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ANTHROPOGENIC IMPACTS IN THE RUHR DISTRICT (GERMANY): A CONTRIBUTION TO ANTHROPOGEOMORPHOLOGY IN A FORMER MINING REGION

ABSTRACT: HARNISCHMACHER S., *Anthropogenic impacts in the Ruhr District (Germany): A contribution to Anthropogeomorphology in a former mining region*. (IT ISSN 1724-4757, 2007).

The Ruhr District, formerly the major industrial region in the western part of Germany, extending over parts of the northern lowlands (Westphalian Bight) and the southern highlands (Süderbergland), was dominated by coal mines and steel mills from the second half of the 19th century to the end of the 20th century. Different landforms have emerged from man's direct and indirect impact. The most important are waste heaps with a total mass of 35.9 million tons in 1989. A widespread geomorphological feature from man's indirect impact is mining subsidence with a total volume between 4 and 7.2 km^3 as estimated by Bell & *alii* (2000), resulting in a calculated annual lowering rate of 4.7 mm and 8.5 mm, resp. This rates exceed the denudation rate caused by suspended load discharge in a river catchment of a hill country by two magnitudes. Furthermore, channelization of the whole Emscher river catchment represents an early measure against flooding and to conduct wastewater in open channels. Earth materials were moved to excavate a deep incised channel bed as well as to build dikes in mining subsidence areas. Coal mining waste heaps and lakes caused by mining subsidence are often landscaped and turned into nature reserves with recreation areas.

KEY WORDS: Hard coal mining, Man-made landforms, Earth removal, Ruhr District (Germany).

INTRODUCTION

The Ruhr District in the western part of Germany used to be famous for hard coal mining from the mid-18th century on. Peak coal production was more than 130 million tons in 1939 (Huske, 1987). Anthropogenic landforms can be divided into two major groups: landforms due to man's direct impact on the earth surface and features resulting from man-induced geomorphic processes (see later). Both groups call for remedial activities in order to prevent damages, to stabilize new structures or to restore former geomorphology (fig. 1). The paper intends to present a preliminary estimation of the amount of earth moved on the surface in the Ruhr District.

DESCRIPTION OF THE RUHR DISTRICT

Since it extends over several natural landscapes, the boundaries of the Ruhr District (Federal State of North-Rhine-Westphalia) are not well defined. The borders described here represent the area of the «Regionalverband Ruhrgebiet», an administrative association of cities and districts. The Ruhr District is a metropolitan area with an overall population of 5.7 million people living in 11 cities with more than 100 000 inhabitants and 4 districts. It extends to the river Rhine in the west, to the river Ruhr in the south and borders on the rural areas Soester Börde in the east and Münsterland in the north. Its west to east ex-

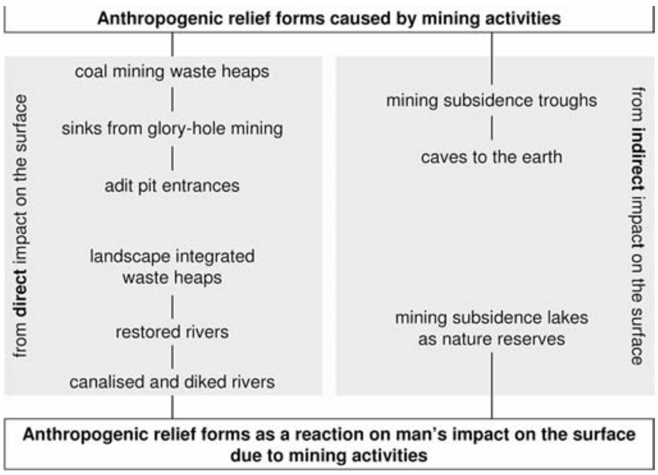

FIG. 1 - Anthropogenic impacts on the surface from coal mining activities in the Ruhr District.

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tension is 116 km, while from north to south it is 67 km. The total area of the Ruhr District amounts to 4,435 km^2 (Regionalverband Ruhr, 2006).

