Channel Metamorphosis, Floodplain Disturbance, and Vegetation Development: Ain River, France

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Abstract

The purpose of this paper is to describe and explain channel metamorphosis of the Ain River in east-central France and the effects of this metamorphosis on floodplain disturbance and vegetation development. The Ain River is a 195 km long stream originating in the Jura Mountains which flows into the Rhône River between Lyon, France, and Geneva, Switzerland. The lower 40 km of the Ain River, beyond the mountain front, are situated in a valley of outwash deposits where the floodplain is 0.2 to 1.2 km wide. A complex mosaic of floodplain landscape units has developed. Maps dating back to 1766 and six sets of aerial photographs dated between 1945 and 1991 were used to document changes in channel pattern. Aerial photos and field surveys were used to compile maps of landscape units based on dominant vegetation life-forms, species, and substrate. Six maps dated between 1945 and 1991 were digitized in ARC/INFO and an overlay was generated to determine the changes in landscape units as related to channel disturbance. Change from a braided to a single-thread meandering channel probably took place in the period 1930–1950. The process of river entrenchment has occurred throughout the Holocene but has accelerated in the present century due to shortening of the river course, construction of lateral embankments, and vegetation encroachment following reservoir construction and cessation of wood-cutting and grazing. The increase in horizontal channel stability coupled with channel entrenchment have decreased floodplain disturbance and lowered the water table by approximately one meter. Pioneer and disturbance-dependent landscape units have experienced a more terrestrial-like succession to an alluvial forest. Abandoned channels have also been replaced by alluvial forests. On poorly drained soils, shrub–swamp communities of willow and hydrophytic herbaceous plants have been replaced by mixed forests of ash, alder, black poplar, and oak. On well drained alluvial soils, ash and oak dominated hardwood forests have declined in favor of mesophytic stands of black poplar. All types of vegetation, but particularly dry grasslands–shrublands, have been cleared for mines, campgrounds, agriculture, and other types of development. Using several measures, landscape diversity decreased between 1945 and 1991.

1. Introduction

Floodplain vegetation development depends on the influence of disturbance processes (i.e., flooding, horizontal and vertical channel instability, erosion and sedimentation) and on population dynamics and seed dispersal (Vale, 1982; Hanson et al., 1990; Baker, 1990; Amoros and Petts, 1993; Malanson, 1993). The disturbance regime can be altered by flow regulation, channelization, and climate change. At the landscape

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scale (e.g., floodplains), greater importance has been ascribed to the influence of allogenic factors (Zimmermann and Thom, 1982; Wissmar and Swanson, 1990). One of the most difficult challenges facing landscape ecologists is that of separating the effect of human activities on change in the interactions between the channel and floodplain from change which would have occurred without human interference. Another difficulty comes in predicting the direction of change in floodplain vegetation as the disturbance regime is altered. Our state of knowledge concerning this topic was nicely presented by the advertisement for an International Symposium on "European Floodplain Forest Ecosystems" held at the University of Leicester in March 1995 (Rowan, 1994): Lowland alluvial forests are one of the rarest, yet one of the ecologically richest, landscapes in Europe. They are also one of the least studied and understood. Their ecological richness stems from the remarkable mosaic of habitats maintained within a small area by distinct hydrological gradients, and by the close inter-linking of geomorphological processes with biological processes. The underlying causes of the maintenance of this biological diversity within a hydrologically dynamic system are unknown although the dependence of the biological diversity upon the physical processes is clear.

The purpose of this paper is to describe and explain channel metamorphosis of the Ain River in east-central France and the effects of this metamorphosis on floodplain disturbance and vegetation development.

The relationship between channel dynamics and hydrology, on the one hand, and floodplain vegetation mosaics, on the other hand, has been addressed by several groups of researchers. Perhaps the most comprehensive review of general principles on this topic is provided by Naiman and Décamps (1990), Amoros and Petts (1993), and Malanson (1993). Salo et al. (1986), working in the Amazon lowland forest, found that landscape diversity was enhanced by active channel migration and flooding which creates, destroys, and recreates fluvial landforms. Bravard and his colleagues (Amoros et al., 1986, 1987, 1988; Bravard et al., 1986), working in the upper Rhône drainage, also found that instability enhanced biological diversity. In contrast, Marston (1993), working on the Snake River in Grand Teton National Park, found that extreme rates of channel migration and flooding can truncate succession, limiting the development of older seral stages of vegetation, thereby decreasing relative evenness of landscape units. The work on the Snake River brings to light the question of whether floodplains should be managed to obtain maximum landscape biodiversity or managed to obtain the landscape diversity that existed under pre-settlement conditions, which may be less than the maximum possible because of extreme levels of disturbance. Miller et al. (1995) found that reservoirs on the North Platte River in Wyoming decreased the frequency and intensity of flooding and this induced a shift from young dense stands of cottonwood (*Populus* spp.) to older, more open stands. However, landscape diversity was insensitive to these changes.

Better understanding of the relationship between channel dynamics, floodplain disturbance, and vegetation will improve the ability of natural resource management agencies to attain management goals in the areas of watershed condition (Marston and Anderson, 1991), wildlife habitat (Johnson and Jones, 1977, Thomas et al., 1979), aquatic ecology (Amoros and Petts, 1993; Statzner et al., 1994), and the aesthetic value of riverine landscapes. New relevance to this research is provided by a 1992 French law that recognizes the need to "preserve the integrity of ecologic hydrodynamics." For an outstanding discussion of issues related to river–floodplain interactions and the need for ecosystem management of these systems, see articles by Bayley (1995), Sparks (1995) and other articles in the March 1995 issue of *BioScience*.

