ENGINEERING IMPACT ON RIVER CHANNELS IN THE RIVER RHINE CATCHMENT

With 12 figures, 3 tables, and 5 photos

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Zusammenfassung: Menschliche Eingriffe in Flussläufe im Einzugsgebiet des Rheins

Auf Grund der zentralen Lage in Mitteleuropa werden die Flüsse im Einzugsgebiet des Rheins seit Jahrtausenden als Schifffahrtsweg genutzt. Örtliche Klippen, Untiefen und Sandbänke führten schon entsprechend früh zu menschlichen Eingriffen in die Gerinne; der Bau von Kanälen begann sogar schon im Jahre 12 vor Christus. Bei näherer Betrachtung lassen sich fünf Phasen intensivierter Flussbaumaßnahmen ausmachen. Die Spannweite der Maßnahmen im Rheineinzugsgebiet ist in einer Übersicht dargestellt und durch drei näher beleuchtete Beispiele illustriert: Am Beispiel des Binger Lochs wird die Entwicklung der Eingriffe mit der Zeit dargestellt, während die Oberrheinkorrekturen komplexe Aktivitäten veranschaulichen, die die Flussrinne und angrenzenden Auen gemeinsam betreffen. Am Beispiel des vermuteten Flussbaus zu römischen Zeiten vor knapp 2000 Jahren an der Lippe wird deutlich, dass derartige Aktivitäten auch in Mitteleuropa schon in der Antike begannen.

Summary: Due to the central location of the River Rhine catchment the channels have been used for navigation for millennia. Local cliffs and bars led simultaneously to measures for the improvement of the navigation and even construction of artificial channels as early as 12 BC. By a closer look, five periods of intensified modifications of the river channels and floodplains can be identified. The spectrum of engineering impacts is presented in a review and additionally illustrated by three examples from key locations: the so-called "Binger Loch" demonstrates the development of measures on one specific location over time, the rectification of the upper Rhine River exemplifies a more complex location where the channel and floodplains were shaped in combination while postulated measures nearly 2,000 years ago at the River Lippe catchment indicate engineering activities on river channels already in Antique times.

1 Introduction

It is not surprising that the entire catchment of the River Rhine was influenced by engineering projects modifying the river channel and related floodplains over a long time, based on human demand to make use of it. The efforts can be grouped according to their main objectives. Flood protection and drainage of the floodplain represent activities for the protection against the water, while improvements of navigation or built hydro-electric power stations make use of the river water. Following the industrialisation and the accelerated population growth, questions of water supply and sewage disposal became more and more relevant from the mid-19th century (Henneking 1994; Dix 1997; Cioc 2003). Nowadays, rehabilitation of previous channel and floodplain modifications can be added as subject, because several projects resulted in unexpected disadvantages like increased peak discharges of floods after melioration of the floodplains. Still most projects have anthropocentric goals, and hence focus on re-cultivation. The rehabilitation of river channels and valley bottoms are only locally considered as their own value. And even at those projects the request to keep control over the river dynamics is left (Kalweit 1993a, 200).

Based on a profound review by Kalweit (1993b), the main goals of engineering impacts can be regionalized for a general overview, even if activities changed over time and were added to by local projects. The alpine River Rhine endangered settlements and cultivated valleys by floods: the energy of the flood flow destroyed the infrastructure and deposited sediments covered previously fertile fields and gardens. Hence, flood protection became the main target for the uppermost parts of the River Rhine catchment. The broad floodplains of the Upper Rhine downstream of Lake Constance between the Vosges Mountains and the Black Forest were repeatedly inundated for long periods after floods. To cultivate this extended area and to oppose epidemics of typhus and malaria drainage was the main objective. The narrow valleys of the Middle Rhine and most of its tributaries have always been an important traffic route (Böcking 1979), which needs repeated improvement mainly to provide capacity for the increasing size of ships and intensified traffic. North of the Rheinische Schiefergebirge, where the River Rhine reaches the lowland areas of northwestern Central Europe, flood protection was the most important task, especially in the extended delta areas in the Netherlands.

A more detailed summary can be given by a focus on the chronology of the increased engineering impact on the river. Already in Roman times, more than 2,000 years ago, measures to improve navigation on the River Rhine and its tributaries were carried out (ECKOLDT 1980; HÖCKMANN 2000). The most famous example is the "Fossa Drusiana" (Canal of Drusus), an artificial channel which was built at 12 BC before the Roman campaign against the tribes of the Frisian and Chaukian to connect the Lower Rhine with the River Ijssel (SMITH 1977/1978). Another early and spectacular project was the attempt to link the catchment area of the River Rhine with the River Danube at the end of the 8th century with the so-called "Karlsgraben" or "Fossa Carolina" (KELLER 1993; TRÖGL 1995). Protection against floods by dams was already achieved in some locations and intensified in medieval times, while the period in between is not well documented. The first meander cuttings were carried out in medieval times (KUNZ 1975; STRASSER 1992). Sediment fluxes in the tributaries were blocked by an increasing numbers of watermills. Also the groundwater level was changed by these mills, which showed a dense spatial distribution (e.g. SOMMER 1991; KREINER 1996). Erosional sediment delivery was influenced by extended forest clearings within the catchments on the one hand side and riverbank protection and towpaths along the river channels on the other. Due to split territories in these times, in most areas projects were only of local character and usually not substantial partly because of destructions during different wars. One exception is the delta area in the Netherlands, where a first system of dykes was established as early as the 14th century (GOTTSCHALK 1975). In modern times, especially after the consolidation of many territories in Germany, the number of projects increased drastically and became more efficient throughout the entire catchment of the River Rhine and its tributaries. A famous and later copied example of durable influence on sediment transport was the diversion of the Kanderbach into the Lake of Thun upstream of Berne in the alpine River Aare catchment, started in 1713 (GERHARD 1993; VISCHER a. FRANKENHAUSER 1990; VISCHER 2003). To reduce flood peak discharge and stop sediment delivery into the River Aare the creek was diverted into the lake basin. Due to backward erosion along the steep diversion, the artificial channel incised up to 25 m and the transported sediments of about 120,000–150,000 m^3/a created a delta in the deep lake of about 0.5 km^2 within two years. Afterwards, floods from the Kanderbach catchment caused repeated lake level rises of the Lake of Thun and inundated the city of Thun for several days. This unexpected result let to the demand for more systematic activities like e.g. the enlargement of the channel of the River Aare along its course through the city, which found their final stage in the middle of the 20th century by the extended modification of all rivers in the area, the so-called "Juragewässerkorrektion". The extending of the anastomosing channels of the upper Rhine valley by *Tulla*, also belongs to the period of systematic stabilisation of the valley bottoms (MUSALL 1969). Downstream, in the meandering area of the Upper Rhine valley, meander cuttings in combination with raised dikes were carried out for protection against floods. On the other hand, these measures caused significant incision of the river channel already in the mid-19th century, which was related with problems for navigation especially during periods of low water levels.

In the Alps, the Lac de Pérolle was the first reservoir built in 1872 while by today the volume of all reservoirs upstream of Basel has reached 1.8 x 10^9 m^3. These reservoirs were built for hydroelectric power stations and flood protection. But they also limit sediment delivery from the high energy alpine environment to the Rhine valley upstream of Lake Constance as a side effect. Downstream of this important sediment trap, the further improvement of navigation and the intensified use of hydropower became a focus in the 20th century. After World War I artificial channels with ten weirs parallel to the Upper Rhine were built and several hydroelectric power stations with sluices were installed. As the weirs interrupt sediment transport, erosion occurs downstream of the dams, e.g. at the weir at Gerstheim the river incised up to 2.5 m within 15 months and eroded about 370,000 m^3 of sediment (BUCK 1993). To avoid further lowering of the groundwater level in the adjacent areas of agricultural use about 300,000 t/a of gravel are supplied artificially below the lowest weir at Iffezheim into the river channel (GÖLZ 2002). This bed load supply of an equivalent of about 180,000 m^3/a stabilized the riverbed successfully.

One of the largest engineering projects in the River Rhine catchment is the so-called "Delta-Plan", which was set up after the catastrophic flood of 1953. In the estuaries of the Rhine delta barriers stretch along the coastline to protect the lowland areas from catastrophic flooding from the North Sea (KALWEIT 1993 b). Most of the barriers are permanently closed, which causes a shift of the fresh water level towards the coastline. Also the natural channel displacements within the delta are blocked by these measures to assure safe and stable conditions for navigation. The measures of the Delta-Plan are the temporary finale to protect the Netherlands, where most parts of the country would be inundated during floods without artificial dams. The main period of activity was during the end of the 19th century when the river channel was directed in the way left over until today (Jasmund 1901; Sympher 1921–1925; Nessler 2001).

All main tributaries and even larger streams in the entire Rhine catchment were modified more or less continuously, e.g. the Erft mainly related to lignite mining, the Ruhr for navigation and water supply or the Emscher for wastewater removal (Photo 1).

The amount of studies on engineering impact on river channels and floodplains within the Rhine catchment are numerous, many of which are considered in the review previously presented by Kalweit (1993b). In this retrospect only a brief overview is possible. The selected case studies presented in more details in the following subchapters are chosen because of their individual importance to local problems and representative character for measures carried out in a comparable way throughout the Rhine catchment.

The famous historic measures by Tulla on the rectification of channels in the upper Rhine valley during the 19th century are described in detail below. The main aim was to transfer the anabranching channel pattern into a single meandering channel for increasing land for cultivation and to narrow down the extension of inundated areas during floods. Beyond the regional importance, his activities are of special interest, because of the methods chosen in former times. Instead of intensive displacement of sediments within the floodplain, the work of forming a new larger channel was done by the river itself. The discharge was concentrated in selected channels by the closure of other channels, leading to an increased shear stress until the chosen channel reached its new larger dimensions. This measure is one of the first systematic activities of engineers on a regional instead of a local scale.

The concept of modification of channel pattern from anastomosing to meandering for floodplain cultivation is transferred below by a scenario about river engineering on the Lippe channel for improvement of navigation. The background to this question is the problem of sufficient supply for the Roman military

Photo 1: River Emscher in Herne (Photo J. Herget). Due to land subsidence caused by coal mining no wastewater removal network by underground pipelines could be established in historic times. In the beginning of the 20th century it was decided to modify the entire River Emscher catchment to an open wastewater removal system. Hence, the channel was straightened and dykes were built at the shorelines to protect the densely settled area of subsidence from floods.

