on the 14th, and a second peak of 940.2 m³/s, which took place at 12:00 that same day. The contribution of this IRES and the adjoining Rambla Primera, with a combined flow of 2,159 m³/s, exceeded the flow added by the Turia river at the confluence between these three channels during the second wave, which devastated the city of Valencia.

3. Materials and methods

The main source of information for this work has been the photographic series called *Itinerario del Turia* (IdT), made by the company CEFTA a few weeks after the flood, between November and December, according to Mateu *et al.* (2012). This series is made up of 238 negatives arranged in eight passes. They are 23.5 x 24 cm negatives, with a focal length of 210 and a scale of approximately 1:7,500, which allowed a pixel size of 0.16 m to be obtained after a precision scan. In total, 14 frames were used, which were georeferenced by introducing ten control points, with a mean residual error of less than 1 m in all images. The resolution of the IdT is notably higher than that presented by Series B, from the 1956–1957 flight made by the US Army. This series was performed at a scale of 1:33,000 and with a pixel size of 1.15 m, and it was consulted through the Web Map Service of the National Geographic Information Center (CNIG). Frame 260-032 from Series A by the US Army (1946) has also been used. To reduce its distortion, the frame has been cut into eight 1 m resolution images, which have been georeferenced using ten control points, with a mean residual error of 0.34 m. These images have been used for digitisation, but a wider image taken from the same frame has been reproduced in Figures 3 and 4.

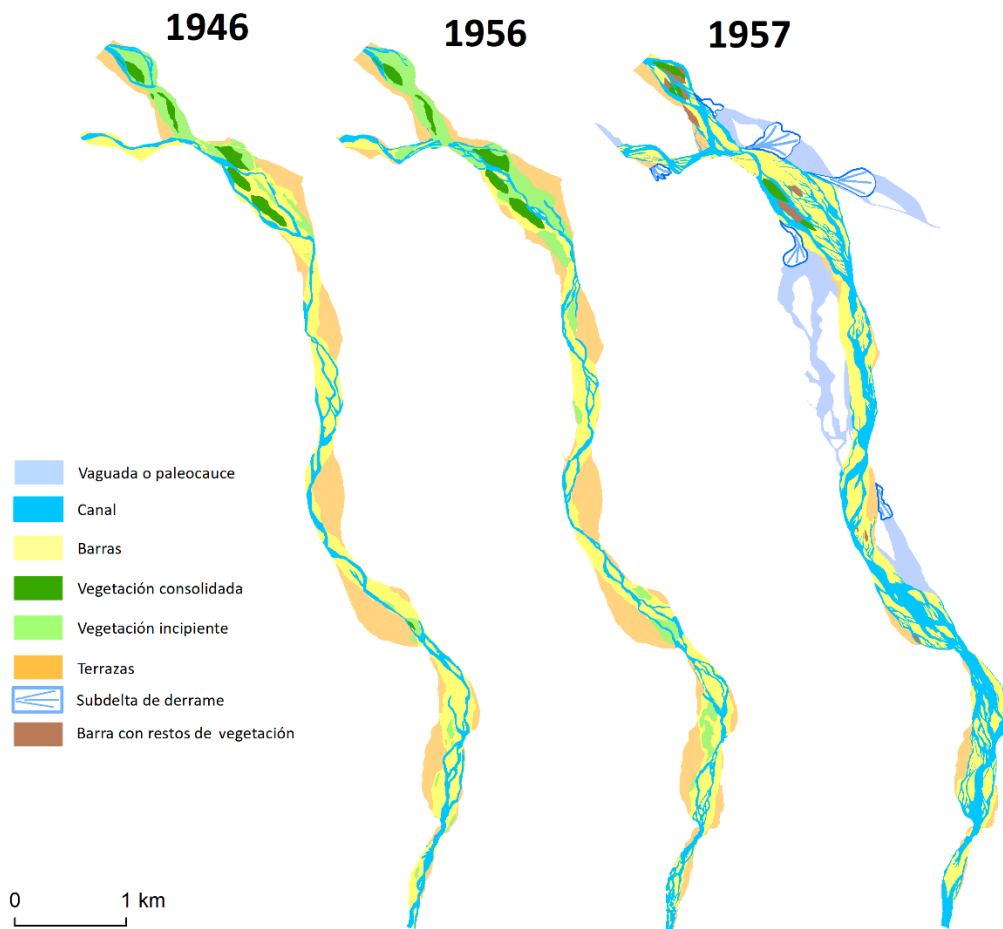


Figure 3. General view of the active channel forms in 1946, 1956 and 1957.

