CHAPTER 255

Salinity and Water Levels in the Weser Estuary during the last hundred years - Anthropogenic influences on the Coastal Environment

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Abstract

Today the Weser Estuary (Unterweser) is one of the most regulated rivers in Europe. It connects the harbour of Bremen with the Southern North Sea (German Bight) and is used by ocean-going ships. The first substantial deepening was done during the last decade of the 19th century. As the vessels became larger, the river has been deepened and widened for several times. The sequence of engineering works changed drastically the hydrological, morphological and ecological conditions within the Unterweser. The tidal water levels and the salinity had been measured since the beginning as part of an extended interdisziplinary monitoring program providing sound data over one century. These data are a valuable base to investigate the impact of the regulation works on the natural ecosystems of the coastal environment and on demands of the society, such as flood protection, irrigation, drainage. New questions arise from the vision, that impacts might be amplified by global climate changes.

Channelization of the Unterweser-estuary

The Unterweser-estuary is an important link for the merchandise town Bremen to the deep water of the North Sea (Fig. 1). The depth of the Unterweser decreased after the middle ages. To ensure the competitiveness of the Bremen-harbour, several attempts to deepen the river had been made since the 18th century. However, they were of limited success - KELLER (1901), ROHDE (1970). The first substantial step towards channalization was executed

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between 1883 and 1895 after the plans of FRANZIUS (1888) by concentrating the tidal currents in a dredged channel (tidedependent draft of 5.0 m), which had been stabilized by embankments, groynes, training walls. In principal, similar techniques were applied during the following construction periods to reach drafts of 7.0 m (1913/16 and 1921/24); of 8.0 m (1925/29, with an extention to 1939); 8.7 m (1953/59) and of 10,5 m (1973/79), which is called 9.0 m -correction due to the sea-chart-zero as the new reference datum-level - WETZEL (1987).

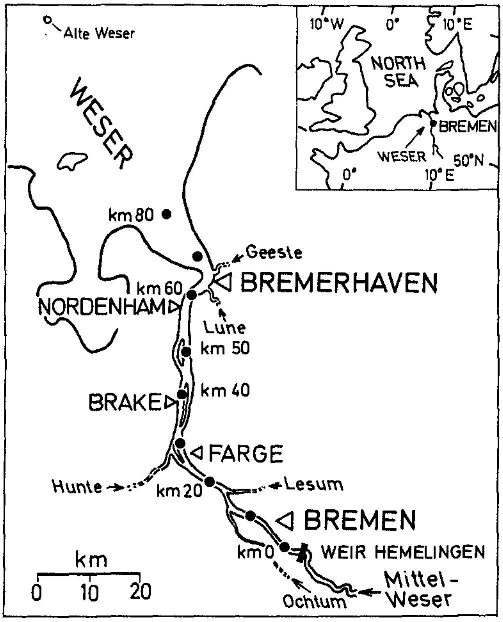

Fig. 1 Location map of the Weser Estuary (Unterweser)

After the first correction it was necessary to limit the tidal influenced part of the river by a weir in Bremen-Hemelingen, stopping erosion and groundwater intrusion (1906/11).

The time scale of the channelization is displayed on Fig. 2, righthand picture. The development of the channel-bottom depth relativ to the German datumn (NN, which is approximately equal to mean sea level) over time is shown on the picture below, lefthand.

The correction works changed the morphology drastically and influenced the hydrological and ecological conditions substantially. Fig. 3 gives an example on the development of the cross-section in the Bremen-area. The river surface, as well as the riparian area between Bremen und Bremerhaven, were reduced by the sequence of works to about one third and about 60 % of the eulittoral embankments of the navigable channel were covered by various packing material; most of the highly valuable backwaters and flats were lost (BUSCH et al. 1989).

Additionally dykes were displaced towards the river and storm surge barriers were installed in tributaries.

