The method of pollution-tracer to measure lowest groundwater velocities in the city of Bremen

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In 1886 was the beginning of the installation of pottash-mines in the drainage area of the river Weser. Up to the first world war many discharges of potashium waste water were derivated into the river Werra/Weser and its eastern affluents Ulster/Leine/Aller (Fig. 1).

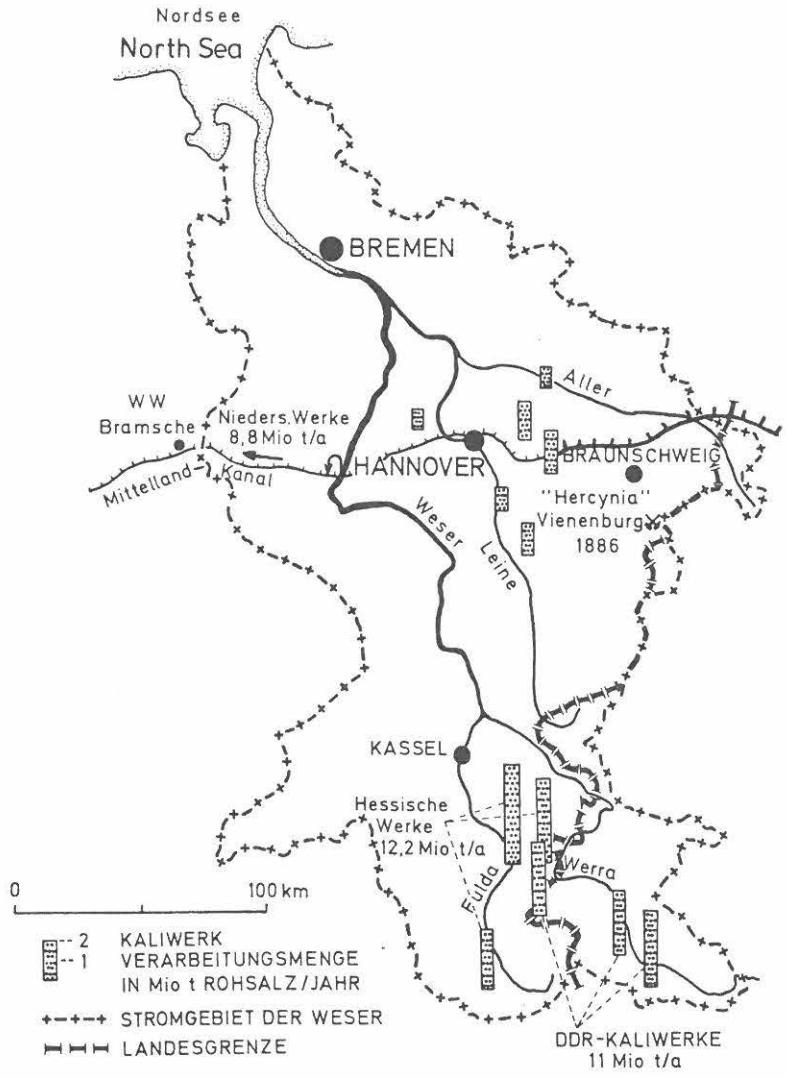

Fig. 1. Area of research (= drainage area of the river Weser) with the outputs of the different potash-mines in nothern Germany (Date: 1987)

Therefore the taking out of river water for the water authorities and the breweries of Bremen and of other towns along the river Weser was very problematical (LÜTTIG & FRICKE 1967). An arrangement between the thuringian potash-mines and the Government of Bremen guarenteed a maximum concentration of chlorides of 350 mg/l in the water of the river Weser in Bremen (Fig. 3).

