Holocene alluvial sediment deposition in contrasting environments in northwestern Europe

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Abstract The total mass of Holocene alluvial sediment storage was estimated for three Belgian catchments (Dijle, Gulp and Amblève), with areas ranging between 47 and 1070 km^2. The Dijle and Gulp catchments have comparable, rather intensive, land-use histories, while the land use in the Amblève catchment is less intensive and developed more recently. Topography is more pronounced in the Amblève catchment and more gentle in the Dijle catchment. In total, 1070 hand augerings were made to study fluvial deposition at 96 cross-sections across the flood plain. Average flood-plain deposition masses for the different catchments were calculated at different spatial scales. The results show that alluvial sediment storage is much higher for the Dijle catchment (464 103 Mg/km^2 catchment area) compared to the Gulp (128 103 Mg/km^2) and Amblève catchment (33 103 Mg/km^2). Comparison with other data from West European catchments shows that alluvial sediment storage is much larger for the Dijle catchment, while that for the Amblève is very low. These differences between catchments can be attributed to their land-use history. Land use plays a role in both the soil erosion rates and in the sediment transport towards the fluvial system. Radiocarbon dating results for the Dijle flood plain indicate that major changes in land use are responsible for changing flood plain sedimentation.

Key words Holocene; alluvial sediment deposition; land-use change

INTRODUCTION

Holocene soil erosion and deposition has reshaped the landscape. Therefore, the study of these past processes is important to get a thorough understanding of the current landscape. Alluvial deposition plays an important role in the study of these Holocene landscape dynamics: it can provide information on both the quantitative aspects of erosion and deposition, and on the palaeo-environment (e.g. Rommens *et al*., 2006). It is clear that alluvial storage not only depends on historical sediment deposition, but also on the connectivity between the sediment sources and the fluvial system, and the capacity of the fluvial system to transport sediment. In this study, we aim to quantify the alluvial storage in three contrasting Belgian catchments, and explain the differences between the catchments.

STUDY AREAS

This study concerns three Belgian catchments with contrasting environments: the Dijle catchment upstream of Leuven (758 km^2), the Amblève catchment upstream of Remouchamps (1003 km^2) and the Gulp catchment (47 km^2, partially situated in The Netherlands).

The Dijle catchment is situated in the central Belgian loess belt, with topography of undulating plateaus and incised river valleys. Land use on the plateaus is mainly cropland with some large historical forest stands. Flood plains are mainly used for grassland and forests. Evidence exists for prehistoric agricultural settlements, but the first large-scale agricultural land use probably dates from Roman times. After Roman times, there was a drop in population and abandonment of cropland. From the Middle Ages on, there was a strong increase and intensification of agricultural practices. The Holocene flood plain of the Dijle is characterized by a strong vertical aggradation (De Smet, 1973; Notebaert *et al*., 2008a). The lower part of the Holocene deposits consists of peat, while the upper parts are clastic. At most locations the thickness of the Holocene deposits ranges between 5 and 9 m.

The Gulp catchment is situated in the east of Belgium and the southeast of the Netherlands. Soils are mainly developed in loess, although the loess cover is occasionally very thin. The

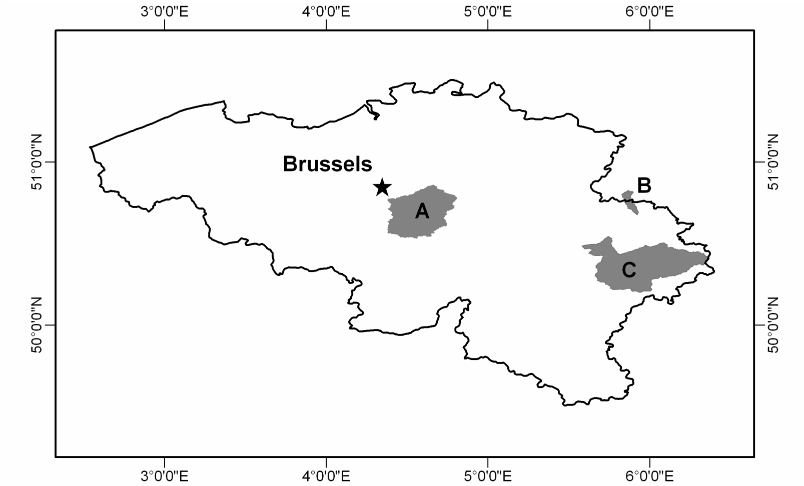

Fig. 1 Location of study areas in Belgium. A: Dijle catchment; B: Gulp catchment; C: Amblève catchment.

