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EVOLUTION OF A CHANNEL OVER 41 YEARS (1956–1997) AND EFFECT OF HEAVY RAINFALL (1994) IN THE JABRON BASIN, SOUTH-EAST FRANCE

Abstract. This paper presents the results of quantitative studies about the spatial evolution (narrowing or extent) of the channel of the Jabron River, a tributary of the French submediterranean Durance River. It focuses on conditions after a rainfall and flood event in January 1994 which brought about major disturbances on the channel of the lowermost flood plain. We studied this rainfall and flood event using meteorological data, details of riparian vegetation and channel cross-sections, and documentary evidence such as aerial photographs and maps for before and after the 1994 rainfall event. The daily rainfall in the Jabron watershed, exceeded 250 mm during this event (the recurrence interval of such an event is 100 years) and the discharge was 250 $m^3 \cdot s^{-1}$ compared to the average annual discharge of 6 $m^3 \cdot s^{-1}$. The channel area widened by 20%, 100,000 m^2 were eroded and the riparian communities were severely disturbed. The 1994 event represents a regression in the general evolution of the landscape of the alluvial plain because the channel widened. We compare these 1994 changes with the changes in the channel and the flood plain over a 41-year period between 1956 and 1997, from meteorological data, flood plain cross-sections, maps (1972) and aerial photographs (1956, 1974, 1986, 1994 and 1997). We calculated the evolution of the active channel surface: between 1956 and 1997, the channel narrowed by 37%. We placed the1994 and other flood events (e.g. 1979) in the general context of the evolution of the landscape of this flood plain over 41 years. We propose a model for flood events in which the channel surfaces increase exponentially with respect to the frequency of the flood.

Key words: Provence, torrent, flood plain, biogeomorphology, riparian vegetation, channel geomorphology, landscape evolution

OBJECTIVE OF THE STUDY

Flood plain management is increasingly affected by temporal variations (Anderson et al. 1996) and plays a particularly important role in Mediterranean and submediterranean mountainous areas, where fluvial landscapes metamorphose over periods of a few years (Batalla and Sala 1994; Gautier 1992; Guilbert 1994; Juramy and Montfort 1986; Miramont and Guilbert 1997; Miramont et al. 1998; Sabater et al. 1995; Surian

1998; Pech et al. 1997). Flood plain landscapes are ephemeral in comparison with long-term changes (i.e. over 10,000 years). Looking at periods of intermediate length, in particular the whole of the historical period, they show successive trends. For each trend, it is important to consider the respective roles of the continuous trend and the exceptional events.

Heavy rainfalls regularly occur in French Mediterranean areas: Nîmes, in 1988 (Davy 1990); Vaison-La-Romaine, in 1992 (Arnaud-Fassetta et al. 1993; Piégay and Bravard 1997; Wainwright 1996). Different scientists have studied catastrophic events in this region and in other areas such as the Eastern Europe, where heavy rainfall with catastrophic consequences has occurred (Czerwiński and Żurawek 1999; Hradek 1999; Kotarba 1999; Niedźwiedź 1999). They compared the consequences of one flood with the general features of the watershed such as the topographic, geological and historical conditions. They did not study the relationship between the history of the alluvial landscape and the fluctuations of the amount of rainfall.

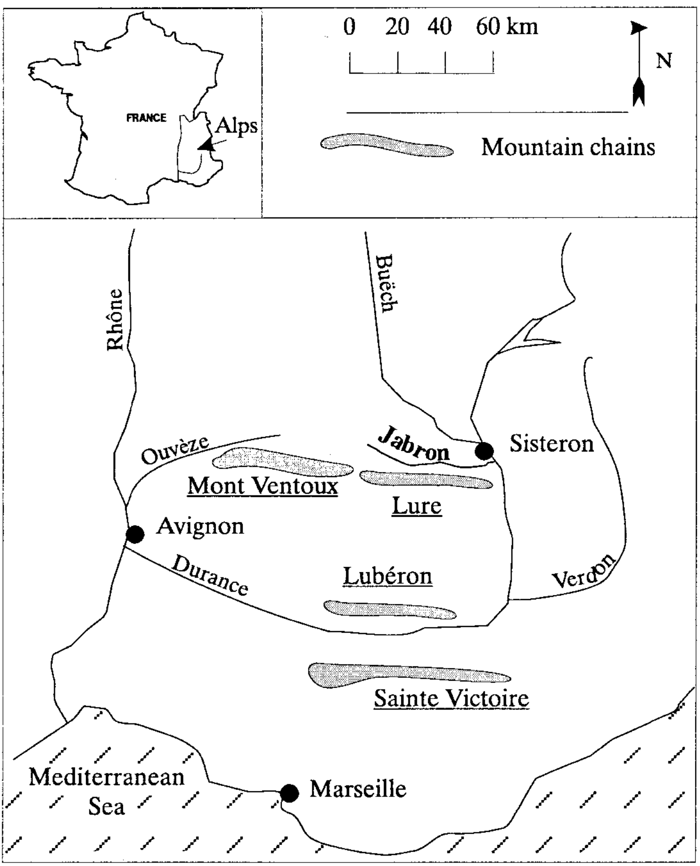

Fig. 1. Location of area examined

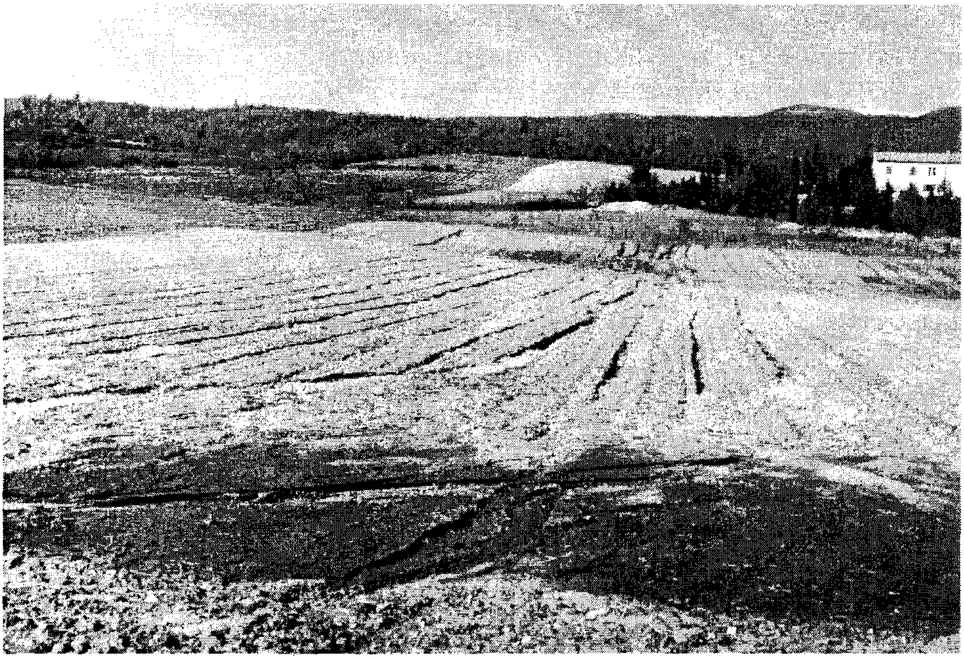

Photo 1. Consequences of flood deposits, Jabron April 1994: extent of high water stage and silt deposits over arable land