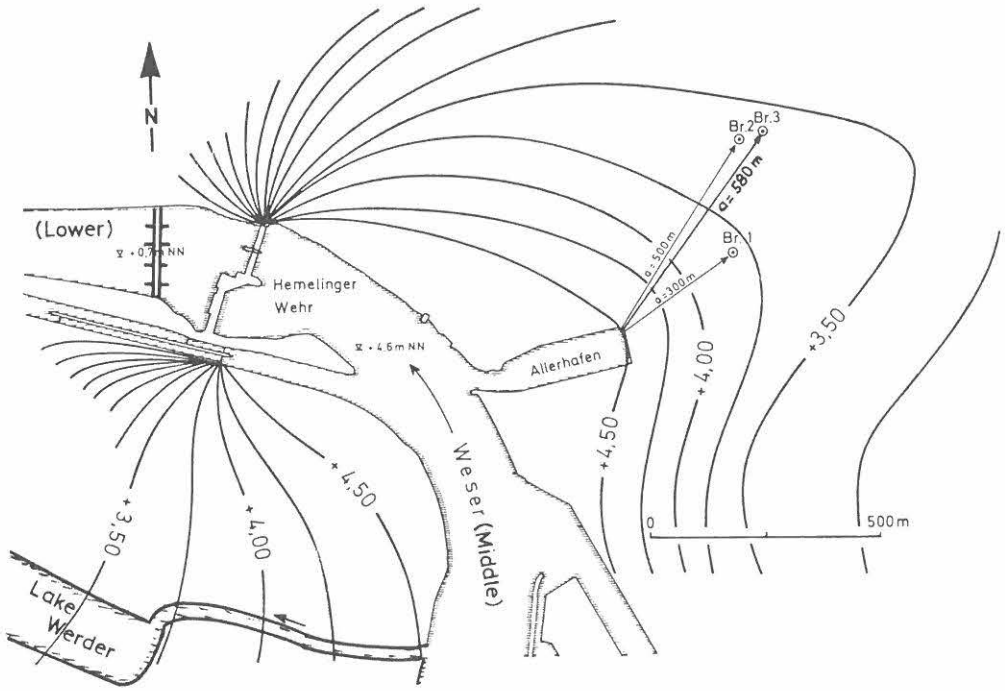

Fig. 2. Siteplan of the wells 1, 2 and 3 (non-tidal region) above the barrage of the river Weser at Bremen-Hemelingen (border Lower to Middle Weser) with the counter lines of the level of groundwater of the upper aquifer (=Wesersande).

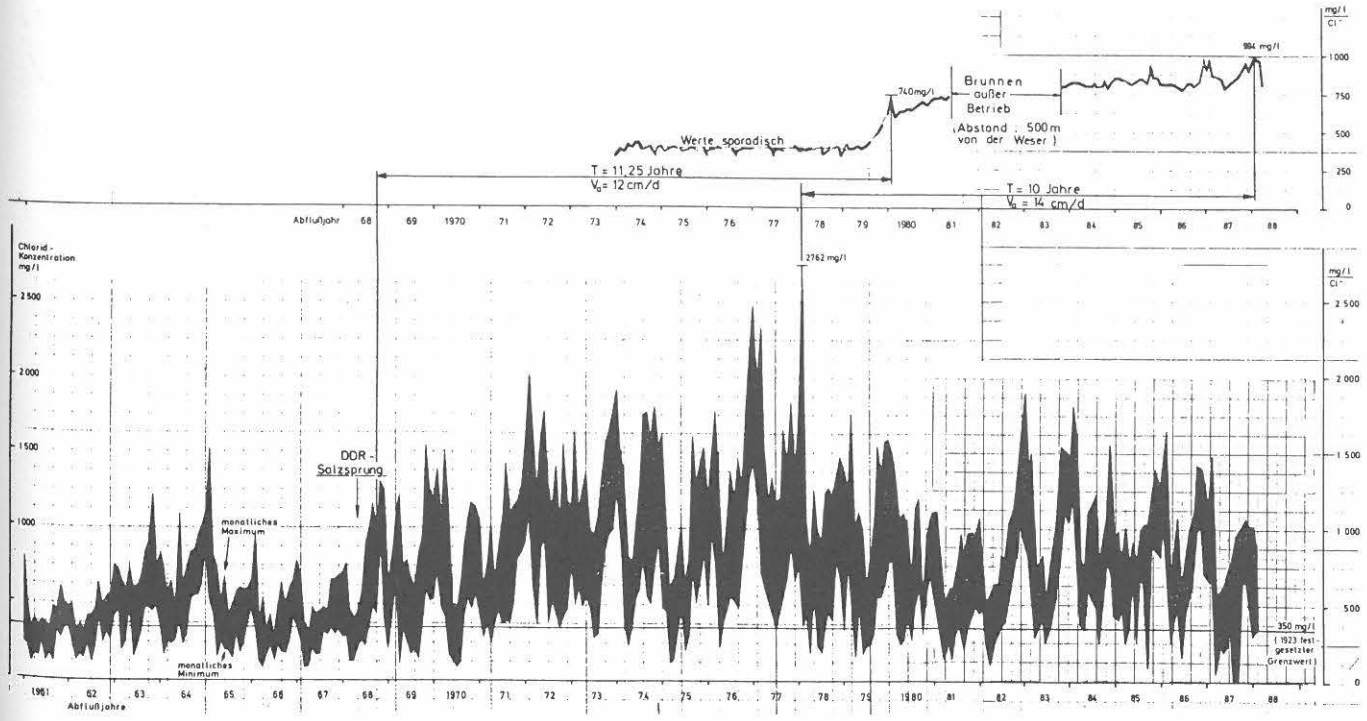

Fig. 3. Temporal correlation of the contents of chlorides in the water of the river (Middle)Weser (between 1960 and 1988) and in the well 2, (non-tidal region) above the barrage of Bremen-Hemelingen

After the second world war the eastern part of Germany (=GDR) allowed their potash-mines to increase this discharge of potashium waste water into the rivers Ulster/Werra/Weser after the year 1950. In 1968 the potash-mines of eastern Germany raised up the production of potashium minerals (Fig. 1). The injection of waste water into the underground (Plattendolomit of the Zechstein, Z 3, Permian) was stopped on account of the groundwater pollution. Therefore a double of discharge of potashium waste water ran into the river Weser (Fig. 3, GDR-saltjump, ORTLAM 1989).

