SEWAGE REMOVAL IN LÜBECK AND ITS IMPACT ON THE RIVER TRAVE

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INTRODUCTION

Lübeck was founded in 1143 by Count Adolf II of Schauenburg around 20 km inland from Lübeck Bay at the point where the Wakenitz River flows into the Trave River. After a fire Lübeck was newly founded in 1159 by Henry the Lion, Duke of Saxony. Henry bestowed Lübeck with privileges, such as the right to free trade, to levy tolls and to strike coinage (BREMSE 1992). In those days ships moored in the town harbour. At the turn of the 13th century there was a need for more space for the ships, and the harbour was extended along the swampy west banks of the river. Lübeck had the status of a Free Imperial City for over 700 years until the act was withdrawn by Hitler in 1937. After the war the major part of Lübeck`s harbour was shifted seawards (BREMSE 1992, HÖPPNER).

Today Lübeck has around 200 000 inhabitants. Its municipal wastewater is discharged into the Trave at a point more than 20 km away from the Baltic Sea. Breakdown and transportation of the wastewater depend above all on the intensity with which the Trave renews its water, which in turn is affected by its different currents and changes in the water level. In order to study the impact of municipal wastewater in the Trave one has to know local abiotic and biotic factors which influence fluctuations in water quality. The survey of the factors that affect the Trave should also take into

consideration the load from the catchment area, but this is beyond the scope of this presentation.

THE TRAVE RIVER

The river system of the Trave is located in the hill and lake area of Ostholstein in northern Germany, where it belongs to the moraine landscape of Schleswig-Holstein. The course of the river was determined by the geomorphological shaping processes of the Weichsel Ice Age (DUPHORN 1995, MEYNEN et al. 1962). The Trave has its source in the village of Giesselrade in the district of Eutin, about 55 m above sea level. Having a length of 112 km, it flows into the Baltic Sea at Travemünde and drains an area of 2665.5 km^2 (VOIGT & BOJE 1990).

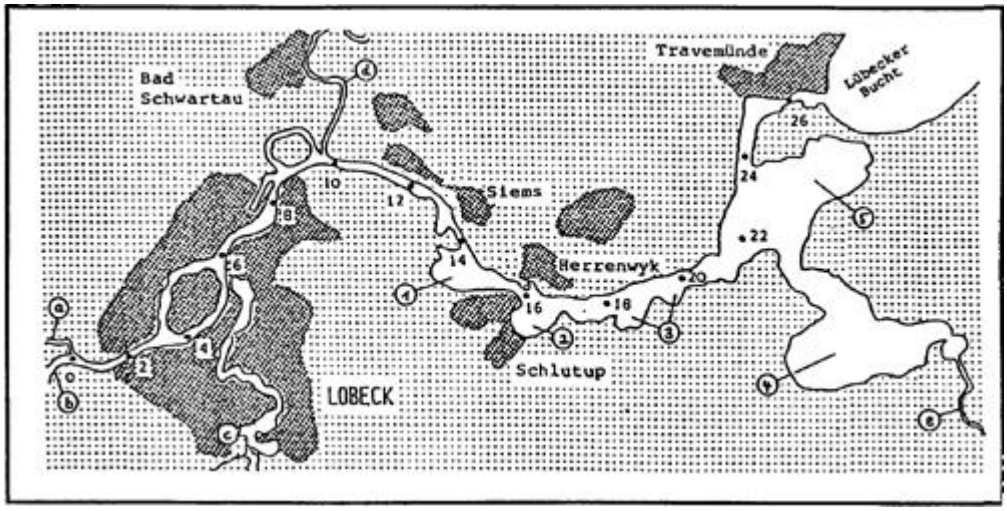

Figure 1 The Trave (a-e: Flusstrave, Elbe-Lübeck Canal,Wakenitz, Schwartau, Stepenitz; 1-5: Breitling, Schlutuper Wiek, Grosse und Kleine Holzwiek, Dassower See, Pötenitzer Wiek. ZIELKE & BLOSS 1981)

The part of the river that is under consideration here covers the area between the point where the Elbe-Lübeck Canal flows into the Trave down to its mouth.