2. Study area

The Ain River is a picturesque 195 km long stream originating in the Jura Mountains which flows into the Rhône River between Lyon, France, and Geneva, Switzerland (Fig. 1). The Ain drains an area of 3672 km^2 and has a mean annual discharge of 130 cms, contributing about 20 percent of the flow to the Rhône where it joins as a right-bank tributary (Vivian, 1989). The Ain drops in elevation from 700 m to 186 m and is situated for most of its length in the Bugey Massif of the Jura Mountains, a region of plateaus and faulted–folded blocks of Jurassic limestones. Extensive karst development in this section prevents the development of any significant tributaries to the Ain. Groundwater discharge moderates seasonal differences in flow. The

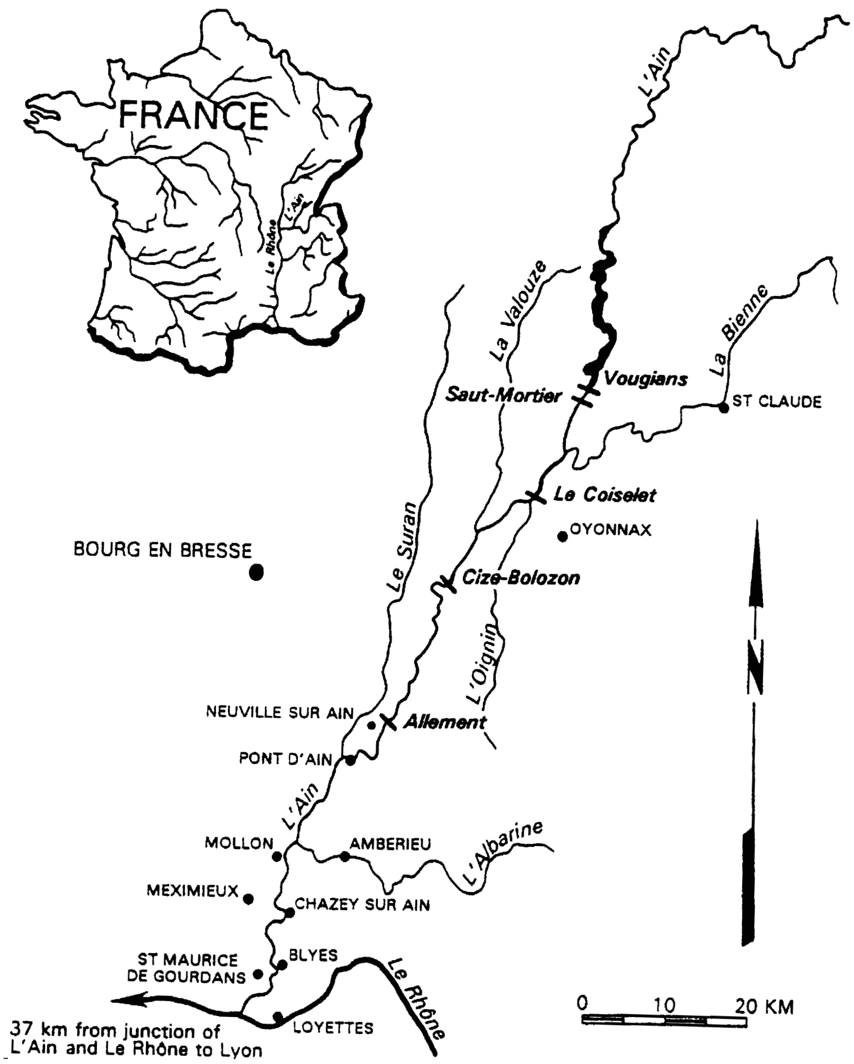

Fig. 1. The Ain River watershed. The study area extended from Pont d'Ain to the confluence of the Ain and Rhône rivers.

entire Ain drainage was covered by ice during the Riss glacial advance, but the upper Ain was unaffected by ice during the Würm advance. In the Jura section, the course of the Ain is geologically controlled in alternating narrow structural basins and gorges where a series of five dams has been constructed for hydropower production. Four of the dams are run-of-the-river dams kept near-full to maximize hydropower production. Only the uppermost, the high-arch Vouglans Dam constructed in 1968 in part for flood control, affects the hydrograph; it controls 31 percent of the watershed area. A flow duration analysis of the Ain River reveals that bankfull discharge of 500 cms is exceeded 10 days per year on the average. Floods originate from long duration frontal storms in the winter–spring or from intense Mediterranean events in the fall; 75 percent of floods occur between October and March. Floods originating in the Ain are usually responsible for flooding in the large metropolitan area of Lyon downstream (Bravard, 1987).

The study section of the Ain involves the lower 40 km of the river after it flows beyond the mountain front onto a plain of glacial outwash. This section was impacted by the outermost glaciation (Würm) down the Rhône River 15,000 to 20,000 years B.P. Till (morainic blocks in a clay matrix) are overlain by outwash deposits of sand to cobble sized sediment. A series of four terraces, late Würm to Holocene in age, have been cut in the outwash, Würmian till, and underlying molassic sandstone (Mandier, 1984). Outwash gravel is mined on the floodplain and lower terrace, but not in the active channel, in contrast to many other French rivers.