Photo 2. Scars and destruction of fields in the Jabron flood plain after 1994 flood April 1994

The heavy rainfall studied in this paper occurred in 1994 in the basin of the middle Durance River in the southern part of the French Alps. In the winter of 1994, many slope movements and geomorphological disturbances of the flood plain occurred in the Durance basin, especially in the western part. The study here is of the Jabron basin, a western tributary of the Durance River (Fig. 1). Since this event, scars have cut into the river banks in the flood plain and the damage has affected agricultural land. Various crops were destroyed and around 100,000 m^2 were eroded along the bank (Photos 1 and 2). The objective of this paper is to document this particular event and to understand the relationship between the evolution of the flood plain and the rainfall trends.

STUDY AREA

The watershed of the Jabron River (Fig. 1) is located in the southern part of a French prealpine massif formed of folded sedimentary rocks, the Massif des Baronnies and drains an area of 200 km^2. The highest point in the Jabron basin lies on the southern side of the valley, at the Signal de Lure (1,826 m a.s.l.) and its confluence with the Durance River is at 460 m a.s.l. (Le Pont des Bons Enfants, Fig. 2). The difference in altitude is 1,366 m over a distance of only 27 km and the mean gradient is 5%. The morphometric characteristics of the basin have typical torrential features (Table 1 and Fig. 3): the Jabron River is a C-type stream in the Rosgen classification (Rosgen 1994; Wharton 1994; Downs 1995). The Jabron watershed has an elongated shape, essentially running WE, with two parallel versant-sides: the southern, right, side being higher in altitude. The southern ridge of the

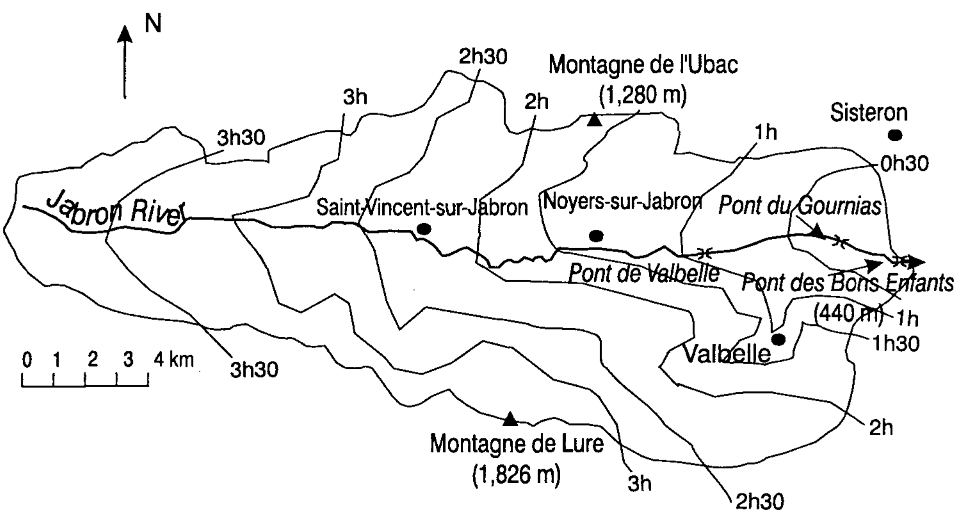

Fig. 2. Flow transfer in the watershed of the Jabron River

Table 1

General characteristics of the Jabron watershed Alpes de Haute Provence, France

Area	A	197 km^2
Basin length	L	31 km
Perimeter	P	73.8 km
Elongation	$Se = A^{1/2}/L$	6.99
Total channel length	Ct	568 km
Maximum altitude	Ma	1826 m
Mean altitude	Mn	876 m
Lowest altitude	Ml	460 m
Modal values of the altitude	600–800 m	27.90%
Aeration ratio	Mn/Ma*100	48%
Order streams	Number	Length km
1st	1122	156
2nd	287	250
3rd	76	131
4th	14	17.2
5th	2	11
6th	1	2.75
Drainage density	Dd = Ct/A	1.31
Compacity ratio	Kc = 0.28 · P/☆A	1.47

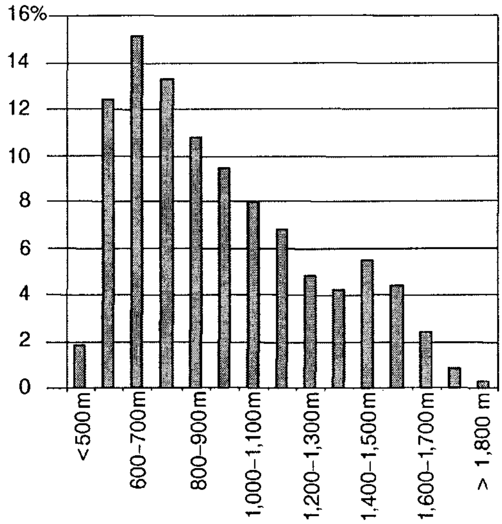

Fig. 3. Area frequencies of the Jabron watershed

Jabron basin is the Montagne de Lure ridge. The basin is steep and the runoff generally takes less than 4 hours to reach the lowermost part of the valley. As shown in Figure 2, there is a short time between the start of the rainfall and evacuation of water from the watershed. This map is constructed with the following formula (Llamas 1993): $Ti = di/vm$, where di is the measured length of water travel between the area of rainfall and the watershed exsurgence and vm is the mean speed of the water.

During the 1994 flood, the lower section of the Jabron valley between Saint-Vincent-sur-Jabron and Le-Pont-de-Gournias was severely damaged. Upstream of this lower reach, the water runoff is particularly concentrated in its channel. In this lower section, by contrast, there is a flood plain. In this latter part of the Jabron watershed, the valley is wider than in the others, because Gargasian marly layers outcrop here. After the lowest point of this section, called Le-Pont-de-Gournias, the Jabron River flows through a gorge until reaches its confluence with the Durance River. This flood plain of the Jabron valley has been examined in detail in this paper. Here, the flood wave spreads over a flood plain which is partly used for agricultural activities.