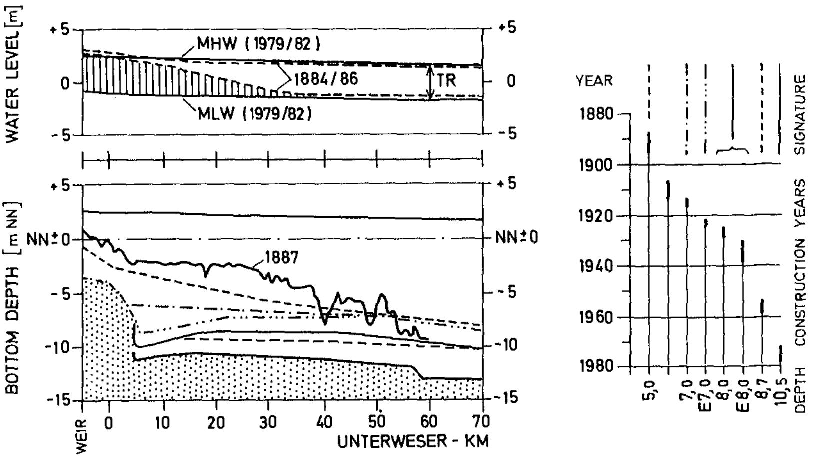

Fig. 2 Channelization of the Unterweser over 100 years. Right: time scale for construction periods. Left, below: bottom depth of the channel. Left, top: high & low water (MHW, MLW), tidal range (TR)

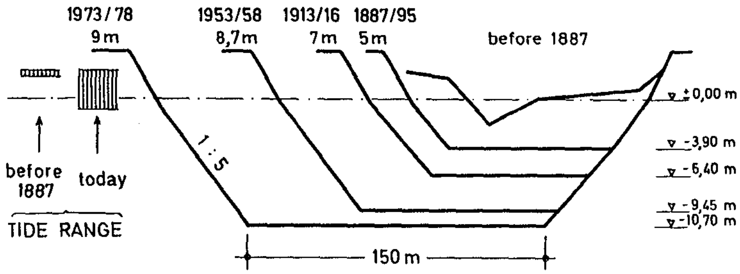

Fig. 3 Cross-sections (Unterweser-km 11, Bremen-Hasenbüren) before 1887 and as designed later

Hydrology

The water levels in the Unterweser are influenced by tides (propating from the German Bight to the weir in Bremen) and freshwater run off (discharge measured at the gauge of Intschede, upstream the weir). General information on these input-data are displayed on Fig. 4: the tides (HW, LW) are semidiurnal (M2 + S2); the high values for the run off (HQ) occur mainly in spring, the low values (LQ) in late summer or autumn.

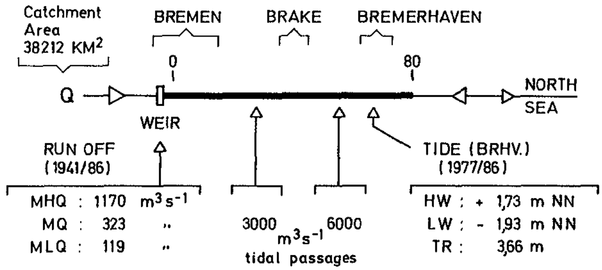

Fig. 4 Hydrological data for the Unterweser

The tidal curves on Fig. 5 provide information, how nowadays the tide propagates into the estuary. A comparision with Fig. 2, lefthand on top, shows how water levels and tidal range have changed with respect to the situation before the first regulation. The low water level (MLW) has been lowered in the upper part of the Unterweser, while the high water level (MHW) remained comparably uneffected. Thus the tidal range increased in Bremen from almost zero to about 4.0 meter. A more detailed picture is given by the graphs on Fig. 6.