Die Emscher bei Herne. Durch die vom Steinkohlenbergbau ausgelösten Bergsenkungen war es lange Zeit nicht möglich, ein unterirdisches Abwasserleitungsnetz aufzubauen. Während des rapiden Wachstums des industriellen Ballungsraum Ruhrgebiet wurde zu Beginn des 20. Jahrhunderts beschlossen, das gesamte Emschersystem als offenen Abwasserkanal auszubauen. Dementsprechend wurde der Flusslauf begradigt und eingedeicht, um die abgesunkenen Gebiete im Umland vor (Abwasser-)Hochwasserwellen zu schützen.

during their campaigns against the German tribes, resulting in a serious need for a reliable connection between the camps in an area without any developed infrastructure. Even if a short period of time of intensified cultivation is indicated by pollen data, the authors could reveal that additional supply was needed from Roman sources. As conditions within the meandering River Lippe channel in modern times were not sufficient for reliable navigation most of the time, the problem must have been even bigger during Roman times, when the channel pattern was anastomosing. Even though there is no consigned description or archaeological evidence of channel modifications by the Roman military, their impact on channel conditions appear plausible. The described case study is not only of regional interest for the Lippe as tributary of the Lower Rhine, but indicates that prehistoric or undocumented engineering impacts should be taken in consideration for the reconstruction of engineering impact in the Rhine catchment.

Dealing with serious navigation problems throughout time is illustrated by the example of the cliffs of the "Binger Loch". Increasing efforts, triggered by the need for larger ships for navigation on the river, led to the final solution: the submerged rocks were destroyed completely and the "Binger Loch" no longer exists.

2 *The rectification of the Rhine by Johann Gottfried Tulla (1770–1828)*

2.1 *Socio-cultural background*

During and immediately after the Napoleonic period important political and cultural changes had a formative influence on landscape development in the German part of the upper Rhine valley (BERNHARDT 2000). By 1815, the strictly divided territories of several dukes were being unified by 1815 – under the "Duke of Baden" with the capital at Karlsruhe. Connections to

Fig. 1: The anabranching river system – Upper Rhine valley near Grissheim in the situation of the beginning of 19th century (HONSELL 1885)

Das verzweigt Flusssystem im Oberrheintal bei Grissheim zu Beginn des 19. Jahrhunderts (HONSELL 1885) the territories under French control were intensified as indicated, for example, by the construction of a channel to connect the rivers Rhone and Rhine. Long-lasting conflicts over the "moving frontier" between France and the German dukes were pacified. The agricultural system with its medieval origins changed under the influence of the new ownership and technical inventions (SCHWABE 1992).

Since the beginning of the 18th century, the population of the Upper Rhine valley had increasingly been entailed in discussions on options to cultivate new land (LÖBERT 1997).

2.2 The condition of the Rhine at the beginning of the 19th century

The maps fit together in HONSELL's comprehensive atlas (HONSELL 1885) (Fig. 1) provide a detailed view of the situation of the River Rhine between Basel and Mannheim at the beginning of the 19th century. They show that the Rhine was an anabranching river with a width of between 1,200 and 3,000 m, and characterised by more than 2,000 altering forested and/or gravel islands – in total more than 2,000. Bankful discharge that inundated some of the islands usually occurred in early summer following snowmelt in the Alps. This impeded agricultural production in the Upper Rhine valley, whereas other rivers with a pluvial regime could be used agriculturally in accordance with the rivers' natural dynamics (Fig. 2).

Continuous cultivation was restricted to the areas far removed from the main channel or was only periodically possible, e.g. in the case of grazing cattle or horses (BOGENRIEDER a. FRISCH 2000) on some islands. An insight into local land use in relation to a particular site is provided by the nomenclature of field-names (Tab. 1).

Since late medieval times, levees, short embankments and artificial consolidations of the riverside (see Fig. 1 of HONSELL 1885) provided the most common protections from floods. However, the effects of these protection measures were very localised and did not provide possibilities for large-scale land utilisation (Fig. 3). Figure 4 gives an example for the distribution of field-names near Sasbach in the Kaiserstuhl region (southern part of the Upper Rhine valley). Table 2 illustrates the situation of the gravel islands in the southern part of the Upper Rhine valley.

2.3 Aims and preparations for the rectification

Several innovations directly encouraged the idea of the rectification (BERNHARDT 2000):

– On the French side of the river a triangulation of the area was initiated under by the engineer *F. Noblat. J. G. Tulla* began to do the same for the German part in 1807.

– *Karl Friedrich*, the Duke of Baden, established a new administration for road- and river construction. In 1797, he appointed *J. G. Tulla* as a main engineer of this administration.

– Administrative reforms on the French side concentrated the knowledge and responsibility of river construction under a "Magistrat du Rhin".

– In 1807, *Tulla* founded an engineering school in Karlsruhe, aiming to teach advanced knowledge of river construction work against floods.

Tulla formulated his main concepts about flood protection and reclamation of cultivable land in the Upper Rhine valley in several papers (*Tulla* 1812, 1822 and 1825, mentioned or referred to in BERNHARDT 2000) (Fig. 5). Generally, they can be summarized as follows:

– the concept of a "main channel" for the chaotic river system especially in the southern part;

– the plan to shorten the channel to promote basal erosion and subsequent self-stabilisation of the river;

– the idea of constructing levees or embankments to divide the floodplain into a forested area (between embankment and the main channel) and an agricultural area (outside the area of the embankment).

Against the background of these ideas, the concept of "Rectification" becomes more understandable: The new channel was to shorten the length of the river between Basel and Mannheim by about 70 kilometres (> 30% of its total length). Instead of meanders and river branches a straight line with well-defined angles should was the model of river construction.

Tulla planned to start the "Rectification of the River Rhine" with a first construction near Karlsruhe in 1812. However, there was a serious resistance to his proposal from the local population and his plans were temporarily prevented. Only after a devastating flood in 1817 and with the help of a new tax system and military force was it possible to start construction work in 1817 (LÖBERT 1997), resulting in systematically designed and constructed dams (Fig. 6).

2.4 Chronology of the rectification

Table 3 describes the chronology of main actions of the rectification procedure. The basis for this overview are the papers by BERNHARDT (1998, 2000), although it should be pointed out that BERNHARDT considered that "the exact procedure and chronology of work done on the construction sites has not been investigated yet" (BERNHARDT 2000, 78).

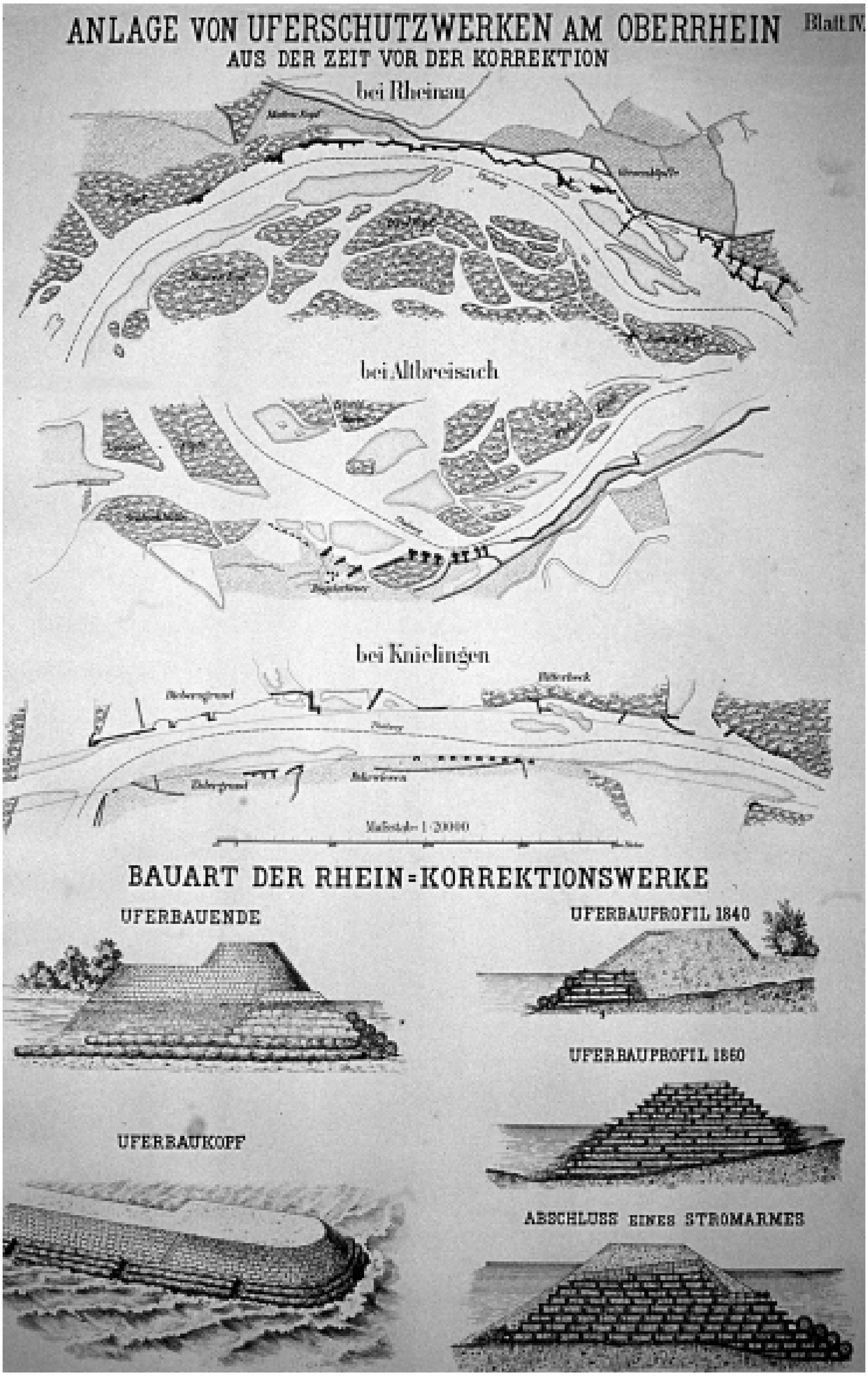

Fig. 2: River construction methods before TULLA (SCHWABE 1992, out of HONSELL 1885)
Flussbaumethoden vor TULLA (SCHWABE 1992, nach HONSELL 1885)