The alluvial plain is filled with Pleistocene fluviatile deposits. The vegetation on the banks allows us to designate the Jabron as a braiding river (Nanson and Knighton 1996). It is possible to distinguish different terraces or steps formed across the river plain:

— The braided channels: the main active channel is from 50 to 100 m wide. There are many braided channels, which lie 50 cm in depth between small islands or banks;

— The stripped bars: on these banks, coarse sediments are associated in an imbricated structure: the long axes of the pebbles overlap each other as they are inclined in the direction of the former current. The elevation of these bars is around 50 cm. They are unvegetated and mobile. Annual floods usually spread over them;

— Other alluvial islands or the lowest terraces, which are flat surfaces, lie 80 cm higher than the usual water level. The alluvial silt covers these vegetated banks;

— The Holocene terraces: lie around 1.5 m higher than the usual water level. They are cultivated (orchards and cereal crops). These terraces are well known from the work of E. Gautier (1992) and T. Rosique (1997).

The regional climate combines western Mediterranean and mountain influences, with hot, dry summers and mild, relatively wet winters in the lower parts of the basin and wetter, colder and snow conditions at altitude. The flow variations of the Jabron River are characteristic of Mediterranean mountains (Mc Neil 1992): the mean annual specific discharge is $20\ l \cdot s^{-1} \cdot km^{-2}$ ($6\ m^3 \cdot s^{-1}$). The Jabron has a pluvio-nival regime. During the autumn, the rainfall is responsible for the increase in flow: 36% of annual rainfall occurs during the autumn. Then the flow decreases during the winter because accumulated snow retains part of the precipitation. In spring, high flows are due to rainfall and snowmelt. Summer is dry with low rainfall and heavy evaporation.

METHODS

This paper studies the flood plain landscape over a period of 41 years (1956–1997) and especially the extent of the channel. An extensive study has been carried out in order to document and analyse landscape changes in the flood plain, in particular to the river channel, and to document one particular event, the rains and resulting floods in 1994.

STUDY OF METEOROLOGICAL AND HYDROLOGICAL DATA

The study involves interpretation of these changes from meteorological and hydrological data. There are three meteorological stations inside or near the basin (Fig. 4). We studied the rainfall figures for a period of 41 years. We also observed other exceptional rainstorms. Hydrological data are drawn from a former hydrological station in the lower part of the fluvial channel, near Pont des Bons Enfants (Fig. 2). There are other hydrological stations on the Durance river and we can compare these data with the Jabron River. Unfortunately, the hydrological station of the Jabron River is no longer operating. A local study (Watt 1996) has evaluated the 1994 flood event using models based on the rainfall figures and watershed features.

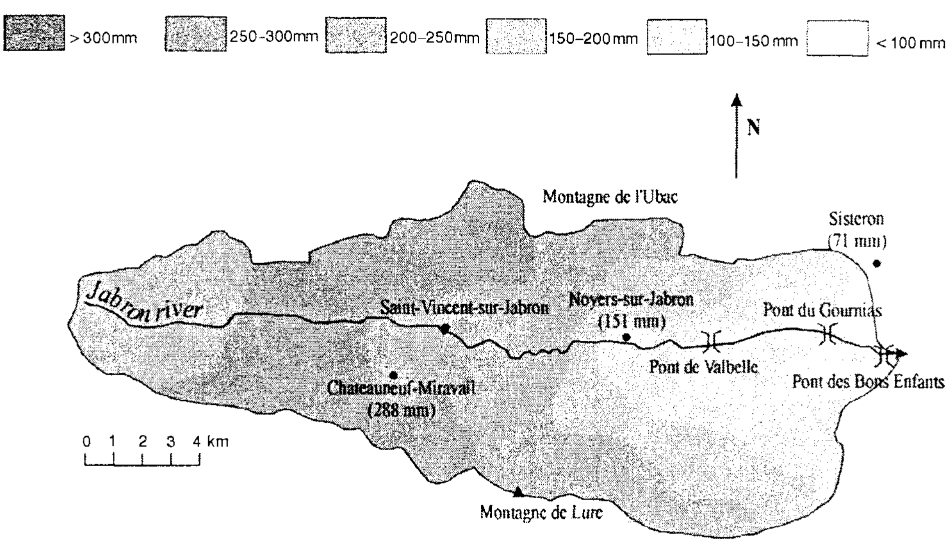

Fig. 4. Amount of rainfall on 6–7th January 1994 in the Jabron watershed 24 h

STUDY OF THE RIPARIAN VEGETATION

Special attention has been paid to riparian vegetation because of its importance (Malanson 1993). A. Kotarba (1999) shows that the effect of the flood on the riparian vegetation documents the importance of the flood event. The vegetation controls channel morphodynamics (Gregory and Gurnell 1988; Gregory and Walling 1973; Kochel and Patton 1998; Piégay 1995; Piégay and Bravard 1993; Richards et al. 1996). K. J. Gregory

Table 2

Evolution of vegetation before and after the flood of 6–7th January 1994 in the Jabron flood plain Alpes de Haute Provence, France

		Before the flood	After the flood
Holocene terraces	cutivated fields	cultivated fields	cultivated fields; 10 ha eroded in the banks; 20 cm of alluvial deposits; coarse deposits
	natural vegetation	*Quercus pubescens, Pinus nigra, Genista cinerea, Juniperus communis*	scars; alluvial deposits silt
Flood plain	banks and terraces	*Fraxinus angustioflia, Populus nigra, Salix viminalis, Clematis cirrosa, Cornus sanguinea, Ligustrum vulgare, Primula elatior, Carex pendula, Viola riviniana*	destruction of tree branches (*Fraxinus angustifolia, Populus nigra, Salix viminalis*) and flood deposits silt
	higher stripped banks, islands	*Calamagrostis arundinacea, Potentilla erecta, Dorycnium suffructicosum, Melanpyrum cristatum, Vicia crassa, Solanum dulcamara, Galium mollugo, Apphyllantes monspeliensis, Ommobrychis saxatilis, Lavandula latifolia, Santolina chamaecyparissus*	destruction of tree or shrub branches; flood deposits, silts and gravel
	lower stripped banks, riparian ecosystems and higher channels	*Alnus viridis, Populus nigra, Salix viminalis*	destruction of tree branches; flood deposits, silt and gravels
	braided channels	no vegetation	no destruction forms

and A. M. Gurnell (1988), A. M. Gurnell (1995) and H. Piégay (1995) showed that investigations concerning interrelations between vegetation and river flow help to explain the dynamics of the river. M. C. Bourke (1994) has also shown that the interrelations between the flood dynamics and channel morphology, sediment transport and vegetation in Australian semi-arid flood plains and our comparative study of the Jabron River is also a contribution to such an approach. We studied vegetation communities before and after the flood (Table 2) using sampling areas of 1 ha or 10,000 m^2, giving particular