The first construction periods, including the 8.0 m-correction, had the main impact on the changes of the water levels. The influence of the first correction had

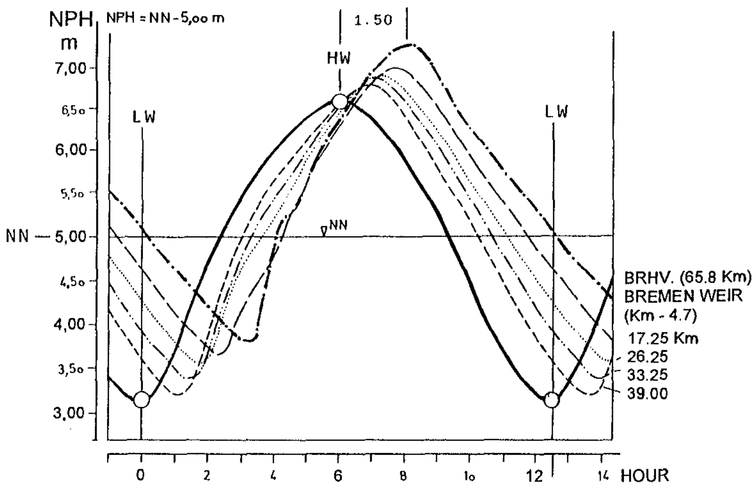

Fig. 5 Tides in the Unterweser (Bremerhaven to Bremen) for averaged conditions. Data: Federal Water and Shipping Authority Aurich,Bremen,Bremerhaven

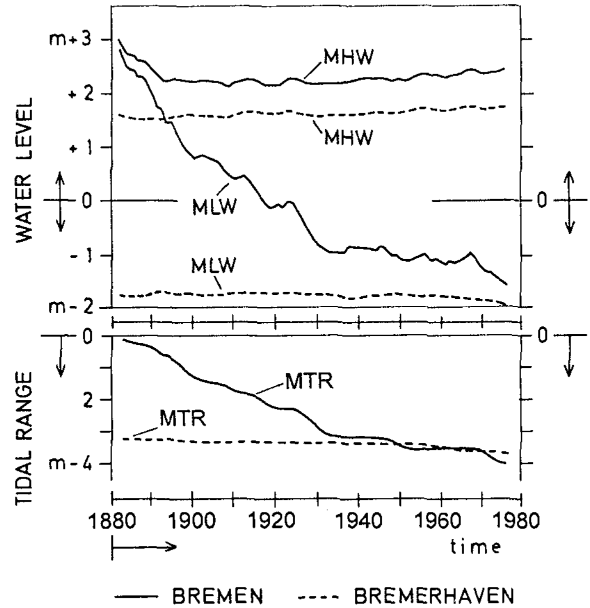

Fig. 6 Development of mean high water (MHW), mean low water (MLW), mean tidal range (MTR) over 100 years in the Unterweser at Bremen and Bremerhaven

been underestimated with an error of prediction up to almost 1.5 m. The impact of the 8.0 m-correction (water level-difference) reached up to about 0.75 m (WALTHER, 1954). An extended discussion concerning the impacts of the distinguished Unterweser-corrections on tides, water levels, tidal range is published by WALTHER (1954), STRÖHMER (1963) and is documented in unpublished reports (WSV 1957/85) of the Federal Water and Shipping Authority. The impact of the regulation works on extrem high water levels during storm floods is overlapped and hidden by the predominant anthropogenic influences caused by the coastal protection means, such as diking (in former days often combined with land reclamation) and storm surge barrages.

Monitoring programs

There had been many objections against the first large Unterweser-regulation proposed by FRANZIUS. An important group were the farmers who especially worried about higher water levels, more salinity and their correlated effects. Thus an extended monitoring program was established and executed over about one hundred years with only one large gap caused by the second world war. Additionally, money was paid to compensate in advance parts the presumed disadvantages (PLATE, 1951). These were about the same actions as they are nowadays required in Germany for the environmental impact assessment and common to promote the implementation of projects: it was a progressive and really successful approach. A substantial part of the program focused on the water quality of the Unterweser-estuary, especially concerning the salinity. Fig. 7, left shows the location were samples were taken; information on the observation-periods are added. The measured data (once a week at high water) were supplemented by a large number of special investigations related to space (e.g. verticals, cross-sections, longitudinal profiles) and time (e.g. tide circles, periods with special hydrological conditions) - WSV (1957/85).

