SPATIOTEMPORAL BUDGETING OF SOIL EROSION IN THE ABANDONED FIELDS AREA OF THE "RAHNSTÄTTER HOF" NEAR MICHELBACH (TAUNUS MTS., WESTERN GERMANY)

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With 6 figures and 5 tables

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Summary: In the former fields of the abandoned manor "Rahnstätter Hof" in the Lower Taunus Mts. (Rhenish Slate Mts, Rheingau-Taunus-Kreis), it was possible to reconstruct and budget the soil erosion over the last 2,500 years, based on a number of soil profiles studied. Also the rate of colluvial deposition was determined. The interdisciplinary study comprises archaeological findings as well as historical records. The "Rahnstätter Hof" manor of 82 ha of fields, meadows and forests was abandoned in 1870, typical of the phase of abandonment mainly affecting isolated farms of the German Uplands towards the end of the 19th century. The total amount of soil erosion on the former farmland has been calculated to 95,000 tons, 65% of it as sheet erosion, the remaining 27% as gully erosion, leading to the deposition of 7,000 tons of colluvium on and behind field balks and of 42,000 tons of colluvial filling in small valleys. 40% of the eroded material is estimated to have been exported. Soil erosion mainly took place during the Early Modern Era, in response to intensified agriculture by the improved three-field crop rotation system and the overexploitation of forest lands in the pre-industrial era. A gully system studied was found to have developed since Early Medieval times. Soil erosion was found not to have caused the abandonment of the farm, but insufficient productivity in the era of incipient industrialization of farmland located on a north slope. For a better understanding of the land-use history of the presently forested area all relics of human activity in the area were mapped, namely charcoal kiln sites, hollow-ways, field balks, boundary stones and gullies.

Zusammenfassung: In der Wüstungsgemarkung „Rahnstätter Hof" im Untertaunus (Rheinisches Schiefergebirge, Rheingau-Taunus-Kreis) wurde anhand zahlreicher Bodenprofile der Bodenabtrag für die letzten 2.500 Jahre rekonstruiert und bilanziert. Gemessen wurde sowohl der Erosionsgrad als auch die kolluviale Verlängerung von Profilen. Interdisziplinär ist zudem die Verknüpfung mit archäologischen Befunden und historischen Aufzeichnungen. Der „Rahnstätter Hof" verfügte über eine 82 ha große Gemarkung mit Acker-, Wald- und Wiesenflächen und wurde um 1870 aufgegeben. Dies entspricht einem typischen Wüstungsphänomen der deutschen Mittelgebirge im ausgehenden 19. Jahrhundert, das hauptsächlich abgelegene Einzelhöfe betraf. Der errechnete Gesamtbodenabtrag in der Gemarkung beträgt 95.000 t. Davon entfallen 64% auf flächenhafte Denudation und 27% auf linienhafte Runsen-Erosion. Als korrelate Ablagerungen finden sich 7.000 t Kolluvien in Form von Ackerrainen und 42.000 t als alluviale Füllungen kleiner Täler wieder. Der Sedimentaustrag aus der Gemarkung beträgt ungefähr 40%. Zeitlich fand der größte Anteil der Erosion erst während der Neuzeit statt. Gründe dafür sind die Intensivierung der Landwirtschaft (erweiterte Dreifelderwirtschaft) und intensive Waldnutzung in vorindustrieller Zeit. Ein untersuchtes Runsensystem konnte auf die Zeit ab dem Frühmittelalter datiert werden. Ein weiteres Ergebnis der Bilanzierung war, dass die Bodenerosion kein Hauptgrund für die Aufgabe des Hofs gewesen sein kann. Vielmehr war es Unwirtschaftlichkeit zu Beginn der Industrialisierung und die schlechte Lage in Nordexposition. Zusätzlich erfolgte eine Kartierung sämtlicher vorhandener Relikte im Wald, wie Meilerplätze, Hohlwege, Ackerraine, Grenzsteine und Gullies, um daraus weitere Details zur Nutzungsgeschichte abzuleiten.

Keywords: Taunus Mts., deserted estate, charcoal burning, field balks, soil erosion, budgeting

1 Introduction

Detailed field work is required for spatiotemporal budgeting of soil erosion, especially in an area of moderate size, when not very much manpower is available.

The area selected for the present study is that belonging to a former manor called the Rahnstätter Hof, near the village of Aarbergen-Michelbach in the Lower Taunus Mts. (Fig. 1; UTM: O 32U 0434910, N 5565266, 306m a.s.l.), which had been abandoned at the beginning of the industrial era. The Rahnstätter Hof was a sovereign estate belonging to the local Earls of Nassau-Idstein, first documented in AD 1194–98 and going out of operation in 1870 (LÖHR 1997), a typical fate of isolated farm sites in the ag-

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Fig. 1: Location of the former "Rahnstätter Hof" manor in the Taunus Mts.

ricultularly less favoured German Uplands towards the end of the 19th century (cf. Born 1989).

Towards the end, the manor comprised 38 ha of fields and 44 ha of forest land (Fig. 2) which, after the abandonment of the estate, became part of the neighbouring village of Michelbach. The fields were forested, and the whole area came under government ownership. Part of the former pattern of fields can still by traced by the balks preserved under the trees. Less than 1 ha of the former farming area was not reverted to forest

For reconstructing the land-use history of the abandoned manor and in particular the impact soil erosion had had on it, the area was investigated between 2008 and 2010. It soon appeared that field balks (*Ackerraine*) and clearance cairns (*Lesesteinhaufen*) also existed in the formerly forested part of the manor. The still existing tell-tale name of the forest plot is "Wickenstück", indicating that it once was a field where the historical crop *Vicia sativa* (vetch; Krünitz 1773–1858) was grown. Of a younger age are charcoal kiln sites telling of one of the later uses of what had become a forest again. Along the north-eastern rim of the Wickenstück forest, a number of hollow-ways (Hohlwege) were identified. The north-facing slope of the manor had been dissected by a gully system named "Wolfskehl".

One aim of the study was to decipher the land degradation of the former farmland from its beginnings, in order to identify the causes possibly relevant to the abandonment of the estate, and also to find out why parts of the manor had been reforested at an early date. To answer the latter question, the colluvial sediments and soils of two well-preserved field balks under forest were studied in detail. This in turn called for a study of the underlying Late Pleistocene periglacial slope deposits.

