Sediment regime of alpine braided rivers (SE France)

Régime sédimentaire des tresses alpines (France du sud-est)

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RÉSUMÉ

Le régime sédimentaire des rivières en tresses alpines du sud-est de la France a été étudié à partir de l'évolution altimétrique du lit au cours du 20e siècle. Les observations reposent sur 31 sites répartis dans les Alpes et leur piémont, qui couvrent un linéaire de 129 km, soit environ 20% du réseau tressé alpin actuel. Pour chaque site, la superposition du profil en long actuel (issu de levés topographiques terrestres réalisés en 2009) avec le profil en long historique des Grandes Forces Hydrauliques (levé entre 1894 et 1931 en fonction des sites) a permis de reconstituer l'évolution altimétrique de la ligne d'eau d'étiage au cours de la période. Les résultats obtenus montrent que 56% du linéaire est en incision, 20% en exhaussement et 24% stable. La variabilité spatiale des réponses morphologiques montre que les tresses les plus actives se maintiennent préférentiellement dans les Alpes du Sud. Des liens statistiques sont clairement établis entre l'évolution altimétrique historique et les forçages exercés sur les bilans sédimentaires (extractions de graviers, apports torrentiels et divagations latérales). On montre notamment que la conservation d'une recharge sédimentaire forte par les torrents exerce un contrôle majeur sur le régime sédimentaire des tresses.

ABSTRACT

The sediment regime of alpine braided rivers in SE France was investigated from the 20th century evolution of the channel elevation. Observations are based on 31 sites distributed over the Alps and their piedmont, that cover 129 km of river length, that is to say about 20% of the present-day alpine braided network. For each site, the merging of the present-day long profile (obtained from 2009 terrestrial topographic surveys) with the historical long profile of the "*Grandes Forces Hydrauliques*" (surveyed between 1894 and 1931 depending on sites) allows reconstructing elevation changes of the water surface at low-flow during the period. Results show that 56% of the river length is in degradation, 20% in aggradation, and 24% stable. The spatial variability of channel responses shows that the most active braided channels are preferentially conserved in the Southern Alps. Statistical links are clearly established between historical elevation changes and forcings of the sediment budget (gravel mining, sediment supply from torrents and lateral shiftening of river channels). We notably show that the persistence of an important sediment recharge from torrents exerts a major control on the sediment regime of braided channels.

KEYWORDS

Braided rivers, channel change, long profile evolution, sediment continuity, sediment recharge.

1 INTRODUCTION

Historical investigations in France showed that alpine braided rivers experienced important channel changes during the 20th century. The braiding landscape declined, as revealed by old maps and aerial photographs (Bravard and Peiry, 1993). A shift from braiding to wandering or meandering patterns is observed for the most disturbed rivers. A recent regional inventory of braided channels in the French Alps showed a 53% decrease of the braided channel network during the last 200 years (Piégay et al., 2009). Embankments, channelization works, dam constructions and gravel mining were identified as the main explaining factors. Similar results were obtained in the small mountain streams of the Southern French Prealps, where a downstream progressing incision following the reforestation of hillslopes lead to the loss of braided channels in proximal floodplains (Liébault et al., 2005). Persistent braided channels in distal floodplains are interpreted as relict landforms, sustained by the sediment supply from upstream degraded reaches.

The fate of braided channels in the Alps is of great concern to river managers, notably since the implementation of the Water Framework Directive which imposes to reach a good ecological status for rivers. It is recognized that the definition of an appropriate management strategy for these emblematic rivers relies on our ability to predict the position and trajectory of the braided channel on a geomorphic gradient opposing contraction and expansion phases. This can not be achieved without a better understanding of the links between braiding intensity and long-term sediment regimes. The aims of this study are to contribute to this general objective by (i) characterizing and interpreting the time-integrated sediment regime of a large set of representative braided reaches in the French Alps through the reconstruction of 20th century long-profile evolution, and by (ii) analyzing regional and local spatial variability of aggradation and degradation conditions.

2 MATERIAL AND METHODS

2.1 Study sites

Thirty one braided river reaches were selected over the French Alps and piedmont to constitute a representative sample of the variety of physical settings associated with present-day alpine and subalpine braiding landscapes. Most of the selected sites were distributed over the Southern Alps since braiding landscapes are more frequent than in the Northern Alps where human pressures on floodplains is more important. The northern alpine braided rivers are characterized by hydrological regimes dominated by snowmelt, with high flows during spring and summer. The southern alpine braided rivers are dominated by Mediterranean rainfalls, with high flows during autumn, and a secondary peak during spring snowmelt.

For each site, we delimited a study reach with a length higher than 15 times the mean active channel width. When it was possible, we fixed the position of the two extremities of the reach so as to integrate a minimum of two bridges along the reach to facilitate the merging of multidate long profiles. The cumulative length of the study reaches was 129 km, which represented approximately 20% of the total length of braided channels in the French Alps according to a recent census (Piégay et al., 2009). Drainage areas spread over 3 orders of magnitude (from 40 to 12 970 km²). Mean active channel widths ranged from 40 to 350 m, and channel slope from 0.3 to 6%.