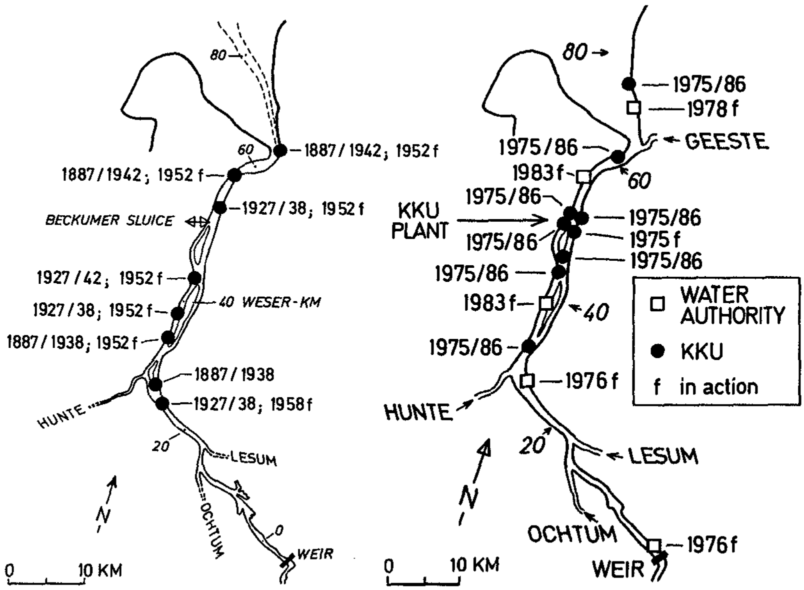

Fig. 7 Location of the Unterweser-Stations.
Left: weekly sampling. Right: permanent recording

A system of permanent working stations had been installed since 1975. Fig. 7, right distinguishes stations which were established by Water Authorities and those, which were specifically established to control the KKU-nuclear power plant KUNZ (1979). These stations are interlinked with measurements, which are regularely done by fast running boats (KUNZ et al. 1984).

The Unterweser is classified as a well mixed estuary; it has been proven, that the data gained by the stations in one measuring point can approximate the average situation of the cross-section sufficently well with respect to the aims of the long term and large scale monitoring programs - e.g. WSV (1957/85), BARG (1979). However, interpretations of the data are limited to the fixed targets.

Salinity

The salinity in the Unterweser-estuary is mainly caused by the intrusion of saltwater from the sea and is addionally affected by the salt which discharge factories into the upper parts of the Weser - e.g. Lüneburg et al. (1975), Arge Weser (1982). The distribution of salinity in the estuary is influenced by the tidal motion and the fresh water run off (Qo). This is shown in principal on Fig. 8. The graphs are simplifications for a defined phases of the tide (Kf, Ke).

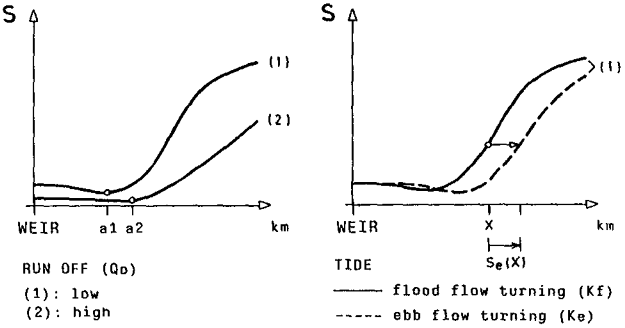

Fig. 8 Distribution of salinity in the brackish area of an estuary. Left: impact of run off (discharge Qo). Right: influence of the tidal motion (Kf, Ke)

The changing of salinity over time (tidal cycles) is shown on Fig. 9, left (salinity is proportional to the displayed conductivity Lf) for different areas (location of the stations see Fig. 7, right)of the Unterweser. The tide-phase-time of the flow turnings (flood, ebb) are indicated as Kf, Ke. The distribution of the conductivity (longitudinal profiles) for the phases Kf and Ke can be drawn from the Lf-values of the five stations. The result is shown on the righthand picture.

