HOLOCENE FLOODPLAIN SEDIMENTATION TRENDS IN THE LOWER RHINE EMBAYMENT (GERMANY)

G. Erkens[1], Th. Hoffmann[2], R. Gerlach[3] & J. Klostermann[4]

[1] Department of Physical Geography, Faculty of Geosciences, Utrecht University, The Netherlands, corresponding author: g.erkens@geo.uu.nl
[2]Department of Geography, University of Bonn, Germany [3]Rheinisches Amt für Bodendenkmalpflege, Germany [4]Geological Survey Northrhine-Westfalia, Germany

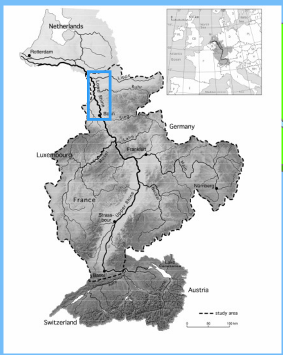


Fig. 1
The Rhine catchment in north-western Europe. The Lower Rhine Embayment is indicated by the blue rectangle

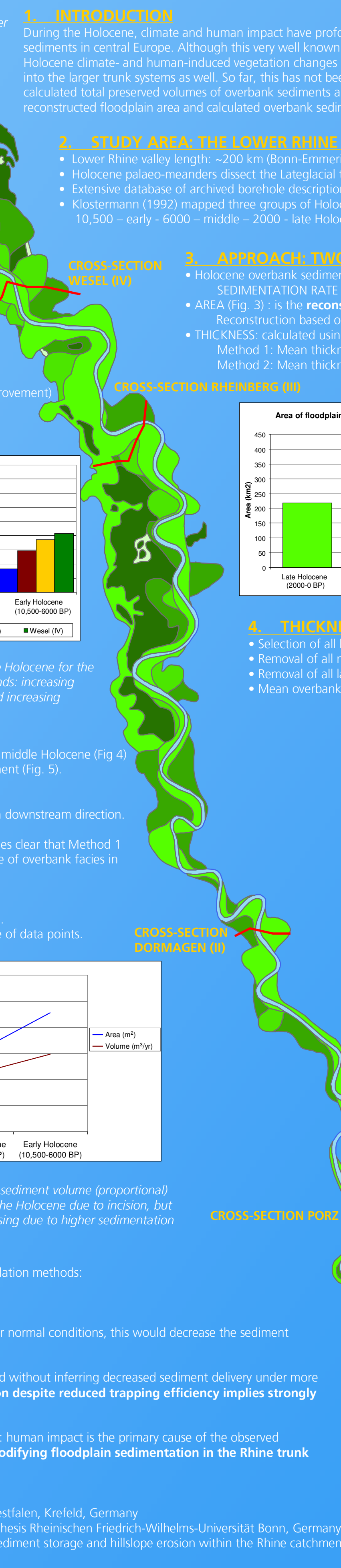


Fig. 2
Geomorphological map of the Lower Rhine Embayment (Klostermann, 1992). Different colours indicate palaeo-meander abandonment (see Fig. 3)

1. INTRODUCTION

During the Holocene, climate and human impact have profoundly altered erosion, transport and deposition of fluvial sediments in central Europe. Although this very well known from smaller upstream catchments, it is expected that Holocene climate- and human-induced vegetation changes in the upstream drainage basin influenced the sediment flux into the larger trunk systems as well. So far, this has not been underpinned by quantitative data. We have now calculated total preserved volumes of overbank sediments along the Lower Rhine (NW Germany, Fig. 1), and have reconstructed floodplain area and calculated overbank sedimentation rates for three time slices in the Holocene.

2. STUDY AREA: THE LOWER RHINE EMBAYMENT

- Lower Rhine valley length: ~200 km (Bonn-Emmerich, Fig. 2)
- Holocene palaeo-meanders dissect the Lateglacial terrace level
- Extensive database of archived borehole descriptions and ^{14}C dates (Geological Survey Northrhine-Westfalia)
- Klostermann (1992) mapped three groups of Holocene palaeo-meanders:
  10,500 – early - 6000 – middle – 2000 - late Holocene 0 cal yr BP; in this study, these are used as time slices.