The geology of the Ruhr District is characterised by folded Upper Carboniferous coal-bearing strata, which gently dip to the north and outcrop along the Ruhr valley (fig. 2). From south to north they are overlain by increasingly thicker Cretaceous strata. Tertiary sediments only occur in the western part of the Ruhr District, while the thin layer of Quaternary glacial, periglacial, fluvial and aeolian sediments builds up the uppermost strata (Hahne & Schmidt, 1982; Füchtbauer, 1993; Richter, 1996).

Geomorphologically, the Ruhr District consists of the northern hills of the Süderbergland in the south and the relatively flat Hellwegzone in the north. That formerly important commercial route marks the Cretaceous outcrops, which locally form an escarpment. Further north the low floodplains of the rivers Emscher and Lippe follow, partly interrupted by Cretaceous or Tertiary sediments (Hempel, 1983; Speetzen, 1988; Liedtke, 1993).

A BRIEF HISTORY OF LAND USE AND COAL MINING

In the early 19th century wide parts of Ruhr District showed rural characteristics, towns were aligned along the commercial route of the Hellweg. The wooded backswamps of the Emscher had no settlements. The southern hills of the Ruhr District were arable and grazeland (Steinberg, 1985). Hard coal mining began in the middle of the 18th century along Ruhr valley in the south, where the Upper Carboniferous coal-bearing strata are exposed on the surface. In the early years coal mining was a business of farmers for self-supply or the local market. With the invention of the steam engine, the groundwater was pumped to the surface and transferred to the rivers, so the coal could be excavated from greater depths. It was used for metal working in small factories within the hills of the southern Süderbergland and shipped along the river Ruhr (Steinberg, 1988). Coal mining companies were established and shifted to the north, where coal mining under the hanging Cretaceous layers became possible, followed by rapid population growth in the cities of the Hellwegzone. Coal mines, heavy industries and new settlements even appeared in the formerly uninhabited backswamps along the Emscher, after they were drained, and it developed to the densest populated and most industrialized areas within the Ruhr District. Meanwhile the coal mining proceeded towards the north into the Münsterland, where the coal is excavated from depths below 1,500 m (Steinberg, 1985).

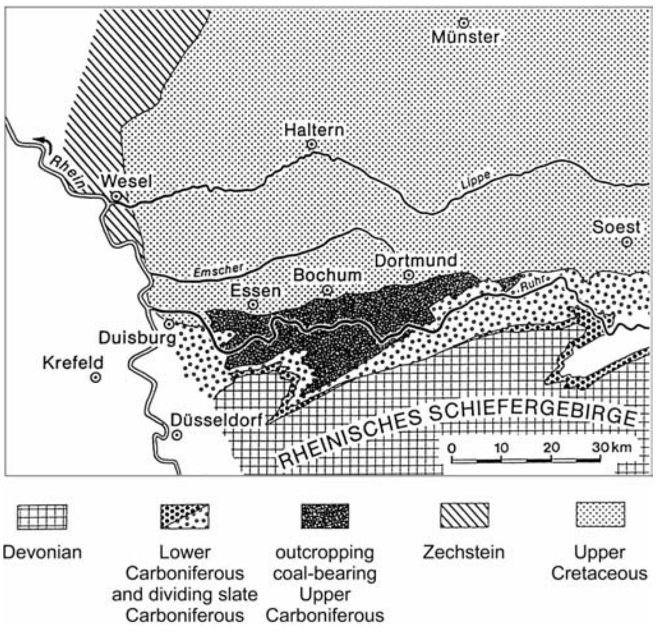

FIG. 2 - Schematic geological map of the Ruhr-Emscher-Lippe area (from Schulz & Wiggering 1991).

In the first half of the 19th century coal mining was concentrated in the Ruhr valley with a total of 956 000 tons coal excavated in the year 1840. Smelting plants were built north of the Ruhr valley, using hard coal instead of charcoal. At the same time the railway arrived to the Ruhr District and did not only represent a new coal consumer but also helped to open new markets for coal. In 1860 coal production already reached 4.3 million tons. After the foundation of the second German empire (1870) it increased to 15.3 million tons by 1874 and reached beyond the Emscher. The growth of heavy industries was followed by the extension of railways and increased shipping along the Rhine. By 1875 the urban population of the Hellwegzone increased to 235 000 and along the Emscher to 52 000. In 1913 114.3 million tons of coal and 9.2 million tons of iron were produced. Smelting plants benefited from the building of new canals. Population grew from 1.5 to 3.3 million between 1895 and 1913. In interwar times coal production decreased to 33 million tons but a peak was reached with 130 million tons in 1939. From the beginning of the 1960's coal and steel production as well as employment in coal mining industries decreased continuously, to 17.8 million tons of coal in 2004 (Steinberg, 1988).