Longitudinal profiles for the phase Kf have been measured by sensors which were installed in fast running boats. Results provides Fig. 10, left: areas in which the measured curves fit in dependency of the significant fresh water run off (Qo/10 after BARG, 1979). The profiles on the right picture have been derived from all easured profiles. The large impact of the run off value on the salinity is obious. Comparable results have been published by BARG (1979) with salinity-data (NaCl) of the KKU-stations.

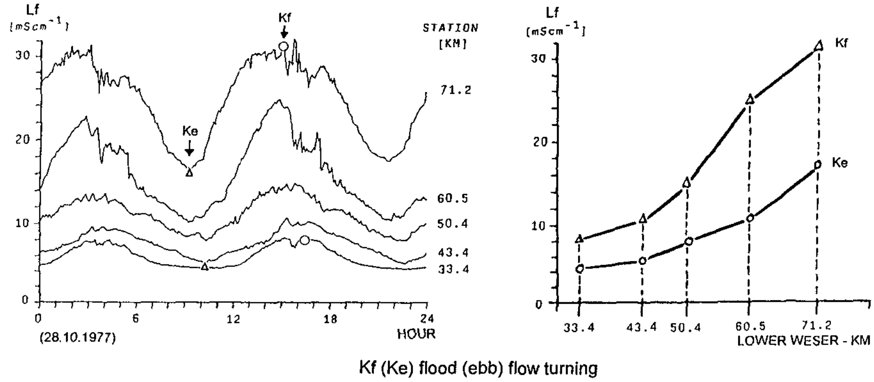

Fig. 9 Left: Conductivity (Lf) over time for different measurement stations in the Unterweser. Right: Conversion of the Lf-data into longitudinal Lf-profiles for the tide phases Kf and Ke (KUNZ 1979)

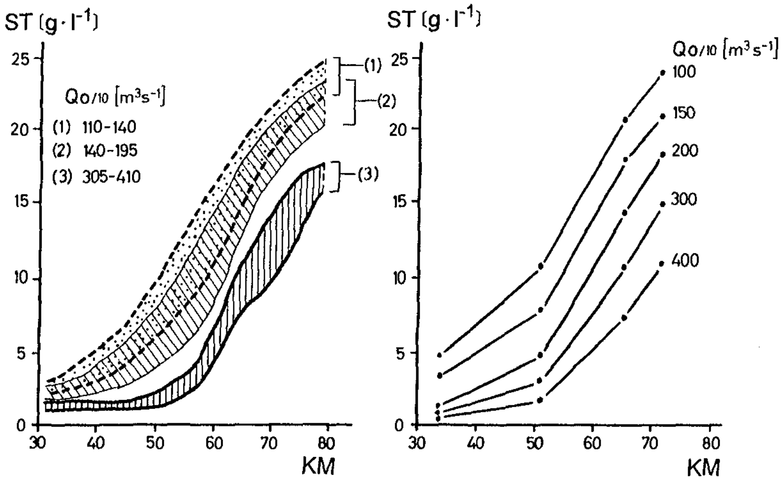

Fig. 10 Longitudinal profiles for Total Salinity (ST) as function of (Qo/10). Left: envelopes for groups of measured profiles. Right: ST-functions (Qo/10 is parameter) calculated with measured profiles

Investigations concerning the influence of the Unterweser-regulation works on the salinity-distribution in the brackish area of the Unterweser have been based on the long term data of the sampling stations. Longitudinal profiles for the phase Kf were constructed with these data, as demonstrated in principal by Fig. 9, right; e.g. STRÖHMER (1963), PLATE (1951), GRABEMANN et al. (1983) and nonpublished reports WSV (1957/85). An example is given by Fig. 11, where salinity-data (NaCl) for the time-period 1890 to 1975, selected for the mean run off (MQ), had been converted into longitudinal profiles. The data for the period from 1890 to 1932 are combined in the picture to the left: no significant influence of the regulation works. The interpredation of the righthand picture (1931 to 1975) is more difficult. GRABEMANN et al. (1983) tried to separate the natural from the man induced fluctuations and came up with the result, that the influences of the natural long-term changes (trends of relative sea level rise, characteristics of the tides - e.g. JENSEN et al. (1993)) - dominate the other impacts. This corresponds to results achieved by HN-models.