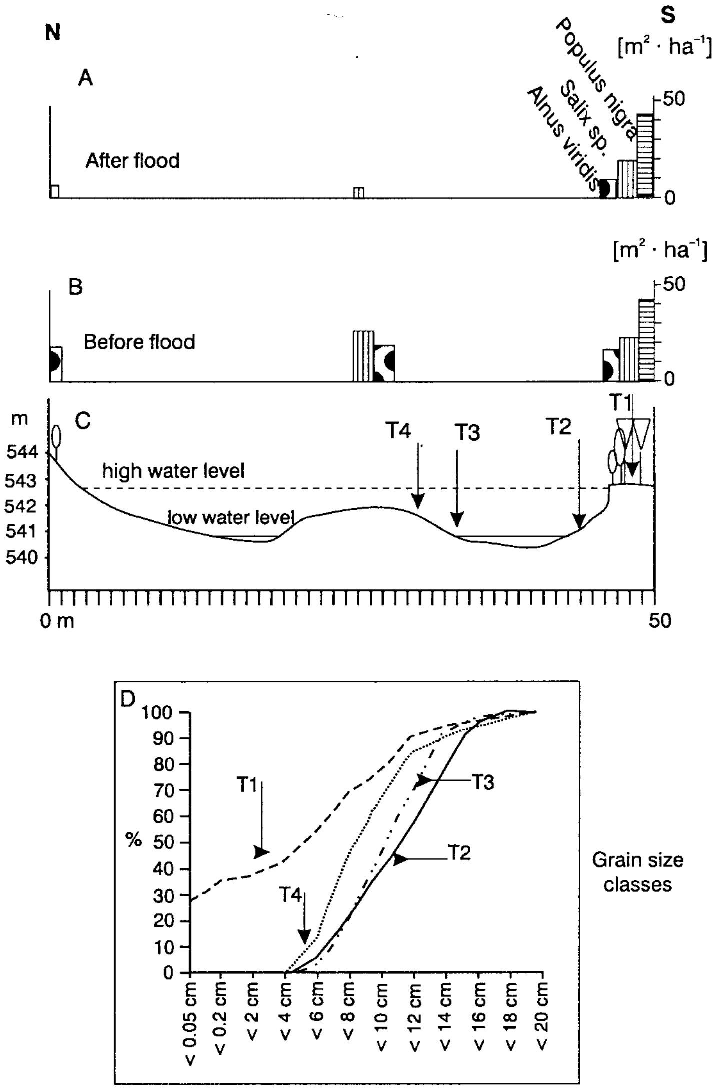

Fig. 5. Upstream cross-section of the Jabron valley transect T of Fig. 7 with cumulative curves of granulometric studies

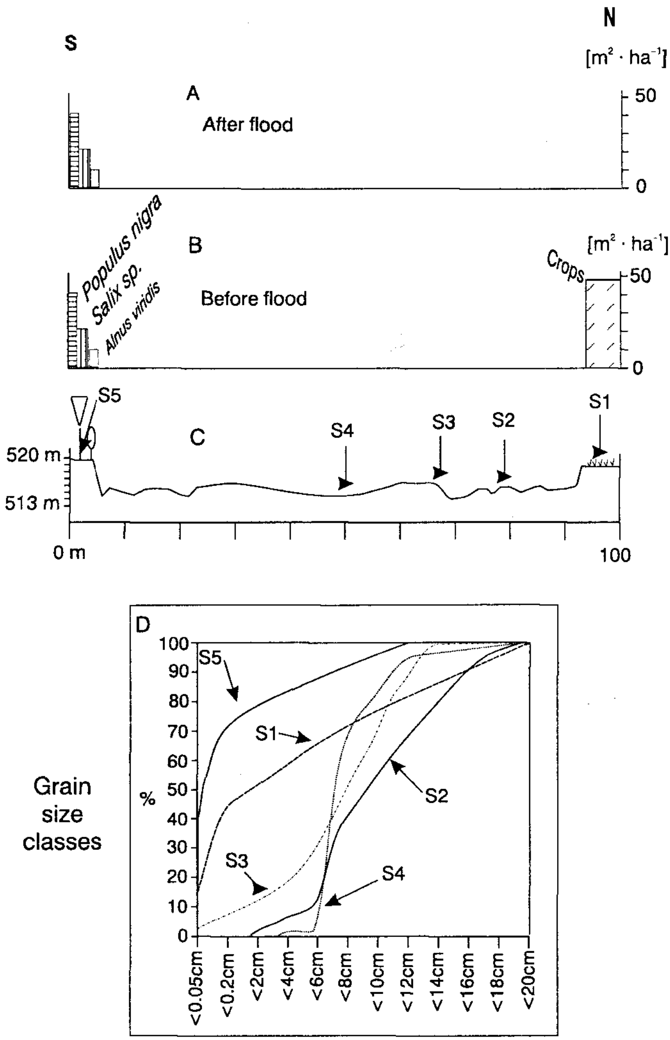

Fig. 6. Downstream cross-section of the Jabron valley transect S of Fig. 7 with cumulative curves of granulometric studies

attention to the destruction of the vegetation. The changes in vegetation cover were also studied on cross-sections (cross sections of Figs 5 and 6).

STUDIES OF THE CHANNEL

The effect of the erosion was observed by taking measurements in the field in 1994, after the flood. We measured the eroded surfaces and we studied the granulometric component of flood deposits (cross sections and curves of Figs 5 and 6).

To study the changes in the alluvial plain and the consequences of the flood on stream morphology, we also compared aerial photographs and maps

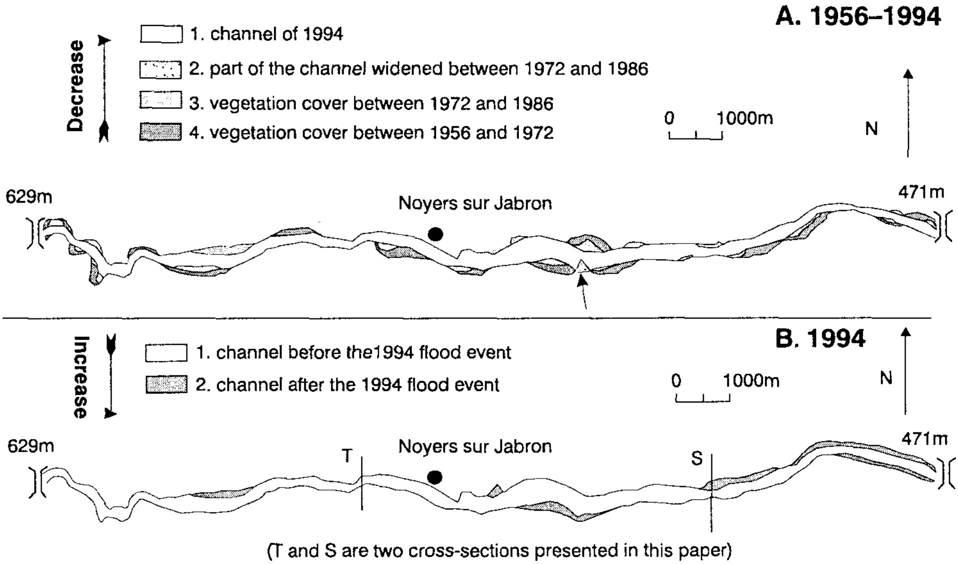

Fig. 7. Evolution of the channel in the Jabron flood plain. A — between 1956 and 1994 before the 1994 flood; B — after the 1994 flood drawn from aerial photographs. T and S are the two cross-sections of Figs 5 and 6

