History of heavy metal contamination in the sediment of the *Mühlenberger Loch*

(an artificial embayment in the tidal River Elbe / Germany)

Temporal development ("annual layers") and overall balance

Sediment core analysis

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Heavy metal status in the Elbe reach Wedel/*Mühlenberger Loch*

In the reach of tidal Elbe designated as the *Mühlenberger Loch* near Hamburg (cf. Fig. 1a, b), heavy metal contamination in the particulate phase, i.e. suspended matter (SPM) and sediments, show a marked gradient. The mixing of SPM/sediment of fluvial origin with high heavy metal loads with SPM/sediment of marine origin with relatively low contamination is characteristic of this reach. The percentages of these two "types" of SPM/sediment is strongly dependent on the freshwater discharge: the SPM sampled since 1980 by the BfG at the sampling site *"Wedel Bauhof*" show regularly, for instance, relatively low Hg levels at low freshwater discharges, because under these conditions in the Elbe near Wedel the marine component in the solid matter obviously prevails. Conversely, Hg levels rise strongly when river discharge is high. These seasonal variations of Hg levels are shown in Figure 2a. This phenomenon has been superimposed since 1986 by markedly decreasing Hg loads or concentrations entering the estuary via the tidal boundary at *Geesthacht*. Similar seasonal variations can also be observed with other heavy metals, although less pronounced.

Over three decades, considerable amounts of SPM (including the adherent contaminants) have been introduced into the *Mühlenberger Loch* by the river Elbe with each tidal cycle and have partially sedimented there: per day about 1,000 tons. Thus, since 1962/64 around 10 to 13 million cubic metres of solids from the Elbe have been deposited in the *Mühlenberger Loch* (MARNITZ, 1995). The sediment layers, which are nowadays several metres thick, therefore reflect the history of heavy metal contamination over the past three decades. The investigation of heavy metal concentrations carried out in a sediment core, taken in 1994 in the *Mühlenberger Loch* (Fig. 1b), shows this development in Fig. 3 for As, Cr, Hg, and Zn. The seasonal variations in the heavy metal concentration, shown in Fig. 2a for the sampling site "W*edel Bauhof*", can also be recognized in the sediments in the *Mühlenberger Loch*. These "annual layers" resulting from seasonal variations of freshwater discharges can be similar observed for all heavy metals. These layers are between 10 and 15 cm thick, corrresponding approximately to the sedimentation of one year. The maxima of heavy metal contamination can be related to the

maxima of freshwater discharge. The portion of the fine-grain fraction <20 µm in the sediment (and also the water content) show the same seasonal pattern (cf. Fig. 3): high fine-grain portions (and high water contents) occur together with low heavy metal levels; i.e. these sediments were obviously deposited in times of low freshwater discharge.
Surprisingly, despite the high bio-production in this reach of the Elbe, bioturbation could not smooth out or destroy these "annual layer"-patterns.

Facts and figures on the *Mühlenberger Loch*

1939 (= "Year of birth" of the *Mühlenberger Loch*): Widespread dredging operations at the site of today's *Mühlenberger Loch* in connection with the construction of a basin for sea planes, the "*Neßhafen*".
1962: Diking-off of the '*Alte Süderelbe* ' (a branch of River Elbe), a few weeks after the catastrophic tidal wave on 17 February 1962.
1962 - 1964: Erosion prevails in the *Mühlenberger Loch*.
1964 - 1994: Sedimentation prevails in the *Mühlenberger Loch*, although considerably disturbed by construction works:

- 1964 - 1969: Deepening of the Elbe to a navigation channel depth of 12 m and artificial accretion of the islands *Hanskalbsand, Neßsand, and Schweinsand*;
- 1972 - 1975: Dumping of 1.5 million cubic metres of dredged material from the Hamburg harbour into the *Neßhafen* harbour and the *Mühlenberger Loch*;
- Deepening of the Elbe to 13.5 m navigable depth and artifical accretion of the *Neßsand* and *Schweinsand*;
- 1976: Dumping of 80,000 cubic metres of material into the *Mühlenberger Loch* (presumably dredged material from the Hamburg harbour);
- 1986 - 1994: Marked decrease in sedimentation rates in the eastern part of the *Mühlenberger Loch* (area of core sampling); an equilibrium of erosion and sedimentation reached over wide areas of the *Mühlenberger Loch*.