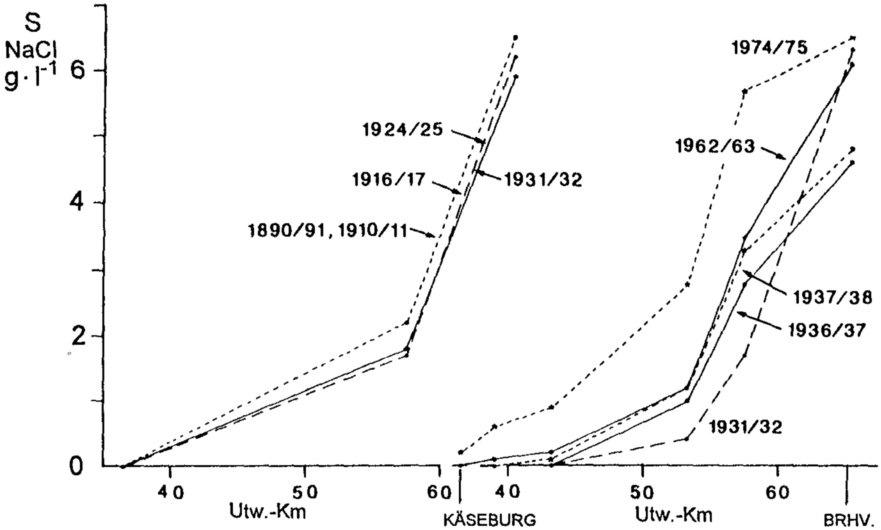

Fig. 11 Development of the NaCl-Distribution (profiles) in the Unterweser between Käseburg/km 36,5 and Bremerhaven/km 65.8 for mean Run Off (MQ), 1890 to 1975 - GRABEMANN et al.(1983), Shipping Authority Bremen/Aurich

The development of the salinity S (NaCl) over time is shown by Fig. 12 to 14 for selected stations. The Fig. 12 combines NaCl values (Station Bremerhaven (Brhv.), Nordenham, Rekum/Farge) with information on the main impact parameters: tides (HW, TR) and run off (discharge Qo). The increase of salinity in the Bremen-area (Rekum/Farge) is caused by industrial salt-discharges into upstream parts of the river in combination with the Qo-parameter - ARGE WESER (1982). The salinity-graphs for Bremerhaven and Nordenham show similar downs and ups related to Qo; there seems to be a trend towards increasing values and a steepening of the gradient since about 1970. This is most likely induced by changed hydrological conditions and not by the sequence of correction-works - e.g. BARG (1979), GRABEMANN et al. (1983), WETZEL (1987), WSA BRHV (1991).