HARD COAL MINING TECHNOLOGY

Hard coal mining begins with the drilling of a mine shaft. Then a network of horizontal and gently inclined galleries and small shafts are established in order to extract the hard coal from different directions. Only after the basic network of shafts and galleries is established any progression along roadways (drifts) and the installation of a longwall face is possible. In the Ruhr District the longwall extraction of coal was introduced in the mid-19th century. It involves removing a panel of coal by working a face of up to 220 m in width between two parallel roadways (fig. 3). The roof is only supported along the roadways and the longwall face. After the coal is extracted and loaded, the face supports are moved into the direction of the longwall face, leaving the strata, from where the coal has been removed, to collapse. Surface subsidence follows almost immediately. In general

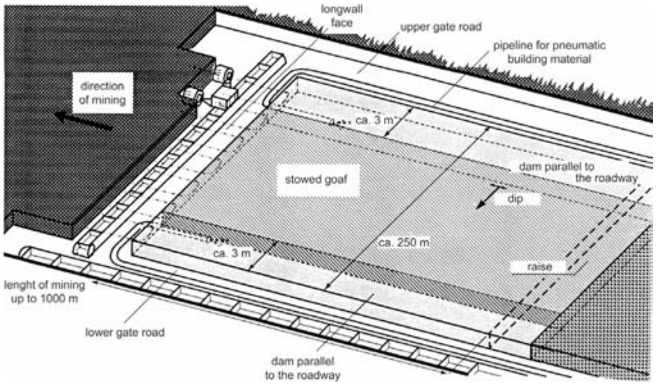

FIG. 3 - Longwall mining in the Ruhr District (from Pollmann & Wilke 1994).

trough-shaped subsidence profiles are associated with longwall mining. Their depths and widths depend on the depth of longwall extraction and the number of overlying seams. In areas of early, near surface and sometimes illegal hard coal mining, instead of wide troughs, small and often suddenly collapsing cavities open to the surface (Wiggering, 1993b; Pollmann & Wilke, 1994; Bell & *alii*, 2000)

LANDFORMS OF DIRECT HUMAN IMPACT

At the outcrops of coal-bearing Upper-Carboniferous strata the refuse rock was deposited next to the adit pit entrance in the early years of coal mining. Here, in the hills of the southern Ruhr District, these small heaps are well integrated within the landscape and do not attract much attention in a meanwhile forested environment. Earth slips only occur during extreme rainfall events. Some of these small heaps are even difficult to identify in the landscape (Wiggering, 1993a; Gantenberg & Wührl, 2006).

Another group of landforms from early direct human impact are small depressions with ca. 10 m diameter and 2 m depth, associated with small waste heaps mentioned above, especially in the southern hills. They witness the glory-hole mining long before 1700. The blossoms of coal were excavated with blades and the coal was transported by wheelbarrows to the next settlement. When the groundwater table rose, the sink was abandoned and the next was excavated. As a result, a chain of small depressions, hard to distinguish from bomb craters of World War II, was created. Comparable landforms are the adit pit entrances from the 1850's, also found in the slopes of the southern hills, where horizontal galleries were established. Nowadays, only minor depressions, sometimes associated with a little coal waste heap downslope, indicate the former mining activities (Gantenberg & Wührl, 2006).

Refuse emerges from collapsed overlying strata, from underlying strata, from dirt bands within coal seams and, in a minor part, from mine shafts, mine workings, roadways and the maintenance of mine workings. In 1989 along with 55.7 million tons of coal, 50.3 million tons of refuse rocks were also excavated from the hard coal mines of the Ruhr District. Almost 36 million tons of refuse was deposited on heaps, the rest is used for underground works, as a substitute for building materials or within the coal mines for stowing in order to reduce surface subsidence (Wiggering, 1993a).