The modern alluvial plain of the Ain River is 200 m to 1200 m wide, depending on the controls imposed on lateral reworking of local outcrops of molassic sandstones or Würmian till. This modern plain was probably shaped by the braided Ain River during the 18th and 19th centuries. In constricted areas, the 100 year flood does inundate low Holocene age terraces (2–3 m above the floodplain) and even the early Holocene level terrace at Pont d'Ain (+4 m). The only low Holocene level to have been dated so far is located close to the confluence at Loyettes (+4 to 5 m). On this level, former courses of the Ain are still visible. They are dated 1444, 1544 and 1673 on an old map dated 1781 (Bravard, 1986). The 1781 map reveals the relative importance of river bed degradation since the Middle Ages close to the confluence of the Rhône.

The present-day Ain River is a single-thread meandering river (sinuosity = 1.26) with a wide and shallow cross-section. The gradient ranges from 0.0004 to 0.0018, the average slope being 0.00125. The steepest reaches are controlled by outcrops of morainic sandstones and morainic cobbles or rounded blocks exhumed by river incision. They alternate with long flat sections where bedload is comprised of large gravel and small cobbles; the d_{50} is 80 mm averaged over the entire study reach. Bankfull width ranges between 40–80 m. In places, modern bridges and motorways constrict the river and inhibit lateral migration. Moreover, artificial cutoffs (constructed 1900–1930) and bank revetments reduce the length of the river, increasing slope and limiting lateral migration of the river. The decline in reworking of floodplain alluvial by lateral migration and the sediment trapping by the six dams in the upper watershed have combined to reduce the rates of bedload transport in the lower Ain (Fagot et al., 1989; Bravard et al., 1991).

On the graphical plot of bankfull discharge versus slope by Leopold and Wolman (1957) and another by Brookes (1988), the Ain River plots in the domain of braided rivers. Using the method of Richards (1982) which relates stream power per unit channel length to the d_{50} of the bed material, the Ain falls clearly in the regime of multiple channels. Thus, the present-day meandering channel pattern which prevails for the Ain is not in equilibrium with controlling factors.

The development of vegetation on the lower Ain River floodplain can be traced from the time of the Little Ice Age (ca. 1830). From 1830 to 1945, the floodplain was used extensively for cattle grazing and fuel production. Because of the former use, these communal lands were known by the local term "brotteaux" which is Latin for grazing. The fuel production was primarily in the form of poplar plantations. Panoramic postcard photographs dated 1916 confirm the relative lack of forest vegetation on the Ain River floodplain except along the immediate river margin. Human activity on the floodplain decreased after World War II with the modernization of agriculture on the lower terraces and as wood was replaced by other sources of fuel. After 1945, an alluvial forest progressively developed because of the shift in land use activities away from the floodplain. Alluvial forests tend to be found on deep, fine-textured soils and include the following dominant softwood trees: black poplar (*Populus nigra*), alder (*Alnus glutinosa*), and maple (*Acer* spp.). An alluvial forest of hardwoods can be found on coarse substrates, including the following trees: ash (*Fraxinus excelsior*) and elm (*Ulmus minor*). The shrub layer is dominated by various species of willow: *Salix eleagnos, S. viminalis, S. alba, S. triandra.*

Piégay (1995) states that the alluvial forest has declined even before the installation of Vouglans Dam in 1968 due to a drop in magnitude (if not frequency) of floodplain disturbance, river entrenchment, and a concordant drop in the floodplain water table. Additional vegetation clearing has occurred since 1945 due to gravel mining, construction of campgrounds and renewed wood cutting, grazing, and agriculture. Still, the Ain River is recognized as one of the most picturesque, unpolluted, and uncontrolled rivers in France providing great attractions for swimming, fishing and canoeing.

3. Methods

Maps of landscape units covering the 100 year floodplain of the Ain River were constructed for 1945 and 1991. The total area of the 100 year floodplain between Pont d'Ain and the confluence of the Ain with the Rhône River is 32 km^2. The 1991 map was compiled by extending past mapping efforts by Pautou et al. (1979), Pautou and Décamps (1985), and Pautou and

Girel (1986). This work was accomplished using aerial photos with field checks and two systematic surveys along transects near Mollon and Blyes as described in Newton (1995). The 1945 map was derived from interpretation of 1945 aerial photos using the photokey developed by Girel (1986). The 1991 map was constructed from an expansion of Girel's 1986 map using 1991 aerial photos. Landscape units were classified based on dominant life-forms of vegetation, species, and substrate.

All available aerial photos for the post-dam period were collected for the 40 km long Ain River study reach between Pont d'Ain and the confluence with the Rhône. These included photosets for 1945, 1954, 1964, 1971, 1985 and 1991. A map of the river was constructed for each year and registered to the UTM coordinates of various highway and road intersections throughout the map.

The vegetation and channel maps were then digitized using ARC/INFO GIS software running on a Silicon Graphics UNIX workstation. Using the ARC/INFO union routine, the digital maps were overlaid to produce: (1) a landscape unit change matrix depicting the percent of change in each 1945 landscape unit to 1991 units; (2) a map depicting the last year of channel disturbance on the floodplain; (3) statistics describing the spatial and temporal trends in lateral channel migration; and (4) statistics relating the year since last channel disturbance to 1991 vegetation. Finally, from the matrix data, several indices of landscape diversity were calculated to determine the cumulative effect of channel metamorphosis and direct human interference on landscape diversity (Miller et al., 1995):

(1) richness (n): number of different landscape units present;

(2) Shannon index (H) which combines richness and evenness using the formula:

$$H = -\sum_{i=1}^{m} [p_i \times \ln(p_i)]$$

where p_i is the proportion of the landscape in unit i and m is the number of landscape units present. Large values of H indicate a more diverse landscape, combining richness and relative evenness of landscape units (Turner and Ruscher, 1988).

