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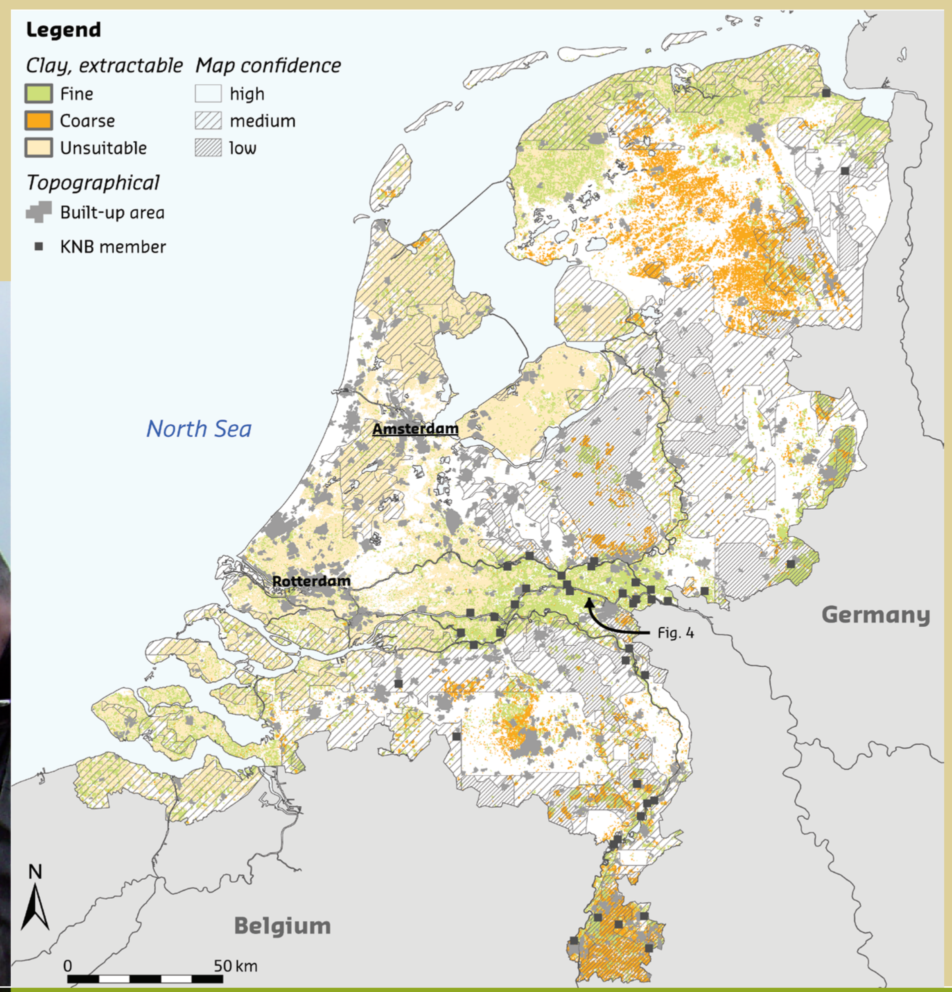


Background, Aim and scope

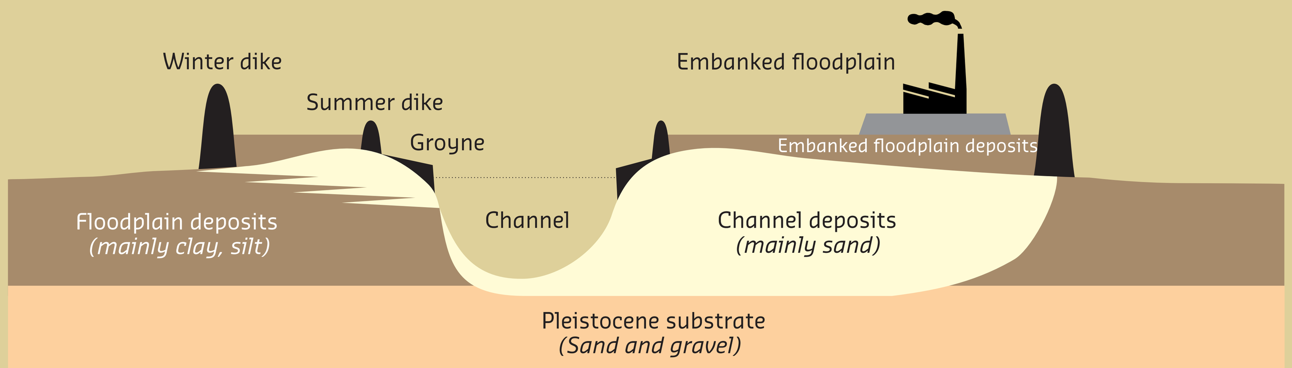
The Netherlands has vast resources of clay that are exploited for the fabrication of structural-ceramic products such as bricks and roof tiles (Fig. 1, 2). Most clay is extracted from the so-called embanked floodplains along the rivers Rhine and Meuse, areas that are flooded during high-discharge conditions (Fig. 3, 4). Riverside clay extraction is – at least in theory – compensated by deposition. Based on a sediment balance (deposition vs. extraction), we explore the extent to which clay can be regarded as a renewable resource, with potential for sustainable use. Beyond that, we discuss the implications for river and sediment management, especially for the large engineering works that are to be undertaken to increase the discharge capacities of the Rhine and Meuse.