From the mid-19th century, when the coal mines moved to the north into the lowlands between the rivers Ruhr and Lippe, the disposal of refuse became a problem. In 1970 more than 170 refuse dumps were counted, one third of them still in use. They are in the area of coal mines, covering 5-7 ha. The heaps of the first generation were cone-shaped and did not integrate well into the landscape (fig. 4). Some of the refuse rocks heaped were used as building material. Heavy erosion by water and wind on steep slopes made the planting of vegetation difficult. Another problem was spontaneous combustion because of the still high amount of hard coal (above 20 per cent) and availability of oxygen. Smoke plumes polluted the air of settlements next to coal mines (Wiggering 1993a; Schulz & Wiggering, 1991).

In order to prevent landslips and flows terraced waste plateaus (of second generation) were constructed (fig. 4). But these artificial mountains with sharp edges and terraces were aesthetically disturbing elements in the plains. Furthermore, from 1968 on coal mining was concentrated on few, but high-capacity coal mines. It became impossible to dispose the high amounts of refuse on heaps close to the large mines. Instead, few larger waste heaps collecting the refuse from several coal mines were established. Such heaps of high capacity and moderate height occupy large areas. Under these strict structural requirements and ecological aspects of the early 1980's the third generation of waste heaps better integrated into the landscape (fig. 4). Geomorphologically, the heaps show flowing silhouette lines, echeloned slopes and benches, sweeping base lines, smooth edges and domes and in general a form more or less adjusted to the character of the landscape. Today these heaps are recreation sites with foot- and bike paths, indices on industrial benchmarks and attractive viewpoints (Hofmann & Winter, 1991).

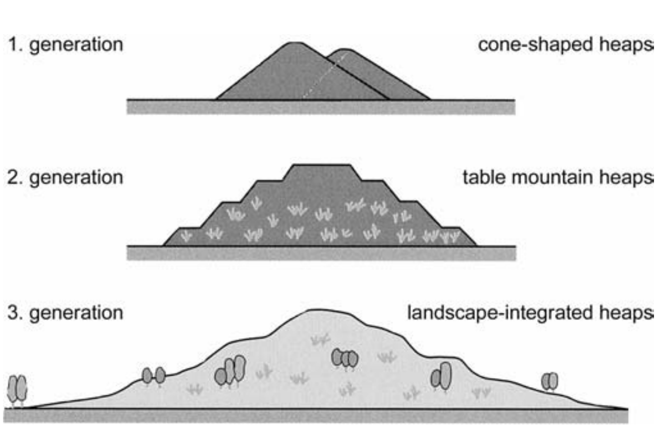

FIG. 4 - Types of coal mining waste heaps in the Ruhr District (from Held & Schmitt 2001).

LANDFORMS OF INDIRECT HUMAN IMPACT

Mining subsidence from longwall mining in the Ruhr District is well known since the second half of the 19th century. After the coal has been excavated, the hanging and underlying strata are pushed by high rock pressure into the hollow (fig. 5). With increasing distance from the working level the rock tends to exfoliate creating a deflection of the strata, which forms a wide and shallow trough on the surface. Its shape depends on the depth of working, the dip and thickness of the seam, the dimensions of the working level and the kind of stowage. The development of a mining subsidence depends on the rate of coal excavation. Mining operations may extend over several years and accordingly the mining subsidence develops slowly. The surface area affected by ground movement is greater than the area worked in the seam and defined by the limit angle of draw or angle of influence. This angle of draw extends upwards and outwards from the working face and varies from 8 to 45° depending with coalfields. It is influenced by depth, seam thickness and local geology, especially the location of the self-supporting strata above the coal seam. The first displacements at the earth surface are starting after half a year, depending on the size of the excavated area. Within two years after the end of coal excavation about 80 per cent of the expected displacements at the surface occur. It takes three more years before underground movements die out (Szelag & Weber, 1993; Bell & *alii*, 2000).