The water level in this part of the river mainly depends on winds and the water level of the Baltic Sea. Normal changes of the tide of $\pm$ 10 cm only play a minor role. Every change of the water level in Lübeck Bay affects the water level of the Trave (GROSCH 1972, ZIELKE & BLOSS 1981). Direct measurements of the efflux of the Trave are difficult to make because of the influx of the Baltic Sea water and because there is only a slight incline of the water level between Lübeck and Travemünde, which is around 4 cm at mid-tide and under normal flow. In 1890 the Director of the Lübeck Office for Waterworks calculated that the average outflow of the Trave was 12.64 m^3/s, which corresponds to 1.09 million cubic metres per day. During the average low tide it drops to 3.16 m^3/s and with the average high tide it rises to 71.1 m^3/s (KÄNDLER 1951, KLUTH 1939).

The flow conditions in the lower Trave depend on prevailing winds. Westerly winds push the surface water, which has low salinity and density, out to the sea. As the saltier deep water is forced out the sea, less Baltic Sea water flows at the bottom of the Trave. Easterly winds retain the surface water and cause a slower outflow of fresh water into Lübeck Bay. When the water level is low, water from the Baltic Sea flows upstream by counter currents (GRIESEL 1934, STEYER 1932). Because there is no elevation at the bottom at the point where the Trave flows into the Baltic Sea, the sea water can flow far upstream at the bottom of the river. The effect of saline water in the Trave reaches beyond the inner city of Lübeck (KÄNDLER 1953).