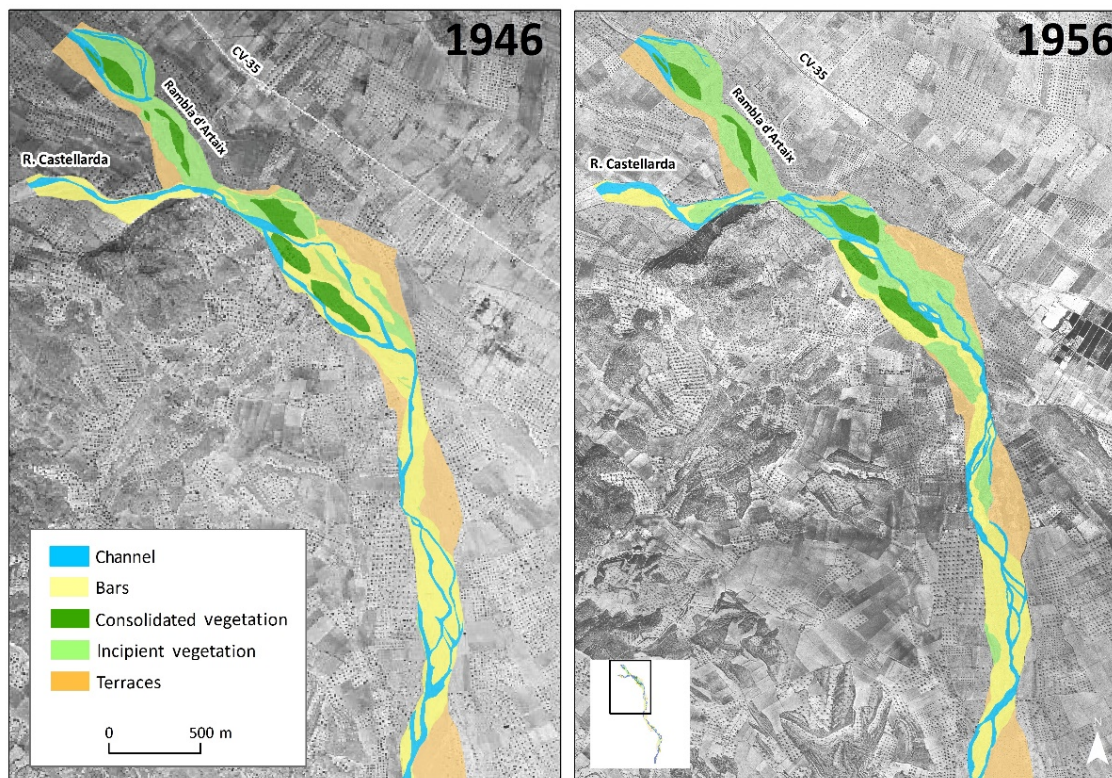


Figure 4. Active canal forms in the northern sector of the study area in 1946 and 1956.

For the analysis of flood and overflow processes and changes in fluvial forms, the study area has been photointerpreted and mapped before and after the 1957 flood. This cartography, prepared using ArcGIS v10.8 (Redlands, California), has been carried out over the entire area that shows evidence of water flow in the IdT images, both in the active channel and in the vegetated areas of the riverbed or on the alluvial fan. For the pre-flood situation, six features have been distinguished as polygons, according to the following criteria of classification:

- Channel: areas devoid of vegetation with evidence of water flow.
- Bars: sediment deposits devoid of vegetation.
- Incipient vegetation: stretches of channel, bars or islands covered by herbaceous vegetation and scattered shrubs or trees.
- Consolidated vegetation: stretches of channel, bars or islands covered by crops or shrub or tree vegetation.
- Terraces (active): sedimentary platforms attached to the banks of the channel and occupied by crops, separated by more or less pronounced escarpments from the body of the alluvial fan and the active channel.
- Alluvial fan: this category includes only those parts of the alluvial fan of the Rambla Castellarda through which the overflowing waters ran in the October 1957 flood. This has not been represented in the figures that represent the Rambla Castellarda before the flood, but its extent has been mapped and quantified in Table 2 to facilitate pre- and post-event map comparison.

Table 2. Area occupied by the forms identified in 1946, 1956 and after the October 1957 flood.

	1946		1956			1957	
	ha	%	ha	%		ha	%
Channels	32.6	9.2	35.5	10.0	Channels	115.1	32.6
					<i>Main channel</i>	108.4	
					<i>Channels on bars</i>	6.7	
Bars	100.5	28.5	76.9	21.8	Bars	112.7	31.9
					<i>Medial bars</i>	15.3	
					<i>Lateral bars</i>	48.1	
					<i>Others bars</i>	49.3	
Incipient vegetation	25.5	7.2	48.5	13.7	Incipient vegetation	0	0
Consolidated vegetation	11.8	3.4	12.1	3.5	Consolidated vegetation	5.0	1.4
					Flattened vegetation	5.5	1.5
Terraces	77.6	21.8	75.2	21.1	Terraces	21.7	6.1
Aluvial fan	104.7	29.9	104.6	29.9	Alluvial fan	0	0
					Crevasse splay deposits	24.8	7.0
					Overbank Flow channels	69.2	19.6
	352.8	100	352.8	100		352.8	100

Six other categories have been added for post-flood mapping, two of which are subcategories of the bars:

- Lateral bars: deposits devoid of vegetation attached to the outer margins of the Rambla Castellarda, on which parallel microchannels are recognised that drain the bar towards one of the margins of the active channel.
- Medial bars: spindle-shaped deposits devoid of vegetation, generally in a central position in the riverbed, characterised by the presence of a central channel in its upper part that progressively subdivides into an arborescent network of microchannels, followed by another network microchannels of drainage in its lower part.

The channels have been subdivided into two other types:

- Main channel: channels that divide bars and river islands.
- Channel on bar: channels that go up or drain medial and lateral bars. Only those that are wide enough to be digitised at a 1:2,000 scale have been mapped.

For vegetated areas, the inclusion of a new category has been necessary:

- Flattened vegetation: areas with stumps or degraded remains of crops or other forms of consolidated or incipient pre-event vegetation.

And, finally, two other categories have been distinguished for those areas of the alluvial fan affected by overflow processes:

- Crevasse splay deposits: semicircular or semielliptical accumulations on the alluvial fan at some overflow points.
- Overbank flow channels: swallow depressions of the alluvial fan through which the overflowing water of the Rambla Castellarda has circulated.

In addition, for the interpretation of the flood, the gullies formed in the fan have been identified and digitised as lines, regardless of whether they are associated with the flow of the Rambla Castellarda or that of the small tributaries or the runoff concentrated on the cultivated plots of the floodplain. Finally, the channel mobility index (CMI, Sanchis-Ibor *et al.*, 2019) has been calculated to estimate the shift of the river channels between the three aerial pictures used.

4. Results

4.1. The Rambla Castellarda forms before the 1957 flood

The aerial photographs taken in 1946 and 1956 show very similar forms (Table 2 and Fig. 3, 4 and 5), which define the pre-event situation. In those decades, the *rambla* (watercourse) had a wide channel, mainly covered by gravel bars, the active channel was only slightly incised, and the most significant direct human pressure was the agricultural use of the lateral microterraces.