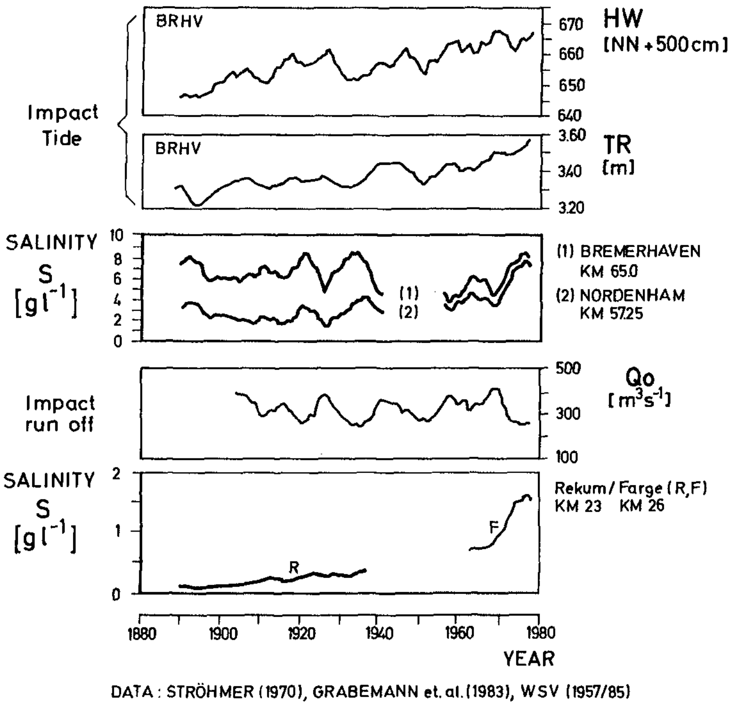

Fig. 12 Development of the Salinity S in the Unterweser (Bremerhaven, Nordenham, Rekum/Farge) and of hydrological Data: High Water (HW) & Tidal Range (TR) at Bremerhaven (BRHV); Run Off (Qo) for Intschede, (all values as five yearly running means)

Fig. 13 displays for the station Nordenham (km 57,25) how the salinity has been controlled by the fresh water discharge (Qo). The diverting graphs before 1906 may be related to the first correction. However, that's not conclusive. From 1955 onwards different behavior is obious, which presumately is caused by the increased tidal range, as mentioned before.

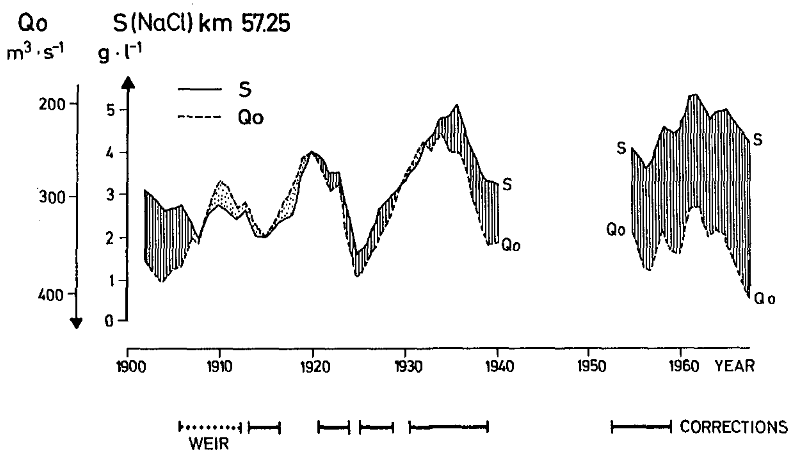

Fig. 13 Combination of Salinity S (NaCl) for Nordenham (km 57.25) with the Run Off (Qo) at Intschede-gauge after STRÖHMER (1970)

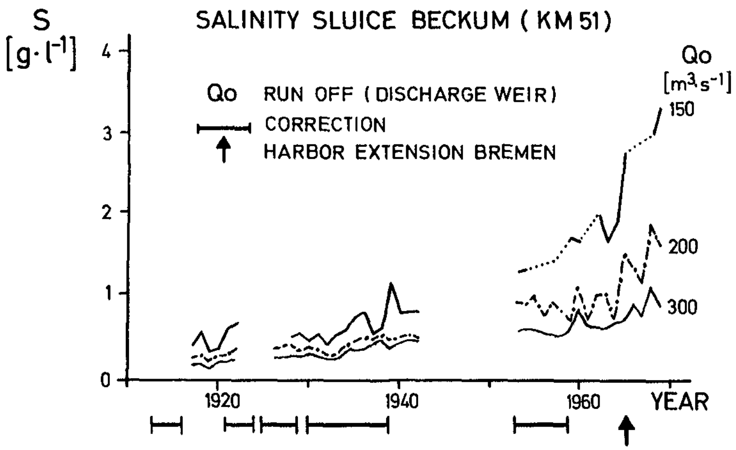

Fig. 14 Development of the Salinity S at the Beckum-sluice (km 51) for Qo = 150, 200, 300 m²/s since 1917. PLATE (1951), WSV (1957/85)

Since the content of salinity in the Unterweser-estuary is important for irrigation means (e.g. drinking water for cattle), the samples had also been taken in the Beckum-sluice (intake for irrigation water) at km 51 - e.g. PLATE (1951), WALTHER (1954). The development of the NaCl over time with respect to distinguished run off-values (Qo = 150, 200, 300 m²/s) is shown on Fig. 14. The salinity has increased and led to problems during periods of low run off (Qo), especially since the fifties as a result of the mentioned effects.