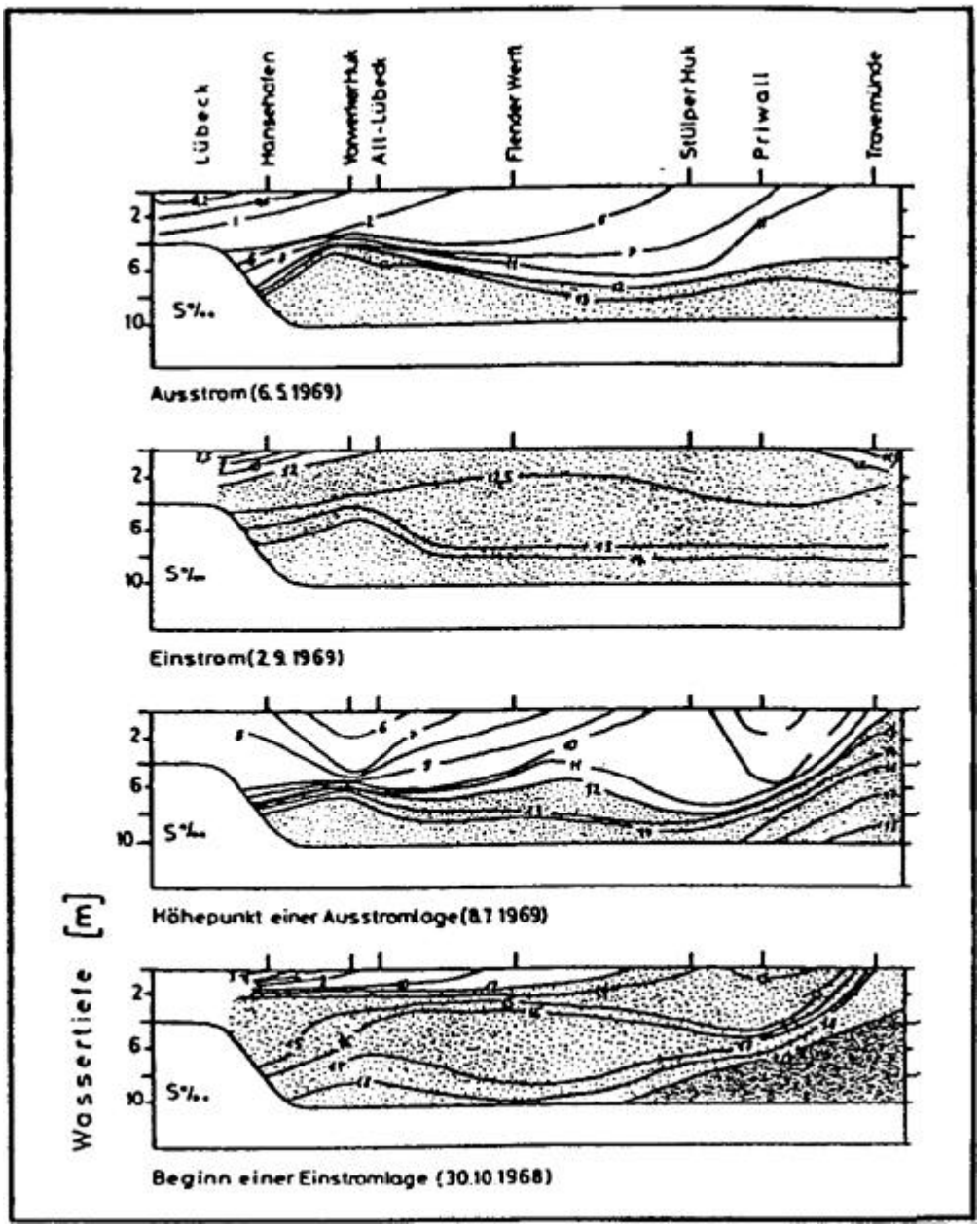

Figure 2 Hydrographic situation of the River Trave on the basis of NaCl concentrations (DIEHL & DIEHL 1979).

The average salinity in the bottom layer is 13-16 per mil and in the surface water four per mil. A turbulent mixing of these two layers occurs only occasionally (GROSCH 1972, VOIGT & BOJE 1990).

The water temperature of the Trave is influenced by the inflowing fresh water and the sea water. Thus comparatively warmer, fresh water flows on the surface during the summer months, reaching temperatures of up to 22 °C. The temperature of the inflowing sea water at the bottom is lower. In winter the process is reversed, and the sea water close to the bottom is warmer than the water at the surface. The thermocline of the two bodies of water often coincides with the halocline (GROSCH 1972). According to Julius (1957), the vertical temperature gradient averages 2-4 °C, but Kändler (1951) noted that it can be as high as 9 °C.

TRANSFORMATION OF THE TRAVE

In the Middle Ages the location of Lübeck`s town harbours provided protection against heavy storms and attacking enemy forces. Later, when the ships became bigger, this location became a disadvantage. From Lübeck to Travemünde the Trave was deepened and straightened to allow bigger ships to sail to the town harbours (KLÖCKING 1954, VOIGT & BOJE 1990).

As early as in medieval times, the shipping lane of the Trave had to be kept free by hoeing and dredging. In meetings of the Hanseatic League in 1460, Lübeck failed to stop the development towards bigger ships. As a result, the Trave was dredged. From 1840 to 1982 five major corrections were carried out, deepening the navigation route from around 7 m to 10.5 m and shortening it by 2.5 km. This led to a stronger influx of sea water at the bottom of the river and thus to an increase of salinity (KLÖCKING 1954, VOIGT & BOJE 1990, VON LILIENFELD-TOAL 1980).

THE DEVELOPMENT OF THE MUNICIPAL SEWERAGE SYSTEM

Increasing population and industrialisation produced more wastewater, and the municipal water courses became polluted. In the 1850s this increased pollution began to pose a threat to drinking water sources in Lübeck. In order to relieve the situation, a sewerage system was constructed in the inner city (1876) and later in the suburbs (1882). All the sewers led into the Trave and the Wakenitz, which also was serving as a water source (BALTZER 1908, REHDER 1890). When the Elbe-Lübeck Canal was finished in 1900, nearly all of the sewers were removed from the Wakenitz and the sewage was led into the canal.

In 1925 it was decided to build a mechanical wastewater treatment plant in Lübeck. The plant was completed in 1934, and similar plants served the city until the Second World War (DALSTEIN 1952).

The refurbishing of Lübeck`s municipal drainage system began in 1953. The central purification plant with partial biological treatment was built first (1967) followed by purification plants in Priwall (1973) and Ochsenkopf (1979). For the transition period several temporary mechanical and biological plants were built. In 1989 and 1990, respectively, chemical phosphorus removal was introduced to the central purification plant and in secondary plants. In 1993 nitrogen removal was added to the Ochsenkopf plant, and 1995 marked the beginning of biological nitrogen and phosphorus removal in the Priwall plant (HELD 1988).