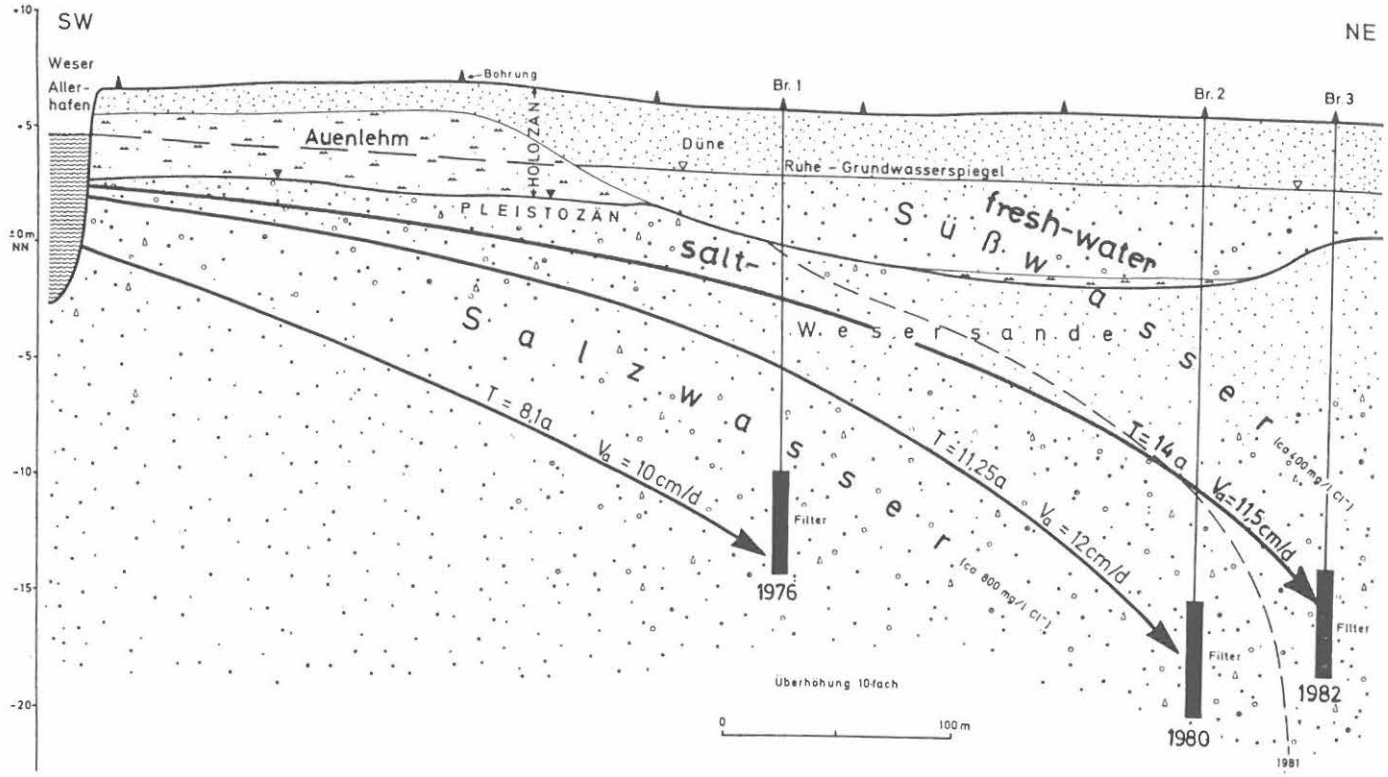

Fig. 4. Hydrogeological section between the river Weser (Aller-Harbour) and the saltwater intrusion to the wells 1, 2 and 3,(non-tidal region) above the barrage of Bremen-Hemelingen

In the flat and deep landscape of the Bremen bassin the velocity of groundwater flow in the upper aquifer is very low (< 10 cm/d) on account of the very little height of fall of the groundwater table (1:1000 to 1:6000, ORTLAM 1980). Therefore it is impossible to prove the velocity of groundwater flow with the normal tracers in hydrogeology (salt, uranine, eosine, fluorescëine etc.).After drawing the monthly maximum and minimum concentrations of the water in the river Weser in Bremen (ORTLAM 1983a) you can see very typical curves in the pollution by chlorides after the second world war (Fig. 3 and 6). Beyond 1980 many wells nearby the river Weser showed increasing contents of chlorides and of iron/manganese in the groundwater (ORTLAM 1989). Upstream of the barrage of Bremen-Hemelingen (built 1910) the river water ist dammed up about 4 m. In view of this highwater situation the saltwater intrusion of the river Weser permanently went into the upper aquifer of the river flanks (Fig.2, HOLZ 1971, ORTLAM 1980 and 1983b). There are three wells in several distances to the Allerhafen (Aller-harbour).Until to the year 1968 the medium concentration of the chlorides moved around 450 mg/l and after 1968 the double with 900 mg/l (= GDR-saltjump) was reached (Fig. 3). Now we are able to compare this typical curve of the river chlorides with the curve of the groundwater chlorides of three wells nearby. You can see the GDR-saltjump of 1968 after 11,25 years in the year