(3) dominance (D) which emphasizes the deviation from evenness using the formula:

$$D = \ln(n) - H$$

(4) reciprocal Simpson's index ($1/S$) which measures the probability of encountering two patches of the same landscape unit when taking a random sample of two patches:

$$1/S = 1/\sum_{i=1}^{m} p_i^2$$

Larger values of $1/S$ indicate a decrease in landscape diversity.

4. Results and discussion

Ten landscape units were identified on the Ain River floodplain (Fig. 2):

1. unvegetated gravel–cobble deposits, perhaps with some herbaceous vegetation
2. sand, gravel, and cobble deposits colonized by low willow shrubs < 1.5 m high; *Salix* spp.
3. sand, gravel, and cobble deposits with dense willows 1.5–5.0 m high; *Salix* spp.
4. abandoned channels with hydrophytic herbaceous vegetation (*Carex*, *Phragmites*, *Typha*, *Phalaris*, *Filipendula*) bordered by trees (*Ulmus minor*, *Fraxinus excelsior*, *Alnus glutinosa*)
5. dense, diverse, mesophytic shrubs (*Crataegus monogyna*, *Lonicera xylosteum*, *Ligustrum lantana*, *Ligustrum vulgare*, *Prunus spinosa*, *Viburnum lantana*) with some softwood trees (*Populus nigra*)
6. mixed hardwood–softwood forest, trees > 6 m high, DBH > 15 cm; *Populus nigra*, *Fraxinus excelsior*, *Alnus glutinosa*, *Quercus robur*, *Acer* spp., *Ulmus minor*
7. dry grassland with some willows and spiny shrubs on sandy soils; *Bromus erectus* with *Salix eleagnos*, *Prunus spinosa*, *Crataegus monogyna*
8. very dry grassland on gravel–cobble deposits, often bare of vegetation; *Teucrium* spp., *Euphorbia seguieriana*, *Fumana procumbens*
9. cleared land for mines, campgrounds, agriculture, etc.
10. water (Ain River active channel, oxbows, backswamps)

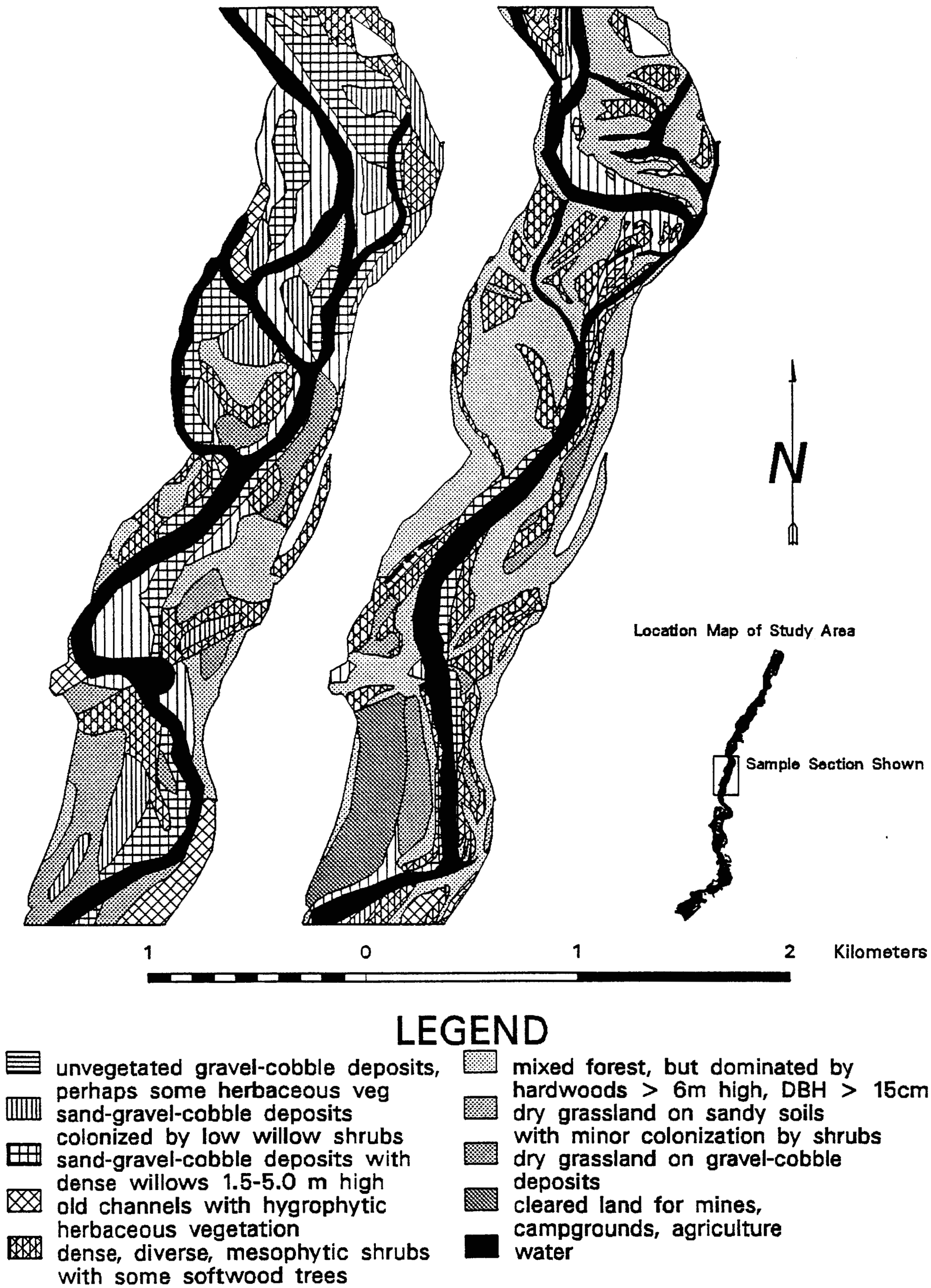

Fig. 2. Landscape unit maps for a portion of the Ain River 100 year floodplain near Mollon.