The abundance of sediments is clearly perceived in the upper part of the study area, where the riverbed seems practically levelled with the alluvial fan, particularly on its left bank. Only a small cliff is observed on the banks of the Rambla Castellarda, where it narrows (downstream, bottom part of Fig. 4). This scarp progressively increases as the river approaches the confluence with the Turia river.

In both pre-event aerial pictures (1946 and 1956), the Rambla Castellarda presents more signs of recent activity than the Rambla de Artaix, since the former has a wide active channel, while the latter is completely covered by sparse vegetation, with some islands occupied by crops and denser vegetation (Figure 4). The Castellarda channel, narrow and winding, is continuous and seems to carry a little water in 1946, while that of Artaix is dry in both aerial pictures and vanishes before the confluence.

After the confluence, the active channel (bars and channels) has a high sinuosity, alternately leaving wide terraces on one side and the other, in a regular sequence (Fig. 4 and 5). As occurs in many IRES in this Mediterranean region, the number of simultaneous channels rarely exceeded three, so it was closer to a wandering than to a braided type river.

The active channel was wide, occupying 133.1 ha in 1946. Most of it featured large gravel bars (100.5 ha), while the channels extended over 32.6 ha. Ten years later, the active channel had slightly reduced, down to 112.4 ha, but the channels barely occupied 0.8% more than in 1956 – a fact that is irrelevant, given that the presence of water in the 1956 aerial pictures does not allow their area to be quantified with sufficient precision. Vegetation was scant in 1946: the bars covered by incipient vegetation extended over 25.5 ha of the rambla and 11.8 ha were occupied by islands with consolidated vegetation. In 1956, incipient vegetation almost doubled (48.5 ha), but consolidated vegetation remained practically stable (12.1 ha). The terraces, which also stabilised (77.6 in 1946 and 75.2 ha in 1956), were mostly parcelled up and planted, mainly with carob trees (Table 2).

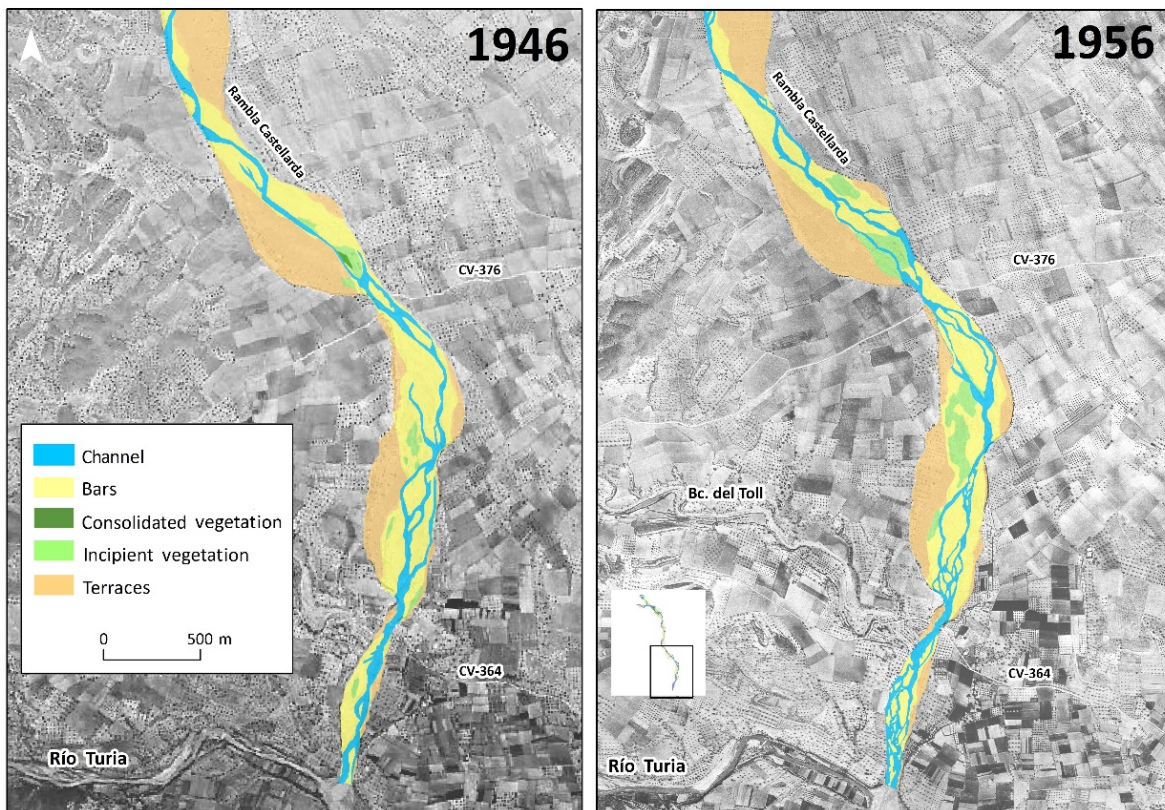


Figure 5. Active channel forms in the southern sector of the study area in 1946 and 1956.

Between 1946 and 1956, only one significant flood was registered, on 28 September 1949, which also dramatically affected the Turia river and the city of Valencia (Portugués, 2012; Portugués and Mateu, 2012). This event explains the change in the course of the channels, which presents high mobility, as shown by the CMI index (4.3) calculated between both dates. The channel shifted but maintained similar forms and significant changes have been detected in the margins of the active channel (Fig. 4 and 5). The bars and terraces maintained their position, almost with complete accuracy, from which we deduce that the flood was not extraordinary in the Rambla Castellarda. This also explains the abovementioned stability, in terms of area, of the consolidated vegetation and the terraces, and the lack of evidence of erosive or depositional processes in the river banks. The advance of the areas covered by incipient vegetation (+ 23%), which is produced at the expense of the bars (-23.6%), proves that no significant floods took place after the 1949 event, and the vegetation expanded in the zones closest to the deposits already vegetated in 1949.

