# Supplemental Online Material

## Supplement A: Technical details for 3.1

Weber (1991) compared cross profiles with profiles from official surveys provided by water management authorities (District Government Cologne 2015). To compare those with the present status, values had to be extracted from the published diagrams, as original data do not exist. The accuracy is therefore approximately +/- 0.2 m, generating comparability to the LIDAR data, which have similar height accuracy.

Because of the vague documentation of the profile location, the locations of the corresponding DEM cross profiles were chosen from various profiles within an interval of 25 m upstream and downstream from the location mapped by Weber (1991). Ground truthing was carried out with pictures of the equal reaches taken by the authors in 2012, that is, in the same year as the LIDAR data were captured. The current profiles were generated by retrieving the z-values of the DEM raster along polyline features, reciprocal to the recent river channel.

The measurement of cross sections with a dumpy level was quite difficult because of the very deep thalweg scoured into the loamy bed material. In addition, the water level is highly variable because of the WWTP: in dry weather conditions, up to 90 % of the river water is ‘generated’ by the WWTP. Furthermore, the water consumption of the city of Aachen translates into peaky diurnal variations of discharge. The method applied shows a difference between the LIDAR water surface and bed surface that is approximately equal to the mean water depth measured at the gage. Bed correction was therefore carried out by subtraction of the mean difference between data of nearby official survey cross profiles and DEM-derived data. Values vary for straight and meandering reaches. In case of the unavailability of nearby official data, the correction was done by deriving the mean differences between DEM and surveyed data at random points in the river segment.

The original profile data from 1965 are given in relative heights. We corrected these data by adding correction values (130 to 132 m) to achieve comparability with the absolute heights. Correction values were chosen on the basis of the floodplain elevation, considering mean sedimentation rates. To generate comparability, the floodplain surface also had to be corrected on this basis. Cross profile CP7 (Supplement E) serves as a control profile for our correction method, as it incorporates a road that is constant in height over all periods.

## Supplement B: Technical details for 3.2

The longitudinal profile for the valley floor was extracted from the DEM by deriving the z-values averaged for polygons in regular intervals along the river segment (area of 200 m² for each polygon; 100 m spacing along rkm).

The mapping of the terrace bodies was carried out in two steps. First, we identified the terraces based on aerial photos and the DEM with a hillshade overlay (using ArcGIS 10.4). To refine the mapping, we used the DEM derivates of ‘aspect’ and ‘slope’ to generate distinguishing features that are more precise for visual classification.

## Supplement C: Technical details for 3.3

We used persistent reference objects, like manor houses, farms, churches, road junctions, and outcrops, to georeference the map of 1810 by focusing on the study segment. Links are set on several georeferenced data from different times, including the DEM, German Base Map, aerial photos, and cadastral maps. Hence, a single map sheet is georeferenced based on multiple features of different sources, depending on its respective accuracy. Additionally, the map of 1965 was corrected on the basis of the cross profiles, using terrace risers and banks as markers. Applying a spline transformation in the GIS Georeferencing Tool, local accuracy was enhanced at the expense of the overall accuracy of the foreland. The map of 1810 was then iteratively corrected on basis of the map of 1965.

## Supplement D: Dataset of cross profiles (original names, verification reference, location and correction)

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Cross profile | Compiled from (original name) | | | | Verified via | Position (UTM 32U) | | River kilometer | Floodplain Correction | Bed Correction |
|  | 1965 | 1986 | 1990 | 2012 |  | Left | right | km | cm | m |
| CP1 | 25+51 |  | 1 | DEM1 | 2828\_45330 | 296002/  5633089 | 296037/  5633114 | 45.1 | 0,75 cm \* 22 y | -0,938 |
| CP2 | 22+0,35 |  | 2 | DEM1 | 2828\_45270 | 295950/  5633198 | 296012/  5633215 | 45.0 | 0,75 cm \* 22 y | -0,826 |
| CP3 | 23+41 |  | 3 | DEM1 | 2828\_44960 | 296042/  5633380 | 296087/  5633344 | 44.75 | 0,75 cm \* 22 y | -0,722 |
| CP4 | 24+60,6 |  | 4 | DEM1 | 2828\_44755 | 296120/  5633495 | 296178/  5633460 | 44.6 | 0,75 cm \* 22 y | -1,228 |
| CP5 | 25+41 |  | 5 | DEM1 | 2828\_44690 | 296160/  5633543 | 296199/  5633510 | 44.45 | 0,75 cm \* 22 y | -0,48 (side channel)  -0,82 (main channel) |
| CP6 | 31+67,3 | 1000 |  | DEM1 | 2828\_43660 | 295867/  5633866 | 295902/  5633855 | 43.4 | 0,75 cm \* 26 y | -0,938 |
| CP7 | 35+22 | 1100 |  | DEM1 | 2828\_43290 | 296035/  5634174 | 296062/  5634162 | 43.05 | 0,75 cm \* 26 y | -0,326 |

## Supplement E: Cross profiles CD2, CP3, CP5 and CP7

Cross profile CP2 is located 100 m downstream of CP1 in a straight reach at rkm 45. It is characterized by erosion of the right bank and aggradation on the left side, building a terrace within the river corridor. Vertical accretion in the form of a natural levee appeared on the left side. In 2012, the riverbed was approximately 20 cm lower than in 1965 (Fig. 4). The profile shows a shift in the channel of 11 m from left to right. The wetted width expanded from 11 to 13 m (1965 to 1990) and narrowed to 11 m (1990 to 2012), whereas the corridor widened by approximately 55 % (Fig. 5).

Cross profile CP2. See Fig. 1 for location.

Cross profile CP3 at rkm 44.75 shows a meandering reach with extensive changes. Massive erosion on the left bank is accompanied by the development of a flood channel and accretion of a natural levee, which led to a widening of the corridor by 54 m (33 m in 1965). The channel form changed from an asymmetrical profile to a rectangular profile. Wetted width expanded from 13 to 16 to 18 m, along with a lateral channel shift of 20 m. Bed height reduced by approximately 30 cm from 1965 to 2012 (Fig. 5).

Cross profile CP3. See Fig. 1 for location.

Cross profile CP5 (rkm 44.45) is situated 400 m upstream from the former milldam of Adamsmühle. Instead of a deepening tendency, the riverbed experienced substantial accretion (46 cm from 1965 to 1990) (Fig. 9). A second channel, separated by an accretion bank, evolved between 1965 and 1990. The widening tendency at the bed level and bankfull stage is the strongest in the set of cross profiles (Fig. 5). The bank height is 3 m at both sides, with a levee accretion of approximately 50 cm on both sides. The comparison of the asymmetric channel geometry in 1965 and 2012 indicates a phase-shifted flow direction.

Cross profile CP5. See Fig. 1 for location.

Cross profile CP7 at rkm 43.05 is located within a revetment that was built in 1901. Changes in the cross profile must therefore be interpreted with caution. An increase in bed height, for instance, could be explained by a renewal of the bed armoring. Changes in the left bank must also be considered as man-made. The lowering of the right bank floodplain reflects the conversion of a paddock to a riding ground between 1998 and 2003 (per historical aerial photos, available online at www.tim-online.nrw.de). The road on the left bank and the corners of the rectangular profile are stable over all periods. This circumstance verifies the methodological approach to lower the height values of the DEM-derived cross profile within the wetted width and shows a good accordance between the terrestrially measured values and the LIDAR-measured ones.

Cross profile CP7. See Fig. 1 for location.