Unravelling mixed sediment signals in the floodplains of the Rhine catchment using end member modelling of grain size distributions.

G. Erkens[1,2], W.H.J. Toonen[2,1], K.M. Cohen[2,1] and M.A. Prins[3],

[1] Deltares Research Institute, Utrecht, THE NETHERLANDS, gilles.erkens@deltares.nl
[2] Department of Physical Geography, Faculty of Geosciences, Utrecht University, Utrecht, THE NETHERLANDS.
[3] Department of Earth Sciences, Faculty of Earth and Life Sciences, VU University Amsterdam, THE NETHERLANDS.

1. The mixing of sediment in fluvial systems

During sediment transport downstream, river systems mix sediments from different parts of their catchments. During deposition, sediments are often unmixed again in different depositional environments (facies). During fluvial transport, between erosion and deposition of sediment, the sediment is sorted too. A commonly observed phenomenon is downstream fining (Frings, 2007), which is the tendency for bed sediments of many rivers to become finer downstream. All processes mentioned above make that fluvial sediment, and thus the fluvial record, is spatially variable.

On top of this, sediment delivery is not constant in time.
On timescales of the Holocene for instance, climate change and human impact, in excess of autogenic variations, changed the amount and characteristics of sediment delivered downstream in many catchments around the world. This makes the fluvial records also temporally variable. Overall, fluvial deposits form a 3D mosaic of sediments with different properties across a catchment.

This makes the fluvial sedimentary record notoriously difficult to use: a single site is not representative for the entire sediment flux at that point (selective trapping) and often constitutes of a mixed signal of the upstream section of the catchment. This study utilizes a new technique to unravel the mixed sediment signal on the scale of a catchment.

2. The Rhine catchment

As a study area, we choose the Rhine catchment. The sediment dynamics within this sizable catchment (~185 000 km^2) are well studied over recent years (e.g. Erkens, 2009). The timeframe of focus is the Holocene, because the fluvial record is considerable as a result of generally good preservation. The fluvial morphology, the key to the fluvial record, is thereby preserved too. In addition, the Holocene is the period that humans cultivated the Rhine catchment. Deforestation in the Rhine catchment to create arable land started as early as 6300 cal BP, at the onset of the Late Neolithic (e.g. Lang et al., 2003). This caused increased erosion and sediment production on the hillslopes in the upstream part of the fluvial system. Recent studies show that this human-induced erosion also increased the suspended load sedimentation rates in the Rhine trunk valley and delta from approximately 3000 years ago (Erkens, 2009). Although the integrated fluxes of sediment are well understood, grain size trends over catchments remain unresolved. This means that paths of sediment down through a catchment are not well understood. It is hypothesised that human land use may also have changed the source of the sediment supplied to the fluvial system. Sediment released by erosion during agricultural practises may be different than the sediments that erode under conditions of forest cover. If this is true, the Late Holocene floodplain sediments have different characteristics in terms of grain size and texture than older floodplain deposits (Middle Holocene).

3. Approach, Materials and Methods

For this study, we used an end-member modelling algorithm EMMA, which is frequently used on for instance deep marine sediment cores and loess-paleosol sequences to unravel different source of sediment input (e.g. Prins et al, 2007). To the knowledge of the authors, this is the first application of this type of models on a catchment-scale fluvial dataset of this size.

We collected 15 cores from three large stretches along the trunk Rhine River: the Upper Rhine Graben, the Lower Rhine Valley, and the Rhine Delta (total range along the river is approximately 600 km). Using detailed palaeogeographic reconstructions of the area, the cores were carefully selected in order (i) to obtain the longest possible record (preferably up to 5000 years), and (ii) to have a continuous sedimentation record as much as possible (see Toonen et al., 2012 for criteria). Cores are taken from residual channels, and distal flood basin and plains, although very distal sites were avoided to minimise the amount of peat or soil formation. Individual age-depth models are derived from radiocarbon dates taken in the cores, correlation of the regional deposits with a known age, and by using groundwater models (in the delta). Grain size characteristics of the siliciclastic sediment fraction were analysed every 2-5 cm with a laser-diffraction particle sizer at VUA, which yielded a record of grain size variations of the floodplains depositions in time. Using the end-member modelling algorithm EMMA it was possible to decompose the sediment mixtures in the floodplain in a series of sedimentary components (end members) reflecting the transport process (suspended and bed load transport), and sediment source.

4. Results: the grain size composition of the Rhine floodplains

Figure 1 shows the grain size distribution of the end-members of all samples (approximately 2000) in the floodplains of the Rhine catchment. This shows that a wide range of grain sizes occurs in the floodplain, including those grains that can only have been transported as bed load. Some of the cores studied reach the bed load deposits underlying the floodplain or residual channel deposits, which explain the inclusion of the coarse grains. We tested the sensitivity of the model to different sample sizes (excluding cores), which was very low.

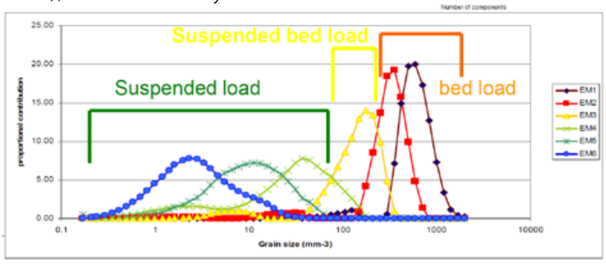

Figure 1. The grain-size distributions of the 6 end-members as recognised by the EMMA model. Note that there are two end-members that are transported mainly as bed load, one as suspended bed load, and three as suspended load.