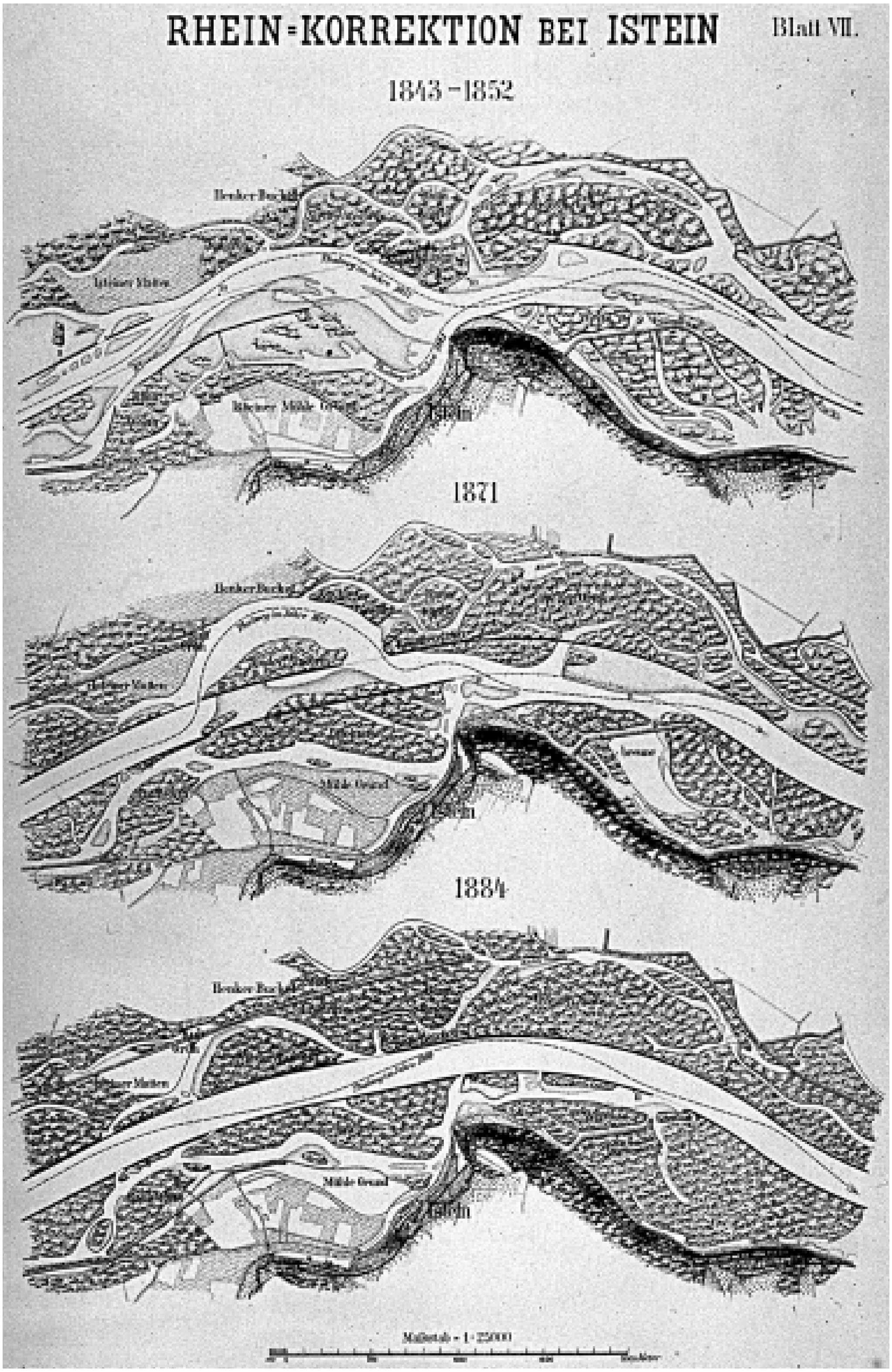

Fig. 3: River constructions near Istein between the measures by TULLA and HONSELL (HONSELL 1885)
Flussbaumaßnahmen bei Istein zwischen den Maßnahmen durch TULLA und HONSELL (HONSELL 1885)

Table 1: Nomenclature of field-names in the alluvium of Upper Rhine valley (Schülin a. Schäfer 1977)
Flurnamen und ihre Charakteristika im Oberrheintal (Schülin u. Schäfer 1977)

Field-name (in German)	Meaning
„chöpfeli", „kopf"	Dry island, only less covered with vegetation, gravel island
„grund"	Wet islands or depressions
„aue"	Island with the possibility of grazing
„jöhne"	Hay meadow with only one late cut per year
„werder"	Island covered with coppice or high forest – marking a productive site
„griene", „grün"	Island without possibility of timber production because of an unproductive site
„brenni", „brenne", „heißbrenne"	Extremely dry gravel island
„hoth", „hod"	Old branch of the river

Table 2: Total area and medium size of gravel islands in the southern part of Upper Rhine valley (Coch 2000)
Fläche und mittlere Korngröße der Sedimente im südlichen Teil des Oberrheintals

Region	Total area of the alluvium (km2)	Total area of the gravel islands (km2)	Percentage (%) gravel island / total area of the alluvium	Medium size of the gravel islands (ha)
Istein (partly)	4.3	0.30	7	3.4
Klein-Kems	3.0	0.34	11	2.8
Rheinweiler	2.8	0.28	10	3.5
Bellingen	3.6	0.52	14	2.3
Steinenstadt	9.9	1.09	11	2.0
Neuenburg	6.3	0.66	10	2.8
Zienken	4.0	0.23	6	2.2
Grißheim	10.4	0.58	6	0.7
Heitersheimer Bann	5.8	0.31	5	0.9
Hartheim	21.8	2.26	10	16
Breisach (partly)	4.6	0.45	10	
Total	76.5	7.02	9	

2.5 *Successors of Tulla and overview of further periods of construction on the River Rhine*

The main successor of *Tulla* was M. Honsell (1843–1910). Being a river construction engineer himself, he was one of the founders of the first central agency for meteorology and hydrology ("Badisches Zentralbureau für Meteorologie und Hydrographie") in Germany that was established in 1883. Between 1860 and 1867 he worked on construction sites of the river correction near Mannheim. His main actions relating to the correction of the Rhine focussed on a stage called "the complete navigability of the Upper Rhine". Regulation of the minimum discharge (low-flow) by forming the main channel with a new type of embankments called "Buhnen", solved the long-lasting problem of navigability. This period started in 1907 and was concluded in about 1920 with the perennial navigability of the entire River Rhine up to Basel.

The construction of the "Grand Canal d' Alsace" as a result of transposition of the complete exploitation rights to France in 1919 (Treaty of Versailles), induced a new period of river construction. Use of the river for electricity production necessitated the canalisation of the main channel. This was achieved by means of a completely new construction of a channel beside the old *Tulla* channel. Because of these changes in the southern part of the Upper Rhine valley, ecological

Fig. 4: Detail of a regional map from Sasbach (Kaiserstuhl, early 19th century (Repro: COCH)

Ausschnitt einer Regionalkarte des Bereichs um Sasbach (Kaiserstuhl) aus dem frühen 19. Jahrhundert (Repro: COCH)

problems of the correction were exacerbated with enormous effects on sinking ground water level (RAABE 1968; COCH a. EWALD 1992a).

For the same purpose only short artificial channels or dams in the main channel were constructed in the middle and northern part of the Upper Rhine valley. Therefore, in this case, a rise in ground water level often turned relicts of floodplain forests into "drowned areas" (COCH a. EWALD 1992b). A first detailed description of the new ecological situation was given several years later by LAUTERBORN (1938).

3 *The "Binger Loch" – an engineering challenge*

During Tertiary and Quaternary times the uplift of the Rheinisches Schiefergebirge forced the Rhine to

Table 3: Chronology of main actions during the "Rectification of the Upper Rhine"
Chronologie der wesentliche Teilschritte zur Begradigung des Oberrheins

	Action	Results/Problems
1817	First construction sites north and south of Karlsruhe: Shortening of meanders	Resistance movements of the landowners because of loosing area or ownership
1824	A new flood illustrates the efforts of the planning	Some resistance movements change to being supporters
1825	Convention between Baden and Bavaria on continuation of the correction	New conflicts over the 16 planned shortenings of meandes, the planning must be reduced because of the interest of capitals such as Speyer and Mannheim
1826/27	Serious interventions of the northern capitals and countries (e.g. Cologne, The Netherlands)	Temporary stop of the correction (in 1827), further discussion on the effects of floods on lower reaches
1828	Tulla's death	No serious interruption of the discussion about the correction
1832	New compromise over the correction between all riparian parties	Legal justification of the reduced planning
1840	Legislation between France and Baden about the new frontier-line in the correction procedure	First construction sites in the southern part of Upper Rhine valley
1841	First legal rules about the protection of salmon in the correction area	Founding of fish-farming to support the natural population of salmon
1856	Decree about the ownership of the new constructed riverside	The state of Baden owned a strip of 100 meter width on each new constructed riverside
1876	Final construction site near Istein (10 km north of Basel)	The correction of River Rhine ended after almost 60 years of construction.

incise itself, which created the broadest main terrace of Mid-Pleistocene age at an altitude of more than 100 m above the recent water level in the Rhine valley between Bingen at the entrance and Bonn at the exit of the river's pathway through the Rheinische Schiefergebirge (Bibus 1980; Meyer a. Stets 1996; Fuchs 1983). Sections of relatively more resistant rock, like quartz and limestone, formed barriers in the river channel and to some extent handicapped navigation on the river.

The rapids of the middle part of the Rhine valley have become famous in the lyrics of Heine in his poem about the Loreley, a 132 m high rock of shale rising vertically from the river channel near the village of St. Goar. Due to the dramatically narrowed cross-section of the channel – 112 m in a bedrock section at the Loreley, and about 580 m upstream of Mainz and 520 m downstream of Cologne, where the river flows through Quaternary gravels – and resistant bedrock layers at the river benches, the Loreley became a famous barrier for navigation on the river, even though the flow velocity remains similar as the river incised a channel of up to 27 m depth (Brinkmann 1970) and maintains a similar cross-section. Another famous barrier is formed by a quartz hogback stretching through the entire bedrock channel of the Rhine near the small town of Bingen at river-km 530.7 (Fig. 7). Before man-made improvements, this branch of the river was impassable for boats and even afterwards was a dangerous and difficult stretch to navigate (Photo 2). In this local reach the slope increases up to ten times the average value between Bingen and St. Goar (slope over different distances in 1960: along 17 m – 1:120, along 40 m – 1:240, along 110 m – 1:328). Other difficulties for navigation around Bingen included bedrock outcrops in the river channel near the villages of Kaub, Rüdesheim and Aßmannshausen, and the moving bars at the confluence of the Rhine and Nahe made the importance of channel improvements for navigation obvious, especially in the area around Bingen. A focus was laid on the widening of the very shallow passage (only about 4 m in medieval and probably in Roman times) through the quartz layer, mentioned above near the northern bank of the river, the so-called "Binger Loch". Today ships with a length of 186 m and capacities of up to 10,000 t can pass this area in both directions at the