2.2 Active channel elevation changes over the last century

Active channel elevation changes over the last century were reconstructed by using historical long profiles commissioned by the *service des Grandes Forces Hydrauliques* at the beginning of the 20th century. Most of the large alpine rivers and their main tributaries were surveyed between 1906 and 1930. The elevation of the water surface at low-flow was measured at a density of 4 points per kilometre, with a precision of about 10 cm.

The long profiles of the 31 study reaches were surveyed in the field during spring and summer 2009, a period of low-flow conditions for most of the sites, except for northern alpine rivers influenced by snowmelt. We surveyed water surfaces of the main anabranche to allow comparison with historical long profiles. The mean spacing between surveyed points was ~100 m. Surveyed points were positioned at every important break of slope or shift in direction of the anabranche. For most of the leveling operations, we started and ended the survey by measuring geodetic monuments to control the

overall altimetric measurement error. The mean calculated error was 8 cm, with a standard deviation of 7 cm. The level of detection of significant elevation change based on the propagation of uncertainty was calculated for each site, with a mean value of 0.58 m (range: 0.52-1.32 m).

3 RESULTS AND DISCUSSION

The historical long profiles of alpine braided rivers revealed a dominant trend of incision during the last century (Figure 1). Fifty-six percents of the 129-km surveyed stream channels were characterized by a significant decrease in channel elevation. The percentages of aggrading and stable braided channels were 20 and 24%, respectively. A considerable variability was observed between sites, with elevation changes fluctuating between -8 and +11 m. The spatial distribution of elevation changes revealed a clear NS gradient, with an aggregation of aggrading channels in the Southern Alps. An EW gradient was also highlighted, with a concentration of high aggradation ratios in the Eastern Alps.

The 129-km braided network was segmented in 1754 reaches that can be categorized according to the number of mining sites and active torrents that may have influenced their sediment regime during the recent period. This analysis revealed a significant influence of both gravel mining and sediment recharge from torrents on elevation changes. It is notably shown that aggrading braided channels are always associated with catchments characterized by persisting sediment continuity from small active torrents. A link is also obtained between aggrading channels and the ratio of unprotected banks along the river corridor. These results highlighted the importance of conservation and/or restoration of (i) sediment continuity from torrents and (ii) erodible river corridor to sustain braided landscapes in the Alps.

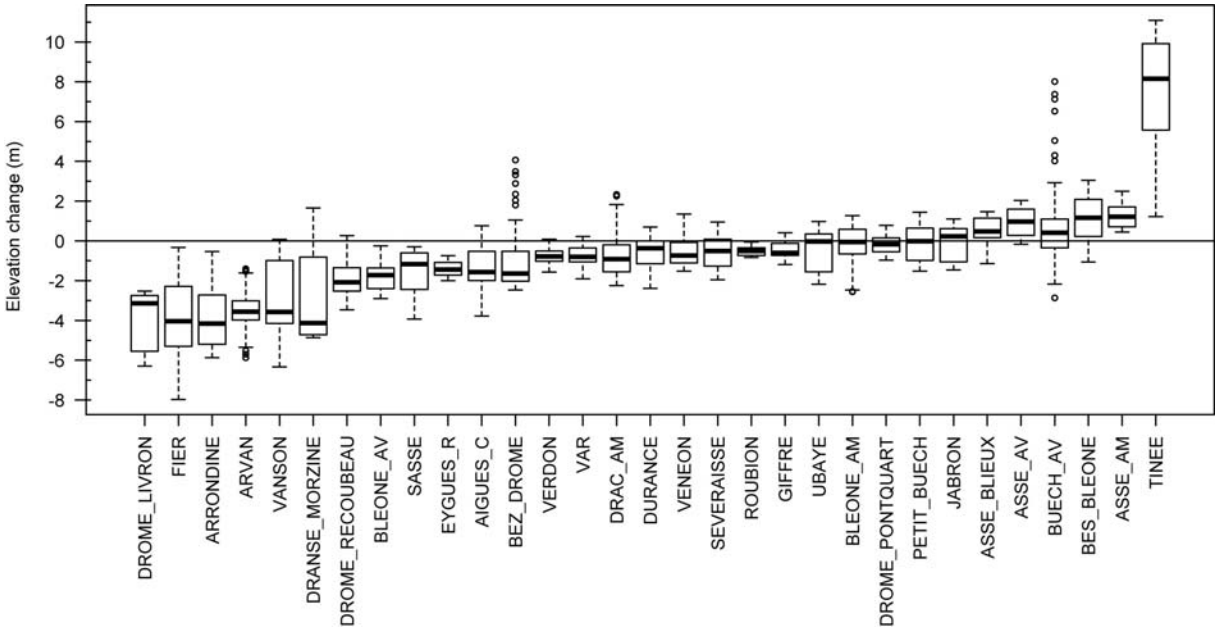

Figure 1. Box plots of elevation changes for the 31 study reaches; boxes represent inner and outer quartiles; horizontal line in the box represents the median; vertical lines represent inner and outer tenths; open circles are extreme values

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