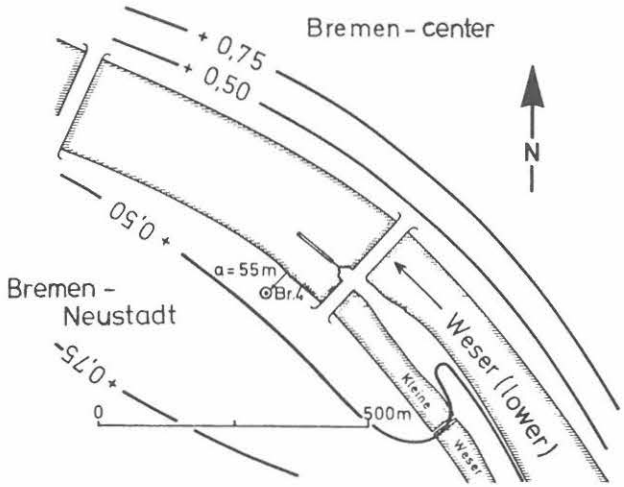

Fig. 5. Siteplan of the well 4 in the tidal region of the river Weser in the center of Bremen with contour lines of the level of the groundwater of the upper aquifer (=Wesersande).

1979/80 (Fig. 3) at the well 2 in a distance of 500 m from the river Weser. The flow velocity of the saltwater intrusion in the groundwater is about 12 cm/d. Well 2 was closed in the years 1981-1983. After this time the groundwater recharge of well 2 and the lowering of the groundwater level were started again and you can observe several typical peaks of chlorides between the curves of the Weser and the well 2 in the years 1976/77 and 1987/88 with a flow velocity of 14 cm/d. It is very interesting that the concentration of chlorides in the groundwater reached 50% of the salt concentration of the water in the river Weser. The groundwater recharge of this region is very low on account of many town settle-

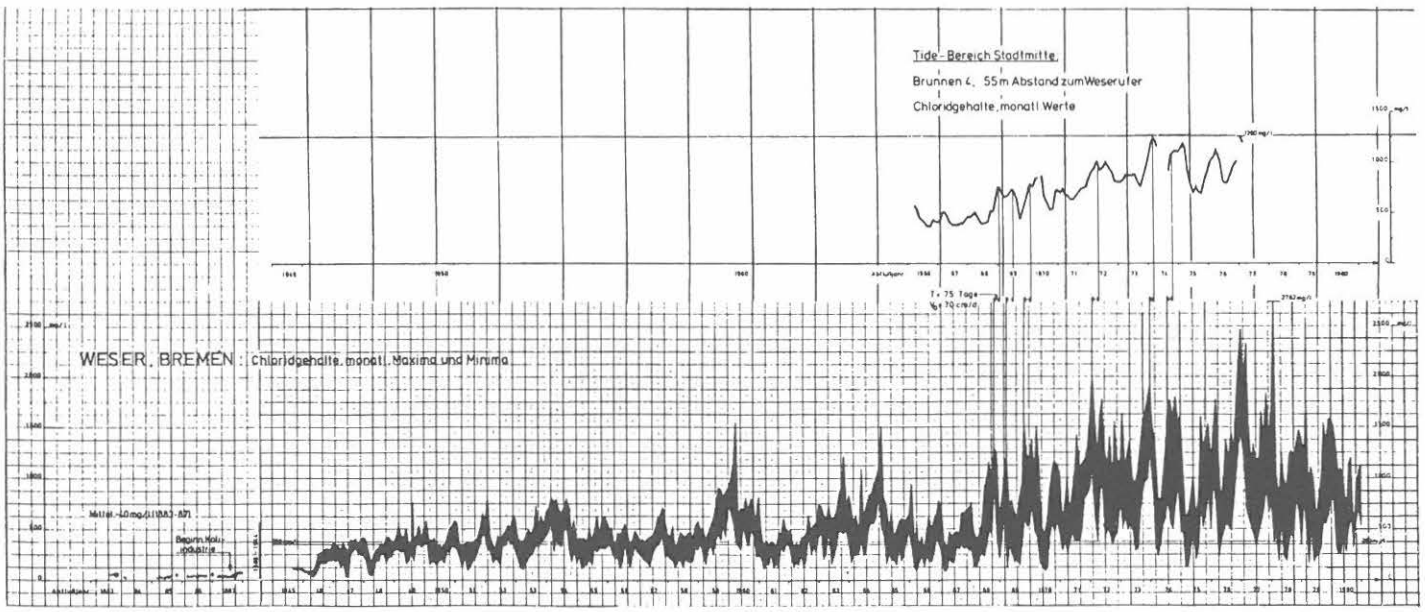

Fig. 6. Temporal correlation of the contents of chlorides in the water of the river (Lower)Weser (between 1945 and 1980) and in the well 4, tidal region of Bremen-Center.