Due to laminar mining of seams of different thicknesses at various depths, mining subsidence from several metres (in older mining regions of the south) to 20 m (between the Emscher and Lippe) is observed. The maximum subsidence recorded is 24 m! Extensive subsidence does not only mean vertical and horizontal displacements on the surface with damage to buildings, but also changes in drainage and groundwater table. Subsidence troughs reaching below the water table cause inundations, impounding ponds and lakes. Although mining has ceased in many southern areas, and subsidence no longer affects the lower Emscher plain, this area will suffer from the legacy of coal mining as long as people will live here. Flooding was characteristic for the lowlands surrounding the river Emscher even before coal mining began, but the situation has been exacerbated by subsidence. Wide areas of the Emscher plain, a region with the highest population density in Germany, has to be drained by numerous pumping stations to protect the inhabitants from flooding. In the eastern lowlands of the river Lippe the situation is similar, so that a belt affected by subsidence extends from the Rhine along the northern Ruhr District to the city of Hamm in the east. In 1989 the area of the drained polder land along the river Emscher amounts to approximately 340 km^2 and along the river Lippe to 243 km^2 (Rathke, 1993; Wiggering, 1993b; Bell & *alii*, 2000).

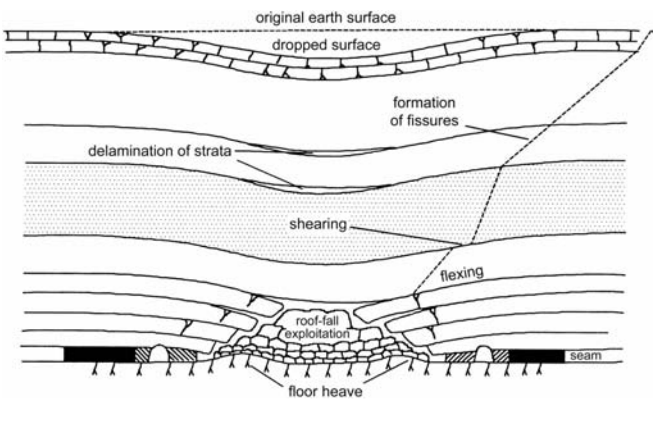

FIG. 5 - Subsidence caused by longwall mining (from Pollmann & Wilke 1994).

Especially in southern Ruhr District with old shallow coal mines of the 19th and early 20th century relatively small cavities reaching up to the surface are typical. They indicate caved-in abandoned mine workings like shafts and gate roads at shallow depths, backfilled insufficiently after closure. Also illegal mining to get fuel towards the end of World War II left empty mine workings behind, not recorded in any data collection. Unlike the mining subsidence due to the longwall extraction of coal the cavities suddenly cave in, leaving holes of up to 20 m in diameter with sharp outlines and reaching to 15 m depth. In January 2000 in the city of Bochum a hollow caved in between two houses and fortunately only affected two garages. The inhabitants were evacuated and a rail traffic nearby was stopped. The collapse took place over a shaft of a coal mine that was abandoned in the year 1904 and backfilled incompletely (Clostermann & Fluechter, 2000; Jaegersberg, 2001).

CHANNELIZATION AND RESTORATION OF THE RIVER EMSCHER AND ITS TRIBUTARIES

By the end of the 19th century subsidence lead to the reversal of natural drainage in extensive areas, especially along the river Emscher and its tributaries. In the early periods of industrialization the wastewater of households and industries was conducted into surface waters, resulting in problems with sanitation and associated outbreaks of typhus and cholera. In the growing cities of the central Ruhr District the aftermath of subsidence was amplified during floods. As a consequence, in the year 1899 an association (Emschergenossenschaft) was founded, entrusted with the disposal of wastewater and the design of a new sewage system. Concrete-lined canals were constructed in order to avoid possible damage of sewer tunnels and subsurface contamination by any mining subsidence. All channels of the Emscher area (approximately 600 km) served wastewater disposal. In order to maintain the discharge of the wastewater and to accelerate the drainage of large areas beds were deepened and straightened. In areas with remarkable mining subsidence the channels had to be diked for flood protection. As a consequence the water table of the river Emscher sometimes reaches the roof top levels of houses next to the canal (fig. 6) (Emschergenossenschaft, 1977; Rathke, 1993; Peters, 1999; Held & Herget, 2005).