Fig. 1: Occurrences of clay in the Netherlands that are extractable, i.e., having (1) a thickness ≥ 1 m without intercalations, and (2) < 25% chance of encountering particulate organic material or shells. For details of the underlying resource assessment see Van der Meulen et al. (2005, 2007). KNB is the Royal Association of Dutch Brick Producers, a sector organisation that represents the larger part of Dutch structural-ceramics industry. NB: plotted are brick-production sites, not (necessarily) clay-extraction sites

Sediment management and the renewability of floodplain clay for structural ceramics

Materials and methods

Extraction rates are based on production statistics for clay, as well as those for fired end-products (fig c). Deposition rates are estimated from published and unpublished geological data (clay volumes and thicknesses, datings, etc.), and from morphological-modelling studies. Comparisons between extraction and deposition are made in three orders of approximation: (1) long-term (post-1850) / large-scale (all Dutch floodplains), (2) present / large-scale, and (3) present / site-scale. The year 1850 is relevant because it approximately marks the beginning of the current, fully engineered river systems, in which depositional processes are constrained by dikes and groynes. As the Industrial Revolution began in the same period, post-1850 sediments can be identified by their pollution with heavy metals.



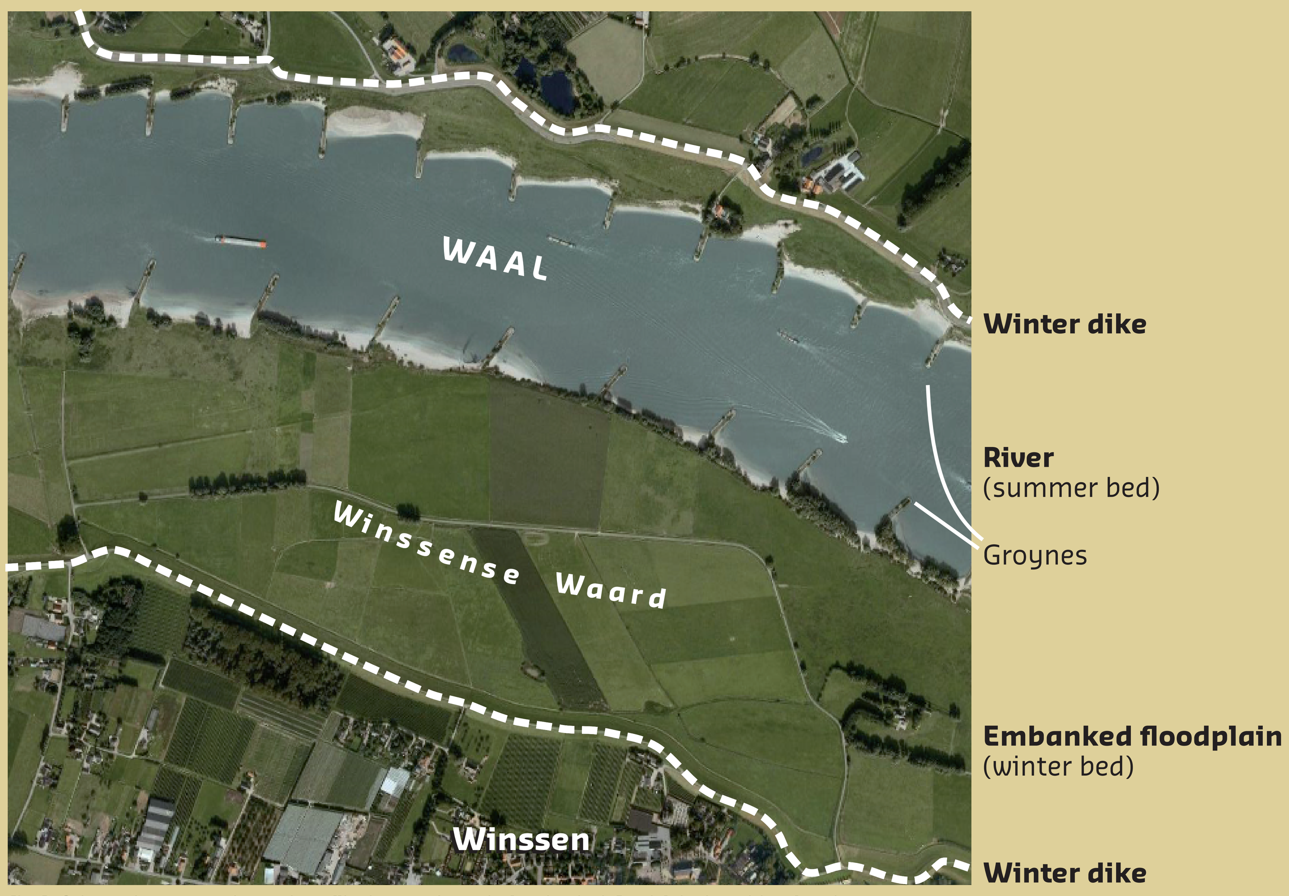


Fig. 3: Schematic cross section and satellite image of a typical embanked-floodplain depositional environment

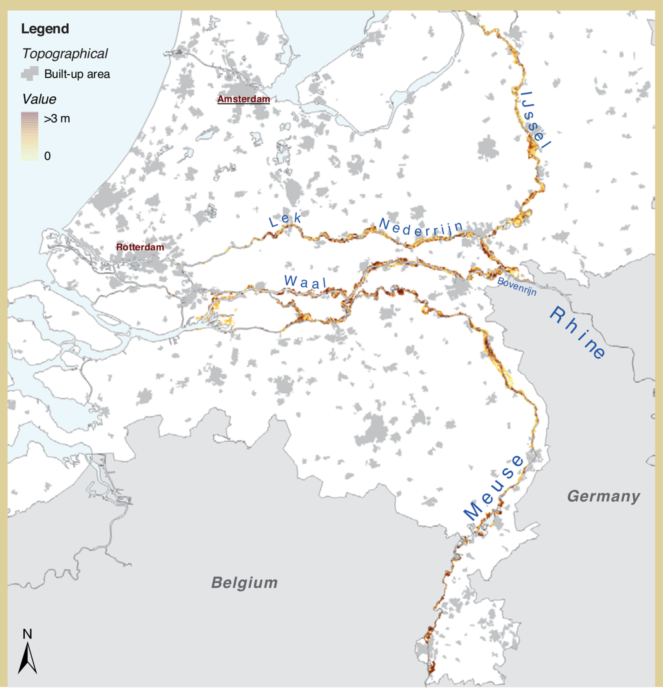


Fig. 4: Clay thickness in the embanked floodplains along the Rhine branches (names indicated) and the lower Meuse, and in the lower Meuse terraces of the upstream Meuse (Modified from Van der Meulen et al., 2007)

Fig. 2. Upper left panel: the extraction of clay using a backhoe. Upper right panel: the extraction depth is about 1 m (including ~30 cm of overburden); relevant lithological variation on that vertical scale is clearly visible. A caliche-horizon within the oxidised clays (not visible on this scale) presents a challenge, as it has to be removed before continuing extraction.