4.2. The 1957 flood. Processes and forms

The flood processes of October 1957 were intense, went beyond the active corridor and radically changed the river morphology. The following lines and figures (Fig. 6 to 9) describe the observed processes and forms, from top to bottom of the study area.

In the upper sector, upstream the confluence with the Rambla de Artaix, the Rambla Castellarda formed a new medial bar (Fig. 6). On its southern shore, the waters overflowed the active channel, destroyed a plot covered with trees and formed a small crevasse splay deposit in the adjacent plots. The overflowing waters soon returned to the channel when colliding with the calcareous reliefs of the Cabeçó de l'Ermita. On the northern shore, the flood eroded the left bank, making the cliff recede 37 m, and followed its course in a straight line to merge with the Rambla de Artaix.

On the Rambla de Artaix, the flood reactivated a paleochannel and opened a new, deeper one, breaking in two a small terrace that had been cultivated since at least before the 1940s. To its left, it set the bank back by up to 37 m (Fig. 6). A first overflow took place along this margin, which formed a small crevasse splay deposit and the channel was divided again. Part of the flow ran through the alluvial fan to the east, and another part returned to the channel 200 m downstream.

At the confluence, the IdT photographs show how the Rambla Castellarda channel was partially perched above the channel excavated by the Rambla de Artaix, a fact that indicates that the peak of the Rambla de Artaix flood was somewhat later than the Rambla de la Castellarda or that it had a greater erosive capacity. The coincidence of two asynchronous peak flows had another very clear hydraulic effect. The flow from the Castellarda, supported by the Cabeçó de l'Ermita hill, contributed to diverting the waters of Artaix towards the opposite shore, overflowing and forming a large semi-circular splay deposit, with a radius greater than 300 m. In the shadow of the aforementioned hill, protected from the main flow, a bar was formed, attached to the right bank (Fig. 6).

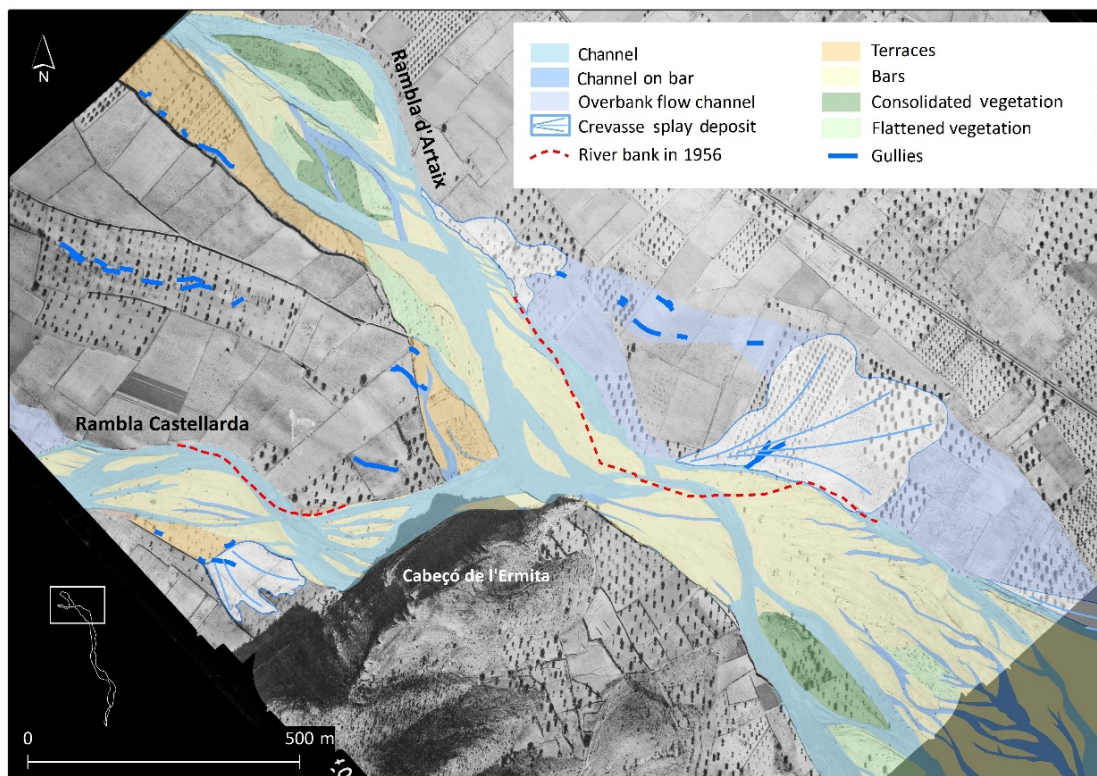


Figure 6. Confluence of the Artaix and Castellarda ramblas. Post-event forms in the first photograph of the IdT series.

Downstream of the confluence, the Rambla Castellarda had its least incised sections (Fig. 7). The sediments were practically levelled with the river margins. These conditions favoured the dispersion of the flow and the overflow on both banks during the October 1957 flood. The waters covered all this space, passing over some areas that had been transformed in agricultural plots decades previously. The flood also formed a large medial bar on the left and other smaller ones, on the main channel, on the right.

On the left bank, right at the ford of the Villar Road, a third overflow took place. The ford gave rise to another splay deposit, and the medieval road transported the waters along the alluvial fan. The overbank flow was captured by the Montaragó ravine, which followed a sinuous path and fell on the Rambla Primera, 3.5 km from its mouth in the Turia (Fig. 7). On the right bank, the overflow took place 500 m after the previous one, it also formed a splay deposit and flowed south, forming a diffluence. The area affected by this flow cannot be specified with precision, but, by following the gullies over the fields, it is possible to identify divergent and convergent flow lines, sometimes forced by the small Jurassic reliefs that emerge in the margin of the alluvial fan (Fig. 7). These calcareous hills finally forced the waters to return to the rambla, 2.2 km after having abandoned it. Previously, to its right, this flow had received lateral contributions from small ravines and gullies that eroded the cultivated plots. To its left, more overflowing streams from the Castellarda joined this current (Fig. 7). In its last 500 m, this overbank flow channel activated erosive processes, clearly seen in two confluent channels, wider than 40 m at various points, which had vertical banks and gullies (Fig. 7 and 8).