While there were more than 150 coal mines in 1939, the year of the highest coal production (130 million tons) in the Ruhr District, nowadays only seven large coal mine companies exist, mainly concentrated in the northern part. With decreasing mining subsidence problems in the central and southern parts, the closure of steel factories and coking plants and developed sewage disposal systems, concrete-lined channels call for restoration. However, it is not only technical circumstances but also socio-economic changes turning the Ruhr District from a heavy industrial into a service and high-tech area that provoke the idea of restoration. As a consequence the open water sewage system of the early 20th century was called into question from the beginning of the 1980's (Held, 2002; Held & Herget, 2005).

Early projects began in 1981, when a small tributary of the river Emscher in Dortmund was restored and others between the cities of Oberhausen and Dortmund followed. The construction of sewer tunnels and facilities for storm water treatment were needed before restoration could begin. More than 400 km of sewer tunnels are necessary, the largest one next to the river Emscher to collect wastewater from the whole Emscher catchment. The circumstances caused by mining subsidence, like the reversal of natural drainage, can not be eliminated. The channelized rivers in the Emscher catchment can only be restored by removing concrete beds, flattening the river banks, infilling river sediments, provoking a gentle sinuous river course and establishing plants along the river banks. Especially in the less densely populated areas along some tributaries of the river Emscher, the restoration of a fluvial morphology even comparable to the situation before industrialisation is possible. For instance, near the city of Castrop-Rauxel parts of the Deininghauser Bach are flowing over a wide floodplain with no restrictions due to settlements, traffic routes or industries nearby (fig. 7). Here, the Deininghauser Bach now shows the typical fluvial morphology of a meandering river in a loess covered area at the transition between the hills of the southern Ruhr District and the central lowlands. The description of reference conditions of the fluvial morphology in different natural landscapes, the so called «Leitbilder», is provided by the North Rhine-Westphalia State Environment Agency (LUA NRW). The complete restoration of the Emscher catchment area will cost approximately 4.4 billion Euros and is scheduled to be terminated in the year 2020 (Londong, 1995; LUA 1999a; LUA 1999b; Grote, 2002; Harnischmacher, 2002, 2003; Held & Herget, 2005).

FIG. 6 - The channelized and diked river Emscher in the city of Herne (photo by J. Herget).

FIG. 7 - The Deininghauser Bach in the city of Castrop-Rauxel after restoration (photo by S. Harnischmacher).

COAL MINING WASTE HEAPS AS LANDSCAPE STRUCTURES

Waste heaps of the third generation is constructed since the early 1980s, accompanied with legally prescribed environmental impact assessments. The oldest heaps were mainly cone-shaped due to the steep natural angle of slope of the refuse rock deposited. Later on these heaps experienced some changes when parts of the refuse were carried off or additional deposition took place, producing irregular or plateau shaped heaps. Their average height was approximately 19 m and they covered an area of 10 ha. The plan view of the heaps depended on the property boundaries, the morphology, the technical infrastructure and extension. The steep slopes were regular shaped without any discontinuity, partly structured resulting from irregular property boundaries. The table mountain heaps of the second generation emerged from small plateaus, after terraces and designed deposition were implemented. Higher production rates demanded an economical use of space, leading to heaps of 40-60 ha area. Their height was not allowed to exceed (approximately 40 m) the double height of a tree, although some (e.g. in the city of Bottrop) were more than 90 m high. Slope inclination averaged 26° (Wiggering, 1993a).

From the mid-1970's landscape designers were involved when the plateaus of the table mountain heaps received a hilly structure and slopes were echeloned. Also ideas about the use of this third generation heaps for recreation, sports, forestry or agriculture were discussed. Meanwhile, waste heaps occupied more than 100 ha area. Today landscape ecological criteria are pre-eminent when waste heaps are created. The optimum integration of the heap into the surrounding landscape is attended as well as a compensation for the intervention by restoration measures. After all, even a heap with an improved design will remain an alien feature within the former central floodplain area of the Ruhr District. A certain volume of refuse from coal mining industries has to be deposited in a limited area. However, not only landscape ecological criteria control heap shape, but first of all the required capacity affects its size, slope inclination and shape. For example, a height of 50-60 m is a compromise between the requirements of capacity and integration into the landscape. A smooth dome shape often promotes the latter. Furthermore, a central wind protected lower part is favourable for biotopes or recreation purposes. For visual appearance of the heap it is important to flatten sharp plateau contours. Additionally, a break of slope between the lower and upper parts of the heap is necessary to remove the top of the heap from the visitors view and apparently reducing its height. The impression of steepness is clearly reduced when the base line forms protrusions and bights (Hofmann & Winter, 1991).