to obtain two maps showing the successive positions of the channels (Fig. 7). The study involves interpretations of landscape changes and evidence from:
— local maps dated 1953, 1972, 1996;
— aerial photographs dated 1956, 1972, 1979, 1986, 1993, 1994 and 1997;
— direct observations and maps of the landscape after the flood.

With the different documents, we made successive maps, drawing the shape and the extent of the channels and of the flood plain. The best data were taken from the aerial photographs because local features, such as bridges, were good reference points. Seven maps were drawn: 1956, 1972, 1979, 1986, 1993, 1994 (after the flood) and 1997.

The maps have been scanned and stored in a computer. We have delineated the limits of the active channel and calculated its surface. The data which have been computed, concern the limits of the active channel, i.e. the increase or decrease of this surface, however it was impossible to assess the part of the channel which was destroyed by erosion. Only the changes in the surface which is more or less uncovered by vegetation has been computed. We used the map (1 : 25,000) from 1972 and aerial photographs from 1956, 1974, 1979, 1986, 1993 (before the flood) and 1994 (after the flood). The point the map is the D 946 road. On the different aerial photographs, the channel was drawn and computed. The area of the successive channels was calculated in order to obtain a statistical model of flood effects on the increase or decrease of the flood plain. This study helps to explain the changes in the flood plain.

RESULTS

CONSEQUENCES OF THE FLOOD ON THE FLOOD PLAIN, IN 1994

The rainfall event of January 6th 1994 occurred in winter, after a long period of wet weather. The mean quantity of this heavy rainfall was more than 200 mm, especially in the higher parts of the watershed (Fig. 4). The local study (Watt 1996) estimated that the value for a ten-year rainfall in the Jabron watershed is 128 mm. The intensity of the October 1979 fall in the Jabron basin seems to have a 50-year recurrence. The study of the rainfall shows the mean quantity of the rainfall per 24 hours during the January 1994 event as being more than 200 mm in the Jabron catchment: $0.2\ m^3 \cdot m^{-2}$ which is equivalent to $2 \cdot 10^5 m^3 \cdot km^{-2}$. January 1994 seems to have a 100-year recurrence. Near Noyers-sur-Jabron, the discharge is $100\ m^3 \cdot s^{-1}$ for a 10-year recurrence, $210\ m^3 \cdot s^{-1}$ for a 50-year recurrence and $290\ m^3 \cdot s^{-1}$ for a 100-year recurrence. The water of the Jabron overflowed the Valbelle bridge: the height of the water level was around 6 m above the usual river bed. The discharge of the Jabron was around 250–290 $m^3 \cdot s^{-1}$ during the flood of January 1994.

Different features can be recognised from a study of the channels and of the riparian vegetation, before and after the flood:

— The Holocene terraces are mainly occupied by agriculture but there are also forests with *Populus nigra, Quercus pubescens, Pinus sylvestris,* and *Pinus nigra.* During the flood, the river overflowed its banks. The water left silt (Photo 1) and coarse deposits as shown by the curves of Figures 5 and 6, especially where the land was being cultivated. In 1994 the river overflowed its banks many times and damaged the cultivated fields: more than 50 ha were flooded and crops were destroyed. Thus, the flood partially destroyed the Holocene terraces by lateral erosion of approximately 100,000 m^2. In some places, on the edge of the terraces, the erosion is due to the destruction of trees and there are scars (Photo 2). The riparian forest *Alnus sp., Salix sp.* is less overlapped by flood sediments and in particular silts and sands are to be found (Figs 5 and 6).

In the flood plain the usual riparian vegetation is *Alnus viridis, Populus nigra, Salix viminalis*, i.e. mainly shrubs on the higher stripped banks and islands. These are pioneer plants, growing on silty and sandy flood deposits. After the flood, a great deal of vegetation was destroyed, amounting to around 20% of the riparian shrubs.

— No vegetation layers are present on the bars overflowed by annual floods and the consequences of 1994 flood are not significant.

Two cross-sections allow us to consider the changes in the flow dynamics. The first cross-section (Fig. 5) shows the variation of the granulometric component between the banks and the channels. The classical granulometric composition of the bank (T4) is less coarse than that of the channels (T3 and

T2) and is the result of the flood deposit. This deposit is even silty on the flood plain T1. In the channel, the granulometric composition is homometric and coarse whereas on the flood plain, where there is riparian forest, it is more heterometric but there are thin sediments. Downstream, near the bridge and the confluence, (Fig. 6) the granulometric composition of the channel shows fewer variations because of the acceleration of the flow at this place. The flood plain is cut by scars and bank collapses.

The vegetation depends on regional bioclimatic conditions: the submediterranean vegetation is loosely adapted to the flood plain dynamics. In the flood plain, the vegetation is better able to withstand the flood, which had a major impact on the riparian vegetation, as is frequently in such situations (Gregory and Gurnell 1988; Kochel and Patton 1998; Malanson 1993; Piégay and Bravard 1993, 1997). The water overflowed the silty or gravelly river banks, the shrubs (*Salix sp.*) retained sediments or vegetation debris carried by the flow and many shrubs were bent over and some were flattened. On the upper part of the vegetated banks or on the lowest terrace, the flood left deposits, especially silty mud flows. Bank accretion is due to obstruction by trees and shrubs. The effect of floods and of active flood deposits is also the result of the annual cycle of plant growth: in winter, the vegetation is less coarse than in spring or summer. In the channels, on the lowest banks or the bars, a perennial plant, *Galium mollugo*, can grow up rapidly even if it has been cut off by the flood. In the pits and scours, the summer growth is only composed of a few grass plants (Table 2).

LANDSCAPE CHANGE OVER 40 YEARS

The analysis of aerial photographs taken between 1956 and 1997 documents the evolution of the flood plain over a 41-year period. The surface of the channel (Figs 7 and 8) decreased from 2,258,650 m^2 in 1956 to 1,719,950 m^2 in 1997. The overall trend is a decrease in the surface of the active channel over 41 years as shown on the curve in the Figure 8. This change follows the general trends seen in the landscapes studied in the Jabron watershed (Pech et al. 1997).