Table 1
Landscape unit change matrix, 1945–1991, 100 year floodplain, Ain River, France

1945 Units	1991 Landscape units (1000 m^2)										
	1	2	3	4	5	6	7	8	9	10	Total
1	166	47	103	77	789	740	37	160	85	357	2561
2	98	105	59	55	800	755	142	344	460	421	3239
3	217	90	89	191	1287	1654	134	314	343	725	5044
4	13	0	15	70	166	509	9	28	352	71	1233
5	45	86	388	37	1304	1257	216	621	417	387	4758
6	89	30	37	107	615	1385	136	109	316	190	3014
7	131	12	9	22	626	663	1093	413	3117	447	6533
8	37	26	29	6	429	29	174	596	87	187	1600
10	246	109	304	101	886	850	35	141	89	1253	4014
Total	1042	505	1033	666	6902	7842	1976	2726	5266	4038	31996

1: unvegetated gravel–cobble deposits; perhaps some herbaceous vegetation.
2: sand, gravel, cobble deposits colonized by low willows < 1.5 m high.
3: sand, gravel, cobble deposits with dense willows 1.5–5.0 m high.
4: abandoned channels with hydrophytic herbaceous vegetation bordered by trees.
5: dense, diverse, mesophytic shrubs with some softwood trees.
6: mixed hardwood–softwood forest, trees > 6 m high, DBH > 15 cm.
7: dry grassland with some willows and spiny shrubs on sandy soils.
8: very dry grassland on gravel–cobble deposits, often bare of vegetation.
9: cleared land for mines, campgrounds, agriculture, etc.
10: water (Ain River active channel, oxbows, backswamps).

The relative extent of these 10 units has changed dramatically between 1945 and 1991 (Table 1, Fig. 3). Water (unit 10) is approximately the same in extent. This reflects the fact that the change from braiding to a single thread channel probably took place in the years 1930–1950. The Ain River developed irregular meanders across the former braided belt, including extensive gravel bars on convexities. The unvegetated and pioneer communities (units 1–3) experienced a 76 percent reduction between 1945–1991. Similarly, abandoned channels experienced a 46 percent reduction. These changes reflect the decline in lateral migration of the Ain River and the associated entrenchment. The channel has become more stable and overbank flows are less frequent and of lower magnitude than would be expected without entrenchment and without Vouglans Dam. Therefore, the disturbance of the floodplain has decreased in terms of destruction of vegetation and deposition of new substrate on which units 1–3 proliferate. Moreover, abandoned channels are renewed by overbank flows on a less frequent basis, allowing a more terrestrial type of succession to dominate. The alluvial forest units 5–6 have expanded greatly at the expense of disturbance-dependent units 1–4. On poorly drained soils, shrub–swamp communities of willow and hydrophytic herbaceous plants have declined in favor of mixed forests of ash, alder, black poplar, and oak. On well drained alluvial soils, ash and oak dominated hardwood forests have declined in favor of mesophytic stands of black poplar.

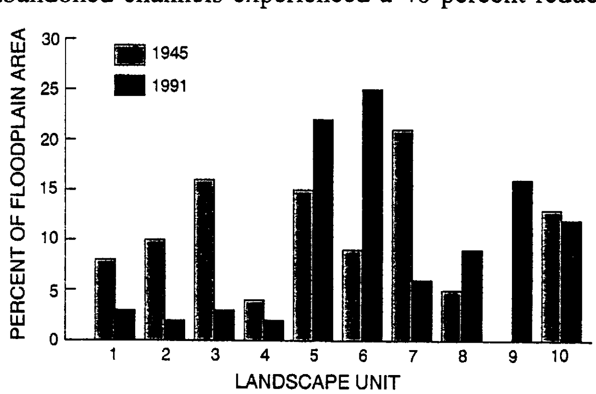

Fig. 3. Change in relative portion of the Ain River 100 year floodplain covered by the various landscape units, 1945–1991.

The encroachment of vegetation on gravel bars may be partly due to the increase in discharge during summer since 1968. The increase in July and August is motivated by the needs of fish (the salmonid *Tymallus thymallus*) in cool water so that minimum discharge

Table 2
Measures of landscape diversity for the 100 year floodplain, Ain River, 1945–1991

	1945	1991, incl. Unit 9	1991, excl. Unit 9
Richness	9	10	9
Shannon index	2.09	1.98	1.84
Dominance	0.11	0.32	0.36
Reciprocal Simpson's index	5.96	13.8	9.04

must now average 10–15 cms instead of the 5–10 cms expected under uncontrolled conditions. This increase in summer low flow may indirectly benefit the riparian vegetation.