Length and width of the *Mühlenberger Loch*: ca 3.5 km and 2.5 km, resp.
Sediment deposit in the *Mühlenberger Loch* (1962 - 1994): about 10 - 13 million cubic metres.
Sediment thickness: up to 5 m in the eastern part of the *Mühlenberger Loch*.
Sedimentation rates: about 10 to 15 cm/a in the eastern part of the *Mühlenberger Loch*.

From: W. SIEFERT, Hamburger Küstenforschung 43 (1984)
U. MARNITZ, Die Küste 57, 95 (1995)
J. DÖRJES AND H.-E. REINECK, Natur und Museum 111, 275 (1981).

Dating of sediment core

The dating of the layers in the sediment core is based on the following time marks or events (cf. Fig. 3):

Depth 400 cm to 365 cm: All heavy metal levels range within the natural background; i.e. these sediments are old mud deposits without anthropogenic pollution.

Depth 365 cm to 300 cm ≈ 1962/64 to around 1971: Deposits of recent, distinctly heavy-metal contaminated sediments.

Depth about 300 cm to about 220/230 cm ≈ 1972 to 1976: Dumping of dredged material from the Hamburg harbour:

- 1.5 million cubic metres into the former harbour *Neßhafen* and into the *Mühlenberger Loch* (1972 to 1975);
- 80,000 cubic metres into the *Mühlenberger Loch* (1976).

This dumping activities resulted in

- the introduction of coarser material into the *Mühlenberger Loch*: The fine-grain fraction <20 μm decreases notably and varies strongly and irregularly;
- a strong increase in the concentrations of As, Hg, and Zn by a factor of two to three at a depth between 300 cm and 250 cm. The regular patterns of seasonal variations in concentration are distorted.

Depth about 220 cm and about 70 cm ≈ 1977 to 1985: The period after the extensive construction activities or dumping actions in the *Mühlenberger Loch*. Sedimentation is steady with few disturbances. The "annual layers" for Zn, Hg, and Cr are particularly distinct.

Depth 60 cm = June/July 1986 (137-Cs peak following the Chernobyl accident).

Estimate of heavy metal quantities stored in sediments of the *Mühlenberger Loch*

Assumptions:
Since 1962/64 about 10 - 13 million cubic meters of sediment have been deposited in the *Mühlenberger Loch*. This is equivalent to about 10 million tons of sediment (all fractions) or about 5 million tons in the fraction <20 μm. An average concentration of 1 mg/kg of a heavy metal (in the fraction <20 μm) thus corresponds to a total mass of this metal in the *Mühlenberger Loch* of some five tons.

	Metal quantities in the *Mühlenberger Loch* [t]	n-fold of the annual load in 1994 near *Schnackenburg* (Elbe-km 474.5)	Maximum concentration in <20 μm [mg/kg] and time of deposition	
Ag	**30**	??	15	late 1970s/early 1980s
As	**600**	5	250	mid 1970s
Cd	**45**	7	25	late 1970s
Cr	**850**	8	350	late 1970s
Cu	**900**	9	400	late 1970s
Hg	**45**	10	30	early 1970s
Ni	**350**	2	100	early 1980s
Pb	**1200**	23	400	mid 1970s
Zn	**7000**	3	3700	mid 1970s

Although this estimate has an uncertainty factor of at least 2, it is obvious that a considerable reservoir of heavy metals is stored in the *Mühlenberger Loch*. In the context of a planned re-opening of the *Alte Süderelbe* branch, it is necessary to check carefully to which extent these sediments contaminated with heavy metals may become resuspended and be distributed all over the whole Elbe estuary or transported in the long term, to the *North Sea*.

Sampling, sample pre-treatment and analyses

Date of sampling: 21 April 1994
Sampling device: Vibration corer, inner diameter 76 mm.
Length/division of the core: 400 cm, in slices of 1 cm.
Sample pre-treatment: Freeze-drying, determination of grain-size distribution and separation of the fraction <20 μm by ultrasonic sieving.
Heavy metal analyses: As, Co, Cr, Hg, Zn etc. by instrumental neutron activation analysis (INAA); Cd, Cu, Ni, Pb by Atomic Absorption Analysis (AAS).