ment and streets and of the holocene loam of the valley in the underground (Fig.4). In the hydrogeological section you are able to observe (Fig.4) the GDR-saltjump in the well 1 after 8,1 years in 1977 (V_a = 10 cm/d), in well 2 after 11,25 years in 1980 (V_a = 12 cm/d) and the well 3 after 14 years in 1982 (V_a = 11,5 cm/d). It is remarkable that we can find all peaks of the chlorides as well in the water of the river Weser as in the groundwater of the different wells, after 15 years of detention period in the upper aquifer. You are able to observe that the heavier saltwater from the river Weser went down after1968 beneath the freshwater of the upper aquifer (Fig. 4) and reached now a distance from the river Weser about 800 - 1000 m (ORTLAM & SAUER 1993).

In the center of Bremen there was an other example to measure the groundwater velocity by the pollution-tracer "chloride". A brewery well 4 situated in a distance of 55 m from the southern border of the river (Lower)Weser and in the tidal region (Fig. 5) produced much saltwater of unknown origin and with bacteriological problems.The comparison of the two curves of chlorides between the river Weser and the well 4 exactly demonstrated the GDR-saltjump and other typical peaks (Fig. 6). The temporal difference between the comparable peaks amounts to 75 days.

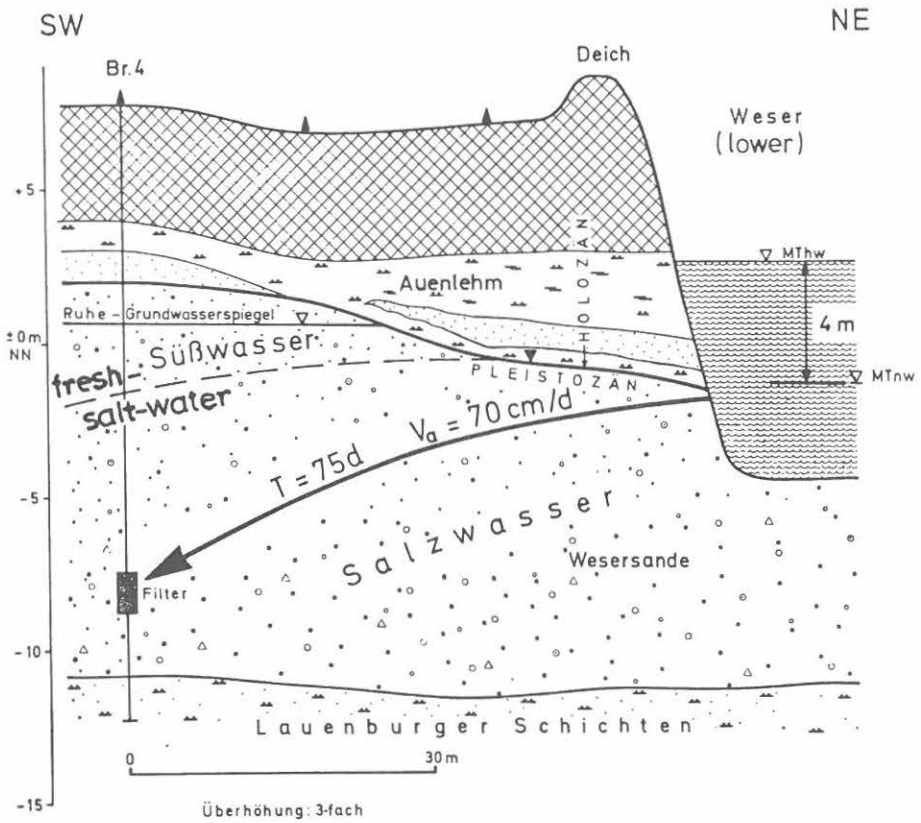

Fig. 7. Hydrogeological section between the river (Lower)Weser (tidal region) and the saltwater intrusion by tidal pumping to the well 4 (pilgrim step method), Bremen-Neustadt

In the hydrogeological section (Fig. 7) we are able to watch the pumping effect of the river Weser with a tidal difference of 4 m, the covering holocene loam of the valley (= Auenlehm), the upper aquifer (= Wesersande) and the active well 4. The flow velocity of the saltwater from the river Weser amounts to 70 cm/d (V_a), in consideration of the pilgrim step flow of the groundwater by tidal movements. Corresponding to the detention time of 75 days the bacteriological influence of the groundwater of the well 4 did not come from the river Weser as the first idea but from other local influences.