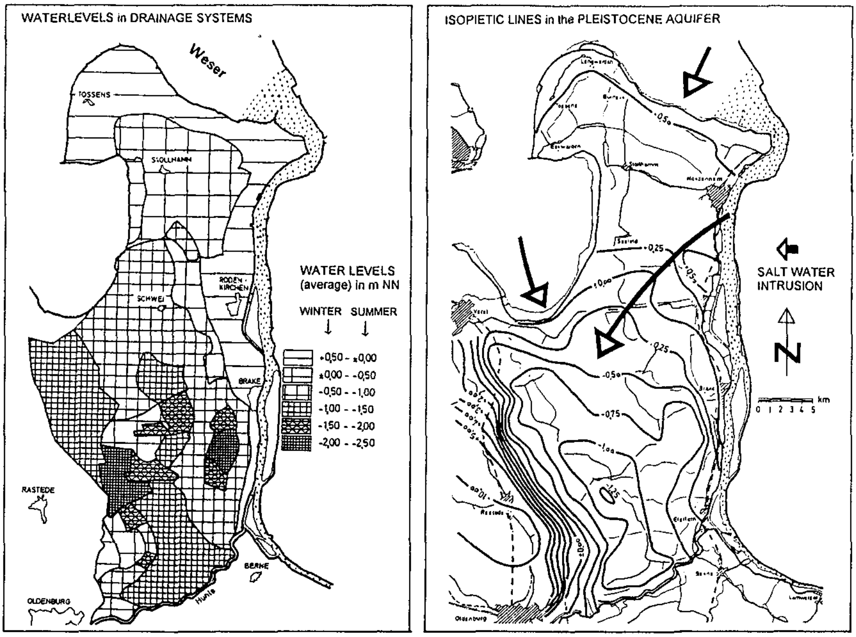

Fig. 15 Saltwater intrusion from the Unterweser into the aquifer of the lowlands. Left: Water level in the drainage system (ditches). Right: Isopietic lines in the pleistocene aquifer and direction of the anthropogenic induced salt water intrusion - KUNZ (1993)

Effects on groundwater

The intrusion of saltwater out of the Unterweser into the groundwater (holocene and pleistocene) of the low lying areas is influenced by the regulation works. This question has become more important, as extensive drainage systems were installed. Nowadays the water levels in the drainage ditches are far below the mean water level of the Unterweser (about NN), as to be recognized from Fig. 15, left. Consequently the isopietic lines of the pleistocene groundwater has been changed and the intrusion of salinity out of the Unterweser can increase - Fig. 15, right. This impacts the holocene cover layers by vertical directed flows. The main driving force in the synergism of the addressed impacts is the drainage; the effects of the Unterweser-regulation works are comparatively small - KUNZ (1993).

Conclusions and final remarks

For almost 100 years regular water samples were collected at several stations along the Unterweser-estuary on a scheme which remained unaltered. The combination with the tide gauge data provide an unique data set on salinity and water levels. This is a remarkable achievment of the Federal Water and Shipping Agencies and their scientific staff, who devoted time and effort into this admirable task. Today this valuable data set is of more than local interest. The traditionel sampling scheme has been supplemented by extensive measurement programs and numerical modelling throughout the last decades. However, many controversially discussed questions concerning developments and impacts were only to be answered by referring to the long term data. This is an example which should encourage society to require appropriate long term monitoring programs beeing obligatory for every human activity that has substantial impact on the environment. The modern tools, such as modelling, information systems etc. should not lead to the believing, that we can do without providing sustainable field data-records on the anthropogenic changings of our environment to the next generations.

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