Lübeck's municipal wastewater treatment plants lead the treated wastewater directly into the Trave. The sludge is treated in the central purification plant, transported to the

central plant by ships or by trucks, and later used as a fertiliser (AMT FÜR STADTENTWÄSSERUNG 1995).

STUDIES ON THE WATER QUALITY OF THE TRAVE

The quality of the water is affected by municipal wastewater inflows as well as by natural factors of the drainage area, the nature of the river bed and banks, and the prevailing outflow conditions. Most rivers receive the majority of their organic and inorganic loads from anthropogenic wastewater inflows (SCHÖNBORN 1992).

CHEMICAL STUDIES

Chemical studies before 1900 showed no signs of essential changes in the Trave`s and Wakenitz`s water quality due to the increases in wastewater discharges. After the Elbe-Lübeck Canal was built in 1900, the prevailing opinion was to keep the Wakenitz free from wastewater inflows for hygienic reasons. A proposal had already been made to collect and treat wastewater, but it was not carried out. However, several chemical tests conducted from 1906 to 1912 showed that contamination had become worse due to oxygen deficit and increasing deposits of sludge at the bottom of the Trave (BEHN 1909-12, GROSSE-BOHLE 1909, REHDER 1896, RENK 1888, SCHORER 1883, SPITTA 1906).

Subsequent chemical examinations of the Trave were not undertaken until 1940-1941. They showed, through a comparative examination of oxygen, that a change for the better had not taken place despite the fact that mechanical purification plants had been built.

Therefore it became necessary to construct a biological purification plant, to enlarge the existing plants, and to extend the outlets (RICHTER 1940/41).

In the post-war years the condition of the waters worsened again. In 1948 and 1949, for instance, this led to a large fish kill in the Trave. As tests for poisoning were negative, Kändler (1951) thought the reason for the fish kill was the low oxygen content of the water, mainly caused by municipal wastewater discharges. Chemical tests conducted in 1967 also showed that the water quality of the Trave had not improved despite refurbishment of the municipal treatment system. In the Lübeck portion of the Trave, the water lacked oxygen and contained considerable concentrations of hydrogen sulphide and nutrients. Only close to the mouth of the river did contamination decrease, because there the river water was mixed with sea water (KÄNDLER 1971).

In 1978, studies were undertaken by the Federal Office of Hydrography in Koblenz. When compared with previous data from 1961-1973, the results showed that the water quality had improved, especially in Lübeck. This was the result of shutting down an overloaded mechanical purification plant. Measurements of the oxygen level, as well as of organic matter and nutrients, made by the State Office for Waters and Coasts in Schleswig-Holstein in 1979-1994 showed that the water quality had not deteriorated substantially.