Another aim was to determine the amount of soil eroded in response to the normal land use during the times of agriculture, charcoal burning and forest clearing. In doing so, we separated soil loss by denudation from that by linear erosion along the gullies and hollow-ways for the whole terrain of the abandoned manor. This was made possible by the rather homogenous structure of the farm land and uniform land use system within a historically well-defined boundary. This distinguishes the present

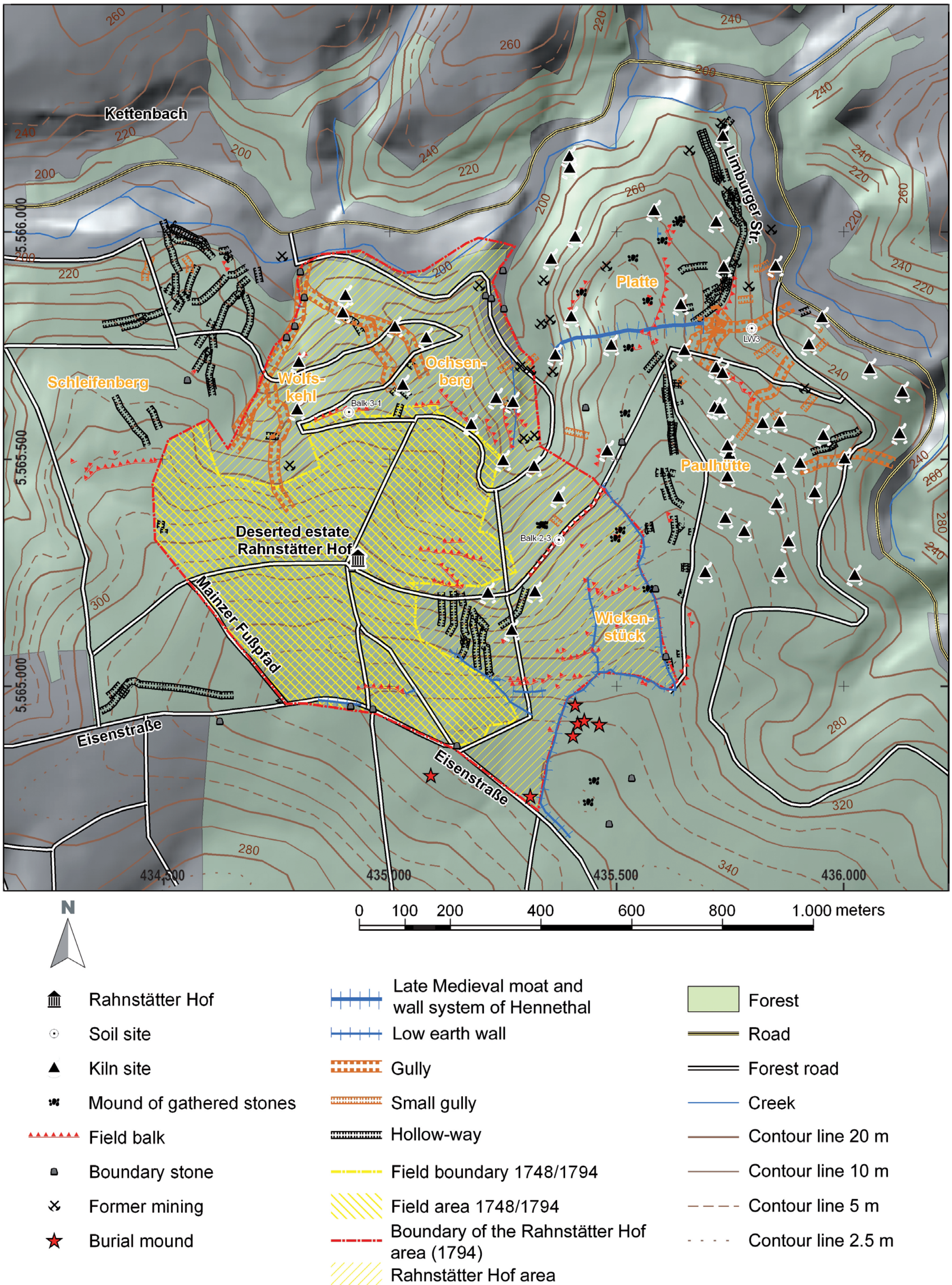

Fig. 2: Geoarchaeologically relevant relics on the ground of the former "Rahnstätter Hof" manor and in the area to the east around the Landwehr earthwork of Hennethal, based on a digital landscape model, and the location of the soil profiles described in the text (coordinate system: UTM)

study from related ones, which usually deal with a small catchment of most likely various types of land use (cf. Fuchs et al. 2010; Bork and Kranz 2008; Bode et al. 2003).

Land use in the past was almost exclusively the reason for the accumulation of Holocene colluvium. In some regions of Germany, the human impact reaches back at least to the Early Neolithic (approx. 7500 BP) (Dreibrodt et al. 2010; Dotterweich 2008; Andres 1997; Semmel 1995a), but this is not likely for the region under discussion.

For the historic epoch after the breakdown of the Roman Empire, two main periods of settlement and cultivation of new agricultural lands are known in Germany (Born 1989). In the times before, the population was concentrated in the low hill country areas with their cover of loess. This explains why prehistoric colluvial and alluvial sediments are almost exclusively found in such terrains (cf. Dreibrodt et al. 2010; Houben 2007; Schulte and Heckmann 2002; Lang and Nolte 1999). In the 7th century, more than 90% of Germany was densely forested (Bork et al. 1998). For the following phases of settlement of the Early and High Middle Ages (AD 400–1000 and 1000–1320), however, there is evidence of young slope deposits almost everywhere in the lower German Uplands.

It is the aim of this paper to trace the land use history of a small section of this environment from the beginning of deposition of those colluvia, supported by other historic relics, and to determine the amount of soil erosion up to the abandonment and reforestation of the site.

2 Regional setting

2.1 Natural environment

The study area is located in the eastern part of the Rhenish Massif of Palaeozoic slates and other metamorphic rocks (Lower Devonian, *Bornich-* and *Sauerthal-Schichten*; BUNDESANSTALT FÜR GEOWISSENSCHAFTEN UND ROHSTOFFE 2001), which are locally dissected by quartz veins that are up to 0.5 m wide.

The land of the abandoned manor dips northward from the Tertiary etchplain level of 340 m a.s.l. down to the floor of the Aubach valley, at 200 m a.s.l. The northward orientation of most of the fields was very unfavourable for cultivation, at inclinations from 2° to 9°. The lower slope to the incised Aubach stream is as much as 24°.