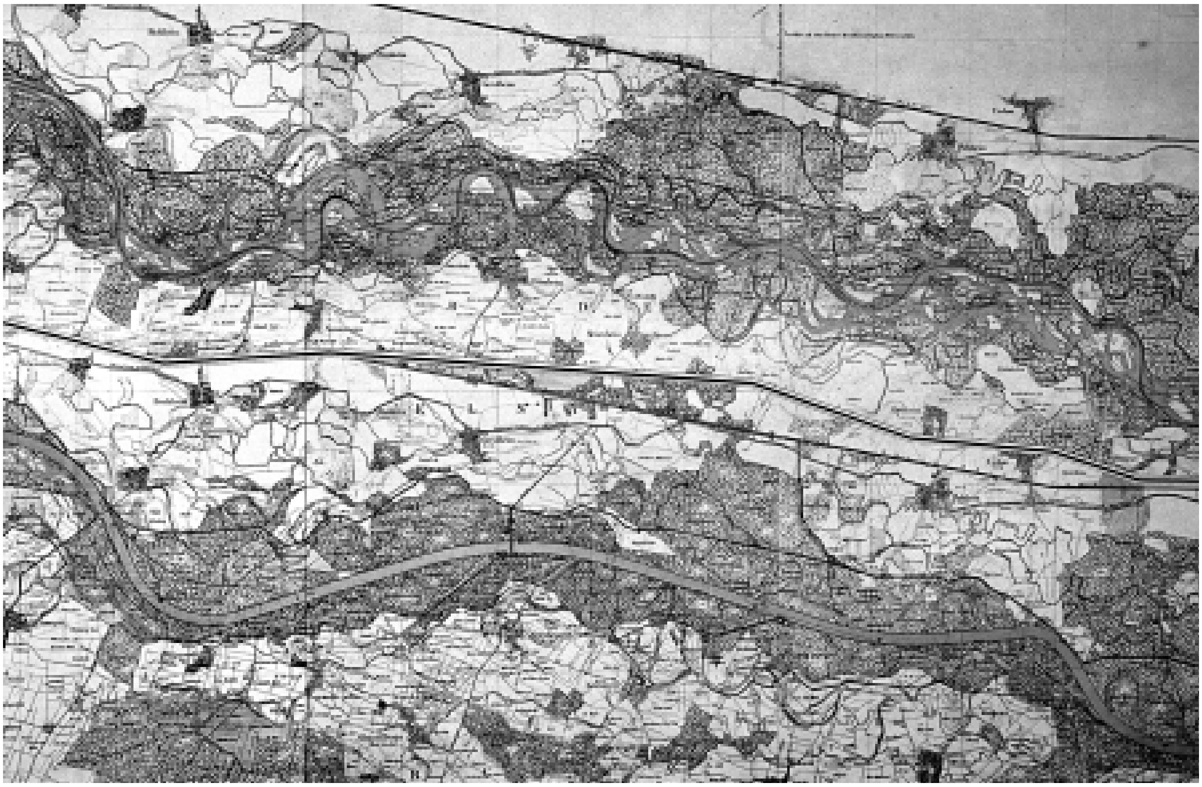

Fig. 5: The situation before and after TULLA's correction near Hartheim (southern part of Upper Rhine valley). HONSELL 1885
Die Situation vor und nach der TULLAschen Korrektur bei Hartheim (südliches Oberrheintal) – HONSELL 1885

same time. This is the result of long and hard efforts on the channel at this branch of the Rhine, which are the subject of this paper.

3.1 From antique to modern times

The problem of non-stop navigation along the Rhine started after the conquest of Gaul by C. J. Caesar, the Roman governor during that time. The Rhine connected the new provinces in the northwest of the empire and was the border against the hostile Germanic tribes after the abandonment of the Limes around AD 259/260 until the collapse of the empire during the 5th century. During medieval times there was also serious interest in an easy and accessible connection in the central part of the river's course. So, human efforts on channel improvement especially at the "Binger Loch" can be assumed, even though no supporting evidence has emerged from historical sources (FELKEL 1961). But even if there existed attempts to create a reasonable passage the results could only have been marginally effective, because of the limited technical abilities of the time.

Travel by boat along this route had to be adapted to the geological conditions, affecting both the construction and size of ships, and the methods of overcoming the rapids. Until modern times the regular passage of the "Binger Loch" was limited to small boats. An impression of the river traffic during the 19th century is provided by evidence from historic sources that most of the ~2,500 boats travelling along the Rhine in 1819 had a tonnage of less than 15 t (FELKEL 1961).

Before the introduction of steam navigation in the 19th century boats had to be towed upstream by man- or horsepower. Because of the high velocity of the current up to 40 horses were needed to pull a single boat. The draught of the typically flat-bottomed boats is not expected to exceed 1 m. For larger ships, which were in use since Roman times, non-stop passage of the rapids would have been very difficult until the 17th century. Their freight had to be transported by land along the rocky branch of the river and reloaded on another ship

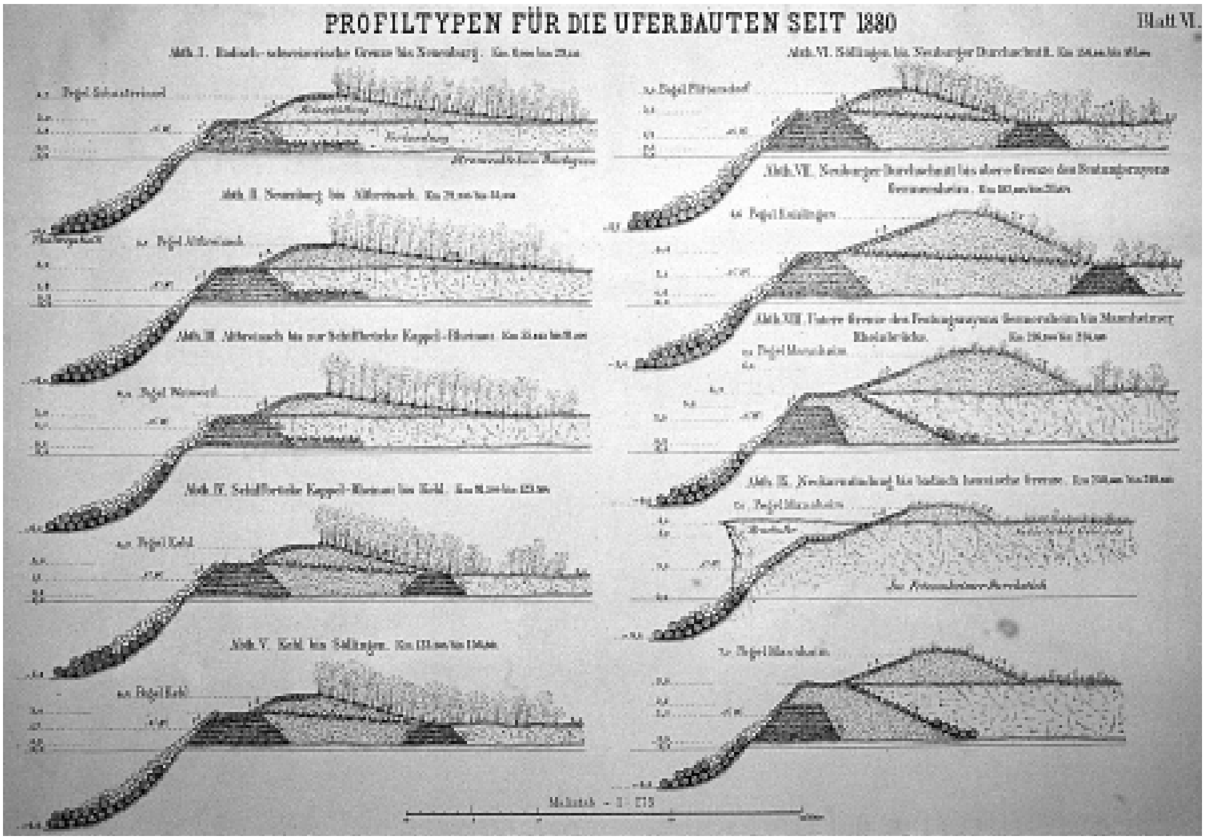

Fig. 6: Different types of dam-construction (HONSELL 1885)
Unterschiedliche Dammtypen (HONSELL 1885)

at the opposite side of the "Binger Loch". For the existence of large ships already during Roman Caesarean times the archaeological evidence of ships with tonnages up to 50–70 t and a maximum width of 5.20 m is documented by BOCKIUS (2000). BOCKIUS assumes that granite pillars from the Odenwald Mountains were transported by ship to the city of Trier. The pillars weighed 30 t and must have either crossed the "Binger Loch" by boat or have had to pass it by land transportation.

The first evidence of blasting at the "Binger Loch" comes from a travel report published in 1828 (KLEIN 1828). It is summarised that most activities on the widening of the passage were carried out by French and Swedish troops using gunpowder after they had conquered the castle of Ehrenfels and became established in the area. At the end of the 18th century further efforts were made by rich traders and ship-owners from Frankfurt who hired Dutch engineers. These activities resulted in the more or less safe passage of ships and rafts of up to 6 m in width.

3.2 Enlargement activities during 19th century

After the Rhineland was taken over by Prussia at the beginning of the 19th century the expansion of the "Binger Loch" branch continued. After a survey of the narrowest section by the surveyor Umpfenbach from Koblenz, it was decided to enlarge the passage of the so-called "Lochstein" up to about 23 m by blasting. From a historical report, details about the most difficult activities between 1830–1832 are given (VAN DEN BERGH 1834), which from a modern perspective appear to have used the simplest means. To prepare the rocks below the water level a wooden triangular box with a width of 7.20 m was built, lowered into the water and fixed upstream besides the locations for the planned explosions (Fig. 8). In the slackwater area behind this box, a floating work station was fixed and 0.75 m deep holes were drilled by hand into the extremely resistant quartz using a manual auger. Metal tubes long enough to reach the water surface were then installed and filled with cartridges of gunpowder. The blasts were started by quick-matches. The largest parts of the resulting debris were excavated from the channel using locking pliers. On a memorial-board onshore, it is proudly stated that in a period of three years the passage through the rapids was enlarged up to 66 m, ten times the former width. This dimension is related to high water levels: during low water levels the width should have been only 23 m. During summer and autumn the depth of water was 1.60–1.90 m (FELKEL 1961).

Because of the increasing navigation and the difficulties of passing and overtaking traffic, the channel soon became too small again. In 1850 the kingdom of Prussia and the dukedom of Nassau arranged to continue the enlargement of the passage by building a second channel at the left shore at the "Binger Loch" (Fig. 9). The target width for the upstream traffic was 57 m and for ships navigating downstream it was 75 m, while in areas where ships were travelling along the channel in both directions the minimum target width was 113 m. In addition all abutting states agreed to enlarge the whole branch between Mannheim and Koblenz to a mean minimum depth of at least 2 m at all times of the year, including low water level periods at the "Binger Loch".