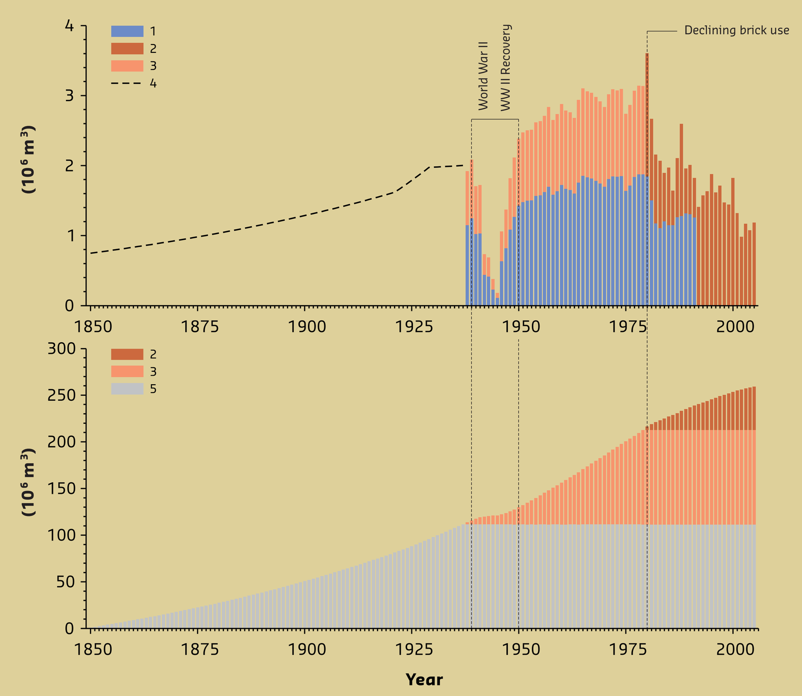


Fig. 5: Upper panel - Annual clay extraction from 1850 to 2006: (1) Clay required for recorded brick production from 1938 to 1991; (2) clay-extraction statistics (1980-2006); (3) an estimate of total clay production based on (1) and (2), see text for explanation; (4) retrodicted clay production (see text for explanation). Lower panel - Cumulative clay extraction volumes from 1850 to 2006: (2), (3) and (5) are the cumulative volumes corresponding to (2), (3) and (4) in the upper panel, respectively.

Results

(1) We estimate the post-1850 clay volume in situ at about 0.20 km³ (Fig. 4) and the total extracted volume in the same period at about 0.17 km³ (Fig. 5) This puts the long-term average deposition rate of clay at ~2.3 Mio m³/yr and the corresponding extraction rate at ~1.1 Mio m³/yr. (2) Current accumulation is approximately 0.4 Mio m3/yr (table 1) and expected to increase, current extraction about 0.7 Mio m³/yr and expected to decrease (Fig. 5). (3) Clay extraction creates a depression that has an increased sediment-trapping efficiency. This local effect is not considered explicitly in large-scale morphological modelling. Based on maximum observed sedimentation rates (Table 2), we estimate that replenishment of a clay site takes in the order of 150 years. As clay extraction lowers some 0.5 km² of floodplain yearly, a surface area of approximately 80 km² would be required for sustainable clay extraction. This is less than 1/5 of the total embanked-floodplain surface area.

Discussion

On the long term, clay extraction from the embanked-floodplain depositional environment has been sustainable. At strongly decreasing deposition rates, the ratio between extraction and replenishment seems to have shifted towards unsustainable. However, current sedimentation is estimated conservatively. The site-scale approach suggests that, even if extraction would currently exceed deposition, this could be resolved with sediment management, that is, with site-restoration measures aimed at higher sediment-trapping efficiency. Our results have implications for river engineering, especially where substantial digging is involved (floodplain lowering, high-discharge bypass channels, obstacle removal). First, this inevitably affects the clay resources that we studied, while resource sterilisation should be avoided. Secondly, the effect that any form of digging has on subsequent sedimentation – increased rates – relates to long-term river maintenance.

Conclusions, recommendations and perspectives

We conclude that clay is a renewable resource, especially if managed accordingly. Beyond that, we established that clay extraction is a significant, lasting factor in floodplain evolution along the Rhine and Meuse. The interests of the extractive industry and river managers could be served jointly with sediment management plans that are based on sediment-budget analyses.

Acknowledgements
This study was funded by KNB (Velp), as well as from the Deltares R&D programme (project 092.81015/01.03.03 KIP Kust & Zee - Sedimenthuishouding), and the BSIK-Delft Cluster project 'Safety against Flooding' (4.30). The authors wish to thank Ewald van Hal, Leen de Jong, Gijs Sigmond, Ad van der Spek and Sytze van Heteren for discussions and suggestions. This poster is based on Van der Meulen et al. (2009).

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Table 1: Current sedimentation rates for the Rhine distributaries (Van der perk et al., 2008) and for the Meuse (sediment-trap data from Middelkoop & Asselman, 1998). See Fig. 4 for river and distributary names.

River /distributary	Embanked floodplain surface area (km²)	Average accumulation rate (mm/yr)	Overall sedimentation rate (103 m³/yr)
Meuse	223.5	0.85	190.0
Waal and Bovenrijn	91.5	1.21	110.7
Nederrijn-Lek	82.2	0.82	67.4
IJssel	93.3	0.54	50.4
Total / Average	490.5	0.85	418.5

Table 2: Maximum sedimentation rates as (a) derived from geological/historical reconstructions (e.g. Middelkoop & Asselman, 1998) and (b) obtained from modelling; see Fig. 4 for river and distributary names)

River /distributary	Embanked floodplain surface area (km²)	Maximum average accumulation rate (mm/yr)(a)	Modelled maximum accumulation rate (mm/yr)(b)
Meuse	223.5	12	9
Waal and Bovenrijn	91.5	18	9
Nederrijn-Lek	82.2	6	9
IJssel	93.3	6	9
Total / Average	490.5	11	9

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