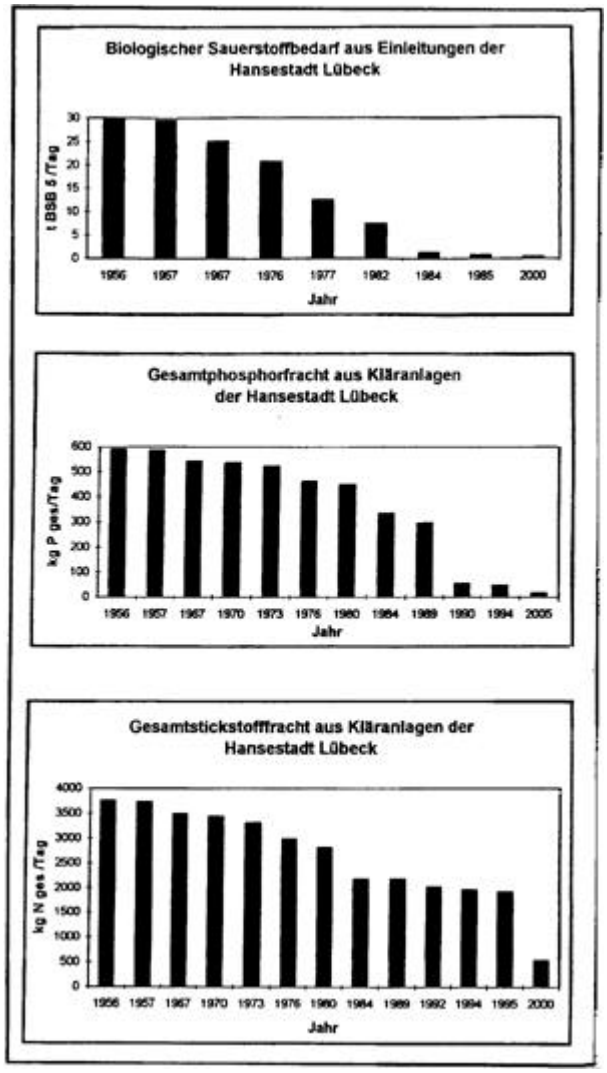

Figure 3 Data on BOD5, KMnO4, and nutrients in the Trave at Schlutup at depths of 1 m and 9 m (Classification 1: not polluted, 4: very polluted; source: LANDESAMT FÜR WASSERHAUSHALT UND KÜSTEN, 1975-1995)

BIOLOGICAL STUDIES

We can measure the changes in the water quality by studying those organisms which do not succumb to rapid local and temporal fluctuations. While plankton strongly depend on the prevailing hydrographic and temporal conditions during the time when samples are taken, the colonisation of molluscs shows more permanent tendencies in the changes of the Trave. The adult animals are exposed to bad environmental conditions because of their stationary way of life, and their life-span of more than one year shows their reaction to various stresses, for example to the lack of oxygen (MÖLLER 1980, VOIGT & BOJE 1990).

The first surveys of molluscs living in the Trave were made by LENZ (1882) and ARNOLD (1882). LENZ found that the influx of marine fauna from Lübeck Bay was limited by the low concentration of salt in the river in the area above the Herrenbrücke. Later on, the decline of the molluscs in number and density of the species was studied by SCHERMER (1950), JULIUS (1957) and GROSCH (1972). They believed that the decline was due to the severe lack of oxygen and the presence of hydrogen sulphide at the bottom of the river. High concentrations of hydrogen sulphide at the bottom were common in the deeper areas, causing mollusc kills. Consequently, in 1950 live molluscs could be found in Lübeck harbour only in the upper water layer to a depth of one metre (KÄNDLER 1951, SCHERMER 1950).

Table 1 Number of mollusc species found in different areas of the Trave

	Untertrave oberhalb Herrenbrücke	Herrenbrücke - Stülper Huk	Stülper Huk - Travemündung
LENZ (1878, 1882)	1	6	21
SCHERMER (1950)	3	7	11
JULIUS (1957)	0	1	4
KLEIN & KOTHE (1967)	0	3	7
GROSCH (1972)	2	3	5
KLEIN & TITTIZER (1980)	0	2	4
MÖLLER (1980)	1	5	6
GOERSCH (1989)	2	4	6

These data do not show any significant increase of mollusc colonisation in the Trave according to the number of species.

CONCLUSIONS

Lübeck was the most important trading city on the Baltic Sea, and its history has always been connected to its location on the Trave River. During recent centuries the hydrographic conditions of the Trave between Lübeck and Travemünde have changed substantially. Between Lübeck and Herrenbrücke the Trave used to have several branches and islands, and distinct sedimentation zones, but after dredging and straightening it was transformed into a canal-like water course. As a result sea water can enter upstream up to Lübeck, thus changing the abiotic conditions significantly.

Summarising the development of the sewerage system in Lübeck over a period of more than one hundred years, it started with simple mechanical grids at the outlet of the sewer pipes and now includes modern purification plants with phosphorus and nitrogen removal. A general historical overview shows that the water of the

Trave used to be very polluted, but that during the last decades the water quality has improved, mainly because of efficient wastewater treatment.

The water quality of the Trave has been extensively studied during last hundred years and the results of these studies have had an important role in the development of wastewater management. The pollution problems that were noted already in the end of the 19th century rapidly led to suggestions that wastewater treatment be introduced in order to avoid pollution caused by untreated sewage.

No in-depth study on the damage caused by the municipal discharges of the Trave has been made, and such a study should receive high priority.

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