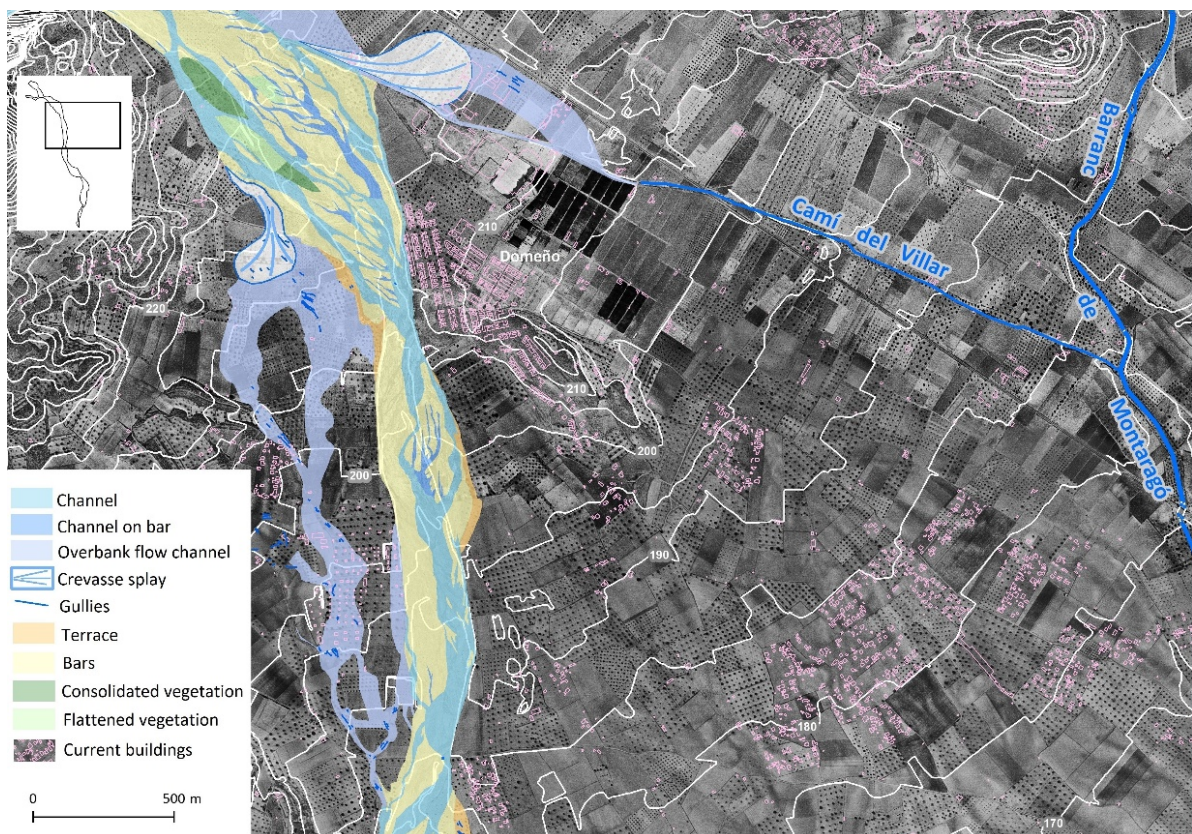


Figure 7. Forms of the Rambla Castellarda after the confluence with the Rambla de Artaix, in 1957. At the top, an overflow channel crosses the area where the industrial park of Domeño stands today and is captured by the ravine (barranc) of Montaragó. The contour lines show the convexity of the Castellarda alluvial fan, in its apical zone. The Rambla Castellarda crosses this sedimentary body and leaves, as evidenced by the contour lines and the humidity lines, various paleo-channels on the surface of the fan, one of which has been used as a road since the medieval period (Camí del Villar).