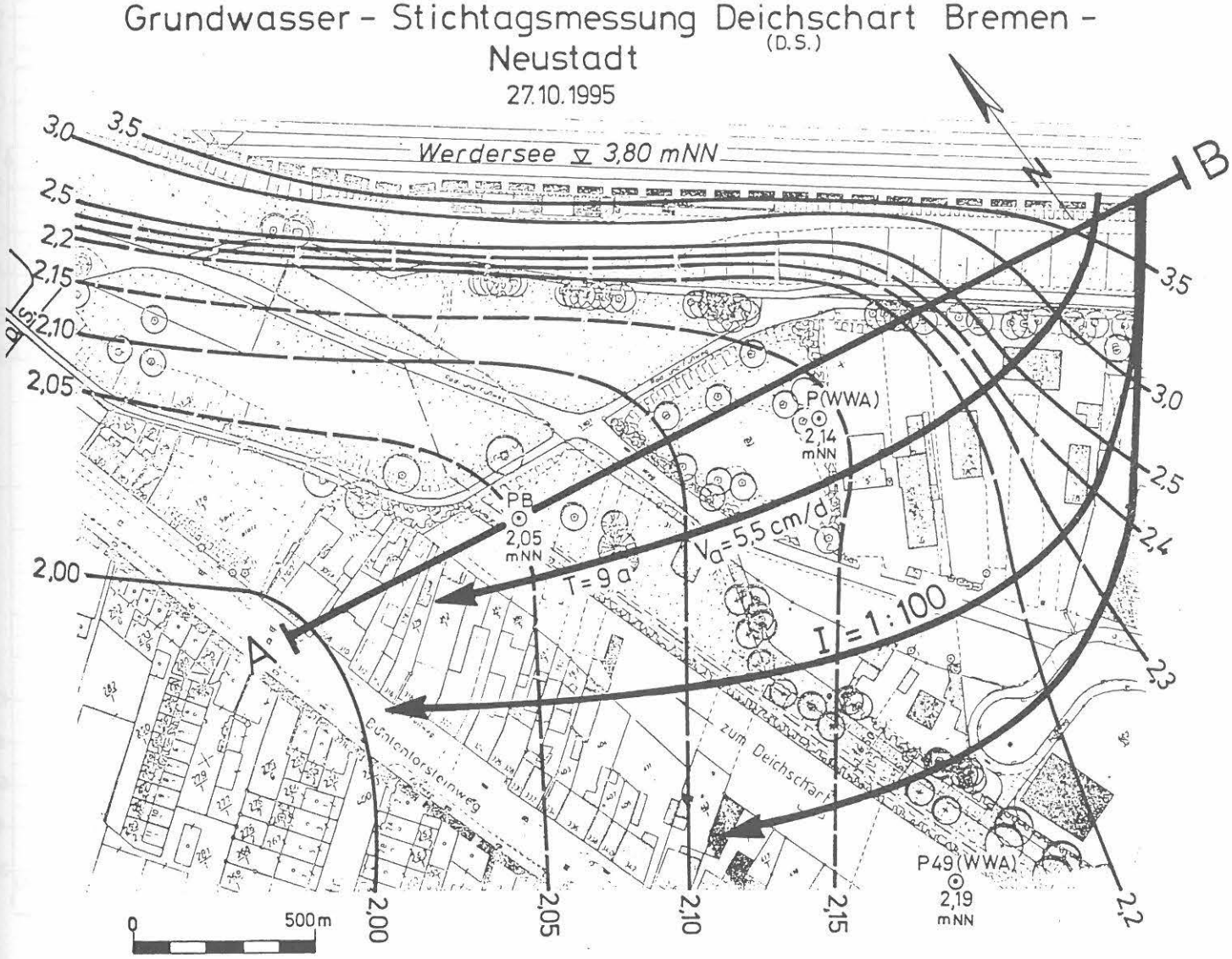

Fig. 8. Siteplan of the southern border of the Lake Werder, water input from the river (Middle) Weser (see Fig. 2), of the different depth gauges, of the section line and the counter lines of the groundwater level of the upper aquifer (= Wesersande)

In Bremen-Neustadt the (artificial) Lake Werder is situated south of the river Weser. The water of this lake comes from the river (Middle)Weser above the barrage of Bremen-Hemelingen (Fig. 2). The lakewater is dammed up to 3.80 m NN (Fig. 8). Considering the local groundwater level of 1.30 m NN there is a saltwater intrusion from the lakewater into the groundwater at the southwestern border of the Lake Werder (Fig. 8 and 10). In the years 1981-1986 the Lake Werder was empty because of a catastrophical act of highwater. In April 1986 the Lake Werder was filled up again with saltwater from the river (Middle)Weser and the saltwater infiltration into the groundwater began. Two times a year we observed the conductivity of the water of the Lake Weser in comparison with the groundwater at the depth gauge PB in a distance of 80 m from the southwestern border of the lake (Fig. 8). The groundwater flow is very irregular due to the hydrogeological situation (Fig. 10) and shows a western direction with a dipping of the groundwater level of 1:100. In comparison of the two curves of conductivity of the water of the Lake Weser and the groundwater in the depth gauge PB you are able to observe that in the year 1995 higher conductivities reached the depth gauge after 9 years (Fig. 9). The flow velocity of the saltwater intrusion amounts to 5.5 cm/d (V_a).