INUNDATED SUBSIDENCE TROUGHS TURNED INTO RECREATION AREAS AND NATURE RESERVES

The development of mining subsidence troughs below the groundwater table leads to surface areas being inundated, resulting in the formation of lakes and ponds. Especially in densely populated areas they can be developed for recreational purposes and as nature reserves. As an example the subsidence area in north-eastern parts of Dortmund is mentioned here. Five seams at depths between 300 and 500 m had been worked before coal mining finally came to an end in 1999. Several lakes and ponds have formed as a result of subsidence; some of them were pumped dry or filled. Lake Lanstrop, the largest of them (200 m wide, 400 m long and 4 m deep) developed between 1963 and 1967. The subsidence amounts to a maximum of 14 m in this area. As a consequence, roads had to be rerouted, an old moated castle was in danger of collapsing and had to be preserved, houses were affected by reversals of sewer gradients, and farmers suffered from the rising groundwater level. Meanwhile, a part of Lake Lanstrop was declared a nature reserve as a favourite habitat for plants and rare birds (Bell & *alii*, 2000).

The nature reserve Hallerey in Dortmund of 50 ha area (fig. 8) is among the best observed in Germany. Coal mining subsidence led to areas of open water developed around 1900. In 1920 a pond with the present-day dimensions already existed. Some years later it dried out, but in the 1950's coal mining subsidence caused pond formation again. The open water areas were filled or used as a settling pond. In 1963 an open wastewater canal crossed the centre of the subsidence area before a leakage of the canal floor required the construction of a sewer tunnel. The water table in the subsidence trough could rise again and formed a lake, which still exists today. Around a 35 ha lake a nature reserve was established with rare plants on the shores. The pollution of the lake proceeds due to contaminated groundwater and percolation water from a former coal mining area. Otherwise, water flowing into the lake ensures dilution and reduces the concentration of pollutants. The rise of the groundwater table is evaluated unambiguously: On one hand it ensures a certain concentration of oxygen, even in periods without rainfall, on the other the lake shore will be inundated and rare plant species are destroyed. This case demonstrates the problems of establishing a biotope within an urban, formerly highly industrialized area. In addition to ecological aspects, conflicts arising from recreational demands of the inhabitants also have to be regarded (Marks, 2002).

FIG. 8 - The mining subsidence area Hallerey in Dortmund (from Marks 2002).

The Lake Bever near the city of Bergkamen in the north-eastern part of the Ruhr District exemplifies the case of a lake within a subsidence trough, fed by a rising groundwater table and mainly by a small river, flowing into the subsidence area from the early 1940's. The water level of the lake of 8.7 ha area, 800 m length, 150 m width and 3.7 m depth is regulated by a pumping station. In 1979 the lake and the surrounding forests were declared a nature reserve, nowadays the home of a rich flora and fauna. A network of hiking trails allows the observation of rare bird, water and plant species as well as the visit of an adjacent landscaped waste heap originating from coal mining. The top of the 90 m high heap is an attractive viewpoint (Duckwitz, 2002).

MATERIAL REMOVAL BY HUMAN ACTIVITIES IN THE RUHR DISTRICT

The estimation of mobilised earth material resulting from the human impact is of great research interest in anthropogeomorphology. Among others, Rivas & *alii* (2006) calculate mobilisation rates (mm per year) due to excavation and mining activities in Spain and Argentina, which accounts for 2.4 and 0.8 mm per year, resp. The calculation of earth moved by indirect human impact in the Ruhr District due to coal mining activities requires data on the total volume of coal mined. Sources indicate that ca. 9.5 billion tons (7 km^3) of coal were extracted between 1800 and 1990 (Meyer, 1986; Wiggering, 1993b). By adding 2.5 km^3 of mining waste (Bell & *alii*, 2000) – a low portion in consideration of the today's volume of mining waste (ca. 50 % of the total volume excavated, see Wiggering, 1993a) – gives a total volume of ca. 9 km^3 coal and mining waste extracted by longwall mining (Bell & *alii*, 2000). Furthermore Bell & *alii* (2000) assumed overall subsidence ranging from 50 to 90 per cent of seam thickness (in volume 4-7.2 km^3). For the total area of the Ruhr District (4,435 km^2) an annual surface lowering of 4.7-8.5 mm can be calculated for the period 1800-1990. Such rates are compared to the denudation rates of river catchments. The catchment area of the river Ruhr, which covers the economically defined Ruhr District in the north and extends to the southern hills of the Süderbergland, is 4,485 km^2. Its denudation rate calculated from suspended load transport at a gauging station near the river mouth is 0.013 mm per year (Schmidt 1984). So the calculated lowering rate of the Ruhr District resulting from mining subsidence is 362-654 times higher than the denudation rate in the Rurhr catchment!