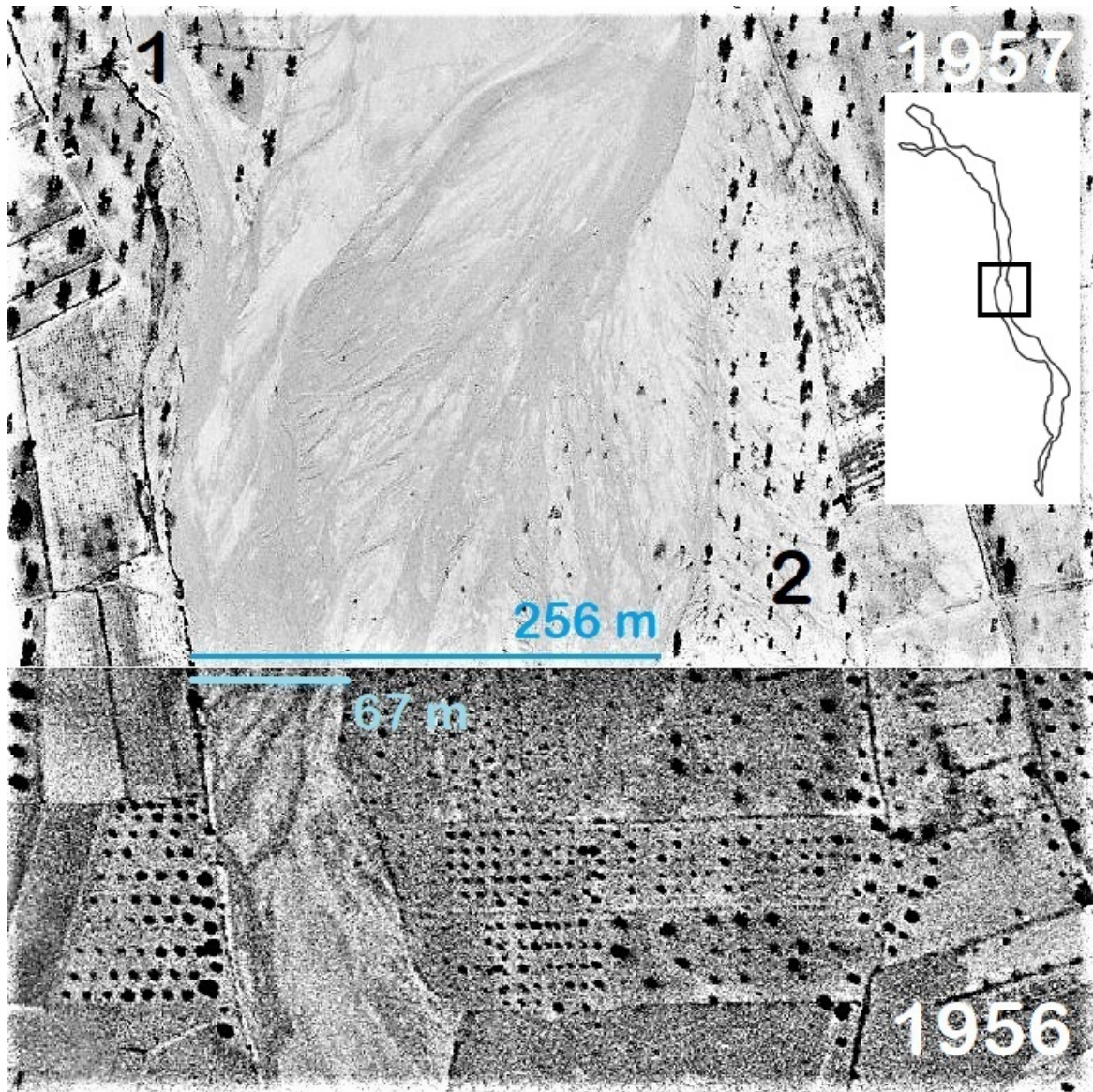


Figure 8. Comparison of pre- and post-event photographs. The contrast of the images has been increased to improve the perception of the printed version. Above, in the IdT image, a broad medial bar formed by the flood can be seen. In this image, at the top left, readers can see the channel excavated by the overbank flow channel that acted as a diffluence (1) and, to its right, (2) the overflow that occurs immediately downstream on the other bank. The blue lines represent the width of the active channel before and after the flood. Below, the image from 1956, with an active channel narrowed by rainfed crops.

The channel of Rambla Castellarda was unable to absorb all this return flow and overflowed again, this time on the opposite bank, starting right at the point where these waters joined the main current (Fig. 8 and 9). In this lateral overflow, the flood did not generate any deposit and presented two lines of flow: one that dissipated its flow through the alluvial fan and left a small splay deposit; and another that forked and converged, to return to the main channel 1.3 km downstream of the overflow point.

In this 4 km long section with various outflow and return flows (Fig. 7), all the spontaneous vegetation and crops located within the 1956 channel were washed away by the waters, but there are no signs of destruction or retreat of the banks. The channel had its lowest sinuosity in the first 2 km of this reach. It circulated contiguous to a large lateral bar and only formed a medial bar in the initial section, which was wider. Further down, there are two consecutive wider areas that had a more complex

morphology, probably conditioned by the change in section and the lateral discharge of flows, which gave rise to various lateral bars, ranging between 300 and 500 m in length, and two medial bars, with an uneven degree of development.

This pattern was repeated in the next reach of the Castellarda (Fig. 9), between the ford of the road CV-376 and the bridge of the CV-364, where the river is more incised, passing between vertical banks formed by silts, clays and cemented gravels. However, at the beginning of the narrow section used by the CV-364 bridge, the flow destroyed the left bank, which was lower than the right, and moved it 36 m from its former position. The road bridge, of which only the abutments remained, was also swept away, and 50 m of the access road to the bridge disappeared. Downstream, it also set back the left bank between 10 and 15 m, in a combination of the Venturi effect and the confluence of the Toll Ravine flow. This ravine also partially destroyed another bridge of the CV-364.

Downstream, in the last section of the rambla, the microchannels of the river clearly drew the network of convergence and divergence of flows typical of a large medial bar, which barely protruded from the adjacent channels, probably due to the intensity of the river flow in a narrow, straight and partially confined section. On the left bank, where the terraces gradually descend to the riverbed, the flood washed away several plots, expanding the active channel section up to 50 m. Finally, at the end of the study area, the waters of the Castellarda, together with those of the Turia, destroyed the Benaguasil irrigation canal and all the crops surrounding the confluence (Fig. 9).