The terrain is coated by Pleistocene periglacial cover beds up to 120cm thick, made up of a loess-containing upper and a debris-rich basal layer (cf. Semmel 2002; Völkel and Leopold 2001; Kleber 1997). Traces of the middle layer known from other German upland cover beds could only be found along the only slightly inclined rim of the etchplain and in some slope hollows. The basal layer consists of saprolitic slate regolith of Tertiary chemical weathering, which, especially on the planation surface relics and on only gently inclined slopes, has led to stagnant water conditions and the development of pseudogleys.

The upper layer can be dated by the general occurrence of Laacher See pumice (12.9 ka BP, Schmincke 2009). In some places, loess from the upper layer has been washed into the coarse pores of the basal layer (cf. Sauer and Felix-Henningsen 2006). In many places, the cover beds have been eroded or buried by Holocene colluvium. Detailed knowledge of the cover beds is necessary for identifying and understanding the soil-erosion processes, as they have almost exclusively taken places within them, and as they are almost exclusively the source of the colluvial and alluvial deposits. Only the well-known composition and texture of the cover-beds permits the safe identification of the younger sediments reworked from them. During the Holocene, at a present precipitation of as much as 620 mm/y, cambisols have developed, often affected by stagnant water.

2.2 Historical development

The first known reference to the Rahnstätter Hof, on the downslope side of the historical *Eisenstraße* (iron road), a former traffic link across the plateau to the Rhine, dates from the 12th century, but the manor is probably older, having been administered, from the High Middle Ages to the Early Modern Times, by the Monastery of St. Ferrutius at Bleidenstadt near Wiesbaden (18 km away).

The suffix -statt suggests that the place was settled during the early inland colonization period (*Landnahmezeit*; Born 1989) from ca. AD 300 to 600. It is uncertain, though, whether there ever was a village, possibly partly abandoned (*partielle Wüstung;* Abel 1976; Bach 1927), prior to the manor.

Around AD 1600, the manor was sold to the Earls of Nassau-Idstein, who leased the buildings and the fields to several farmers. In the final years of its existence, there were several changes of ownership. In a document of such a change in 1747/48 it appears that the proportion of fields to forest was already the same as in 1870, indicating that the plot named "Wickenstück" had already been reverted to forest by the time (HStAW), and that its use as agricultural land dates back to an earlier period.

3 Material and methods

3.1 Mapping

Field work on the abandoned farmland of the Rahnstätter Hof, and soon beyond it to the area of a Late Medieval linear earthwork called *Hennethaler Landwehr*, was started by searching the area on foot, based on a 20 m grid, and mapping all anthropogenic traces (charcoal kiln sites, field balks, clearance cairns, hollow-ways, historic boundary ditches, landmarks boundary stones and burial mounds) by GPS and entering them into a GIS (Fig. 2).

3.2 Pedological and sedimentological field work

The intensity of former soil erosion and the pattern of colluvial sediments were studied by digging 16 soil profile pits, as much as 265 cm deep, supplemented by hand augering at about 30 sites. The data were recorded primarily following the standard of the international World Reference Base for Soil Resources 2006 (INTERNATIONAL UNION OF SOIL SCIENCES 2006) and, in addition, the official German *Bodenkundliche Kartieranleitung*, (AD-HOC-AG BODEN 2005), plus a paper form particularly drafted by the author for geoarchaeological soil profile description.

The samples taken were analyzed for their grain size (method after Köhn; cf. Blume 2000), organic matter (loss on ignition), pH ($CaCl_2$), carbonate content, and, in some cases, the heavy-mineral content of the fine-sand fraction (0.063-0.2µm) at the Geoecological Lab of the Department of Geography at the University of Mainz (methods employed according to Blume 2000). Dateable fragments of charcoal were separated from the loam by an archaeobotanical elutriation procedure (Jacomet and Kreuz 1999), and then identified under the microscope with episcopic illumination (Schweingruber 1990); some fragments could be radiocarbon-dated at the Physics Department of the University of Erlangen (Tab. 1).

For the charcoal samples taken from field balks, it can be assumed that they were transported over a short distance only from the rather low slope above, so that the age determined will be close to that of its sedimentation. Nevertheless, the radiocarbon dates can only render the *terminus post quem* of field-balk formation; as for determining its beginnings, recourse has to be taken to other methods, such as the use of written documents. To identify Laacher See pumice in the upper layer, the fine and finest sand fractions were eliminated for heavy mineral analysis (Boenigk 1983). In the field, the presence of pumice can easily be tested by wetting the sample, placed on a filter paper treated with phenolphthalein (Sauer and Felix-Henningsen 2006), with a few drops of NaF solution, which then shows by a purple coloration.

3.3 Budgeting

Budgeting of soil erosion, and correspondingly, the deposition of colluvial sediments, comprises several forms of erosion and accumulation. Erosional landforms are gullies, hollow-ways and field surfaces lowered by sheet erosion, all of them mostly in-

Tab. 1: Radiocarbon dates obtained from charcoal fragments within colluvium of the study area

Nr.	Type	Site	Depth [cm]	Material	Age [a BP]	Calibration [cal. a AD]
Erl-13762	^{14}C	Colluvial depression filling, LW3	25-59	Charcoal	1392±40	616-663 AD
Erl-14431	^{14}C	Colluvial depression filling , LW4	46-76	Charcoal	1053±41	998-1021 AD
Erl-13759	^{14}C	Field balk, 2-3	50-75	Charcoal	652±39	1356-1387 AD
Erl-13758	^{14}C	Field balk, 2-3	75-90	Charcoal	918±439	1042-1106 AD
Erl-13760	^{14}C	Field balk, 3-1	60-80	Charcoal	319±40	1514-1600 AD
Erl-13761	^{14}C	Bw horizon underneath a long earth wall, RH 1	35-40	Charcoal	9006±59	8293-8204 BC

duced by agricultural land use. Depositional forms are alluvial fans, the fillings of the lower reaches of small valleys, and deposition along downslope field margins, with the field balks becoming thinner upslope. A widespread sheet of colluvium was not found on the surface of the former fields of the Rahnstätter Hof, but was identified in a slope hollow in the *Hennethaler Landwehr* area. The latter was not included in the budgeting, though, in the present context only serving for comparison.

For determining the amount of erosion, the soil profiles were likely to have been subjected to, a standard initial thickness of the upper layer of 50cm was assumed (cf. Stolz and Grunert 2010; Förster and Wunderlich 2009; AD-HOC-AG BODEN 2005; Völkel 1995), and then the remaining thickness of the layer was measured.