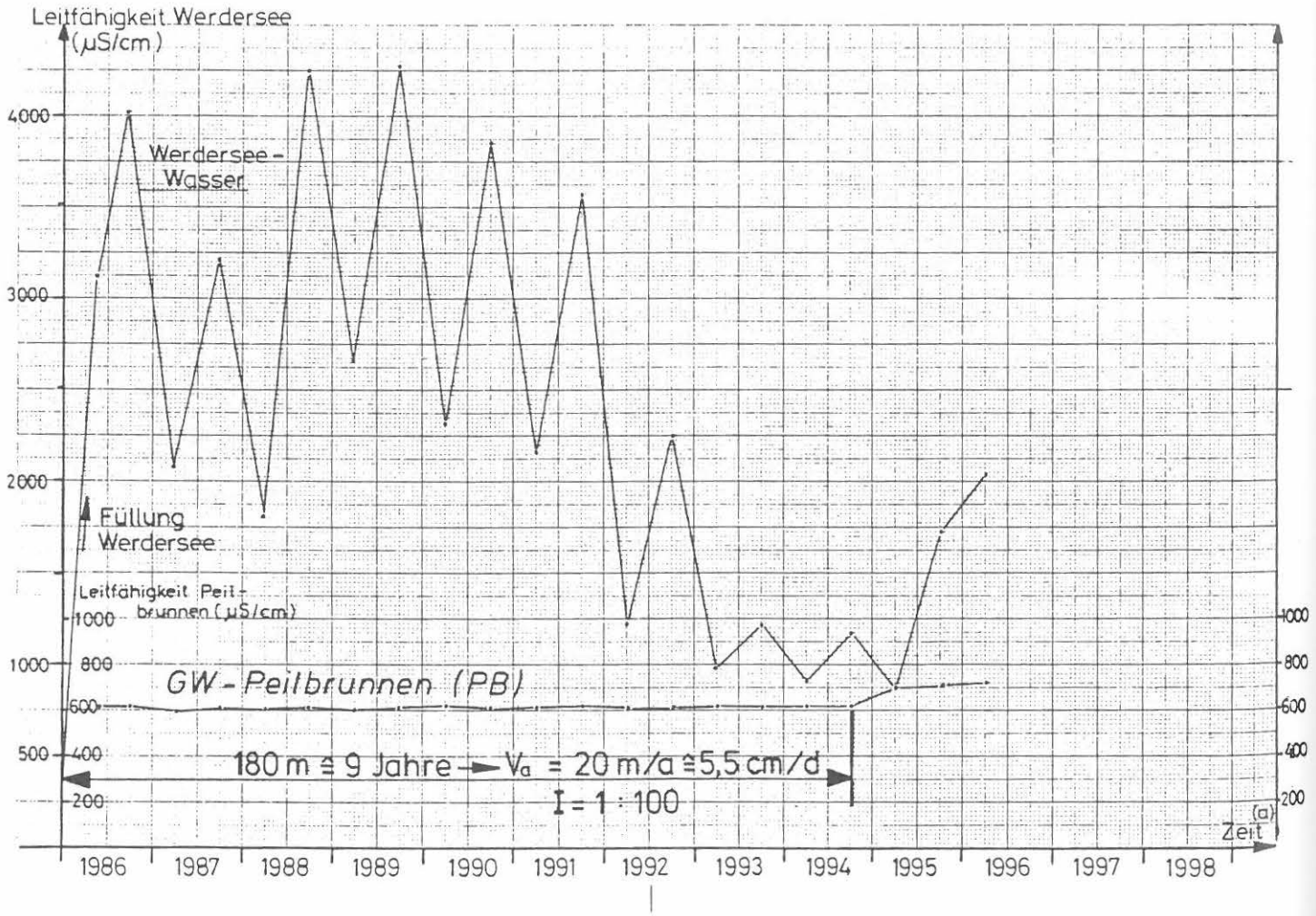

Fig. 9. Temporal correlation of the conductivity (µS/cm) in water of the Lake Werder (non-tidal region) and the depth gauge PB, near Deichschart of Bremen-Neustadt