5. Results: on the level of a single site

At single sites, grain size trends follow the expected pattern of fining upward. As the river moves away from floodplains and residual channels, either by lateral migration and/or by incision, deposits get finer. In residual channel fills, specific intervals shows grain size variation related to migration of channels in the surroundings. These site specific characteristics inhabit comparison between sites, and across the catchment.

6. Results: trends throughout the catchment

Using the recognised end-members, a comparison between sites is made (Figure 2). This shows that the overall composition of the upstream floodplains are very similar, despite that they are located ~300 km from each other. The floodbasins in the delta contain much more fine sediment than the upstream floodplains. This downstream fining is similar to what is found in bed sediments. The residual channel fills are coarser than the delta floodbasins, but finer than the upstream floodplains. They show similar filling, despite differences in their position along the river, both longitudinal and lateral.

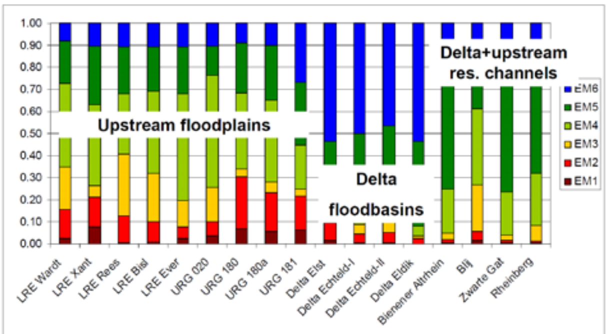

Figure 2. The contribution of the end-members to the floodplain deposits along the Rhine. Colours of the end-members relate to figure 1.

7. Results: temporal trends

Figure 3 shows the contribution of the end-members in selected sites in the three study areas. The available dating points and the composition of the base of the core is indicated. The three sites to the left show a coarsening towards the top, although the absolute increase in grain size differs between the sites. The results of all sites generally show that in the last 2000-3000 years significantly more silt and fine sand are present in floodplain deposits. We explain this as the human-induced sediment flux that is the result of early agricultural practises upstream. Because this signal is found throughout the entire catchment, it shows that (pre-historic) human impact was already capable of changing the sedimentation on the scale of the Rhine catchment before the modern era. The panel on the right in figure 3 shows a younger record, stretching for only 400 years. Here, no coarsening is observed, because this site records only after the coarsening happened.

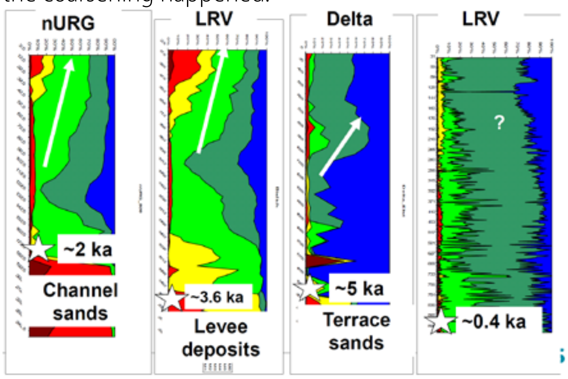

Figure 3. Temporal trends in end-members for selected sites. Colours relate to figure 1. nURG = northern Upper Rhine Graben, LRV = Lower Rhine Valley.

6. Conclusions

Using end-member models, we were able to compare grain size trends within floodplain deposits across the Rhine catchment. On a local sale, grain sizes vary strongly as a result of river processes. Along the Rhine, a downstream fining is observed, for the first time in suspended sediments. In time, human land use resulted in more soil erosion, causing coarser sediment to be deposited in the floodplains. Human impact is shown to be of impressive scale and magnitude, and has to be regarded a forcing factor that acts drainage-basin wide already millennia ago.

References

Erkens, G. (2009) Sediment dynamics in the Rhine catchment – quantifications of fluvial response to climate change and human impact. Published PhD-thesis Utrecht University. *Neth.Geo. St.*, 388, 278 pp.

Frings, R.M. (2007) From gravel to sand – Downstream fining of bed sediments in the lower river Rhine. *Neth. Geo. St., 368, 219 pp.*

Lang, A., **Bork, H.-R.**, **Mäckel, R.**, **Preston, N.**, **Wunderlich, J.**, and **Dikau, R.**, (2003). Changes in sediment flux and storage within a fluvial system: some examples from the Rhine catchment. *Hydrological Processe,s* 17, 3321-3334.

Prins, M.A., **Vriend, M.**, **Nugteren, G.**, **Vandenberghe, J.**, **Lu, H.**, **Zheng, H.**, and **Weltje, G.J.**, (2007), Late Quaternary aeolian dust flux variability on the Chinese Loess Plateau: Inferences from unmixing of loess grain-size records. *Q.S. R.*, 26, 230-242.

Toonen, W.H.J., **Kleinhans, M.G.**, and **Cohen, K.M.**, (2012). Sedimentary architecture of abandoned channel fills. *Earth Surface Processes and Landforms*, 37, 459-472.