The volumes of earth moved directly by man in the Ruhr District mainly result from the deposition of coal waste heaps. It is very difficult to find a data series on their volumes from the beginnings to the present. Over all, the portion of coal mining waste increased, although the total mass of coal excavated decreased since the 1940's. In 1940 18 per cent of the material excavated was mining waste; in 1960 it amounted to 33 percent, its total mass being 27 million tons in 1970 and 50.3 million tons in 1989. Meyer (1986) compares the total mass in 1985 (65 million tons) to the total mass of the well-known landslide in Goldau (Switzerland, 1806). Another problem for the estimation is represented by the portion of mining waste deposited. For example, in 1989 35.9 million tons were deposited while 14.4 million tons were used for stowing or building. Moreover, many waste heaps of the first generation were dipped off: While 140 waste heaps existed in the year 1960, only 30 major heaps still remained in 1980 (Meyer, 1986; Schulz & Wiggering, 1991).

Furthermore, earth is also moved as a reaction to human impact on the surface triggered by coal mining. It seems the most important activity in this respect is the construction of the open sewage system in the first half of the 20th century, which equally required excavation (canal building) and accumulation (flood-control levees). Finally, the self-dynamic of the restored rivers in the Emscher catchment has to be considered since sediment will be eroded and accumulated due to seminatural fluvial processes induced after restoration. For the estimation of the earth moved knowledge both from fluvial geomorphology and empirical investigations is needed.

CONCLUSION AND OUTLOOK

During coal mining activities beginning in the early 19th century in the Ruhr District different landforms have emerged from man's direct and indirect impact. The most important are waste heaps with a total mass of 35.9 million tons in 1989. A widespread geomorphological feature from man's indirect impact is mining subsidence with a total volume between 4 and 7.2 km^3, resulting in a calculated annual lowering rate of 4.7 mm and 8.5 mm, resp. The values are comparable to the denudation rate caused by suspended load discharge of a river catchment in a hill country. Furthermore, channelization of the whole Emscher river catchment represents an early measure against flooding and to conduct wastewater in open channels. Earth materials were moved to excavate a deep incised channel bed as well as to build dikes in mining subsidence areas. In the 1980's restoration projects on these concrete canals started, and will be completed in 2020. Coal mining waste heaps and lakes caused by mining subsidence are often landscaped and turned into nature reserves with recreation areas.

For the estimation of true earth volumes moved by human's indirect impact on the surface, more detailed information on mining subsidence is required. Detailed levelling data from the Ruhr District exist but are hardly available. An intensive research and analysis of data records from the coal mining companies and federal survey offices will be necessary to calculate not only overall but also local estimated subsidence volumes. This is also possible by comparing elevation data on old maps with digital elevation models. However, the oldest maps with elevation data are only available from the early 20th century and thus the period of peak production and possibly also of largest subsidence in the late 19th century is not covered. Unfortunately, data from closed coal mining companies are hard to obtain. They are supplied by the federal mining department of North-Rhine-Westphalia. A data source on channelization in the Emscher catchment is the Emschergenossenschaft, the water alliance responsible for waste water disposal and river restoration measures. Sediment mobilization after river restoration can be studied by sediment cascade models and detailed information on properties of each catchment within in the Emscher drainage area. Not mentioned so far are road and rail constructions as a reaction on mining subsidence. Estimations of earth volumes moved for these purposes are only possible with the help of high-resolution digital elevation models based on data from road and rail construction offices.

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