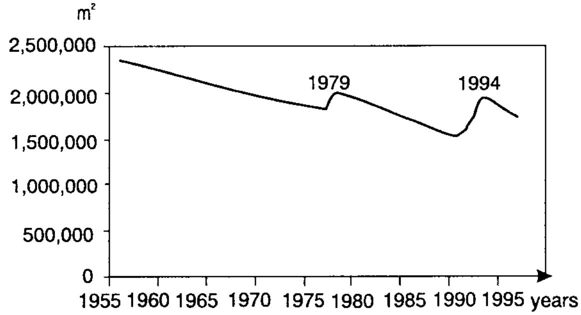

Fig. 8. Evolution of channel surface between 1956 and 1997, for the Jabron River

Between 1956 and 1994 (Figs 7 and 8), the bed became progressively narrower and the flow was concentrated in the central channel. The riparian vegetation (shrubs or forest) widened, covering parts of the flood plain, especially old and higher banks. The vegetation cover widened and the channel narrowed by 37% between 1956 and 1994. After the flood, the river bed and the flood plain widened (20%). We calculated the comparative area of the channel before (1.485 km^2) and after the flood (1.785 km^2) using the different aerial photographs but local measurements showed that more than 10 ha of channel edges were eroded, especially where the natural riparian vegetation was destroyed in order to extend cultivated fields; it is more protected where the riparian forest is preserved, as shown in Figures 5 and 6.

The impact of each flood event on channel width increases with the seriousness of the flood; there is a correlation between flood frequency and

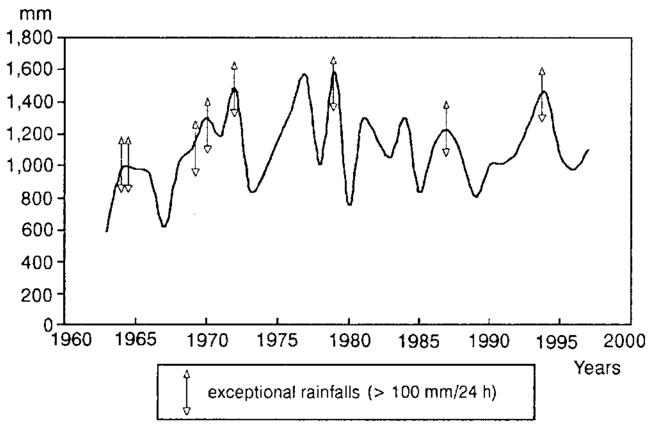

Fig. 9. Annual rainfall variability between 1956 and 1997 in the Jabron catchment and exceptional rainfalls events > 100 mm per 24h

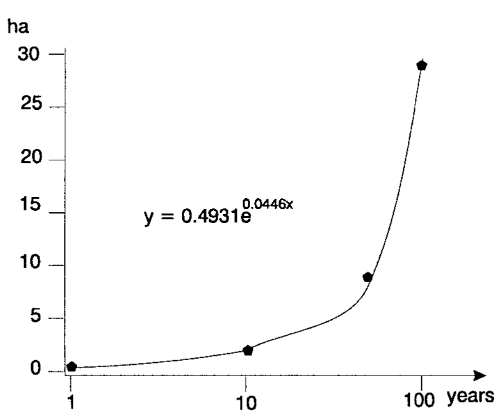

Fig. 10. Model of channel surface increase in relationship with flood frequencies

the size of increase in flood plain ($r = 0.895179768$). The data collected in 1979, 1994 and 1997 suggest an exponential function: $y = 0.4931\ e^{0.0446\,x}$ (e is a constant = 2.718281). This statistical model is the expression of potential flood plain changes (Fig. 10). The landscape evolution of the flood plain, with respect to flood events, matches an exponential model.

INTERPRETATION

The evolution of the vegetation is a consequence of the dynamics of the river. The fluctuations of the discharges allow the colonisation of different kinds of plants on the different parts of the flood plain. If the vegetation cover is old, the flow does not often spread over these banks. The vegetation is a protection and it grows because the frequency or intensity of the flow is not high enough to destroy it. Before the 1994 event, the flood plain was covered with riparian vegetation and human crops, especially tree crops. After the flood, much of the vegetation was destroyed and the lower terraces were covered with flood deposits. We can conclude that the riparian vegetation was a kind of filter for the flow.

The flood event had serious consequences on the flood plain landscape leading to modification and widening of the channels. The Jabron is a braided river and its flood plain records changes (Nanson and Croke 1992); the period between 1956 and 1994 shows the progressive concentration of the channel, which has been reduced. The flood event of 1994 widened this channel.

Processes of flood plain destruction include channel widening, flood channels, return channels, overflows and deposits on higher parts than usual channels. The water overflowed on the higher levels shown in the cross-sections (Figs 5 and 6) and silty but also coarse deposits occurred on the river terraces, which are used for agriculture (Photo 1). Where there is riparian forest, the deposits are large but strictly limited by the vegetation. The most effective actions of erosion, such as scars or bank collapses, occurred where the land was cultivated. The riparian vegetation is very important because it can be considered as a filter for flood surges.

Upstream this low flood plain, water runoff was very much constricted in the channels. By contrast, in the lower part of the watershed, the flood wave spread out over the flood plain. In this part of the Jabron watershed, the valley is wider than elsewhere, because Gargasian marly layers outcrop here and because the local people have altered the flood plain for agricultural settlement. After the lower point of this section, called Le-Pont-de-Gournias (Fig. 2), the Jabron flows through a gorge as far as to its confluence with the Durance River. The damaged area is a wide flood plain consisting of successive levels of inherited versant-sides and terraces.

In the Jabron watershed, as in other Mediterranean or submediterranean watersheds, it is commonly admitted that the hydrosystems were never natural during the Holocene period because deforestation linked to cattle razing was responsible for high erosion rates (Brown 1996). The flood events had a greater impact but the landscape and the flood plain morphology were not very different before and after the floods (Lewin 1989). For around 50 years, the decrease in human interference in such a watershed has been responsible for the development of a forest cover such as probably never existed during the Holocene period: before and around the Atlantic period, there was a pine forest (*Pinus sylvestris*) (Rosique 1994, 1997); after this optimum, human activities prevented the forest from growing until the forest cover disappeared around the end of the 19th century (Pech et al. 1997). The flood plain was unoccupied because it was frequently flooded but since the beginning of 20th the century, this flood plain has progressively been settled, first for pasture and, until recently, by tree crops. The lowering of the water levels is due to repeated drilling and pumping and we are now facing a fluvial metamorphosis. This is in direct contrast to the rivers in the Northern Alps where management is exercised under stricter controls (Petit et al. 1996; Summer et al. 1994). In the Jabron flood plain there is an increasing risk of floods because the channel is concentrated and the river bed is prevented from forming in the natural way because of constant interference. In different parts of the flood plain and in relation with the variations in the flow or the variations in the kinds of human activities, lateral edges and banks are either being eroded or subject to alluvial deposits.