The dry grassland–shrubland on sandy soils (unit 7) decreased 70 percent between 1945 and 1991 but the very dry grassland (unit 8) has increased 41 percent. The contrast can be attributed to the differences in substrate. With the lower water table because of entrenchment, grasses are more dependent on soil moisture holding ability. The finer soils of unit 7 are better able to hold rainfed moisture than the gravel–cobble soils of unit 8. Therefore, unit 7 has either remained as dry grassland–shrubland, been converted to alluvial forest (units 5–6), or has been cleared for new human activities (unit 9). The very dry grassland (unit 8) has increased because of the impact of the lower water table on the other landscape units. Cleared land (unit 9) was not identified on the 1945 map, although it should be noted that land which had been cleared in the early 1900s had recovered to some other landscape unit type by 1945. Most of the cleared land in 1991 had been derived from the dry grassland–shrubland (unit 7) and is being used presently for gravel mines, campgrounds, renewed agriculture, motorways, and various commercial enterprises.

Measurements of landscape diversity were calculated both including and excluding cleared land (unit 9) (Table 2). The calculations demonstrate that diversity has decreased in terms of relative evenness of the landscape units from 1945 to 1991. The alluvial forest (units 5–6) and cleared land (unit 9) dominate the floodplain landscape in 1991, with 63 percent of the floodplain area. In 1945, no single landscape unit occupied more than 20 percent of the floodplain. The changes in relative coverage of the floodplain by various landscape units confirms the direct relationship between channel instability and landscape diversity observed by Salo et al. (1986), and by Bravard and his French colleagues (Amoros et al., 1986, 1987, 1988, Bravard et al., 1986). The Ain River appears to be more sensitive to a shift in channel dynamics than the North Platte in Wyoming, as reported by Miller et al. (1995). The contrast can probably be attributed to the longer history of human impact in the Ain system and the added effect of channel entrenchment. Vegetation changes on the Ain River floodplain confirm the relative importance of disturbance factors as controls, as described by Naiman and Décamps (1990), Amoros and Petts (1993), and Malanson (1993).

The decrease in lateral migration of the Ain River between Pont d'Ain and the confluence with the Rhône River, as derived from the GIS analysis of channel location is illustrated in Fig. 4. This figure demonstrates the cumulative area eroded between years of available maps declined. The change from a braided to single-thread meandering channel has been accompanied by vegetation encroachment on the channel banks and entrenchment. Entrenchment of 1–2 meters is common along the study reach, but incision approximates 3 meters near the confluence as an adjustment to downcutting in the Rhône dating to 1860. This entrenchment began during the Holocene, but has accelerated in the last half of the 20th century due to: (1) shortening of the river by artificial cutoffs which has increased channel gradient; (2) construction of lateral embankments which constrict the river, modify the cross-profile, and promote a shortage in sediment supply by preventing lateral reworking of floodplain alluvium; (3) stabilization of riverbanks by encroaching vegetation, partic-

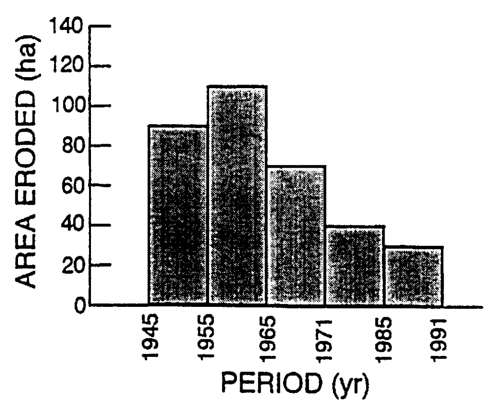

Fig. 4. Area of the floodplain eroded by lateral channel migration in the periods bracketed by years of available maps.

Table 3
Area (1000 m^2) of landscape units[a] in portions of the 100 year floodplain last occupied by the Ain River at different times, 1945–1991

1991 Unit	Last year the Ain River occupied the 100 year floodplain						
	Never	1985	1971	1964	1954	1945	Total
1	665	50	194	83	28	22	1042
2	283	50	63	14	36	59	505
3	278	93	132	291	40	199	1033
4	382	35	99	60	80	10	666
5	5315	130	368	339	462	288	6902
6	5818	181	780	325	408	330	7842
7	1896	8	40	0	0	32	1976
8	2308	49	54	113	123	79	2726
9	5023	88	46	36	9	64	5266

[a] See text or Table 1 for landscape unit descriptions.

ularly alluvial forests; and (4) construction of reservoirs which limits bedload transport from the upper watershed. Gravel harvesting has not been responsible for channel degradation because mining has been limited to the floodplain and low terraces.

The decrease in lateral migration of the Ain River as a response to the impacts of upstream reservoirs confirms the impacts observed by Marston (1993) and Miller et al. (1995). In the absence of tributary inputs of sediment to the mainstem river, the mainstem will experience a metamorphosis from a braided to meandering pattern.