This paper was first published in the poster session OA2 of the XXII General Assembly of the European Geophysical Society, Vienna/Austria , 21-25 April 1997, and also as report BfG-1017e of the Federal Institute of Hydrology, Koblenz, Germany (1997)

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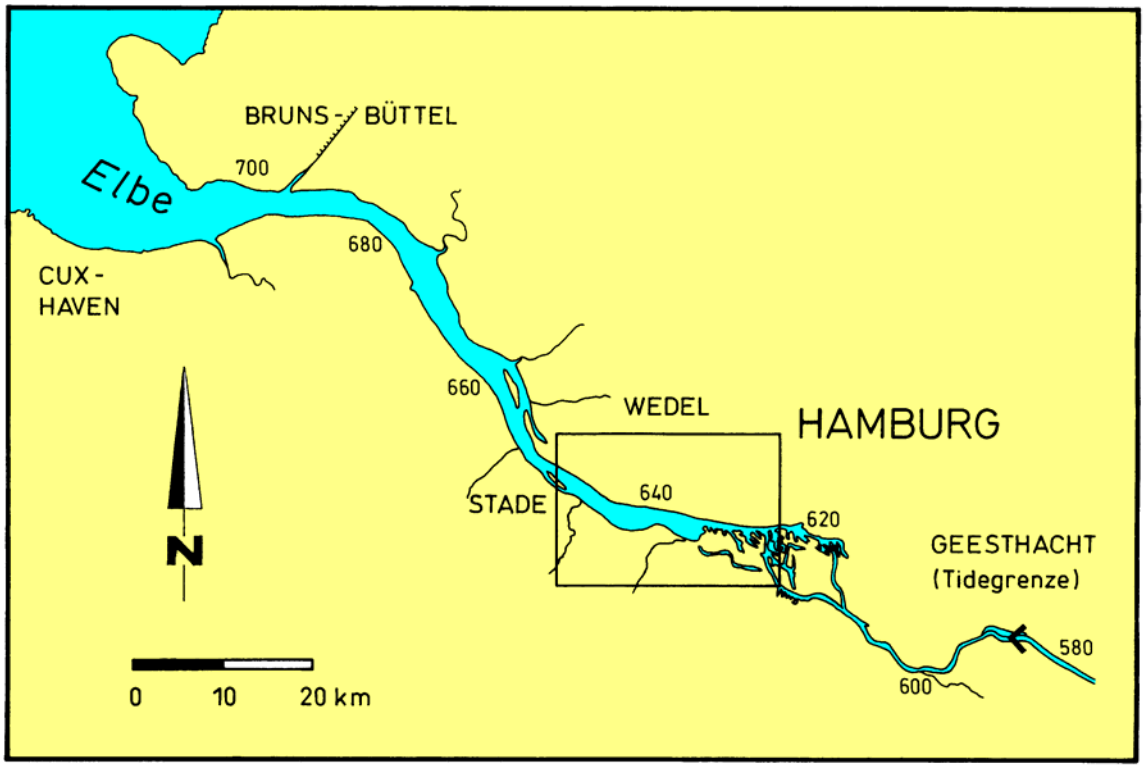
Fig. 1a,b: Sampling site