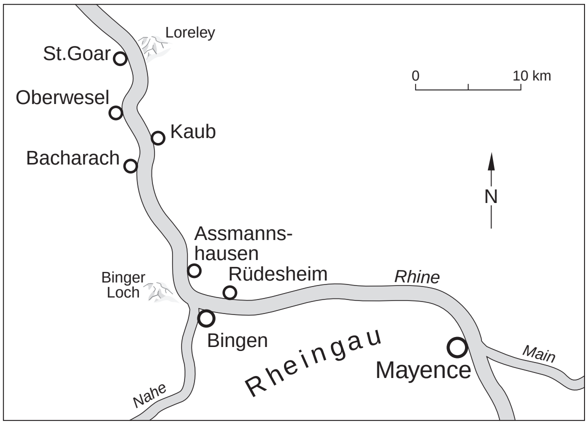

Fig. 7: Overview map of locations at the middle branch of the Rhine valley

Übersichtskarte zu Lokalitäten im Mittelrheintal

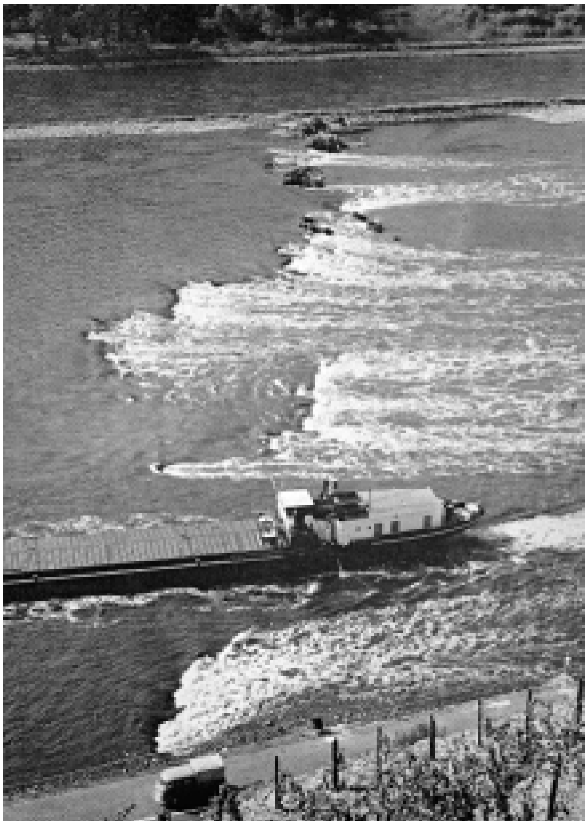

Photo 2: Ship passing the "Binger Loch" on its way upstream

Ein stromaufwärts fahrendes Schiff passiert die Klippen am „Binger Loch"

The influence of channel enlargement at the "Binger Loch" on water levels upstream in the Rheingau area was also considered at the time. In order to prevent it from sinking, the channel width between the confluence of the Rhine and Nahe was decreased by building breakwaters into the channel and their heads became connected by a nearly 1,500 m long dam built in 1864. The importance of this measure can be shown by regarding the influence of a further widening of the "Binger Loch" in 1893/1894 of up to 30 m with a cross-sectional area of 48 m^3; and the mean low water level immediately upstream of the barrier decreased by 0.25 m and by 0.1 m 2 km further up.

The work on the second channel at the "Binger Loch" began in 1860 with intensive exploration of the rock surface in the area. Until 1876, 85 locations of shallow hard rock surfaces were determined below the water level. The agreements of 1850 and 1861 caused unexpected amounts of work: between 1851 and 1879, 23,367 bores were drilled with an accumulated length of ca. 35 km. On the traffic channel alone 33,369 m^3 of rock were blasted.

Naturally, the challenges of the river channel measures stimulated development in a number of techniques and methods. The technological progress in the 19th century is summarised by FELKEL (1961). First, the classical drilling equipment was modernised by the use of weight drop augers, which drilled by the use of their own weight. Instead of the floating work station a platform was built between two small boats 4 m apart.

Serious difficulties were caused by the residual rock peaks after the blasts as they limited the passage of ships through the enlarged cross-section. By modifying the idea of a diving bell, a diving shaft was developed by installing a metal tube of 2.50 m diameter between two ships. The diving shaft was equipped with two air sluices, which were driven by a small steam engine. After blasting, the remnant rock peaks were removed manually by using this shaft. The method came into continuous use after 1873, after the first steam-driven auger in 1861 and before the first excavator in 1885. Dynamite replaced gunpowder in 1885, compressed-air drill and electrical detonators came into use in 1889.

In 1855 a medieval tower on the Mäuseturm island near the Nahe mouth was rebuilt into a signal station to observe and direct the traffic on the river.

The driver of the engineering activities in the middle branch of the Rhine was the demand for navigation. But the measures also influenced other interests in the area, like those of the wine-growers (KLEIN 1974). After 1850 the channel enlargement at the narrow section of the "Binger Loch" was accompanied by narrowing of the wide channel upstream in order to increase the water depth during low water levels. As early as 1867, a local protest emerged as decreased water surface was assumed to result in less fog forming during autumn and reduced light reflection was expected. Chancellor Bismarck himself stopped the measures and in 1880 a commission was founded to balance the conflicting interests. After a tough battle parts of the original plans were cancelled: some forks of the natural channel network were left open and construction, which influenced the alluviation of parts of the shallow channels, was avoided.

3.3 Plans of the early 20th century

Around the turn of the century the "Binger Loch" had a width of 30 m and a minimum depth of 2 m during mean low water levels (Fig. 9). The newly built second channel had a width of 94 m, but reached a depth of only 1.5 m. Therefore, this channel was mainly used by partly loaded ships travelling in a downstream direction. But the problem was not finally solved as a constantly rising amount of especially larger ships came in use. According to FELKEL (1961) the number of ships on the Rhine with a tonnage of more than 1,000 t was as high as 1,229 units in 1910. For those ships with a draught of up to 2.5 m the branch of the Rhine between St. Goar and Bingen was passable for only 156 days in the dry year of 1911.

It is not surprising that many new suggestions for channel improvement were developed at this time. Of these, the idea of building a hydroelectric power station at Bingerbrück (BUCHHOLZ 1926) would have had the most dramatic effect on the environment. More realis-

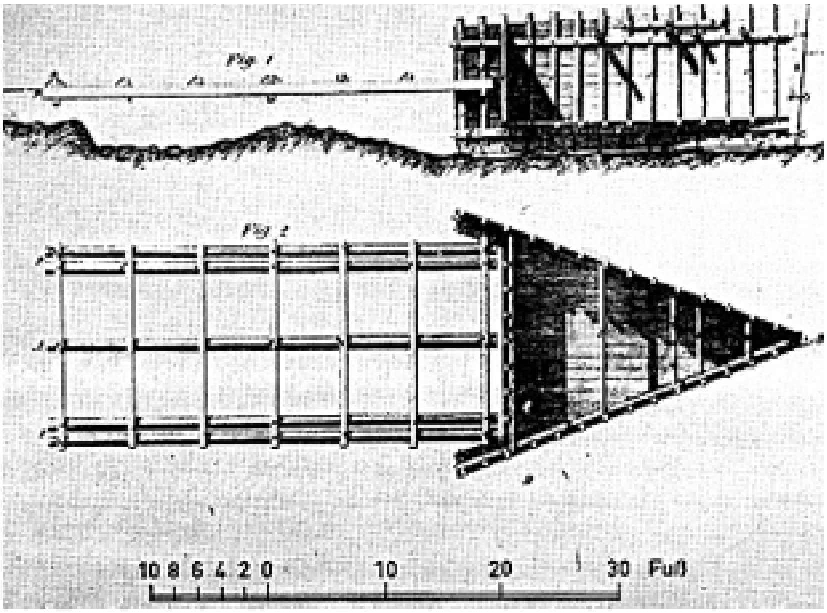

Fig. 8: Working installation of 1830 (Fuss = foot) (cross-section and plan view)
Arbeitsfloß von 1830 (Querschnitt und Aufsicht)

tic appears to have been an idea of the navigation administration in 1908 to build a third channel through the "Binger Loch" equipped with a sluice 26 m wide and 400 m long for large ships. In contrast to this idea a memorandum from 1914 suggested further channel enlargement up to a width of 110 m with a proportional extension of the depth. None of these ideas have been realised, partly as the expected consequences, especially for the hydraulic balance of the channel, were controversial, but mainly because of the beginning of World War I.

Between 1925 and 1931 modification on only the second channel was carried out. The discharge conditions in general were improved and the channel width was decreased from the over-dimensioned 94 m to 60 m. After 1931 until the beginning of World War II no extended modifications were carried out at the "Binger Loch" branch.

3.4 The "Binger Loch" – where has it gone?

After World War II, the need for further improvement for the navigation became all the more urgent. During the conference of the European transport ministers in 1953, the flattening of the Rhine bed between Mainz and St. Goar was included in the list of the 12 most important river engineering projects. An increased depth of 0.4 m was planned. Part of the reason for the urgency of this project was the fact that meanwhile most of the ships on the Rhine had a draught of up to 2.5 m when completely loaded. Their maximum tonnage could be used in most parts along the River Rhine valley throughout the year, except in the "Binger Loch" branch, where passage with full load was not possible during half of the year (PICHL 1961).

In addition, a higher density of traffic and the crossing of shipping channels at the "Binger Loch" increased the number of accidents. The crossing of pathways was introduced by faster passenger boats that used the second channel on upstream traffic, which was originally built for the downstream traffic The highest number of ships travelling daily through the "Binger Loch" was counted in October 1959 as 480 units. The interest of the neighbouring European countries becomes clear when considering that nearly 60% of the ships were not registered in Germany.

The plans for the best solution to increase the transport capacity of the "Binger Loch" updated older ideas from before World War II and included new technologies like surveying the channel bottom topography using echosounders from boats or the measurement of local flow velocities from a helicopter (PICHL 1961). Finally the favoured idea became that of blasting a second channel with a width of 30 m into the quartzite barrier. But before this plan could be realised it was again cancelled.

The reason for the cancellation was the development of a new kind of ship on the Rhine. New engines allowed the construction of powerful ships, which are able to thrust forward up to four lighters as pairs of two behind each other. The first tests with this new category of ships were inangurated by KLEIN (1974) to check if and how they could pass the critical locations of the "Binger Loch" and near the village of Kaub, further downstream. Intensive measurements showed that because of the extraordinarily narrow channel the second pair of lighters had a draught about 0.75 m higher than on wider branches of the river. For those ships an increased water depth of 0.4 m would not have made any difference – and their future intensive use was a certain prospect as they brought valuable economic advantages.