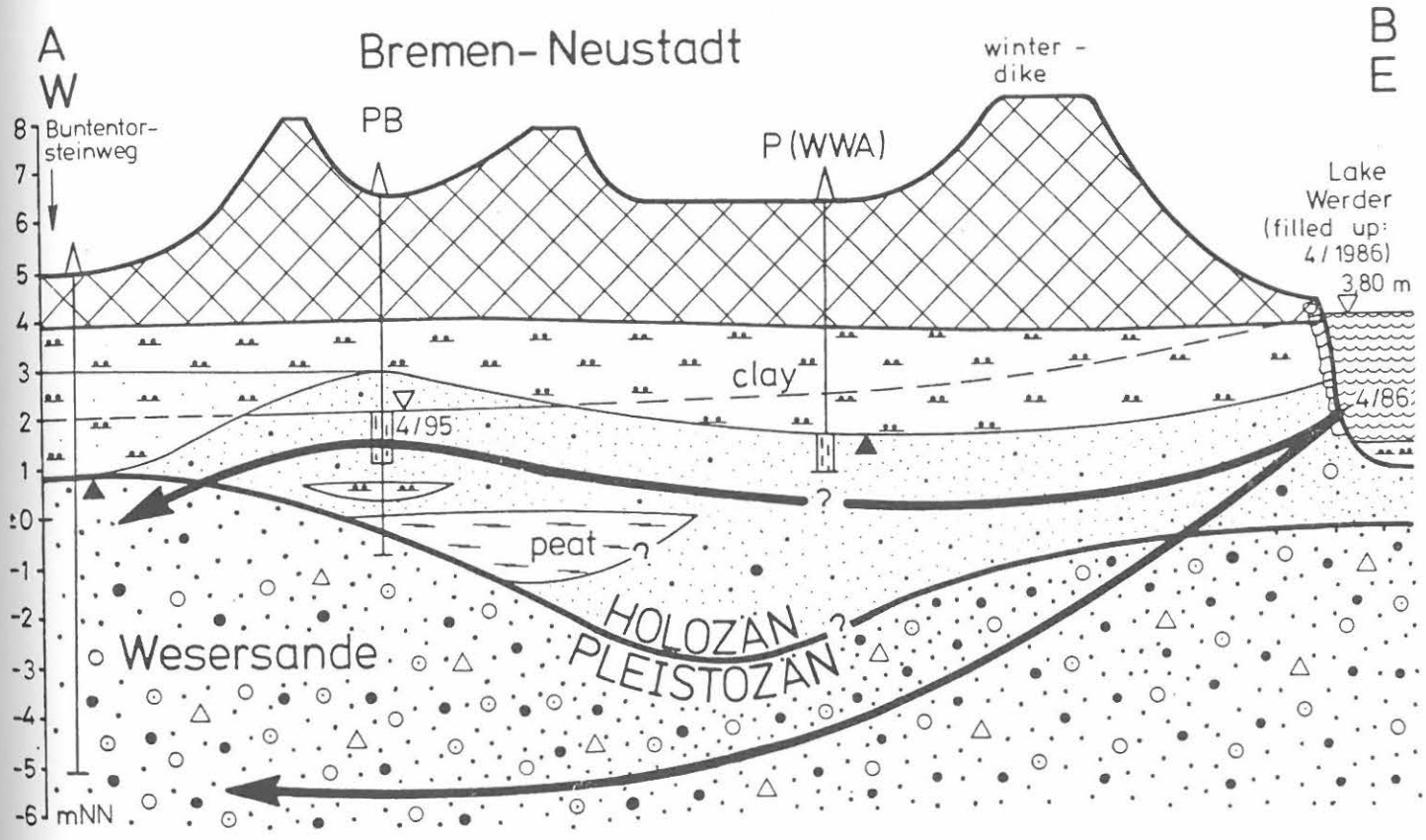

Fig. 10. Hydrogeological section between the Lake Werder and the depth gauge PB, near Deichschart of Bremen-Neustadt

These three examples demonstrate the possibility to measure the groundwater velocity by the pollution-tracer "chloride" with good results after long times (ORTLAM 1982, 1983a), because the chlorides have no retardation and adsorption effect in the aquifer. The different concentrations of chlorides are not mixed during the intrusion. The different peaks are very good recognizable in the several curves.

An application of the pollution-tracer method was the clarification of the origin of saltwater in several wells of the water works of Bramsche, situated nearby the Mittelland-Kanal (Mittelland-canal). The water of the Mittelland-canal was permanently pumped up from the river Weser near the town of Minden, 100 km south of Bremen (Fig. 1). Therefore the typical curves of the chlorides go in the canal, too. The canalwater flows to west in a few days and leaks in the groundwater flow above the wells of the water works of Bramsche. Therefore we are able to observe all peaks of chlorides of the water of the river Weser in the groundwater of several wells of the water works of Bramsche. This clarification proved the leakage of the canal (salt)water into the groundwater by the pollution-tracer method, developed in the town of Bremen.

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