The decrease in human interference in this submediterranean watershed over 41 years was responsible for the development of a forest cover. The concentration of the channel is also due to the development of agricultural fields on the lower terrace near to the water resources.

But two events have disturbed the general trend to decrease. In Figure 8, two short periods of increase can be detected in the changes in the main channel in 1979 and 1994. An examination of rainfall data between 1956 and 1997 can help to explain these changes (Fig. 9). The two events concerned are heavy rainfall sequences in 1979 and 1997, when flood events occurred. In 1979, the month of October was a rainy month (rainfall 8 times higher than the mean), and January 1994 was a stormy event. Exceptional rainfall changed the evolution of the channel surfaces.

CONCLUSION

In such situations, the consequences of exceptionally large floods are well documented (Czerwiński and Żurawek 1999; Hradek 1999; Kochel and Patton 1998; Kotarba 1999); much attention has been paid to the impact of floods on the river channel and resulting flood plain morphosedimentary modifications (Allen 1982; Bourke 1994; Bridge and Jarvis 1982; Gardner 1977; Reading 1986; Wolman and Gerson 1978). To explain the relationship between exceptionally large floods and fluvial plain morphology, much of the research has focused on the immediate geomorphological response to a single event or cluster of events (Kotarba 1999). Their findings have shown that exceptionally large events, although geomorphically effective, are episodic disturbances in the more gradual formation of flood plains (Knighton 1983). Other work concerns the temporal evolution of the channels (Gurnell and Petts 1995; Harvey 1997). Here we have tried to study the flood plain landscape before and after the impact of the flood and rainfall event, especially the 1994 flood and rainfall event, and also to situate this event in the landscape changes in this flood plain over 41 years. However, future investigations into the timing or cyclicity of similar events should enable us to place this particular event in the context of Holocene landscape evolution.

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REFERENCES

Allen J. R. L., 1982. *Sedimentary structures: their character and physical basis.* Developments in sedimentology 30. Elsevier, Amsterdam, 2 vol., 663 pp.

Anderson M. G., Walling D. E., Bates P., 1996. *Flood plain processes.* Chichester, New York, J. Wiley and Sons, 658 pp.

Arnaud-Fassetta G., Ballais J.-L., Beghin E., Jorda M., Meffre J.-C., Provansal M., Roditis J.-C., Suanez S., 1993. *La crue de l'Ouvèze à Vaison-La-Romaine (22 septembre 1992).* Revue de Géomorphologie Dynamique 42, 2, 34–48.

Batalla R. J., Sala M., 1994. *Temporal variability of suspended sediment transport in a Mediterranean sandy gravel-bed river,* [in:] *Variability in Stream Erosion and Sediment Transport,* Proceedings of the Canberra Symposium, December 1994, IAHS Publ. no. 224, 299–305.

Bourke M. C., 1994. *Cyclical construction and destruction of flood dominated flood plains in semiarid Australia,* [in:] *Variability in Stream Erosion and Sediment Transport,* Proceedings of the Canberra Symposium, December 1994, IAHS Publ. no. 224, 113–123.

Bridge J. S., Jarvis J., 1982. *The dynamics of a river bend: a study in flow and sedimentary processes.* Sedimentology 29, 499–541.

Brown A. G., 1996. *Floodplain palaeoenvironments*, [in:] *Flood plain Processes*, ed. M. G. Anderson, D. E. Walling and P. D. Bates, J. Wiley and Sons, Chichester, 95–138.

Czerwiński J., Żurawek R., 1999. *The geomorphological effects of heavy rainfalls and flooding in the Polish Sudetes in July 1997.* Studia Geomorphologica Carpatho-Balcanica 33, 26–43.

Davy L., 1990. *La catastrophe nîmoise du 3 octobre 1988 était-elle prévisible ?* Bulletin de la Société Languedocienne de Géographie 113, fasc.1–2, 133–161.

Downs P. W., 1995. *River channel classification for channel management purposes,* [in:] *Changing river channels.* eds A. M. Gurnell and G. E. Petts. J. Wiley and Sons, Chichester, 348–365.

Gardner J. S., 1977. *Some geomorphic effects of a catastrophic flood on the Grand River, Ontario.* Canadian Journal of Earth Sciences 14, 2294–2300.

Gautier E., 1992. *Recherches sur la morphologie et la dynamique fluviales dans le bassin du Buëch (Alpes du Sud).* Thèse de Doctorat de géographie, Université de Paris X-Nanterre, 439 pp.

Gregory K. J.,Gurnell A. M., 1988. *Vegetation and river channel form and process*, [in:] *Biogeomorphology*, ed. H. Viles, Oxford, Basil Blackwell, 11–42.

Gregory K. J., Walling D. E., 1973. *Drainage basin form and process. A geomorphological approach.* E. Arnold, London, 456 pp.

Guilbert X., 1994. *Les crues de la Durance depuis le XIV^{ème} siècle. Fréquence, périodicité et interprétation paléoclimatique*, Mémoire de Maîtrise Géographie, Université d'Aix-Marseille 1, Aix-en-Provence, 125 pp.

Gurnell A., 1995. *Vegetation along river corridors: hydrogeomorphological interactions*, [in:] *Changing river channels*, eds A. Gurnell and G. Petts. J. Wiley and Sons, London, 237–260.

Gurnell A., Petts G., 1995. *Changing river channels.* J. Wiley and Sons, Chichester, London, 442 pp.

Harvey A. M., 1997. *Coupling between hillslope gully systems and stream channels in the Howgill Fells, northwest England: temporal implications.* Géomorphologie 1, 3–20.

Hradek M., 1999. *Geomorphological aspects of the flood of July 1997 in the Morava and Oder basins in Moravia, Czech Republic.* Studia Geomorphologica Carpatho-Balcanica 33, 45–66.

Juramy S., Montfort I., 1986. *L'évolution des lits fluviaux. L'exemple d'une rivière aménagée: La Durance.* Doctorat de 3ème cycle en Géographie Physique appliquée, Université d'Aix-Marseille 2, Aix-en-Provence, 576 pp.

Knighton A. D., 1983. *Fluvial forms and processes.* E. Arnold, London, 218 pp.

Kochel R. C., Patton P. C. (eds), 1998. *Flood Geomorphology.* J. Wiley and Sons, New York, 384 pp.

Kotarba A., 1999 . *Geomorphic effect of the catastrophic summer flood of 1997 in the Polish Tatra Mountains.* Studia Geomorphologica Carpatho-Balcanica 32, 101–115.