topography is of a plateau that is deeply incised by the river valleys. Land use is mainly of grassland and forest stands, with some cropland areas mainly in the north. Land-use history is roughly comparable with the Dijle catchment, except for the conversion from agricultural land to grassland on the plateaus, starting in the 17th century in the southeast of the catchment and progressing towards the north. Although lateral erosion and sediment reworking are important in the Gulp catchment, there is also vertical aggradation, in particular in the downstream parts of the catchment. Flood-plain deposits are comprised of a basal gravel layer overlaid with a sandier layer which grades into a loamy layer. Holocene flood plain deposits are between 0.7 and 2.5 m thick.

The Amblève catchment is situated in the Ardennes upland region, with a topography consisting of an undulating plateau. The upper reaches of the rivers have a shallow valley in which the river meanders, while the valleys of the lower reaches are deeply incised, more so than in the Gulp catchment, with a straight river bed. Land use on the plateaus consists mainly of forest, grassland and a few cropland parcels, while the slopes are densely forested. Land-use history for this region is less known, but it is clear that it was far less intensive then in the other catchments. Much deforestation for the iron industries occurred from medieval times on (Houbrechts & Petit, 2004). Transition from cropland to grassland has occurred in the 20th century, starting in the northwest of the catchment. The dominant process in the Amblève flood plains is lateral erosion and reworking of alluvial sediments (Houbrechts & Petit, 2004). At most places, this lateral erosion has affected the whole flood plain and, as a result, almost all sediments currently stored within the flood plain were deposited after the 14th century (Houbrechts & Petit, 2004). The flood-plain deposits comprise basal gravel layer, covered by loamy or sometimes sandy deposits. In general the thickness of the flood-plain deposits is less then 1.5 m, and often <1 m.

METHODS

Augering along cross-sections of the alluvial planes was used to study the stored volumes and masses of alluvial deposits. The interpretation of the cross-sections and the identification of sedimentological units were based on fluvial architecture concepts, for which the sediment texture was assessed in the field (Miall, 1985). In order to quantify the total volume and mass of sediment stored within the entire catchments, flood-plain polygons were digitized using soil maps, topographic maps, field observations and, where available, detailed LIDAR DEMs (Notebaert *et al.*, 2008b).

For each coring transect, average Holocene sediment deposition volumes per m^2 flood-plain area are calculated. The mass of deposited sediment per m^2 flood-plain area can be calculated taking the dry bulk density and organic matter content into account. A more detailed description of these calculations can be found in Notebaert *et al*. (2008).

The presence of broad, abandoned and partially infilled river channels has a major influence on the local sediment storage in the Amblève Valley, due to the limited thickness of the sediments and the small flood-plain width. Therefore, the flood plains within the Amblève catchment were divided in to several large, quasi-homogenous zones, and for each zone the average storage per area of flood plain was calculated from the cross-sections and used for further calculations.

In the Dijle and Gulp flood plains, the Holocene alluvial deposit is thicker and depressions related to former channels are less pronounced, occur less frequently and have a minor influence on the local storage. In these catchments, the flood plain was divided into several smaller homogenous zones, in such a way that only one cross-section is representative for each zone.

Augering cross-sections are only situated in parts of each flood plain, but were spread in such a way that they represent all major geomorphological situations that occur in that catchment. In order to achieve a sediment deposition amount for the whole catchment, storage data from the zones in which augering cross-sections are situated were extrapolated to the comparable zones of the tributaries in which there are no cross-sections.