Colluvial overlays were identified by their elevated content of organic matter, including macroscopic charcoal fragments, by their dull colour and low bulk density (cf. Leopold and Völkel 2006). An undisturbed soil profile that had developed in the upper layer could not be found underneath the colluvium, signifying that all of the fields had been affected by soil erosion. There may thus be evidence of soil erosion and colluvial deposition within a single profile (cf. Fig. 5 and the related analytical data in Tab. 3).

For obtaining representative results, the slope, from the valley floor to the plateau, was subdivided into eight segments of uniform inclination, and two soil pits were assigned to each of them. As the slope segments are of different widths, the pits of different sections are representative of different areas. This problem was alleviated by a correction factor calculated from the inclination of each segment, as the susceptibility to soil erosion also depends on steepness of slope. The same procedure was applied to both the fields abandoned in 1870 and those of the Wickenstück plot that were reforested much earlier.

The amount of colluvium stored in the field balks was calculated separately by assuming an average thickness of 0.75m (h), an average width of 7.5m (b), and an average total length (s) of the field balks of 802 m in the Wickenstück plot, as well as of 847 m in the area abandoned in the 19th century. Thickness and width were estimated from sample measurements, and total length calculated from GPS data.

Volume of field-balk colluvium (triangular cross section):

$$V = \frac{(h * b)}{2} * s$$

For calculating the total soil loss by erosion of the Wolfskehl gully system, the average inclination (α) of the gully slopes of each uniform section was measured with an electronic inclinometer (Bosch DNM60L). Slope length was measured for approaching the true cross-section area by an isosceles triangle, and then the length (*l*) of each gully section for calculating the approximate amount of material lost in the course of gully formation. The gentle slope depressions, into which the steep gully sections had been incised, were not included in the calculation, nor could any irregularities of slope that may have existed prior to gully erosion, be considered.

Volume of material eroded by gully formation:

$$V = \frac{1}{2} * l^2 * \sin a$$

The thickness of the sediment fill of two small valleys, one of them downslope of the Wolfskehl gully, and the other to the northeast, close to the Ochsenberg forest (Fig. 2) was determined from several hand-corings. The variable width of sections of the floodplain was accounted for by calculating a trapeze for each of them (s denoting the length of a section and h the thickness of the sediment):

Volume of sediment fill in the lower course of small valleys:

$$V = \left(\frac{a + b}{2} \right) * s * h$$

The amount of material eroded by hollow-way formation was calculated from having measured section length *(s)*, width *(d)* and depth *(h)* by tachymeter and measuring tape. The shape of the cross section was approached by a half-ellipse, one radius denoting the depth of incision, the other one half the width of the hollow-way.

Volume of material eroded by hollow-way formation:

$$V = \frac{\frac{d}{2} * h * \pi}{2} * s$$

As the colluvium deposited beyond the lower end of hollow-ways could hardly be seen morphologically, its volume could not be calculated. Therefore, the total volume of empty space of the hollow-ways, equivalent to the amount of material eroded, was added to the accumulation within the district.

The amount of soil and cover-bed material exported from the fields area of the manor was calculated by subtracting the amount of colluvium deposited within the area from the amount calculated to have been eroded.

4 Results

4.1 Mapping and inventory of geoarchaeological relics

By using GPS, all relics in the Rahnstätter Hof area and around *Hennethaler Landwehr* were mapped (Fig. 2). Dividing them into two sections, distinguished by their age of abandonment of tillage, the following types of relicts were registered:

1. Former farmland of the Rahnstätter Hof manor as of 1870 (cross-hatched area in Fig. 2; 38 ha)
   - Location of the manor house, a level surface remaining after demolition of the building after 1870, later used as a timber yard.
   - A total of 802 m of field balks in the south-eastern and northern parts of the area.
2. Those parts of the Rahnstätter Hof farmland that had been reforested before 1870 (hatched area of Fig. 2; 44 ha)
   - Six partly levelled burial mounds, probably from the Iron Age.
   - The filled-in and washed-down remains of a moat-and-wall system of five sections, with an average width of 2.5 m and a relict height of 0.3 m. The two outer ones followed the Rahnstätter Hof boundary of 1794, as could be ascertained from a historic map (HStAW, section. 3011, No. 1628 H) georeferenced by ArcGIS.
   - A number of historic boundary stones marked "H" for "Hennethal", and "HR KW" for "Hof Rahnstatt, *königlicher Wald*" (royal forest).
   - A total of 847 m of former field balks under the old forest of the Wickenstück plot, in the western part of the farmland.
   - Several hollow-ways parallel to the historic *Eisenstraße* (Iron Road, used since an unknown date of the Iron Age to the Early Modern Era. A part or tributary of it is likely to be identical with the "*Mayntzer Fuspfad*" (footpath to Mainz; HStAW) mentioned in a document of 1794.
   - 16 charcoal kiln sites of an average diameter of 12 m, partly cutting across field balks and thus of a younger age, at a statistical density of 0.38 kiln sites/ha. In the adjacent forest around the *Hennethaler* Landwehr, with 41 sites on 69 ha, the density is 0.58/ha (for comparison: In the Harz Mountains, kiln-site densities ranging from 0.05 to 1.66 per ha were determined by Kortzfleisch 2008)
   - Seven decayed tunnel portals and quarries of historic slate mining.

4.2 Former fields

Field balks and the terrace structures upslope of them were not formed by following a plan. They grew in time due to small-scale erosion and deposition processes, mainly induced by ploughing. Stones gathered from the fields, dumped along the lower field margins, and the bushes growing on them retained the fines washed in from upslope (Stolz and Grunert 2010).

One of the field balks of the reforested Wickenstück plot, was studied in detail by digging a pit into it (Figs. 3 and 4).

The area is nearly level (0-2°) and overgrown by beech (*Fagus sylvatica*) and spruce trees (*Picea abies*) 60 to 130 years old, as determined by dendrochronology and from records of the regional forestry office; FORSTAMT BAD SCHWALBACH 2005).