The map depicting the last year of channel occupance was used to calculate the area of each vegetation unit in portions of the floodplain which had been occupied by the river at different times (Table 3). These data may provide some idea of the time needed for each landscape unit to develop without destruction by the channel. Of course, disturbance by flooding and sediment deposition are not considered in this analysis nor is destruction by channel migration in intervening years, two confounding variables. A chi-square analysis using the data in Table 3 generated an overall chi-square value of 5738; with 48 degrees of freedom, the differences in frequency of each landscape unit by year are significant at the $p < 0.00001$ level. Some intriguing findings are revealed. First, all 1991 landscape units are found in portions of the floodplain which were "never" destroyed among the years 1945, 1954, 1964, 1971, and 1985. For pioneer communities and disturbance-dependent units 1–4, this may mean that flooding and sedimentation during floods are more important than destruction by channel occupation of the floodplain. Second, for alluvial forest units 5–6, a period of time without destruction by channels is clearly important. Nevertheless, some alluvial forest units 5–6 are abundant even in areas destroyed by channel migration as recent as 1985. It is possible that these units were able to "resist" destruction by the active channel. Evidence for this was observed in the field during the summer of 1993 in areas which had been occupied by the active channel in 1985. Flood debris from a 10 year flood in September 1992 was found in trees two meters above the ground surface. The base of trees had been scoured in some places and buried by new sediment in other locations. In spite of these impacts, the alluvial forest was flourishing. Third, grasslands (units 7–8) are primarily found only in portions of the floodplain not occupied by the channel during the timespan considered; grasslands tend to be located far from the active channel where the water table is low or where this unit represents derelict land recovering from land clearing in the last century.

The shift to a more terrestrial-like pattern of vegetation development on the floodplain following the geomorphic and hydrologic changes in the Ain River is consistent with the findings by Marston (1993). The relative resistance of forest stands to destruction by channel shifting confirms findings by Baker (1990), Marston (1993) and Miller et al. (1995). More work is needed to quantify the thresholds of vegetation destruction by floods, sedimentation, and channel migration.

5. Conclusions

The effect of reservoir construction, artificial cutoffs and lateral embankments has been to trigger a shift from a braided to single-thread meandering channel and to accelerate entrenchment. The change in pattern and entrenchment had begun during the Holocene but accelerated after 1930 due to the forms of human interference listed above. With entrenchment came less disturbance of the floodplain by floods, sedimentation, and lateral channel shifts. In addition, the water table dropped in elevation. As a result, the development of floodplain vegetation was altered from a pulse-like disturbance regime to a more terrestrial-like pattern of vegetation succession. Terrestrial-like refers to succession in the absence of channel disturbance. Alluvial forests and very dry grasslands have expanded at the expense of pioneer, disturbance-dependent communities. A positive feedback continues to exist because entrenchment leads to lower disturbance and vegetation encroachment which, in turn, further restricts channel migration and overbank flows. Only the presence of large morainic blocks and sandstone outcrops in selected reaches of the channel bed has put a halt to entrenchment. In the case of the Ain River, landscape diversity has decreased. It is apparent that one group of changes (reduction of strong floods, bedload entrapment, revetments, and artificial cutoffs) has sensitized the systems to irreversible impacts from river entrenchment and vegetation encroachment.

This study has sought to separate the human impact on linkages between channel metamorphosis, floodplain disturbance, and vegetation development from change which would have occurred without human interference. Accounting for these linkages for the Ain River between Pont d'Ain and the confluence with the Rhône River has demonstrated that the geomorphic heritage of channel metamorphosis is the change in ecological impact of floods and channel instability.

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References

Amoros, C. and Petts, G.E. (Editors), 1993. Hydrosystèmes Fluviaux. Masson, Paris, 301 pp.

Amoros, C., Bravard, J.P., Pautou, G., Reygrobellet, J.L. and Roux, A.L. 1986. Synthèse, prévisions et gestion écologique. In: A.L. Roux (Editor), Recherches Interdisciplinaires sur les Ecosystèmes de la Basse-Plaine de l'Ain: Potentialitées Evolutives et Gestion. Doc. Cartogr. Ecol., 29: 147–160.

Amoros, C., Rostan, J.C., Pautou, G. and Bravard, J.P., 1987. The reversible process concept applied to the environmental management of large river systems. Environ. Manage., 11: 607–617.

Amoros, C., Bravard, J.P., Reygrobellet, J.L., Pautou, G. and Roux, A.L., 1988. Les concepts d'hydrosystème et de secteur fonctionnel dans l'analyse des systèmes fluviaux à l'échelle des écocomplexes. Bull. Ecol., 19: 531–546.

Baker, W.L. 1990. Climatic and hydrologic effects on the regeneration of *Populus angustifolia* James along the Animas River, Colorado. J. Biogeogr., 17: 59–73.

Bayley, P.B., 1995. Understanding large river–floodplain ecosystems. BioScience, 45: 153–158.

Bravard, J.P., 1986. La basse vallée de l'Ain: dynamique fluviale appliquée à l'écologie. In: A.L. Roux (Editor), Recherches Interdisciplinaires sur les Ecosystèmes de la Basse-Plaine de l'Ain: Potentialitées Evolutives et Gestion. Doc. Cartogr. Ecol., 29: 17–43.

Bravard, J.P., 1987. Le Rhône du Léman à Lyon. La Manufacture, Lyon, 451 pp.

Bravard, J.P., Amoros, C. and Pautou, G., 1986. Impacts of civil engineering works on the successions of communities in a fluvial system. Oikos, 47: 92–111.

Bravard, J.P., Malavoi, J.R. and Amoros, C., 1991. L'Ain, ou la difficulté de gérer une rivière en cours de métamorphose. In: J.P. Bravard and J. Untermaier (Editors), Rivières en Crises: Saône, Ain, Durance. Actes de la Journée d'Etude du 17 mars 1989. Université Lyon III–Jean Moulin, Lyon, pp. 57–72.

Brookes, A., 1988. Channelized Rivers: Perspectives for Environmental Management. Wiley, New York, 326 pp.

Fagot, P., Gadiolet, P., Magne, M. and Bravard, J.P., 1989. Etude de dendrochronologie dans le lit majeur de l'Ain: la forêt alluviale comme descripteur d'un changement morphodynamique. Rev. Géogr. Lyon, 64: 213–223.