RESULTS AND DISCUSSION

The total flood-plain storage masses for each catchment are summarized in Table 1. These data are based on 17 cross-sections (187 hand augerings) for the Dijle catchment, eight cross-sections (72 hand augerings) for the Gulp catchment and 61 cross-sections (712 hand augerings) for the Amblève catchment. As the data also allow the calculation of deposition amounts for some subcatchments, these are also added to in order to make a comparison at the same catchment scale possible.

Although differences between the catchments can partially be attributed to a scaling effect, it is clear that this can only explain part of the difference between Dijle and Gulp catchment, especially when taking into account the values for the subcatchments. Overall valley and hillslope morphology of the Gulp and Upper Dijle are comparable, with longitudinal valley slopes ranging between 6 and 35 m/km, and 3 and 23 m/km, respectively. However, the catchment area-specific sediment storage is about 2.5 times higher for the Upper Dijle (Table 1). For the Geul River, which has the Gulp as a tributary and which has comparable catchment settings, current suspended-sediment yield (SSY) is estimated at between 38 Mg km^{-2} year^{-1} (140 km^2 catchment area) and 81 Mg km^{-2} year^{-1} (380 km^2 catchment area) (Leenaers, 1989). For the Dijle (770 km^2), the current SSY is around 90 Mg km^{-2} year^{-1} (Verstraeten *et al*., 2006), a value that is consistent with the long-term sediment export (80–130 Mg km^{-2} year^{-1}) from the Dijle catchment during agricultural times (last 1000–1200 years; Notebaert *et al*., 2008). As a result, the differences in storage can to a large extent, be attributed to a difference in hillslope sediment supply, which in turn can be attributed to

Table 1 Holocene alluvial sediment storage in the studied catchments and some selected subcatchments.

Catchment	Area (km^2)	Flood-plain area (km^2)	Flood-plain sediment storage (10^6 Mg)	Alluvial storage per catchment area (10^3 Mg/km^2)
Dijle	758	57.8	352	464
Nethen	54	3.2	13.8	256
Upper Dijle	79	4.0	26.8	339
Laan	139	9.6	66.8	481
Gulp	46.7	2.1	5.98	128
Amblève	1003	36.8	33.0	33
Upper Warche	24	1.3	1.09	44
Upper Amblève	106	5.9	4.7	44
Warche	186	9.6	7.8	42

a difference in land use, as the more energetic relief of the Gulp catchment implies a larger potential erosion from the physical settings. Data from the Dijle catchment also show the importance of erosion and sedimentation processes due to anthropogenic land-use change (Rommens *et al*., 2007; Notebaert *et al*., 2008). Land use not only affects soil erosion, but also connectivity between the erosion sites and the fluvial system, which is expressed in the common occurrence of large colluvial valleys and colluvial steps within the Gulp catchment. Although large colluvial valleys are also common in the Dijle catchment, colluvial steps occur less frequently and are often (partially) eroded.

The morphology of the Amblève catchment is less comparable to the two other catchments, except for the (upper) parts of the valleys, situated on top of the plateaus. Here, large stretches have a longitudinal slope of around 5 m/km. Even for these upper reaches (Upper Warche and Upper Amblève), the alluvial sediment storage is much lower than in the other study catchments (Table 1). SSY for comparable Ardennes rivers varies between 5 and 27 Mg km^{-2} $year^{-1}$ (Petit, 1995). From these observations, it is clear that also in this catchment land use is the limiting factor for sediment storage in alluvial valleys. Although colluvial steps and valleys occur, they are less developed than in the Gulp catchment, showing that sediment erosion was lower for the Amblève due to less extensive historical land use.

Holocene flood-plain storage volumes can be compared with the values obtained for the Rhine catchment (Hoffmann *et al*., 2007). When applying the proposed regression line, the storage in the Dijle catchment is about two times the predicted storage. The storage in the Geul catchment is slightly lower than predicted, while the storage in the Amblève catchment is only about 15% of the predicted volume. These values further stress the important differences between the studied catchments.

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