Tests in experimental flumes were carried out with a model of the "Binger Loch" branch (Photo 3) and resulted in a modified plan involving a single 120 m wide channel through the barrier. The existing second channel had to be abandoned and a low water level dam built to concentrate the discharge in the new, wider pathway. Work already begun on the older plan was stopped and the plans adapted to the new version. This was achieved relatively quickly because of the established use of computers in engineering sciences in the 1970s.

The technology to demolish rock was modernized, too. In locations where the blasting of rock was not desirable or could be avoided, the so-called "Euromeißel" was used, a weight drop auger that was installed on a crane, smashing the rock by its weight of 18 t. In other places modern diving shafts were used and the rock broken by pneumatic hammers from inside. The fastest method was still the use of dynamite. Special drilling boats were established, that fixed themselves on the location with four stilts and worked like a drilling platform. From these platforms several drills could be operated simultaneously. The crushed rock and local bars of sand and gravel were excavated using bucket-chain diggers.

On September 5th 1974 the work on the enlargement of the "Binger Loch" branch was complete – it no longer existed (Photo 4, Fig. 10).

The fairway now leads over the remains of the quartzite layer with a width of 120 m and a continuous depth of 1.90 m, related to the so-called "equivalent water level (EWL)". This level is a modern definition of low water level that is reached or felt below during a maximum of 20 ice-free days related to a named gauging station. The "Binger Loch" branch is related to the gauging station at the village of Kaub with a recent EWL of 0.85 m. In practise this means that the water level falls below a depth of 2.75 m to a maximum of 20 days a year. Dangerous traffic conditions were removed by the imposed rule of navigating on the right-hand side of the waterway.

The advantages for navigation were obvious, but the popular and romantic splash of water flowing over the rocks disappeared, too.

It soon emerged that there were several unexpected disadvantages related to the realised plan. The most important deficit was the decrease in water levels during low discharges at Bingen, especially near the roadstead. The necessary modification was the final measure in the branch until now: the aim was a minimum water level of 2.10 m below EWL (= a depth of 2.95 m) especially in the upstream part of the Binger roadstead to avoid ships getting stuck in the shallow channel. In opposition to previous measures, the water depths should be increased by a rise of water level during low or mean discharges instead of lowering the channel bottom, as this would have brought additional problems. This aim could be achieved by narrowing the cross-section. Therefore, a dam running parallel to the shoreline was built that reaches the water surface only during low stages of flow, which is clearly visible in photo 4. In addition the older dam that served a similar function in the second channel was removed and a flood channel was excavated next to the new dam.

Finally a general problem of water resources engineering should be mentioned that constantly plagued engineers at the "Binger Loch" branch. Following channel modification, the sediment load of the river of sand, gravels and pebbles was continuously deposited in front of the lowered quartzite barrier, forming local bars and dunes up to 1.5 m in height and up to 80 m in length, which influenced the river traffic (cf. Carling et al. 2000). In 1989 a sediment collector was built by digging the channel bottom upstream near Mainz 1.5 m deeper over an area of 40,000 m^3. The accumulating sediments in the collector are excavated once or twice a year as needed.

Downstream of Bingen the opposite problem occurs. Here the river shows evidence of permanent erosion of the channel bottom. The removal of local sediment accumulations resulted in small irregularities in the bedrock surface that became a problem to navigation. For that reason the river has been "fed" with heavy and bulky crushed pebbles since 1993. Over a period of five years about 250,000 m^3 of quartzite were supplied as a replacement for sediments into the River Rhine. Such

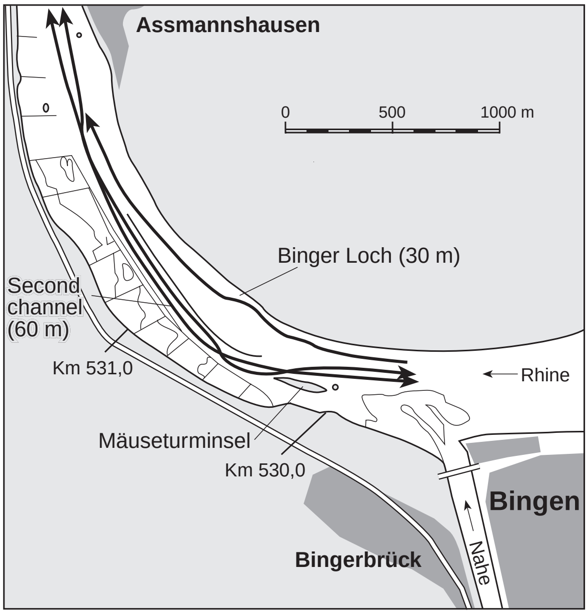

Fig. 9: Sketch map of the "Binger Loch" with two channels for navigation as it appeared from the 19th century until 1974

Karte des „Binger Lochs" mit zwei Schifffahrtskanälen wie es vom 19. Jahrhundert bis 1974 ausgebildet war

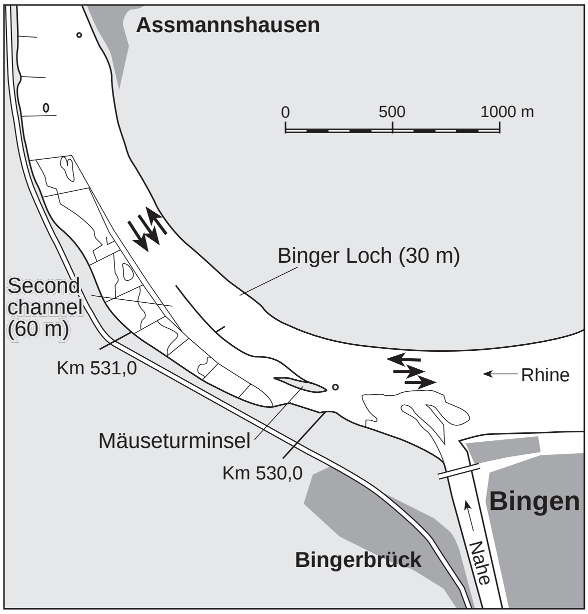

Fig. 10: Sketch map of the "Binger Loch" area after final enlargements of 1974

Karte des „Binger Lochs" nach der abschließenden Erweiterung von 1974

Photo 3: Model of the "Binger Loch" for tests of the hydraulic consequences of further measures

Modell des „Binger Lochs" zur Überprüfung der hydraulischen Konsequenzen von Ausbaumaßnahmen

compensational sediment supplies to stabilize the channel bottom are presently carried out in several locations to avoid a lowering of the groundwater level in the surrounding area and to minimize incision of the river and its tributaries. The importance of these activities becomes obvious in data from archaeological sources from the Lower Rhine that reveal an incision of the order of 6–8 m of the river that occurred some time during the last 2,000 years (Bremer 2001).

This short review of lasting efforts over several centuries to solve navigation problems at the "needle's eye" of the River Rhine has shown that the potential for successful engineering solutions is limited by narrow environmental and social constraints, despite constant progress in methods that developed from hand-driven augers to computer technology. A key factor in developing a practical solution involved understanding the hydraulics of flowing water under constantly changing conditions along the river. Experienced engineers used results from experiments and simulations as an important addition to hydrologic calculations aimed at explaining the river dynamics and adapted additional measures after construction was realised. However, visual judgements and fine feeling must support technology. In addition to this – nowadays more than ever – a reconciliation between conflicting interests in our cultivated landscape is needed. All of these factors are influenced by constantly changing political and economic factors that limit the space available for acceptable decisions.

Photo 4: Air-photograph of the Rhine valley at Bingen during low water level in 1974 – the "Binger Loch" no longer exists

Luftbild des Rheintals bei Bingen während Niedrigwasser 1974 – das „Binger Loch" existiert nicht mehr

4 Anthropogenic changes to channel characteristics of the River Lippe during Roman occupation?

The case study of the tributary River Lippe is chosen because of its unique fluvial features and the obvious anthropogenic influence on their development, which seem to be one of the first known locations of anthropogenic channel modifications (cf. e.g. BROWN 1997; GREGORY 1995). These sections focus on the period of time around 0 AD. After an introductory description of the geomorphology of the present-day valley-bottom and the channel modifications in modern times, anthropogenic influences on the environmental conditions, especially land-use, and the history of the efforts of integrating the area into the Roman Empire are given. Finally, a suggestion for a plausible method of river engineering by the Roman military about 2,000 years ago is presented.

The Lippe catchment is located in northwestern Germany (Fig. 11). The river originates from a karstic spring at the town of Bad Lippspringe and flows westwards along the southern border of the Westphalian Bight to the Lower Rhine at Wesel. The lower part of the Lippe valley is situated north of the Ruhr District industrial zone with Essen and Dortmund, two of the larger cities in the region north of Cologne.

4.1 The modern valley bottom

Two Holocene terrace levels are known in the River Lippe catchment: the so-called “Inselterrasse” and the “Auenterrasse” or “Aue”. Both are interposed between the last glacial Lower Terrace and the river channel. The name Inselterrasse (engl.: Island-Terrace) is derived from the separation of the terrace level into isolated islands by abandoned river channels. This level exists only in the lower branch of the valley downstream of the city of Lünen, which is located at the former military camps at Beckinghausen and Oberaden. The Inselterrasse and Aue diverge in the area around Lünen, reach a maximum vertical difference of 3 m around Haltern, before they converge again in the lower valley. In detail, the Inselterrasse can be differentiated into a higher and a lower level with a maximum difference in height of 0.5 m. Due to the uneven surface topography this distinction is not clearly visible everywhere. The abandoned channels in between are ascribed to different terrace levels, but many channels have no clearly definable inlet. This situation results from the dynamics of sediments transported and deposited during floods, which reached the higher level of the Inselterrasse in historic times. Consequently, the Lippe deposits sands and silts on the floodplain, terrace

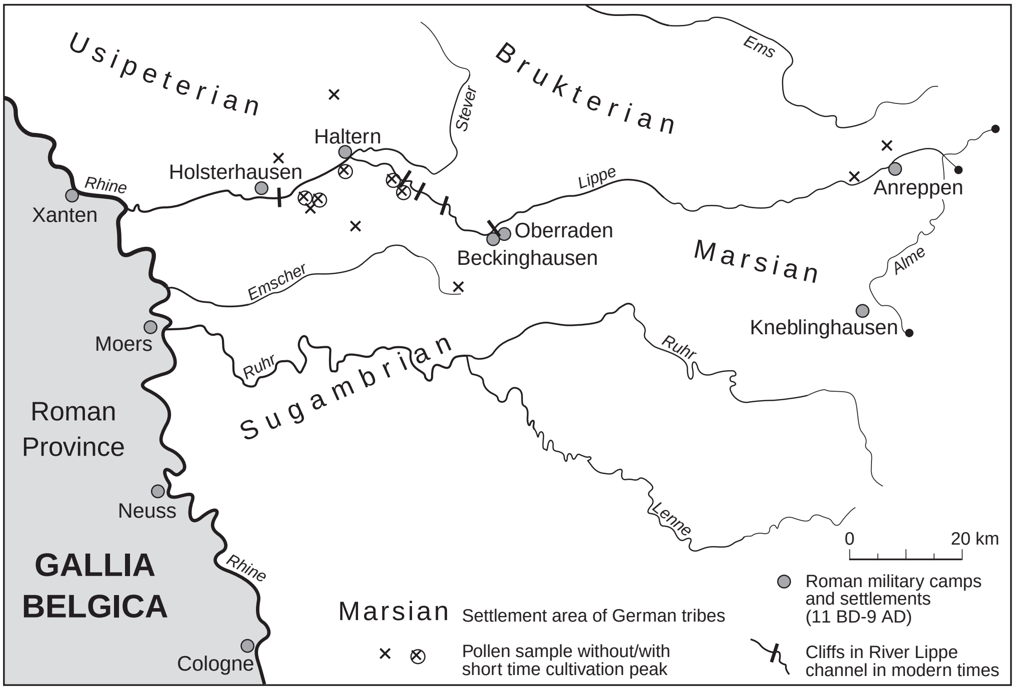

Fig. 11: Map of River Lippe valley in Roman times
Karte des Lippetals in römischer Zeit

surfaces and along the courses of the abandoned channels in the form of sheet deposits and natural levees. Radiocarbon-dates of channel fills and terrace sediments of the Inselterrasse and Aue are distributed throughout the Holocene, without a focused time of deposition (HERGET 1997).