Girel, J., 1986. Télédetection et cartographie à grande échelle de la végetation alluviale: exemple de la basse plaine de l'Ain. In: A.L.

Roux (Editor), Recherches Interdisciplinaires sur les Ecosytèmes de la Basse-Plaine de l'Ain. Potentialitées Evolutives et Gestion. Doc. Cartogr. Ecol., 29: 45–74 plus map.

Hanson, J.S., Malanson, G.P. and Armstrong, M.P., 1990. Landscape fragmentation and dispersal in a model of riparian forest dynamics. Ecol. Modelling, 49: 277–296.

Johnson, R.R. and Jones, D.A., 1977. Importance, preservation and management of riparian habitat. U.S. Forest Service. General Technical Report, RM-43. Pacific Southwest Forest and Range Experiment Station, Tucson, 217 pp.

Leopold, L.B. and Wolman, M.G., 1957. River channel pattern: braided, meandering and straight. U.S. Geol. Surv. Prof. Pap., 292-B: 39–85.

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

Mandier, P., 1984. Le relief de la moyenne vallée du Rhône au tertiaire et du quaternaire: essai de synthèse paléogéographique. Thèse doctorat, Université Lyon II, Lyon, 653 pp.

Marston, R.A., 1993. Changes in geomorphic processes in the Snake River following impoundment of Jackson Lake and potential changes due to 1988 fires in the watershed. Final Technical Report, National Park Service, Denver, 129 pp.

Marston, R.A. and Anderson, J.E., 1991. Watersheds and vegetation of the Greater Yellowstone Ecosystem. Conserv. Biol., 5: 338–346.

Miller, J.R., Schulz, T.T., Hobbs, N.T., Wilson, K.R., Schrupp, D.L. and Baker, W.L., 1995. Changes in the landscape structure of a southeastern Wyoming riparian zone following shifts in stream dynamics. Biol. Conserv., in press.

Naiman, R.J. and Décamps, H. (Editors), 1990. The Ecology and Management of Aquatic–Terrestrial Ecotones. Man and the Biosphere Series, 4. UNESCO, Paris, 316 pp.

Newton, J.W., 1995. The significance of biogeomorphological processes among vegetation communities of the lower Ain River flood-plain, France. M.A. Thesis, University of Wyoming, Laramie, 43 pp.

Pautou, G. and Décamps, H., 1985. Ecological interactions between the alluvial forests and hydrology of the upper Rhône. Arch. Hydrobiol., 104: 13–37

Pautou, G. and Girel, J., 1986. La végétation de la basse plaine de l'Ain: organisation spatiale et évolution. In: A.L. Roux (Editor), Recherches Interdisciplinaires sur les Ecosystèmes de la Basse-Plaine de l'Ain: Potentialitées Evolutives et Gestion. Doc. Cartogr. Ecol., 29: 75–96.

Pautou, G., Girel, J., Lachet, B. and Ain, G., 1979. Recherches écologiques dans le Haut-Rhône fran2çis. Doc. Cartogr. Ecol., 22: 1–63.

Piégay, H., 1995. Dynamiques et gestion de la ripisylve de cinq cours d'eau à charge grossière du bassin du Rhône. Thèse doctorat, l'Université Paris IV–Sorbonne, Paris, 529 pp.

Richards, K., 1982. Rivers: Form and Process in Alluvial Channels. Methuen, London, 346 pp.

Rowan, J., 1994. European flood-plain forest ecosystems: structure, function, conservation (announcement of an International Symposium at the University of Leicester, 22–25 March 1995). Geophemera, 63: 29.

Salo, J., Kalliola, R., Hakkinen, I., Makinen, Y., Niemela, P., Puhkakka, M. and Coley, P.D., 1986. River dynamics and the diversity of Amazon lowland forest. Nature, 332: 254–258.

Sparks, R.E., 1995. Need for ecosystem management of large rivers and their floodplains. BioScience, 45: 168–182.

Statzner, B., Resh, V.H. and Dolédec, S. (Editors), 1994. Ecology of the Upper Rhône River: a test of habitat templet theories. Freshwater Biol. Special Issue, 31: 253–556.

Thomas, J.W., Maser, C. and Rodiek, J.E., 1979. Wildlife habitats in managed rangelands: the Great Basin of southeastern Oregon. U.S. Forest Service, General Technical Report, PNW-90. Pacific Northwest Forest and Range Experiment Station, Portland, 18 pp.

Turner, M.G. and Ruscher, C.L., 1988. Changes in landscape patterns in Georgia, USA. Landscape Ecol., 1: 241–251.

Vale, T.R., 1982. Plants and People: Vegetation Change in North America. Resource Publications in Geography. Association of American Geographers, Washington, DC, 88 pp.

Vivian, H., 1989. Hydrological changes of the Rhône River. In: G.E. Petts, H. Moeller and A.L. Roux (Editors), Historical Change of Large Alluvial Rivers, Western Europe. Wiley, Paris, pp. 57–77.

Wissmar, R.C. and Swanson, F.J., 1990. Landscape disturbance and lotic ecotones. In: R.J. Naiman and H. Décamps (Editors), The Ecology and Management of Aquatic–Terrestrial Ecotones. Man and the Biosphere Series, 4. UNESCO, Paris, pp. 65–102.

Zimmermann, R.C. and Thom, B.G., 1982. Physiographic plant geography. Prog. Phys. Geogr., 6: 45–59.