The pit (UTM: E 32U 0435355, N 5565317; Fig. 2, balk 2-3; Fig. 4; analytical data in Tab. 2) shows an ochre-grey colluvium 75 cm thick. At 28 cm below the surface, incipient podzolization around a line of stones gathered from the field suggests that the vertical growth of the balk had been interrupted for some time. The texture of the colluvium is uniform, but the skeletal fraction varies with depth. The eroded upper layer underneath the colluvium

Fig. 3: A relict field balk in the Wickenstück forest, the arrows marking its upper edge behind it the former field terrace. Such relics have been preserved at several places on this gentle slope

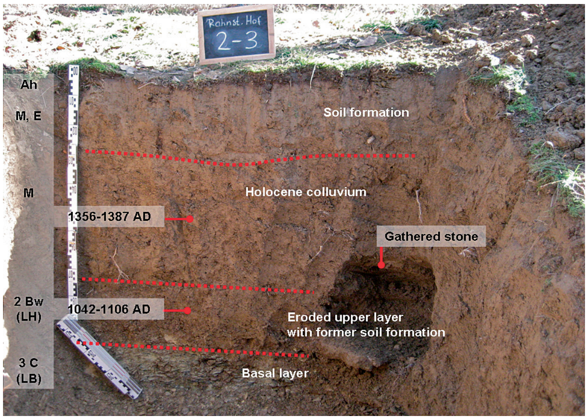

Fig. 4: The pit dug into a relict field balk in the Wickenstück forest (Fig. 2, balk 2-3)

is still 25 cm thick, overprinted by a well-developed Bw horizon. The clay content is 25%, compared to 18% of the colluvium above. The upper layer is rich in the characteristic heavy minerals of the *Laacher See* pumice: Augite (22%), brown hornblende (63%) and titanite (12%; cf. Semmel 2002). The older basal layer underneath mainly consists of the autochthonous slates poor of heavy minerals.

The dating of charcoal fragments washed from both the colluvium and the fBw horizon yielded the following ages (Fig. 4): Cal. 1356-1387 AD (Erl-13759; 50-75cm, tree species not identified; see Tab. 1), cal. 1042-1106 AD (Erl-13758; 75-90 cm, *Fagus sylvatica*). Thus the first phase of colluvium deposition took place at the beginning of the High Middle Ages (11th century). The occurrence of charcoal within the fBw horizon developed in the upper layer of Late Pleistocene age is not unusual, having been worked in by ploughing, often to a depth of 15 cm.

In the agricultural area used up to 1870, another distinctly visible field balk was studied (Fig. 2, balk 3-1; UTM: E 32U 0434922, N 5565611). The balk marks the northern boundary of the fields.

Underneath a grey-coloured dull colluvium (21% clay) there is an eroded upper layer with a distinct fBw horizon (33% clay). Within the colluvium no significant present soil formation is visible, as the field was tilled until 1870. The colluvium contains charcoal particles down to a depth of 80 cm. A sample from 60–80 cm was dated to the Early Modern age: cal. 1514–1600 AD (Erl-13760; Tab. 1). This balk is thus younger than the one previously described.

Another piece of charcoal from a Bw-Horizon (upper layer, pit no. RH1) underneath a low artificial wall parallel to a shallow moat, as described above, in the Wickenstück forest, was dated to an early Boreal age (8293-8204 BC; Erl-13761; Tab. 1).

4.3 Gully erosion

Several gullies studied in the Lower Taunus Mts. are either fully anthropogenic or have become enlarged by human influence (Stolz 2008; Bauer 1995).

Evidence of the age of the gullies in the Rahnstätter Hof area was obtained from the study of a gully close to the *Hennethaler Landwehr* (Fig. 2, site LW3). At its southern flank, at a depth of nearly 8 m, a Holocene colluvium was dug up (Fig. 5, Tab. 3) that had filled an older slope depression, and into which the gully – obviously younger – had been incised. The former slope depression was discovered when measuring the downslope orientation of skeletal particles of the periglacial upper layer and arriving at an average inclination of 29° towards the gully.

The colluvium at the gully flank is from 59 to 145 cm thick (Fig. 5; UTM: O 32U 0435797, N 5565789), as inferred from four pits dug from the upper to the lower end of the gully, where no floods appear to have happened during the last decades.

Tab. 2: Texture and analytical data of the pit dug into the relict field balk of the Wickenstück forest (Fig. 4)

Depth to cm	Horizon/ layer	T %	fU %	mU %	gU %	ffS %	fS %	mS %	gS %	Debris content %	pH value ($CaCl_2$)	Ignition loss %
28	M (E)	18.18	8.97	25.14	31.93	2.74	3.28	4.22	5.53	20.14	3.85	1.88
50	M	18.41	8.80	24.05	34.01	2.60	3.22	4.03	4.87	6.20	3.85	1.64
75	M	18.84	9.54	24.55	32.20	2.76	3.44	4.19	4.48	15.47	3.83	1.47
90	2 Bw (UL)	24.83	10.02	21.00	28.04	2.68	3.26	4.06	6.11	17.26	3.77	1.78
110	3 C (BL)	26.33	11.65	14.90	18.60	2.90	3.43	6.64	15.54	40.72	3.86	1.99

UL = upper layer, BL = basal layer; T = clay, U = silt, S = sand, ff = finest, f = fine, m = middle, g = coarse.

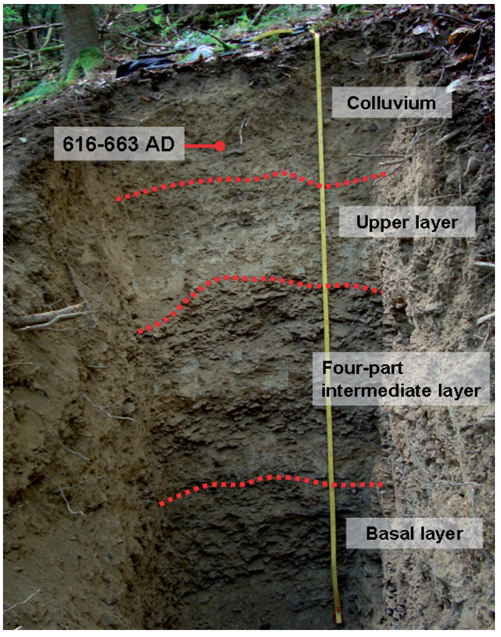

Fig. 5: A pit (Fig. 2, site LW3) at the southern flank of the gully system near the *Hennethaler Landwehr*. A charcoal fragment from the colluvium above was dated to the Early Middle Ages. The colluvium is the filling of a former gentle depression, which existed prior to gully formation. Therefore, the gully must be younger than the 7th century A.D. Underneath there follow the truncated periglacial upper layer with its Laacher See pumice, four different intermediate layers and two basal layers. A piece of charcoal from the same colluvium of a pit nearby (LW4) was dated to A.D. 998–1021

Underneath the colluvium the upper layer, four different intermediate layers, and two basal layers were differentiated, partly by heavy-mineral analysis. The heavy-mineral composition of the upper layer is 17% augite, 61% brown hornblende, and 18% titanite. In contrast, the intermediate layers and the basal one are nearly free of heavy minerals. The heavy-mineral content of the overlying colluvium is similar to that of the upper layer. The colluvium is coloured mid-brown, poor in skeleton, and its texture is similar to that of the upper layer, but it has a higher loess content than the local upper layer, as it originated from the upper slope and the partly loess-covered plateau surface. (Tab. 3).