The natural channel pattern of the River Lippe was anabranching. This was revealed by the determination of the discharge capacity of an abandoned channel, dated by radiocarbon at 2025–1675 BC – doubtless during a time prior to anthropogenic influences on the river morphology. The cross-section of the channel was determined from several bore-hole legs, and its bankfull discharge of 8.3 m^3/s was calculated using the Manning formula. The modern flood with a recurrence interval of two years has a bankfull discharge of 160 m^3/s, which is markedly different from the Roman channel capacity, even allowing for some uncertainties in the palaeodischarge calculation. As there are no significant known hydrological changes between the period around 4000 years BP and modern times (KLOSTERMANN 1992; STARKEL 1996), the limited discharge capacity of the abandoned channel would suggest the existence of multiple channels. Therefore, it can be assumed that the channel pattern did not possess a single, meandering channel like the present day River Lippe, but was anabranching, which was the natural channel pattern of many lowland rivers in Central Europe, such as the Rivers Elbe (SCHÖTTELMEYER 1983) and Weser (CASPERS 1993b) or in the Upper Rhine valley.

The Aue is the first and lowest level above the river channel. During recent flood events the Aue remained dry as the relatively higher level of the Inselterrasse was flooded. This indicates that the relative differences between levels do not necessarily indicate an altitudinal difference, because of the surface topography of the terraces. Upstream of the city of Lünen, where the Inselterrasse rises from the valley bottom, the Aue forms a single and broad level, but downstream it is typically developed as a narrow strip 2–3 m wide running along the river channel.

Since the 15th century, improvements on the river channel have been documented (e.g. RÖDER 1889; STROTKÖTTER 1895; ILGEN 1901; BREMER 2001). Several meanders were artificially cut to shorten the navigation route and mills were established with dams in the river channel. Co-ordinated activities were difficult to organise as, for a long time, the river marked the border between different territories. After the entire area became part of Prussia in 1815, efforts towards channel improvement achieved practical results. Meander cut-offs continued to be constructed and different methods were employed to prevent erosion of the riverbanks. The measures shortened the river course and forced the Lippe into a stable bed. They finally led to intensive incision, which allowed the levels of the Inselterrasse to rise above the mean water level and to form separate terrace levels within the floodplain. Due to the incision, which continues even today (VOLLMER 1993, 1995), hard-rock sections of Cretaceous sediments below the Quaternary fluvial sediments of the Lippe generated reefs in the river channel, e.g. at Dorsten-Hervest, Ahsen-Vogelsang and Datteln-Rauschenburg. They consist of single sections of medium quartz sand grains consolidated by calcite; their locations are shown in figure 11.

Even today, modifications on the River Lippe channel are carried out. Due to forecasted land subsidence following coal mining at depths around 600–1,200 m below the surface, long branches of the river are canalised or framed by dams respectively. On the other hand parts of the Lippe floodplain – which form one of the largest nature reserves in northwestern Germany – are the focus of restoration measures, e.g. upstream of Lippstadt (LOSKE et al. 1993; STELZIG a. VOLLMER 1995). In the branch upstream of Haltern comparable measures are planned (VOLLMER 1995). The aim is to stop the recent channel incision, which has occurred to a depth where only extreme floods reach the floodplain. The increase in flood return periods on the floodplain has had consequences for the ecology of rare flora and fauna species. A broader and shallower channel is planned, similar to the channel conditions after the first Roman modifications (cf. below), but not to the natural anabranching channel pattern that preceded it.

Further details about the valley bottom geomorphology, as well as a critical discussion of the above information and additional descriptions of the improvement measures, are documented elsewhere (BREMER 2000, 2001; HERGET 1997, 2000).

The Holocene morphology of the Lippe valley is unique in Central Europe. Insufficient information is available to allow detailed reconstruction of phases of fluvial activity and stability, but the recent appearance of the valley bottom does not fit generalisations given by e.g. SCHIRMER (1995) or STARKEL (1996). Regarding human settlement in the area around the Lippe valley and necessary improvements for river navigation, the fluvial features of the valley bottom can be explained as follows.

4.2 *Indicators of human settlement*

Mapping of archaeological evidence for the period from 200 BC to AD 16 reveals human land-use, especially in the areas near the region's larger rivers, such as the Lippe, Emscher and Ems, which were preferentially colonised before the Roman occupation. The upper branch of the Lippe and the upland area south of River Ruhr show no obvious indication of a dense settlement. Recent radiocarbon-dated palynological investigations and reviews from the archive of the Geological Survey of Nordrhine-Westphalia (EGGENSTEIN 2002; EGGENSTEIN et al. in print) update the knowledge of the environment during this time and revise previous studies in the area (POTT 1984). Three selected palynological data sets from the valley bottom of the Lippe near Haltern are reported and compared with other data from the area dated to belong to the transition of the pollen zones X/XI according to OVERBECK (1975). The locations are marked in figure 11.

One profile originates from a bog near Haus Ostendorf, located 3 km southwest of the former Roman military camp and settlement of Haltern (Fig. 11). A slight anthropogenic influence on the vegetation cover during the Subboreal period (3000–1000 BC) is indicated in the basic section by low contributions of cereal pollen and cultivation indicators like *Rumex, Artemisia* and *Plantago lanceolata*. This is followed by short peaks of cereal pollen and apophyts indicating increased cultivation and is dated for the time around BC/AD. A significant amount of *Ericacea, Calluna* and *Empetrum* can be interpreted as an index for heath development, possibly due to over-grazing, which is the characteristic process for anthropogenic heath exploitation (KÜSTER 1996). This is correlated with decreasing pollen concentration of *Ulmus, Carpinus* and *Fagus* with a parallel increasing proportion of *Quercus*, which is interpretated as signalling the use of the forests for grazing and a lower vegetation density. A lowering of the groundwater level is revealed by the decreasing concentration of *Alnus* pollen. After this short peak the level of cultivation indicators decreases again, but remains above prehistoric levels until further modifications occur in medieval times.

Pollen samples from an abandoned river channel within the Inselterrasse further upstream near the village of Ahsen show evidence of a comparable peak of cultivation indicators. Unfortunately, this cannot be dated as precisely, but seems to belong to the same period of time, around the late pre-Roman Iron Age and the first decades AD. Due to the wetter location there is a strong influence of aquatic and swamp plants characteristic of an alder forest. The anthropogenic influence is indicated by grass pollen dominating the cereal pollen, which seem to have been derived from more distant areas, while grazing was the dominant influence at the sampling location.

A similar, but more strongly developed pattern is documented from an abandoned river channel about 1 km further upstream. During the last century before Christ, the significant increase of cereals and apophyts as described for Haus Ostendorf occurs again and is also terminated during the first centuries AD.

Undated pollen profiles from the archive of the Geological Survey of Nordrhine-Westphalia contain further information about land-use during the period around BC/AD in the Lippe valley area. In general, they give a comparable picture of cereal pollen on a low and constant level throughout the profiles, indicating cultivation at a distance of about 50 km. Evidence for intensive cultivation is given only from two locations south-east of the former Roman military camp of Holsterhausen by short peaks of pollen indicating settlements nearby, maybe within 10 km.

From the extended bog area north of Haltern, BURRICHTER (1976) and POTT (1984) report pollen data with evidence of cultivation since early Neolithic times and indicators of agriculture since 2900 ± 170 BC. During Iron Age times the density of settlements decreased until Anno Domini up to the Older Caesarean Period (POTT 1984). This interpretation is contrary to the data from the Lippe valley, but is confirmed from other areas in northwestern Germany which were not subject to Roman influences (e.g. CASPERS 1993a; LÜNING et al. 1997; BORK et al. 1998). An alternative interpretation could be found in the character of the extended bog area, which is unfavourable for settlement and might contain a local history that cannot be transferred to other environmental conditions.

One clue to explain the peaks in pollen data indicating a short period of early landscape cultivation can be seen in the Roman Empire's efforts to conquer more distant parts of Germania around the time Before Christ and Anno Domini. The use of areas east of the Rhine for timber for constructions and shipbuilding was already established before the period of interest here (GECHTER 2001), but with the campaigns a new quality of landscape management occurred in the catchment of the Lippe.

4.3 Roman campaigns against German tribes

Overviews of the efforts of eastern expansion of the Roman empire into Germania are given by e.g. POLENZ (1985); REICHMANN (1979) and KÜHLBORN (1995). Starting from the military camps, mainly Xanten (Roman name "Castra Vetera"), in the Roman province "Gallia Belgica", the Roman conquerors obviously orientated themselves on the rivers during their campaign towards the east (KÜHLBORN 1980; HÖCKMANN 2000). Initially the camps at Oberaden and Beckinghausen were established (at 11 BC) but were destroyed by the

Roman themselves during a period of political troubles at 8–7 BC. The second period of the campaign started around 0–3 AD and included the construction of camps at Holsterhausen, Haltern, Anreppen, and the poorly investigated location at Kneblinghausen. Efforts at integrating further parts of Germania into the Roman Empire ended at AD 9 with the disastrous defeat during the Varus Battle against the allied German tribes (cf. e.g. BREPOHL 2001).