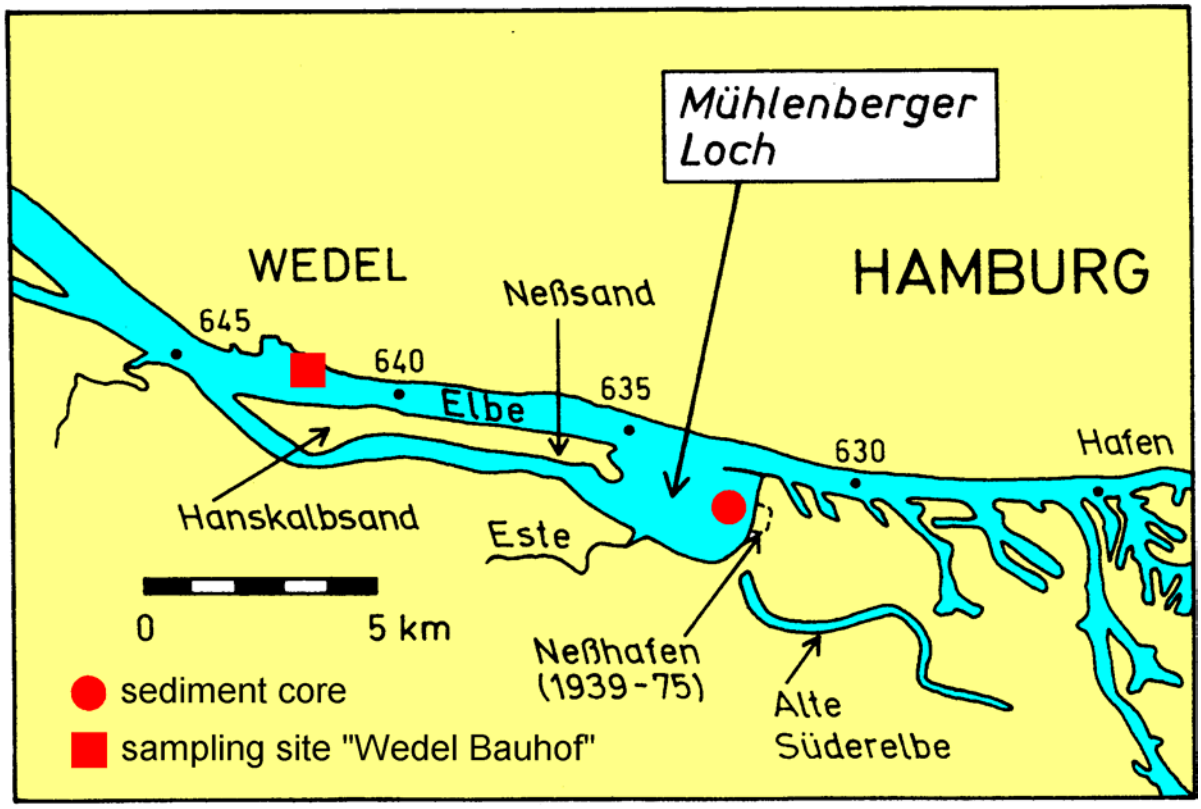
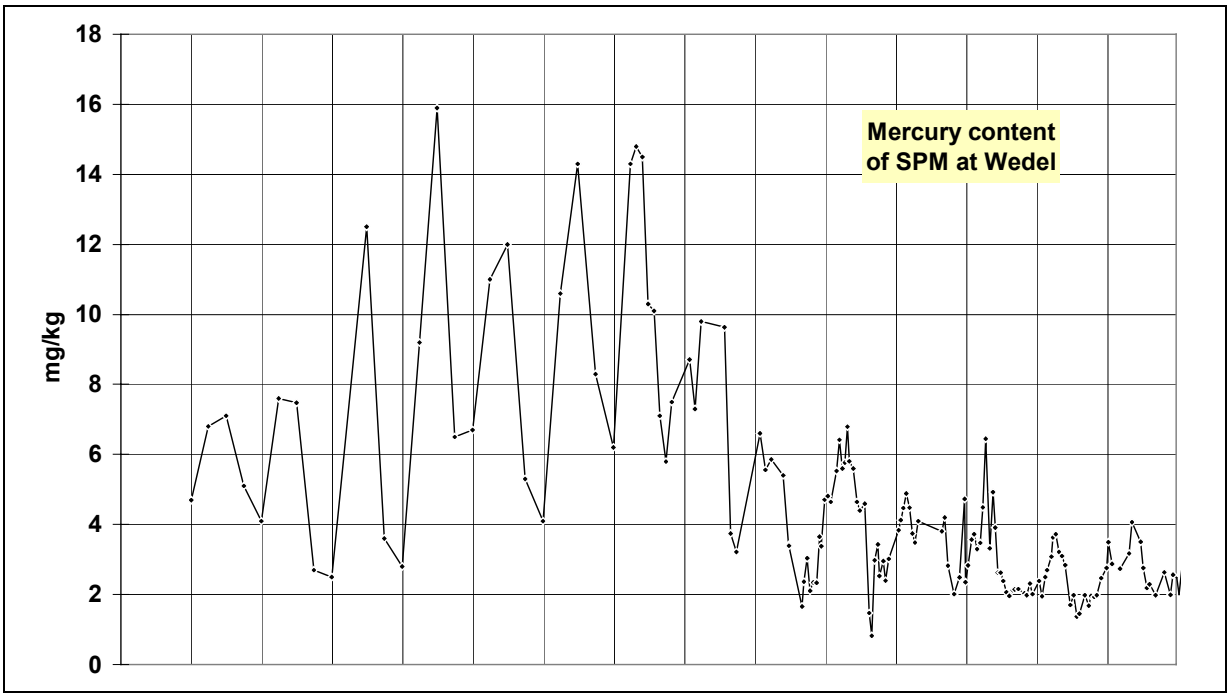