A piece of charcoal (*Fagus sylvatica*) from the colluvium of pit LW3, from between 25 to 59 cm, was dated to the Early Medieval age of cal. 616–663 AD (Erl-13762; Fig. 5). Another charcoal fragment from the adjacent pit LW4 was dated to cal. 998–1021 AD (Erl-14431). Consequently the gully must be younger than Early Medieval.

Normally, at the mouth of a gully, an alluvial fan spreads out to the receiving stream, but not so in case of the Wolfskehl gully, as it enters the Aubach valley at an undercut slope section of the Aubach stream. Therefore, most of the sediment discharged from the gully was carried away immediately during floods. Farther downstream, at the mouth of the *Hennethaler Landwehr* gully, a similar situation exists where gully and floodplain sediments are closely intermeshed (cf. Stolz 2011).

Only one sediment fill developed in the lower reach of the Wolfskehl gully, thickening downstream from 4.6 m to 5.5 m. The sediment irregularly varies from loamy, skeleton-poor beds to coarse gravelly ones. The sediment underneath the gully fill was too coarse for coring.

In another small valley to the north-east of the Ochsenberg forest (Fig. 2), no gully developed, but the floor of its lower reach was also buried by unconsolidated sediment 4 m thick. As the thalweg follows part of the boundary of the Rahnstätter Hof area, only half of the sedimentary body was included in the calculation of the sediment budget of the manor.

Tab. 3: Texture and analytical data of the pit in the gully flank of Fig. 5 with Holocene colluvium above a truncated upper layer, four different intermediate layers, one basal layer, and the strongly-weathered Devonian slate

Depth to cm	Horizon/ layer	T %	fU %	mU %	gU %	ffS %	fS %	mS %	gS %	Debris content %	pH value ($CaCl_2$)	Ignition loss %
40	M, Bw	18.05	9.85	18.33	24.05	3.36	2.62	5.82	17.92	14.72	3.80	2.05
80	2 fBw (LH)	15.89	8.75	9.15	11.15	6.21	4.09	12.66	32.11	40.81	4.25	2.03
100	3 C (LM4)	12.88	6.90	6.03	8.81	4.98	4.42	16.43	39.56	54.71	4.50	1.87
118	4 C (LM3)	18.68	7.71	7.49	8.72	7.54	5.36	16.30	28.18	55.17	4.37	1.98
130	5 C (LM2)	17.81	6.99	5.88	7.43	6.74	5.02	15.61	34.52	75.55	4.63	2.07
145	6 C (LM1)	20.39	6.56	7.92	10.68	7.60	5.70	16.26	24.90	44.67	4.29	1.91
180	7 C (LB)	17.07	5.91	6.01	8.81	6.53	5.28	16.43	33.96	62.36	4.67	1.82
240	7 Cw (slates)	62.52	10.28	6.84	4.79	2.84	2.12	5.11	5.50	12.06	4.43	2.48

UL = upper layer, BL = basal layer; T = clay, U = silt, S = sand, ff = finest, f = fine, m = middle, g = coarse

4.4 Spatio-temporal budgeting of soil erosion in the district

4.4.1 Calculating erosion

The amount of material eroded from the manor area falls into two parts, one part removed by sheet-wash or denudation in direct response to the tilling of the fields, the other part removed by linear erosion along the gullies and hollow-ways. The amounts calculated are presented in table 2. In total, 63,000 m³, equivalent to 95,000 t were eroded, which is an average loss by soil erosion of 1159 t/ha, with denudation being the dominant process.

4.4.2 Calculating deposition

The sediments resulting from denudation due to soil erosion fall into two groups, one of them the colluvium stored in the field balks, the other group being the sediments lining the small valleys. In the valley sediments it is not possible to distinguish between the sediments resulting from the incision of the gullies and the sediments resulting from denudation of the fields of the catchments of the gullies and merely transported through the latter.

From table 4 one can see that 40% of the matter dislocated within the manor area by soil erosion was exported from it, and that thus more than half of it has at least temporarily been stored within it, especially the fines. This figure was arrived at by subtracting the amount of sediment stored within the area from the calculated total amount eroded. Both the colluvium stored in the balks and the valley fill can be identified by having a much higher skeletal fraction than the periglacial deposits underneath.

In the course of formation of the Wolfskehl gully, only 6,100 of a total of more than 25,000 metric tons of eroded material were washed into the Aubach valley.

4.4.3 Spatiotemporal budgeting

From the radiocarbon data obtained (Erl-13758-13760; Tab. 1) and their sampling depths in the field balks, the approximate denudation rates were calculated for different periods of time (Tab. 5, Fig. 6). It appears that the fields of the manor were tilled from at least AD 1075 to 1870, when the last fields were reverted to forest. The data also show that the denudational share of soil erosion of the Late Middle Ages and Early Modern Age was more than twice that of the High Middle Ages. There is no evidence for any earlier soil erosion.

As no radiocarbon dates were available for the Wolfskehl gully, two radiocarbon dates obtained from the *Hennethaler Landwehr* gully (Erl-13762, 14431; Tab. 1) were used; though outside the study area, they show that gully erosion there went on from AD 1010 to 1850. This result is likely to be also valid for the Wolfskehl gully, as it fits well with gully formation data obtained from a study in the Taunus Mts. (Stolz 2008; Stolz and Grunert 2006; cf. also Bauer 1995; Semmel 1995b) as well as with those published from other parts of the German Uplands (e.g., Moldenhauer et al. 2010; Dotterweich et al. 2003). Thus, by analogy,

Tab. 4: Budgeting of soil erosion and deposition within the area of the abandoned manor of the Rahnstätter Hof. The older balks are those formed between A.D. 1050 and 1600, the younger ones dating from A.D. 1560 to 1870. The calculation only refers to the abandoned manor, excluding the area around the *Hennethaler Landwehr*

	m³	t	t/ha	% (of eroded material)
Denudation	40,746	61,119	745	64
Erosion of the Wolfskehl gully	16,974	25,461	310	27
Erosion in hollow-ways	5,613	8,420	103	9
TOTAL EROSION	**63,333**	**94,999**	**1,159**	**100**
Alluvial fans of hollow-ways	5,613	8,420	103	9
Older balks	2,384	3,575	44	4
Younger balks until 1870	2,257	3,386	41	4
Alluvial fan of gully-system Wolfskehl	12,902	19,353	236	20
Filling of the valley to the NE	15,000	22,500	274	24
TOTAL ACCUMULATION	**38,156**	**57,234**	**698**	**60**
DISCHARGE	**25,177**	**37,765**	**461**	**40**

a constant annual erosion rate of 30.3 t/a is assumed for the Wolfskehl gully up to 1870.