3. APPROACH: TWO PARALLEL CALCULATIONS

- Holocene overbank sedimentation rates calculated by using formula:
  SEDIMENTATION RATE (m³/yr) = (AREA * THICKNESS) / DEPOSITION TIME
- AREA (Fig. 3) : is the **reconstructed** area of overbank deposition for the time slices
  Reconstruction based on geomorphological map (Fig. 2)
- THICKNESS: calculated using two methods:
  Method 1: Mean thickness queried from digital database
  Method 2: Mean thickness measured from cross-sections

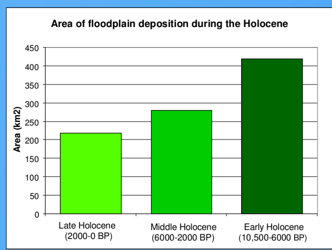


Fig. 3
Reconstructed areas for subsequent Holocene time slices. Note the decreasing depositional area during the Holocene due to incision.

4. THICKNESS METHOD 1: DATABASE MINING

- Selection of all boreholes within Holocene palaeo-meanders (N = 38828)
- Removal of all non-fluvial and pre-Holocene layers
- Removal of all layers with a texture coarser than fine sand
- Mean overbank thickness calculated for each time slice (Fig. 4).

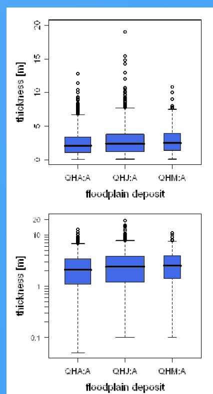


Fig. 4
Thicknesses of overbank deposits from different time slices

(QH:J is late Holocene; QH:M is middle Holocene; QH:A is early Holocene)

Upper plot with normal scale, lower plot with logarithmic scale

5. THICKNESS METHOD 2: GEOLOGICAL CROSS-SECTIONS

- Selection of archived data along 4 lines of section (red lines in Fig. 2).
- Each cross-section is characteristic for a segment of the studied valley.
- Each cross-section a crosses range of palaeo-meanders of varying age.
- Each cross-section is valley-wide.

- Limited amount of fieldwork along two cross-sections (verification of database quality, resolution improvement)
- Interpretation of cross-sections following a facies model (Fig. 6).
- Calculation of overbank cross-sectional area and width of overbank deposits in the cross-sections
  Mean overbank thickness = cross_sectional area / cross_sectional_width

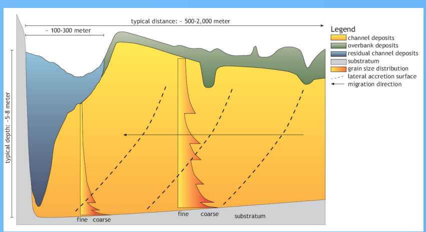


Fig. 6
The applied facies model with lithogenetic units. The overbank deposits (mainly silty loam and clay loam) are on top of the underlying sandy channel deposits.

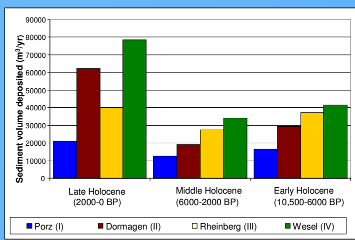


Fig. 7
Deposited volumes (m³/yr) during the Holocene for the 4 valley segments. There are two trends: increasing volumes in downstream direction and increasing deposition in the late Holocene.

6. RESULTS

From Method 1 Database mining:
- Mean overbank thicknesses varied not significantly during the Holocene – only a slight increase in the middle Holocene (Fig 4)
- Results are checked by interpolated of the calculated thicknesses over the entire Lower Rhine Embayment (Fig. 5).

From Method 2 Geological cross-sections:
- Deposited volumes in the 4 valley segments (Fig. 7) show (expected) increasing overbank deposition in downstream direction.