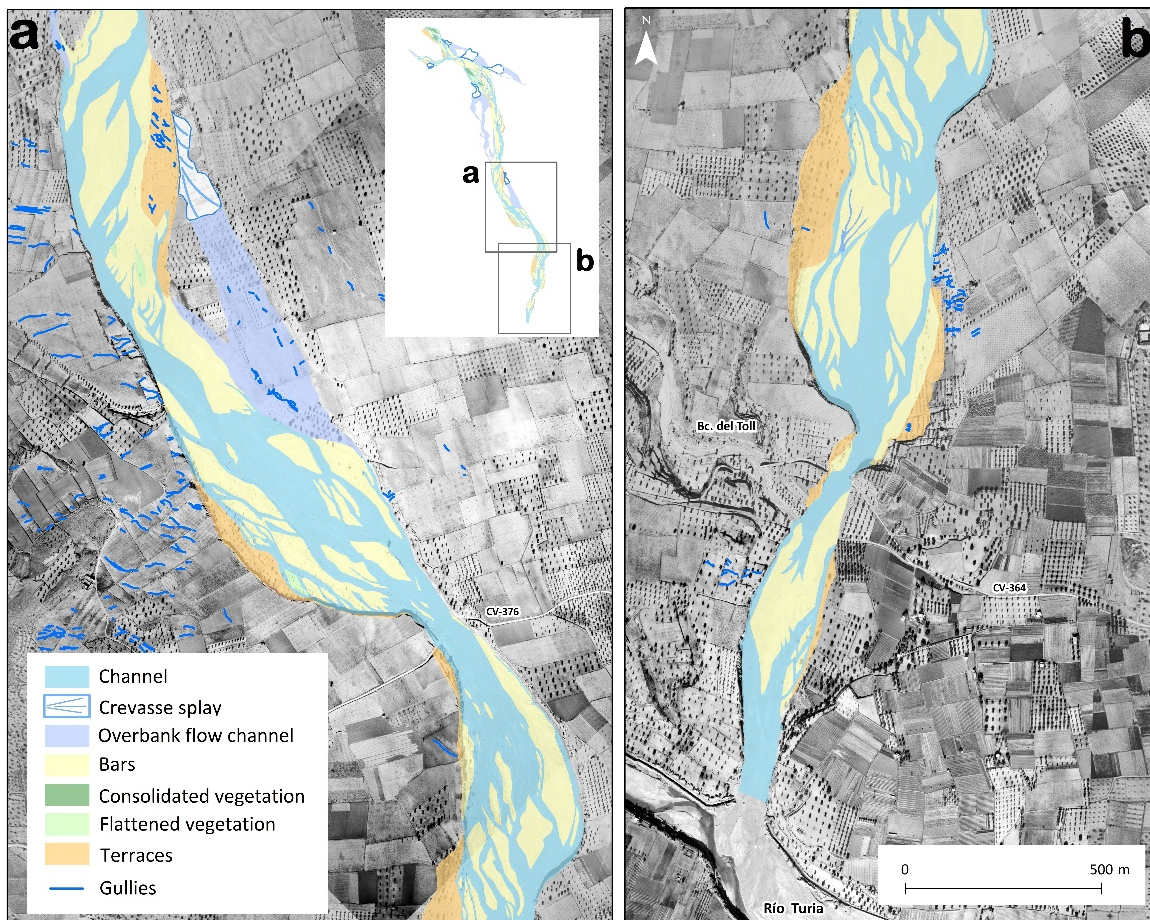


Figure 9. Rambla Castellarda forms after the 1957 event, in the two last reaches of the study area.

5. Discussion

5.1. The 1949 flood compared to the 1957 flood. Ordinary vs extraordinary events

The storm of 1949, despite having dreadful effects in the city of Valencia and other neighbouring basins (Portugués, 2012), had a much lesser impact in the Rambla Castellarda. First, between the images of 1946 and 1956, no displacements of the banks of the active corridor were observed. Second, and although the subsequent plant colonisation and the lower precision of the images may have impaired their observation, channels are scarcely detected on the bars. Finally, the terraces mostly conserved their size, position and crops. However, the canal shows high mobility (CMI = 4.3) between 1946 and 1956, which is just below that observed between the 1956 and 1957 images (CMI = 4.5). In short, despite the evident lower magnitude, the 1949 flood was able to significantly reshape the deepest part of the active canal, the one occupied by bars and canals, but had little influence on the external and higher part of the riverbed, occupied by rainfed crops.

The analysed images also make it possible to ascertain that, following the 1949 episode, there was a brief period of stability. Some vegetation colonised part of the bars, increasing from occupying 25 ha in 1946 to 50 ha ten years later. This short dry period was interrupted by the extraordinary flood of October 1957 which, as has been explained, swept away all these herbaceous communities and completely altered the forms of the active corridor. Therefore, the first flood impact was limited to the active channel, while the second affected the whole active corridor and created ephemeral external forms (crevasse splay deposits and overbank flow channels). This comparison enables the opportunity to adapt the classical quali-quantitative perception and classification of floods as ordinary, extraordinary, and catastrophic, used for paleo-flood reconstruction (Barrera-Escoda and Llasat, 2015) and partially based on the impact on infrastructures. From a river morphology perspective, it is probably more useful to link this classification on three levels to the three areas where significant geomorphic changes can be detected: the active channel, the active corridor and the floodplain.

5.2. The 1957 flood in light of the current sedimentary context

In the current context of sediment deficit, in-channel changes caused by floods are significantly different. The important development of bars observed in 1957, typical of an aggradational river, would be impossible in a flood at present. As observed on field (Fig. 2), the current scarcity of sediments in the active corridor (in this and other IRES in this region) does not allow the complete development of the bars, which are reduced to incipient lobes, with the appearance of erosive bars in compact sediments and outcrops of parent rock being frequent (Segura-Beltran and Sanchis-Ibor, 2011; Calle *et al.*, 2017).

Beyond the river banks, overflow processes are an essential dynamic function of ephemeral rivers, connecting the channel with the alluvial fan and other ecosystems (Ollero *et al.*, 2021), and also conditioning the hydraulics of the in-channel flood processes. In the Rambla Castellarda, the overflows undoubtedly played an important role in laminating the flood peak at the confluence with the Turia river. It is impossible, however, to estimate the amount of this effect. Most of the water spilled by the left bank returned to the channel, since in this bank the topography does not allow the dispersion of flows and returns them to the IRES, as has been seen in Figure 8. Its route through the alluvial fan should have slowed or slightly attenuated the impact of the flood. However, the water that came out on the left bank was dispersed by the Castellarda alluvial fan and a good part was drained by the Montaragó ravine, both of which undoubtedly reduced the flow of the rambla, since most of it did not return to the channel. They partially laminated the flood, but increased the contributions of the Rambla Primera on the Turia river; thus, overall, they cannot have had much effect on the flood peak that devastated the city of Valencia.