5 Discussion

The data obtained for the colluvium of the study area are evidence of an anthropogenic impact from the Early Middle Ages to the second half of the 19th century (Tab. 1, Fig. 5), as is supported by the colluvium-filled depression near the *Hennethaler Landwehr*. The radiocarbon date obtained there refers to the lower part of the colluvium, more skeleton-rich than the upper part, which may therefore have been deposited during a later erosional phase or event. The earthwork of the *Hennethaler Landwehr*, possibly constructed in the Late Middle Ages (14th–15th centuries) to protect the *Limburger Straße*, a major traffic line of the time (Eichhorn 1965), has been preserved as an earth wall 1–1.5 m high between two ditches. Several undated field balks in the surrounding forest (Fig. 2) are evidence that the area was not forested at the time.

Considering these results, gully formation in the area must have started at the onset of the High Middle Ages at the latest. As already mentioned, the gully at the *Landwehr* was incised into an older colluvium and periglacial cover beds having filled a hollow on the slope. It is from the orientation of their clasts towards the centre of the hollow that it can be proved that the hollow pre-dates gully incision.

The gully itself must already have existed at the time of construction of the moat-and-wall system of the *Landwehr* around the turn of the 14th to the 15th century, as it was evidently made use of as the semi-natural continuation of the defence system (Stolz 2008). From the radiocarbon date obtained from the colluvium of the hollow, it appears that the gully must have originated between sometime after AD 1010 and around AD 1400. The well-documented catastrophic year of 1342 falls into this period. The incision of numerous gullies throughout central Europe has been attributed to this date (Bork et al. 1998; Bork and Kranz 2008). The construction of the *Landwehr* would only have made sense in an open landscape. It can thus be assumed that this was also the case when gully incision began.

Its vigorous growth during the Early Modern Era is likely to be related to the intensive charcoal production, of which there is evidence throughout the region. For the floodplain of the Aar catchment, of which the study area is a part, a phase of considerable soil-erosion triggered flood-loam deposition has been identified for that time (Stolz and Grunert 2008).

Tab. 5: Spatiotemporal budgeting of soil erosion at different historic and prehistoric periods

	Period from a	to a	Length of time a	500 BC-0 t/a	0-640 t/a	640-1075 t/a	1075-1370 t/a	1370-1600 t/a	1600-1870 t/a
Denudation	1075 AD	1870 AD	795	0.0	0.0	0.0	39.4	101.0	97.3
Erosion of the Wolfskehl gully	640 AD	1850 AD	1210	0.0	0.0	0.0	30.3	30.3	30.3
Erosion in hollow-ways	500 BC	1870 AD	2370	3.6	3.6	3.6	3.6	3.6	3.6
TOTAL EROSION				**3.6**	**3.6**	**3.6**	**73.2**	**134.8**	**131.2**
Alluvial fans of hollow-ways	500 BC	1870 AD	2370	3.6	3.6	3.6	3.6	3.6	3.6
Older balks	1075 AD	1600 AD	525	0.0	0.0	0.0	4.0	10.4	0.0
Younger balks	1560 AD	1870 AD	310	0.0	0.0	0.0	0.0	3.2	9.7
Alluvial fan of the Wolfskehl gully	640 AD	1850 AD	1210	0.0	0.0	0.0	23.0	23.0	23.0
Valley filling in the NE	1075 AD	1870 AD	795	0.0	0.0	0.0	28.3	28.3	28.3
TOTAL ACCUMULATION				**3.6**	**3.6**	**3.6**	**58.9**	**68.5**	**64.5**
DISCHARGE				**0.0**	**0.0**	**0.0**	**14.3**	**66.3**	**66.7**

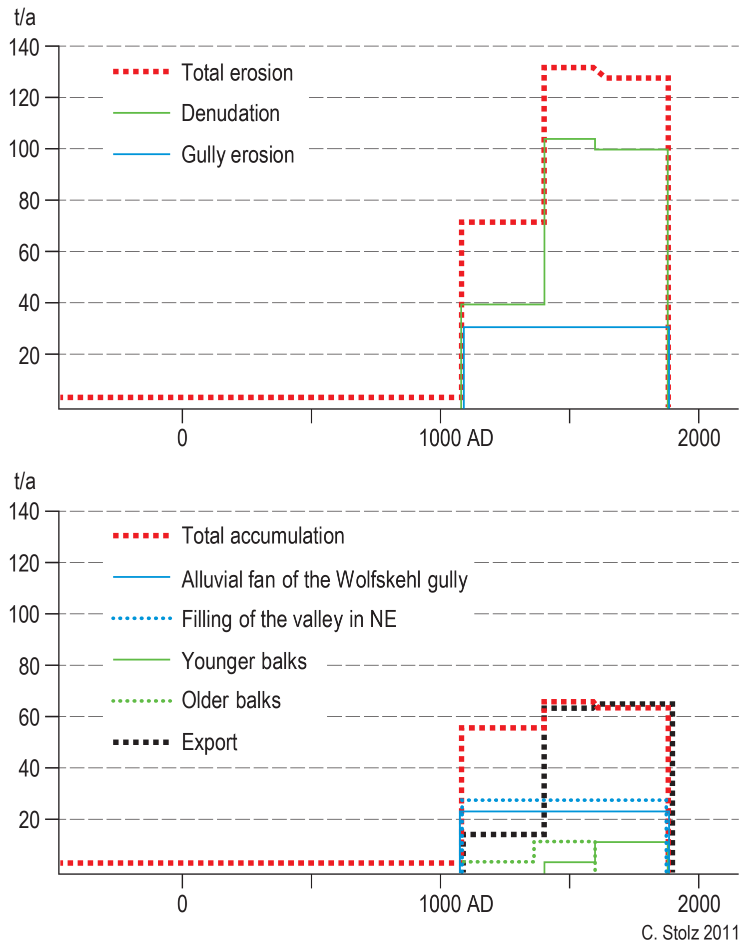

Fig. 6: Spatiotemporal soil erosion of the Rahnstätter Hof area over the last 2000 years

As explained by the history of the Wickenstück forest plot, the tilled area of the Rahnstätter Hof must have been much larger in mediaeval times than at the time of abandonment of the manor in 1870. Soil erosion on the Wickenstück plot set in during the High Middle Ages, a few hundred years later than in the surroundings of the *Landwehr* gully, as the two radiocarbon dates show from the colluvium into which it was cut.