When the volume sedimentation rates from both approaches are plotted in one figure (Fig. 8), it becomes clear that Method 1 gives higher values than Method 2. This is most likely because of decision differences regarding the base of overbank facies in river sequences: Method 2 excludes loamy fine sand – Method 1 includes it.

ADVANTAGES OF BOTH APPROACHES:
- Database approach incorporates all possible corings in certain units, thereby enlarging the sample size.
- Cross-section approach explicitly uses expert (geological) knowledge, which helps evaluating the value of data points.

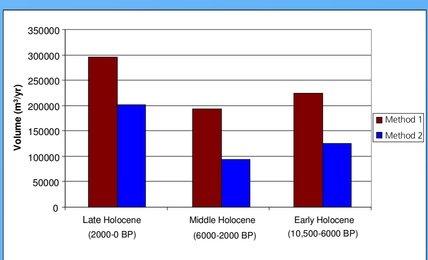


Fig. 8
Volumes deposited per year during the Holocene as calculated by the two different methods. The increasing trend of overbank sedimentation during the Holocene is in both results very clear.

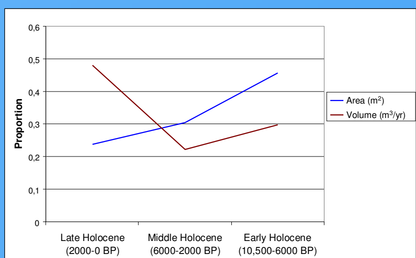
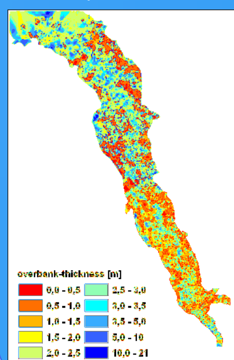


Fig. 9
Floodplain size plotted against sediment volume (proportional). The area is decreasing during the Holocene due to incision, but the deposited volume is increasing due to higher sedimentation rates.

Fig. 5
Interpolation of overbank deposit thicknesses across the entire Lower Rhine Embayment.
The general trend is decreasing thicknesses of overbank deposits further away from the River Rhine, as expected.



7. DISCUSSION

A clear trend is shown in overbank sedimentation rates (Fig. 8), which is yielded by both thickness calculation methods:
1. For 6.0 to 2.0 cal kyr BP, the mean rate is below earlier and later times
2. For 2.0 ka to 0.0 cal kyr BP, the rates strongly increase

Due to continuous incision, the floodplain area in the Lower Rhine Embayment decreased (Fig. 9). Under normal conditions, this would decrease the sediment trapping efficiency (a larger proportion of the input is passed through).

The decrease in trapped volume for 6.0 – 4.0 cal kyr BP, compared to before, can therefore be explained without inferring decreased sediment delivery under more or less stable climate conditions. The increase thereafter however cannot: **net increased sedimentation despite reduced trapping efficiency implies strongly increased sediment fluxes (Fig. 9).**

The size of the increase (150-200 %) exceeds amplitudes expected from intra-Holocene climatic forcing: human impact is the primary cause of the observed enhanced sediment delivery. **Early human land use in central Germany was already capable of modifying floodplain sedimentation in the Rhine trunk valley from at least Roman times onwards.**

8. REFERENCES & FURTHER READING

Klostermann, J. (1992) Das Quartär der Niederrheinischen Bucht. Geologisches Landesamt Nordrhein-Westfalen, Krefeld, Germany
Hoffmann, Th. (2006) Modelling the Holocene sediment budget of the Rhine system. Unpublished PhD-thesis Rheinischen Friedrich-Wilhelms-Universität Bonn, Germany
Hoffmann, Th., Erkens, G., Cohen, K.M., Houben, P., Seidel, J. & Dikau, R. (2007) Holocene floodplain sediment storage and hillslope erosion within the Rhine catchment. The Holocene 17 (1), 105 - 118

Geologischer Dienst NRW
LVR
universitätbonn
Universiteit Utrecht