Fig. 2a, b: Mercury content in suspended solids (<20µm) near Wedel and freshwater discharge near Neu Darchau



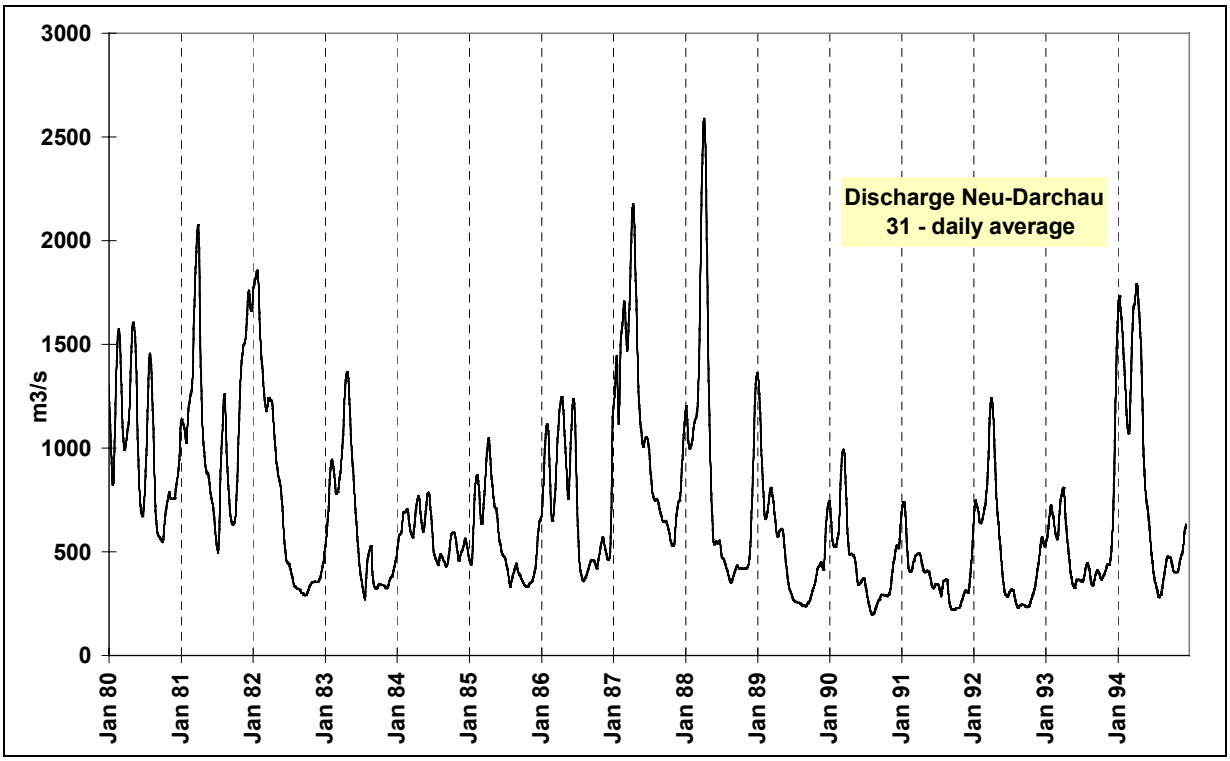


Fig. 3: Heavy metal concentration in sediments (fraction <20µm) of Mühlenberger Loch