Little is known about the German tribes (cf. REICHMANN 1979; ERDRICH 2000). The areas inhabited by the four tribes of Usipeterian, Brukterian, Marsian and Sugambrian around the Lippe valley are shown in figure 11. Archaeological evidence is given for cultivation of the area around the camp of Oberaden before and after its use by the Roman military (EGGENSTEIN 2002). Trade between German tribes and the Romans is certified for the area around the Anreppen camp by Roman goods found outside the central camp area. Less certain is a permanent settlement of the tribes around the other camps; at least an obvious concentration of settlement near the Roman military facilities can be excluded. In summary, an economic exchange between German tribes of the area and the Roman military can be assumed.

This aspect is important because of the question of supply for the nearly 15,000 soldiers and their additional administration and craftsmen in the different camps along the River Lippe valley at the same time. From historic sources it is known that the Roman military outside the province of Gallia Belgica depended on supplies from the province, even on short campaigns (BREMER 2000, 2001). Due to the lack of roads in the conquered areas and especially the huge demand, mainly of wheat for the soldiers, transport on ships must have been the favourite supply route (KÜHLBORN 1980). BREMER (2001) calculated the annual need for cereals for two legions as at least 6,000 tons. Though little archaeological evidence for cereal threshing inside the camps is given, it is supposed that the great bulk of food had to be carried into the Lippe valley from Gaul or the cultivated province Gallia Belgica.

BREMER's (2000, 2001) investigations and interpretation of historic sources, and the archaeological evidence supports the pollen data mentioned above, with the short time peaks of cereal pollen and indicators of intensive cultivation in the area around the camps for a very short time period. Only between 11–8 BC and again from 3–9 AD did a serious need of cultivation for additional supplies for the military forces at the camps come up. Therefore, one can imagine that parts of the locally surrendered German tribes supplied the Roman military with local cereals, as there are doubts whether the Romans planted it themselves (EGGENSTEIN 2002; BREMER 2001). In addition to this cultivated land the space needed for the camps and timber for building the fortifications must be taken into account. For example, up to 25,000 oak logs were needed to build the facilities of the Oberaden camp (KÜHLBORN 1995), which explains the decreased density of vegetation cover near the camps known from the pollen data mentioned above and which are also documented from other areas (e.g. FRENZEL et al. 1994; NENNINGER 2001).

4.4 Roman navigation on the River Lippe

Even if archaeological evidence for cargo ship navigation on the River Lippe by the Roman military, e.g. sunken barges (cf. e.g. ECKOLDT 1980), is laching, several general indicators for navigation exist. MOREL (1987) investigated details of the excavations at the Roman camp at Haltern and found evidence of a slip for six Roman battleships. Another important indicator is the location of all camps – except the facilities at Kneblinghausen – which are close to the River Lippe. Therefore it is likely that the huge amount of supplies for the military forces, including food, weapons, equipment and wine barrels with filled weights of up to 1,300 kg were transported on the waterway (BREMER 2001).

Details of possible navigation on the Lippe by the Roman military are hypothetically reconstructed by BREMER (2001). According to the reconstruction of Roman ships along the Lower Rhine, the conditions of the natural Lippe probably allowed the use of barges that were about 20 m long and 3–4 m wide, and which had a flat bottom that allowed a draught of only 0.6–0.7 m at a tonnage of about 15 tons (Photo 5). It is possible that larger ships on the Rhine were used to travel upstream on the Lippe until Haltern, where the freight was transferred into smaller barges of the size mentioned above to supply the troops in Oberaden and Anreppen. The meandering channels of the anabranching river prevented sailing, so towing must have been established for travelling upstream. For this, a towpath was necessary along the river channel – not a little work for the Roman troops – which probably caused a significant change in the character of the river-plain.

4.5 Possible first efforts at modification of river channel conditions on the River Lippe

Navigation on the Lippe during Roman times and reliable ways of delivering supplies to the military forces upstream seem to have been a difficult task, given that even during the last two centuries navigation on the river has been handicapped by several circumstances.

First, cliffs line the river channel as marked in figure 11: those were passable for ships in historic times only after sluices were built and might be assumed to form serious difficulties for navigation, as documented from historic times (KOPPE 1986; BREMER 2001). Investigations by LAMPEN (1996) revealed that during the time of the Roman campaign the channel bottom of the Lower Lippe was 6–7 m higher than today. This was determined from the altitudes of the ship depot at Haltern, abandoned channels near the Roman camp at Holsterhausen and the harbour at Xanten, where the confluence of the rivers Lippe and Rhine seems to have been located about 2000 years ago (HOPPE 1970, who also discusses controversial aspects) (Fig. 12). The bedrock surface of the cliffs at Hervest did not reach the channel bottom of the river during the time of the Roman campaign. Therefore, no reefs existed there in this time. The authors' own investigations confirm this result for Haus Rauschenburg, one cliff location further upstream between the former camps of Haltern and Beckinghausen/Oberaden. In several drillings on the surface of the Inselterrasse at about 43 m a.s.l. cliff-forming hard-rock surfaces were found at 38.6–39.0 m a.s.l. As the mean depth of the river channel is around 2–2.5 m (LAMPEN 1996) the cliffs seem to have been covered by Quaternary sediments. The slight difference between the rock and terrace surface compared with downstream locations as shown in Fig. 3 can be explained by regarding the increasing altitude of the Inselterrasse above the river channel as the terrace level starts diverging from the Aue at Lünen and reaches a maximum difference further downstream.

Another problem arises from reports in 18th and 19th century documents describing that local bars in the channel handicapped navigation (KRAKHECKEN 1939; BREMER 2001). This report relates to the time following the transition of the Lippe channel from an anabranching to a meandering pattern, which occurred around 2,000 years ago. The bars effectively halted navigation for many days each year as the water was too shallow for boats to pass. This problem must have been more serious for Roman navigation as the smaller channels of the anabranching river were even shallower. As the transport of supplies to the forces upstream must have been steady, it can be assumed that the Roman military considered measures to improve channel conditions for navigation.

During low water periods water depths can be increased by concentrating discharge into a single channel. To reveal this, small dams could have been built at the upstream channel junctions. To achieve a single channel, the construction of a larger channel is unnecessary, as the increased discharge from blocked channels leads to incision in the remaining channel, resulting in a higher water level throughout the year. In order to tow ships upstream, a towpath must be constructed by deforesting a small strip next to the river channel. The result of these measures was a single, incised me-

Photo 5: Roman barge, excavated in Woerden, the Netherlands (BREMER 2001)

Römischer Lastkahn, ausgegraben in Woerden, Niederlande

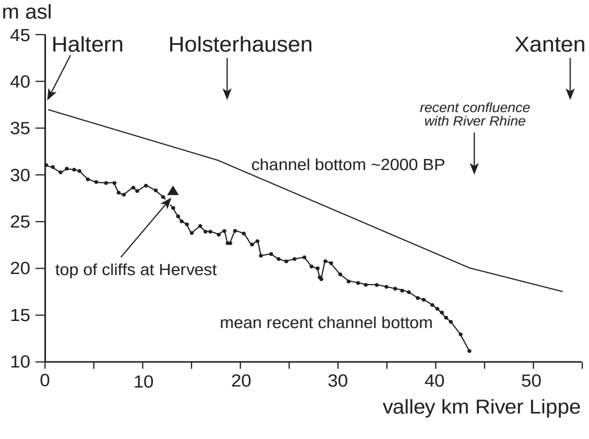

Fig. 12: Longitudinal profile along the River Lippe from Haltern to Xanten between 2000 BP and modern times (modified by LAMPEN 1996)

Längsprofil des Lippetals zwischen Haltern und Xanten zwischen 2000 v. Chr. und heute andering channel in the valley bottom, while the smaller anabranching channels were abandoned at higher altitudes on the floodplain.

The efforts involved in such an operation are comparatively simple compared with the construction of channels by the Roman forces in other areas, such as the "Fossa Drusiana" in enemy's territory at the Lower Rhine (Höckmann 2000) or the channel upstream of Mainz (Hanel 1995). It must be emphasised that there is no archaeological evidence or reports from Roman times for the scenario mentioned above. Due to the local and small-scale nature of the measures, such evidence is unlikely to be found. The main work for channel enlargement was done by the river itself – the same principle as used by *Tulla* for the modifications of the upper Rhine valley about 1,800 years later. As such, the above scenario appears plausible, even if few facts support it. Falter (1999), by describing the Roman attitude towards rivers, mentions that during antique times rivers were supposed to flow straight and fast instead of meandering through swampy plains. Channel modifications were seen as a service to the river, which had an individual spirit. This philosophical aspect also supports the scenario described here.

5 Perspectives on the LUCIFS context

Considering engineering impact within the River Rhine catchment, the main challenge for the LUCIFS project is the lack of quantitative knowledge of natural sediment dynamics. Man's impact on sediment transfer began already about 2,000 years ago, changing from local modifications to more systematic influence by the end of medieval times. Without going into details (cf. e.g. Kalweit 1993b) this is approximately the point of time when written descriptions on channel dynamics begin. Today's investigations are influenced by previous manmade manipulations of the sediment budget to an unknown degree. E.g. the petrographic tracer experiments by Gölz (2002) are carried out in a fluvial environment without any sediment transport from upstream below a weir. An uncertain over-estimation of sediment transport velocities cannot be excluded. These kinds of experiments could be a valuable contribution if the influence of natural sediment dynamics are considered quantitatively. Also man's influence on suspension and solute dynamics by engineering measures cannot be quantified to balance its modifications over time by investigations today.

Even if these problems are considered as negligible, the quantification of engineering impacts on sediment budgets is unknown, and at least difficult to transfer from case studies. Local conditions of experiments must be analysed to quantify the degree of influence on sediment dynamics of the different factors involved.

A main focus of research activities within the LUCIFS projects could be the quantification of sediment budgets over longer timescales (e.g. centuries). These data should be obtained from more or less natural environments in Central Europe and be scaled-up to larger catchments, maybe even to the entire Rhine catchment. Beyond data acquisition in the field in suitable test areas, modelling the transfer to larger scales is the main challenge. One might think about whether it would be useful to split the modelling of sediment dynamics based on more or less homogenous data with a comparable degree of engineering impact on the river channels and floodplain. A first suggestion is five periods:

1.) 8000 BP–500 BC:	no significant human impact
2.) 500 BC–500 AD:	local measures on channel conditions for navigation in a regional context, Roman canals
3.) 500–1500 AD:	local measures like meander cuttings on local scale
4.) 1500–1850 AD:	systematic channel modifications and flood protection measures
5.) 1850 AD until today:	engineering impacts in nearly all catchments, systematic rectification and construction of extended canal systems

The limits of these periods can be related to other periods based on different degrees of anthropogenic influence, e.g. significant changes land use or other human activities in historic times with influence on river channels. Natural dynamics are superimposed (cf. Schirmer et al., this volume).

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