The study of the field balks of the Wickenstück plot has shown that only about one third of the total amount of soil erosion had taken place in the area by the Late Middle Ages, and the remaining two-thirds within a maximum time span of 350 years, until 1740. By that time, the Wickenstück plot had already been returned to forest for quite some time, as is also supported by a historic map (HStAW Abt. 3011, No.1628-H-13). It is unknown, though, how dense the forest was. Reforestation is likely to have occurred in the second half of the 17th century, following the devastation of the Thirty Years' War. There is documentary evidence of severe damage to the region by Swedish troops.

The situation is similar on the fields that were tilled until 1870. From the dated charcoal fragment found in a field balk, it appears that one third of the colluvium was deposited before AD 1600, and the other two-thirds over the next 270 years. The likely reason of this enormous increase may be the introduction of the improved three-field crop rotation system, together with the cultivation of potatoes, during the 18th century (Born 1989). Charcoal production had contributed to soil erosion since at least AD 1000. It peaked, however, in 1656, when the ironworks of Michelbach (2 km away) needed enormous amounts of charcoal. Before, charcoal had been consumed by several small, dispersed ironworks. The forests of the time had been largely reduced to heathland (Geisthardt 1954).

The calculation of an export of 40% of eroded matter from the manor area fits well with the data presented by Houben et al. (2006), who calculated a discharge of up to 50% from a given catchment.

Evidence of an enormous increase of soil erosion in Post-Medieval times also comes from other small catchments in Germany (Dreibrodt et al. 2010). Schmidtchen (2003) identified increasing hill-slope erosion near Schlüsbeck (Schleswig-Holstein) from the High Middle Ages to the end of the Early Modern Period, (17.5 t/ha*a). Similar results were obtained by Schulz (2007) for the Cologne Basin (*Kölner Bucht*).

Also the sediment input to Lake Holzmaar, in the Eifel Mts., reached its peak during that time (Zolitschka 1998), as did the potassium content of lake sediments in Lake Belau (Schleswig-Holstein), serving as a tracer of the input of eroded soil (Dreibrodt and Bork 2005).

The ratio of denudational to linear soil-erosion fully depended on the landforms and substrates of a given area (Moldenhauer et al. (2010), for example, calculated the combined export by denudational and linear soil erosion from an elevated area in the Odenwald uplands. In that case the amount of material eroded by badland-type gully growth by far exceeded that by denudation, in contrast to the Rahnstätter Hof area.

Despite the conspicuous increase of soil loss in Post-Medieval times, soil erosion alone is an unlikely reason for the abandonment of the manor, in contrast to the assumption by Bork et al. (1998, 311; *Bodenerosionstheorie*) that high erosion rates during the High Middle Ages had been the principal cause of abandonment of villages and farmland in central Europe at the time.

As the loess-rich intermediate layer of the cover bed is ubiquitous, and as only 15% of the upper layer is skeletal, even after centuries of tillage the silty substrate was still suitable for agriculture. Nowhere has the basal layer been exposed by soil erosion. Waterlogging by the clayey Tertiary weathering products of the slates underneath the Pleistocene debris layer, is likely to have always had a negative effect on the agriculture of the Rahnstätter Hof area, most likely even more so than its north-facing exposure.

The abandonment of isolated farmsteads of the German Uplands became a common phenomenon of the early decades of the Industrial Age (cf. Born 1989), as people left the countryside, especially less productive areas, in search of better employment. That the conditions were not ideal for a productive agriculture appears from a statement about the Rahnstätter Hof, written in 1756: "The fields are located in prime, middle and poor locations, in most years best suited for rye and oats, whereas wheat, barley and spelt only rarely yield a good crop because of the elevated position exposed to the cold winds [*„[Die Felder] liegen in guth, mittel und schlechter Lage, also dass Korn Haffer darin nach Beschaffenheit der Jahreszeit am besten gesäth, hingegen Weitzen, Gersten, Spoltz [Dinkel] und sonsten wegen der erhöhet liegenden und den kalten Winden exponirten Plagis selten zu Glück schlägt"*] (Poths 2008, 309).

6 Conclusions

The soil-erosion damage quantified for the 82 ha of fields of the abandoned manor of the *Rahnstätter Hof*, as well as the colluvia within the area resulting from it, was largely caused during the Modern Era, with as much as 135 t of eroded material per annum for the whole area (82 ha; Tab. 5). Reckoning from the situation around 1870, one cause may have been the larger area continuously under cultivation as compared to earlier centuries. The other, and possibly more significant cause, was the shift to the improved three-field crop rotation system in the 18th century, in which fallow became replaced by tuber-crop cultivation, including potatoes (cf. Born 1989). For the time following the Thirty Years' War, there is also much evidence of erosion-increasing forest overuse by intensive charcoal production, possibly compounded by the additional use of forest land for grazing and litter extraction.

The second-highest erosion rate were calculated for the High and early Late Middle Ages, up to 73 t per annum (82 ha). From the survey of the area, together with the radiocarbon dates obtained, the tilled area must have been larger, which may have been compensated, though, by the fallow land as an element of the traditional three-field crop rotation.

In the attempt of balancing the soil erosion of the manor, it appeared that not only the amount of erosion and sediment export have to be considered, but also the amount of colluvium in interim storage in the fields area and on the floors of the drainage lines (cf. also Dotterweich et al. 2003). It could also be shown that colluvium need not have been spread evenly on the slopes, but can have been concentrated in the linear landform element of anthropogenic field balks.

Although a small area was studied in detail, the results obtained may not generally be valid for the central-German Uplands as a whole. On the other hand, it is only by extrapolation from such studies that the amount of soil erosion having affected larger units can be estimated (cf. Houben et al. 2006). The observation that the tilled area of the manor was larger during the High Middle Ages than in the Modern Era can be confirmed from many other parts of the German Uplands, as appears from the frequent occurrence of field balks under forest, though as yet mostly undated (cf. Born 1961; Scharlau 1961).

The survey of the two areas around the *Rahnstätter Hof* and the *Hennethaler Landwehr* has demonstrated how high the density of relics of anthropogenic land use under forest can be. The identification of each of them calls for detailed field work, which cannot be fully replaced by any high-tech survey methods.

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