Lewin J., 1989. *Floods in fluvial geomorphology*, [in:] *Floods: Hydrological, Sedimentological and Geomorphological Implications*, eds K. Beven and P. Carling, J. Wiley and Sons, Chichester, 265–284.

Llamas J., 1993. *Hydrologie générale*; 2nde édit., Gaëtan, Boucherville, Quebec, 527 pp.

Mc Neil J. R., 1992. *The mountains of the mediterranean world.* Cambridge University Press, 425 pp.

Malanson G. P., 1993. *Riparian Landscapes.* Cambridge, Cambridge University Press, 296 pp.

Miramont C., Guilbert X., 1997. *Variations historiques de la fréquence des crues et évolution de la morphogenèse fluviale en Moyenne Durance (France, Sud-Est).* Géomorphologie: reliefs, processus et environnement 4, 235–338.

Miramont C., Jorda M., Pichard G., 1998. *Evolution historique de la morphogenèse et de la dynamique fluviale d'une rivière méditerranéenne: l'exemple de la Moyenne Durance (France du Sud-Est).* Géographie Physique et Quaternaire 52, 3, 381–392.

Nanson G. C., Croke J. C., 1992. *A genetic classification of flood plains.* Geomorphology 4, 459–486.

Nanson G. C., Knighton A. D., 1996. *Anabranching rivers: their cause, character and classification.* Earth Surface Processes and Landforms 21, 217–239.

Niedźwiedź T., 1999. *Rainfall characteristics in southern Poland during the severe flooding event of July 1997.* Studia Geomorphologica Carpatho-Balcanica 33, 5–25.

Pech P., Simon L., Tabeaud M., 1997. *Temporalités sociales et temporalités naturelles en montagne de Lure,* [in:] *Les temps de l'environnement.* Communications des Journées du Programme Environnement, Vie et Sociétés PIREVS, Toulouse, t. 2, 183–192.

Petit F., Poinsart D., Bravard J.-P., 1996. *Channel incision, gravel mining and bedload transport in the Rhône river upstream of Lyon, France ("canal de Miribel").* Catena 26, 209–226.

Piégay H., 1995. *Dynamiques et gestion de la ripisylve de cinq cours d'eau à charge grossière du bassin du Rhône (l'Ain, l'Ardèche, le Giffre, l'Ouvèze et l'Ubaye) XIX^{ème}–XX^{ème} siècles.* Thèse, Université Paris IV, 529 pp.

Piégay H., Bravard J. P., 1993. *Processus biomorphodynamiques et métamorphose fluviale : exemple du secteur de Mollon dans la plaine alluviale de la basse vallée de l'Ain.* Revue de Géomorphologie Dynamique 42, 4, 123–138.

Piégay H., Bravard J. P., 1997. *Response of a mediterranean riparian forest to the 1 in 400 year flood, Ouvèze river, Drôme-Vaucluse, France.* Earth Surface Processes and Landforms 22, 1, 31–43.

Reading H. G., 1986. *Sedimentary environments and facies.* Blackwell Sc. Publ., Oxford, 615 pp.

Richards K. S., Hughes F. M. R., El-Hames A. S., Harris T., Pautou G., Peiry J.-L., Girel J., 1996. *Integrated field, laboratory and numerical investigations of hydrological influences on the establishment of riparian tree species,* [in:] *Flood plain Processes,* eds M. G. Anderson, D. E. Walling and P. Bates, J. Wiley and Sons, Chichester, New York, 612–635.

Rosgen D. L., 1994. *A classification of natural rivers.* Catena 22, 169–199.

Rosique T., 1994. *Les gisements de bois fossiles conservés dans les formations détritiques tardi- et postglaciaires du bassin du Buëch (Hautes-Alpes): interprétation géodynamique et paléoécologique.* Compte Rendus de l'Académie des Sciences, Paris. T. 319, série II, 373–380.

Rosique T., 1997. *Détritisme et morphogenèse à la fin du Würm dans les Alpes françaises méridionales (Moyenne Durance).* Quaternaire 8, 1, 39–48.

Sabater F., Guash H., Marti E., Armengol J., Sabater S., 1995. *The Ter: a mediterranean river case-study in Spain,* [in:] *Ecosystems of the World,* vol. 22, *River and Stream Ecosystems,* eds C. E. Cushing, K. W. Cummins, G. W. Minshall. Elsevier, Amsterdam, 419–438.

Summer W., Stritzinger W., Zhang W., 1994. *The impact of run-of-river hydropower plants on the temporal suspended sediment transport behaviour,* [in:] *Variability in Stream Erosion and Sediment Transport,* Proceedings of the Canberra Symposium, December 1994, IAHS Publ. no. 224, 411–416.

Surian N., 1998. *Fluvial processes in the alpine environment during the last 15000 years: a case study from the Venetian Alps, Italy.* Géomorphologie: relief, processus et environnement 1, 17–25.

Wainwright J., 1996. *Infiltration, runoff and erosion characteristics of agricultural land in extreme storm events, SE France.* Catena 26, 27–47.

Watt A., 1996. *Etude du bassin-versant du Jabron.* SIPCCR Jabron, APD, DDAF 04, 130 pp.

Wharton G., 1994. *Progress in the use of drainage network indices for rainfall-runoff modelling and runoff prediction.* Progress in Physical Geography 18, 4, 539–557.

Wolman M. G., Gerson R., 1978. *Relative scales of time and effectiveness of climate in watershed geomorphic processes.* Earth Surface Processes and Landforms 3, 189–208.

STRESZCZENIE

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EWOLUCJA KORYTA W OKRESIE 41 LAT (1956–1997) ORAZ WPŁYW ULEWNYCH DESZCZÓW (1994) W ZLEWNI JABRON, POŁUDNIOWO-WSCHODNIA FRANCJA

Artykuł przedstawia rezultaty ilościowych badań zmian morfologii koryta rzeki Jabron, dopływu rzeki Durance. Określono sposób przekształcenia koryta i niskiej terasy zalewowej podczas powodzi w styczniu 1994 roku. W pracy przeanalizowano warunki meteorologiczne i hydrologiczne, które spowodowały powódź oraz określono wpływ roślinności występującej w dnie doliny. Wykonywano profile poprzeczne przez koryto oraz analizowano zdjęcia lotnicze i mapy topograficzne sprzed i po powodzi 1994 roku. W czasie powodzi dzienne opady w zlewni przekroczyły 250 mm (powtarzalność takich zdarzeń raz na 100 lat), a przepływ osiągnął 250 $m^3 \cdot s^{-1}$. Średni roczny przepływ wynosi 6 $m^3 \cdot s^{-1}$. Koryto zostało poszerzone o 20%. Geomorfologiczne skutki powodzi w 1994 roku porównano ze zmianami koryta w okresie 41 lat, między rokiem 1956 i 1997.