The flood of 1957 inundated some spaces that today feature intensive urban occupation. Although predominantly agricultural land use is maintained on the right bank, with the exception of

some scattered houses and a pyrotechnic factory, the new urban centre of Domeño was built on the left bank in 1967 (Fig. 7). It currently has an industrial park that occupies 16 ha and a scattering of leisure homes. The buildings of the polygon are located in the area that flooded, the waters conveyed by the old Villar road towards the Montaragó ravine during the October 1957 event. In fact, the road has recently been dismantled and replaced by an open-air channel that crosses the industrial estate and disappears downstream among the cultivated fields. However, none of these zones is considered a relevant dangerous area by the official flood mapping, neither have they been taken into account by the regional flood risk planning instruments (PATRICOVA) nor by the national system of flooding zones (SNCZI). This is not an oversight: the massive removal of gravel deposits for construction, and the erosion of the channel experienced in recent decades has incised the active channel to such an extent (lateral slopes between 4 and 10 m depending on the sector), so it is very unlikely that new overflows will occur in this area, at least while the current morphosedimentary conditions are maintained in the IRES. The incision, on the one hand, facilitates the protection of the alluvial fan urbanisation, and on the other, undermines the transversal infrastructures on the riverbed (Fig. 2 c, d and f).

5.3. Floods and adjustment processes: the paradox of the hydro-sedimentary connection

Large flash-floods establish a hydro-sedimentary connection between the river basin and the river channel, which is momentary but instrumental in the evolution of ephemeral rivers. This connexion generates a paradox in the adjustment trajectories of rivers. When sediment is abundant and increasingly available, floods stimulate aggradation and channel widening, boosting and accelerating the river adjustment trajectories to these conditions. However, in contexts of sediment starvation — for natural or human causes — floods temporally invert the predominant trends of channel narrowing and vegetation encroachment, so this brief hydrosedimentary connection slows down the inevitable adjustment trajectories (Croke *et al.*, 2013; Segura-Beltran and Sanchis-Ibor, 2013; Tuset *et al.*, 2015; Calle Navarro, 2019; Scorpio and Piègay, 2021).

The flood of the Rambla Castellarda in October 1957 stimulated erosional and sedimentary processes that clearly consolidated an aggradational river adjustment trajectory. The mobility of the materials was very high, devastating and occupying vegetated and cultivated lands. In some sections there was considerable erosion of the alluvial fan escarpments, whose banks were set back by up to 50 m. Flow circulated over the bars, causing a massive dissection and creating numerous microchannels (Fig. 6, 7 and 8). Channels notably widened, from 35.5 to 115.1 ha (Table 2). Of the 75 ha mapped as terraces in 1956, less than one third (21.7 ha) preserved their trees after the flood. Finally, the areas covered by incipient or consolidated vegetation, were reduced to only 5 ha, with a scant covering of trees that survived the flood or stumps and remnants of destroyed vegetation, whose subsequent viability cannot be verified.

As a whole, the active channel went from representing 31.6% of the mapped area in 1956 to occupying over 64.1% in 1957. Unfortunately, the lack of photographs after the IdT -there are no more images until 1967, when gravel mining was already destroying the riverbed- makes it impossible to know what proportion of this active channel was consolidated after the flood, and which part was shortly after revegetated or returned to cultivation. This hinders the complete interpretation of the river trajectory at the end of its aggradational period. Moreover, the active corridor (active channel + vegetated areas + terraces) barely expanded 11.8 ha after the flood, and the overflow channels and splay deposits did not alter the agricultural matrix.

Had this IRES, and others within the Spanish Mediterranean Region, achieved a steady state by the middle of the twentieth century? Or were they still going through an adjustment process to the consequences of the last stage of the Little Ice Age and the population peak of the rural areas? It is likely that more data is required to reach a conclusion. What this case and others covering the same period (Segura-Beltran and Sanchis-Ibor, 2013; Sanchis-Ibor *et al.*, 2017, 2019) demonstrate is that

spontaneous vegetation was not controlling or limiting channel widening in this region during the decades of 1940 and 1950. This vegetation, easily destroyed by ordinary and extraordinary floods and probably affected by in-channel grazing, did not find space to consolidate itself in the active corridor, and its geo-ecological niche was almost completely occupied by rainfed crops. During these two decades, farmers persisted in the transformation of the microterraces located within the active corridor, maintaining a continuous fight against floods, which is easily visible in the aerial pictures of this period.

6. Conclusions

The October 1957 flood was an extraordinary event, from both a paleo-flood historical perspective and in river geomorphologic terms; it devastated the entire active corridor and modified its forms. In contrast, the 1949 flood can be considered an ordinary event, whose impact was limited to the active channel. Despite their different magnitudes, both floods contributed, in different ways, to sustaining a path of fluvial adjustment to conditions of abundance and availability of sediment.

The three series of aerial pictures consulted are probably not conclusive enough to completely define the two last decades of this aggradational stage, but they are sufficiently valid to make some interesting considerations about this period. The analysis of the 1957 pre- and post-event has highlighted how, during the final years of this stage, in-channel agricultural activity was, together with floods, the most relevant factor conditioning the river channel adjustment trajectory. Both processes left no space in the rambla for spontaneous revegetation processes, which would not be predominant until the last decades of the twentieth century. The channel pattern changes of the Mediterranean rambles during this aggradational stage are a socio-ecological process, in which some factors can be easily followed through aerial pictures, such as rainfed agriculture, but others that are doubtless important, such as in-channel grazing, require different methodological approaches.

The most recent and future floods have taken place or will take place in a context of sedimentary deficit, and consequently will define a different active corridor, adjusted to the new conditions of the basin and channel. In this sense, this study highlights the importance of overflows -and therefore the connection between channel-floodplain- both for in-channel processes and in the lamination of floods. This latter function, which was common in past decades, is currently problematic in many basins, due to the environmental changes that have occurred in river systems and the urbanisation processes of alluvial fans and floodplains. The lateral connection of the channel-floodplain/alluvial fan can be hindered under current conditions, as it adds elements of complexity to land planning. The processes of fluvial adjustment to changes induced naturally or through anthropic action have many facets, which are sometimes contradictory and which should be permanently analysed, since the fluvial dynamics and trajectories are changing.

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